Laboratorio de Microcontroladores

IE-0624

Laboratorio #3: Arduino: PID,GPIO,ADC y comunicaciones

Jordi Louzao von Breymann - B53993
Edward Cerdas Rodríguez - B71956
Grupo 1

31 de Enero del 2022

III - 2021

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1. Introducción

Para este laboratorio, se desea construir una incubadora automática de huevos de gallina. Dicha incubadora cuenta con medición de temperatura y de humedad, además, de que es capaz de ajustar la temperatura deseada, para mantenerla en el rango necesario para que el proceso de incubación se realice sin problemas. El microcontrolador a utilizar, en este caso, será un Arduino UNO (ATMega328P), el cual es bastante sencillo de utilizar y sumamente popular a nivel mundial por su versatilidad y relativa facilidad para usuarios inexpertos en el área de la programación de microcontrolador.

Algunas de las funciones que se quieren implementar son:

- Una pantalla que muestre en tiempo real la información de temperatura y humedad de la incubadora.
- Luces de alarma para cuando la temperatura baje o suba de los límites adecuados.
- Firmware inteligente, capaz de controlar el valor de la temperatura para mantener la incubadora lo más cerca posible de la temperatura deseada.
- Una función que permita el almacenamiento de los datos en un archivo de texto plano .txt.

Se trabajo el código utilizando el repositorio GIT de la escuela de Ingeniería Eléctrica de la UCR. El código esta disponible en `https://git.eie.ucr.ac.cr/jlouzao/Lab_Microcontroladores_III-2021`

2. Nota Teórica

En esta sección se va a incluir la información del microcontrolador, periféricos utilizados, componentes electrónicos complementarios; así como también el diseño del circuito.

2.1. Características generales del microcontrolador

Arduino es una plataforma de creación de electrónica de código abierto, hecha para simplificar el desarrollo de proyectos que necesiten el uso microcontroladores. Para este proyecto, se hace uso de un Arduino UNO, el cual se muestra en la figura 1.

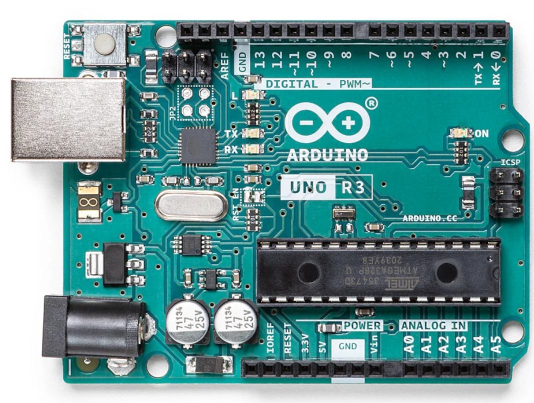


Figura 1: Arduino UNO[1]

El Arduino, como tal, es un conjunto de componentes eléctricos elegidos para realizar funciones específicas que faciliten la programación y comunicación del microcontrolador integrado dentro de la misma placa que los demás componentes, en este caso, dicho microcontrolador es un ATMega328P, el cual tiene el esquema mostrado en la figura 2.

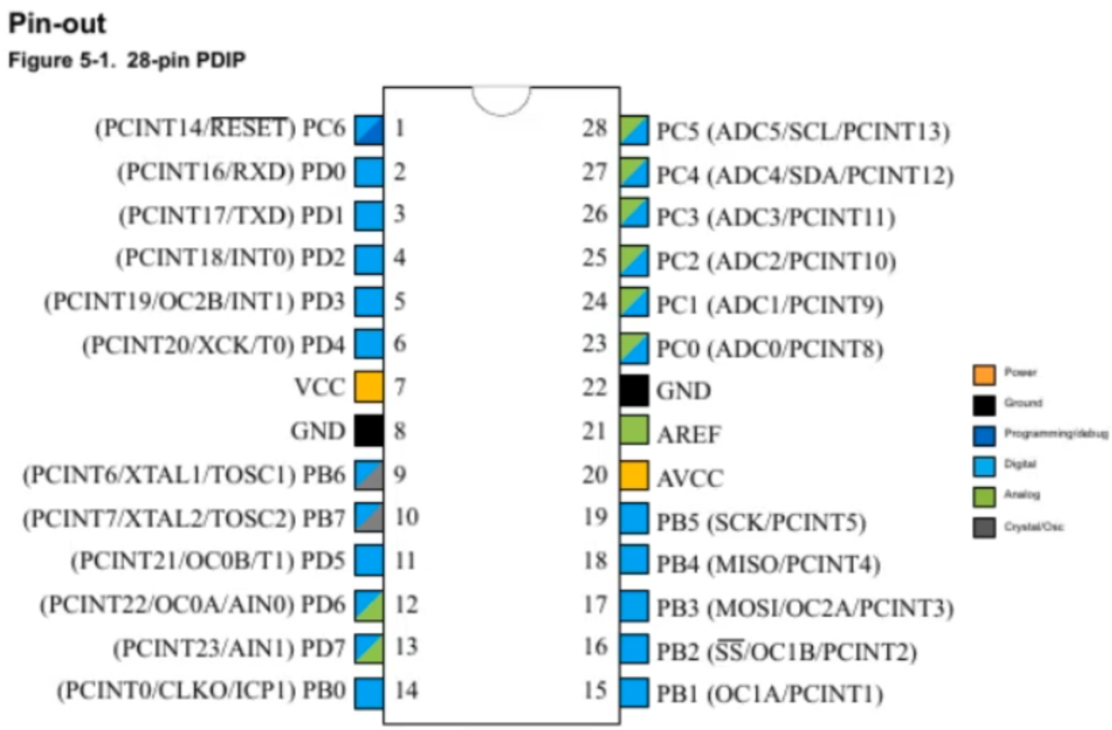


Figura 2: ATMega328P[1]

Algunas de las principales características de este microcontrolador, tomadas de la hoja del fabricante, son:

- 4/8/16/64 Kb Flash
- 512 Bytes/1/2K bytes de SRAM interna.
- Microcontrolador AVR de 8 bits.
- 23 GPIOS.
- Timers/Counters de 8 y 16 bits.
- Interrupciones.
- USART.
- 8 canales PWM.

2.2. Características eléctricas

Algunas de las características eléctricas del ATMega328P se muestran en la figura 3:

MICROCONTROLLER	ATmega328P
OPERATING VOLTAGE	5V
INPUT VOLTAGE (RECOMMENDED)	7-12V
INPUT VOLTAGE (LIMIT)	6-20V
DIGITAL I/O PINS	14 (of which 6 provide PWM output)
PWM DIGITAL I/O PINS	6
ANALOG INPUT PINS	6
DC CURRENT PER I/O PIN	20 mA
DC CURRENT FOR 3.3V PIN	50 mA

Figura 3: Características eléctricas del Arduino UNO[1]

2.3. Periféricos utilizados/descripción de registros e instrucciones

2.3.1. Sensor de humedad DHT11

Para el desarrollo del proyecto se pide medir la humedad relativa de la incubadora, para este fin, se elige el sensor de humedad DHT11, el cual tiene capacidad de medir la humedad relativa de un 20 % hasta un 90 % con una precisión de ±5 % de humedad relativa, lo cual es un rango más que decente para su bajo costo. Este sensor es ampliamente utilizado para proyectos con Arduino y tiene la característica de que es digital, lo que lo hace más resistente a factores como el ruido.

Este útil componente integra un sensor capacitivo de humedad por medio del cual mide el aire circundante. Una vez tomada la medición, muestra los datos mediante una señal digital en el pin de datos.

2.3.2. Termistor NTC de 100k NTCG104EF104FTDSX

Por su parte, para medir la temperatura, se decide utilizar un termistor. Este es un componente electrónico que cambia su valor de resistencia nominal dependiendo de la temperatura a la que se encuentre. Por medio de un divisor de tensión, se puede hacer que la tensión de entrada en el pin analógico del Arduino lea el cambio de temperatura que se presenta en el termistor. En este caso, se utilizó un termistor de 100kΩ, con un valor de β de 4250.

Cuando se utiliza un termistor es muy importante tomar en cuenta que la relación entre la resistencia y la temperatura no es lineal, tal como se ve en la figura 4 donde el eje x horizontal representa la temperatura y el eje vertical la resistencia en Ω.

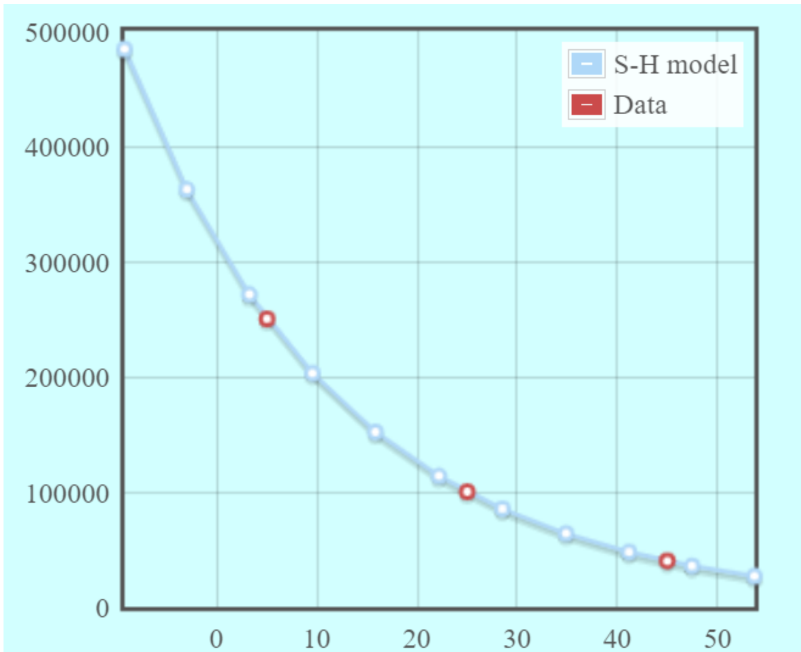


Figura 4: Curva de temperatura vs resistencia en un termistor [2].

Para realizar la estimación de la temperatura de acuerdo a la tensión medida en el pin del Arduino, se pueden emplear la ecuación de Steinhart-Hart:

$$\frac{1}{T} = A + Bln(R) + C(ln(R))^3 \tag{1}$$

Donde, T es la temperatura en kelvin, R es la resistencia en ohmios medida en el punto T. A, B y C son coeficientes de Steinhart-Hart, los cuales varían según el modelo del termistor y en este caso, van a ser calculados por medio de una página web creada por Stanford Research Systems Inc, a partir de 3 puntos del tipo (temperatura, resistencia), los cuales van a ser obtenidos de la hoja del fabricante [2].

Un ejemplo de cómo calcular los valores para los coeficientes A, B y C se muestra en la figura 5.

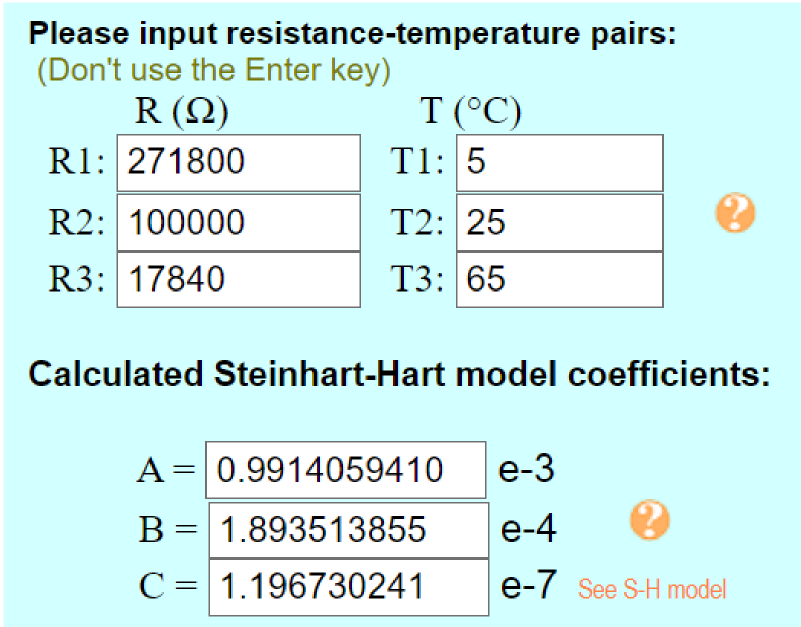


Figura 5: Coeficientes de S-H[2].

2.3.3. PCD8544-4988

La pantalla LCD PCD8544-4988, popular en teléfonos como el Nokia 5110, se utilizara para desplegar información del circuito. La pantalla posee 5 pines, además del pin de alimentación y tierra. El pin de RST se conecta al Reset del Arduino para aplicar la señal de reset cuando se inicializa el microcontrolador. El pin CS se conecta directamente a tierra, este pin normalmente funciona para realizar actualizaciones entre actualizaciones de pantalla. Este pin se conecta a tierra ya que la funcionalidad no es necesaria. El pin D/C es el selector de modo, entre comandos y datos. El pin DIN es la entrada de datos seriales. Finalmente el pin CLK recibe una señal de reloj.

2.3.4. OPA564

Se utiliza un amplificador operacional para controlar la resistencia de calentamiento. Se escoge el OPA564 de TI por su capacidad de proveer corrientes de hasta 1.5A en su salida, con una ganancia suficiente para proveer 12V a la salida con una entrada de 5V[3].

2.3.5. USART

Se utiliza la funcionalidad de USART del Arduino para comunicarse con una computadora. Esto se puede lograr o con los pines 0 y 1, o en nuestro caso, con el puerto USB del Arduino. Se utiliza una taza de datos de 9600 baud. Para activar esta funcionalidad se implemento un switch con un resistor de pullup y debouncing con un filtro paso bajo RC.

2.4. Librerías utilizadas para desarrollar el código del proyecto

2.4.1. DHT

Una de las librerías a utilizar es la de DHT, para el sensor de humedad elegido (DHT11). Esta librería no fue usada, debido a que el simulador no cuenta con este dispositivo para ser añadido al circuito, por lo que fue sustituido por una fuente de voltaje, la cual simula lo que serían los distintos valores medidos por un sensor de humedad. Sin embargo, es importante mencionar que esta librería es necesaria en caso de utilizar este dispositivo en un proyecto, ya que, como se mencionó anteriormente, este sensor tiene una salida digital que requiere de las funciones incluidas en la librería DHT para que funcione adecuadamente.

2.4.2. Adafruit_PCD8544

Se utiliza esta librería para comunicar la pantalla LCD PCD8544 con el Arduino utilizando el GPIO. Esta librería estandariza funciones para escritura de texto, actualización de la pantalla, y control de características como contraste y brillo. Hay otras librerías de apoyo que también permite mostrar figuras y otros tipos de gráficos, pero no se utilizara esto.

2.4.3. pyserial

Se utiliza la librería pyserial para leer los datos del un puerto serial utilizando Python. Esto se utiliza para leer los datos enviados del Arduino a través del puerto serial y escribirlos a un csv.

2.4.4. csv

Se utiliza esta librería de Python para escribir un archivo csv con los datos enviados.

2.5. Componentes elegidos y precios

Todos los precios en colones se obtuvieron de Steren, mientras que los precios en dolares fueron obtenidos en Mouser, a menos que se indique específicamente.

- 1 Arduino UNO -> precio aproximado de entre \$10 y \$20, depende del modelo exacto.
- 2 LEDs (uno rojo y uno azul) -> precio aproximado entre 130 y 370 colones cada uno, depende del color.
- 2 resistencias de 180Ω para los LEDs -> precio aproximado 29 colones cada una.
- 1 switch de un polo -> precio aproximado 190 colones cada uno.
- 2 resistencias de 100kΩ -> precio aproximado 29 colones cada una.
- 1 resistencia de 10kΩ -> precio aproximado 29 colones cada una.
- 1 resistencia de 1kΩ -> precio aproximado 29 colones cada una.
- 1 resistencia de 140Ω -> precio aproximado 29 colones cada una.
- 2 resistencias de 180Ω -> precio aproximado 29 colones cada una.
- 1 resistencia variable o potenciómetro de 1kΩ -> precio aproximado 370 colones cada uno.
- 1 resistencia de calentamiento de 5W y 12V -> precio aproximado de un modelo de 5W y 12V 8000 colones incluyendo envío por unidad [4]
- 1 termistor de 100kΩ (NTCG104EF104FTDSX) -> precio aproximado \$2 cada uno.
- 1 capacitor de 2.2μF -> precio aproximado 85 colones cada uno.
- 1 capacitor de 1μF -> precio aproximado 85 colones cada uno.

- 1 pantalla LCD (PCD8544-4988) -> precio aproximado $10 cada uno.
- 1 amplificador operacional OPA564 -> precio aproximado $6.72 cada uno.
- 1 sensor de humedad y DHT11 -> precio aproximado $4.13 cada uno.

2.6. Justificación del diseño del circuito con los componentes elegidos

2.6.1. Calentador

Se alimenta el opamp con una fuente de 12V y se configura como una fuente de tensión controlada por tensión. El beneficio de hacer esto es que la corriente que sale del pin del Arduino esta en el orden de picoamperes, muy por debajo del limite eléctrico definido por el fabricante. La tensión en la salida viene dada por:

$$V_{out} = V_{in}(1 + (140\Omega)/(100\Omega)) = 2{,}4V_{in} \tag{2}$$

La tensión de entrada V_{in} viene dada por el Arduino, en un rango de 0 a 5V en PWM. Esta señal se pasa por un filtro RC pasa bajo para generar una señal DC estable. La frecuencia deseada para esta salida es lo mas cercano a cero posible. Para lograr esto se utiliza una resistencia de 100kΩ y un capacitor de 1μF. La frecuencia de corte viene dada entonces por:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{0{,}2\pi} = 1{,}592Hz \tag{3}$$

Esta baja frecuencia es suficientemente baja para funcionar como una entrada estable para el amplificador. El opamp entonces tiene a su salida una tensión que varia de 0 a 12V, linealmente con la variación entre 0 y 5V del lado del Arduino. Esto funciona para alimentar al calentador. Se da que la resistencia de calentamiento opera a un máximo de 12V y 5W. Usando la definición de potencia tenemos que:

$$5W = 12V \times I, I \approx 0{,}42A \tag{4}$$

Aplicando a esto la ley de Ohm obtenemos la resistencia equivalente para este calentador:

$$12V = 0{,}42A \times R, R = 28{,}8\Omega \tag{5}$$

Teniendo en cuenta que la resistencia indicada opera de 0 a 80 °C. Como el consumo de potencia es proporcional a la generación de calor, se entiende que a 2.5W, la resistencia generara la mitad del calor que generaría a 5W. Entonces trataremos la generación de calor de la resistencia como si fuera lineal con el rango de temperaturas dadas. Esto se utilizara para el control de temperatura, ya que al 100 % de duty cycle se tendrá la resistencia a 80 °C, a 50 % estará a 40 °C, a 25 % estará a 20 °C, y similarmente para otros valores.

2.6.2. Seleccionador de temperatura deseada

Para la selección de la temperatura deseada simplemente se utiliza un potenciómetro de 1kΩ, el cual se encuentra en un divisor de tensión con una resistencia de 1kΩ, lo cual hace que el pin mida desde 0V hasta 2.5V. La corriente máxima que soporta el pin del Arduino es de 20mA, y esta corriente, debido al valor de la resistencia de 1kΩ, lo máximo que puede ser es de 5mA, además de que se debe repartir esta corriente entre las dos resistencias, lo que hace que como máximo lleguen 2.5mA en el peor de los casos al pin y como mínimo, 0A, ya que toda la corriente se va por el camino que conduce a tierra cuando el potenciómetro tiene una resistencia = 0.

2.6.3. Sensor de temperatura

Para el sensor de temperatura se eligió un termistor de 100kΩ en divisor de tensión con una resistencia de 100kΩ. Al igual que en el caso anterior, lo que sucede es que en el pin, como máximo llegan 2.5V con una corriente aún más baja que en el caso del selector de temperatura deseada.

2.6.4. LEDs de alarma

Para las LEDs de alarma se elige utilizar un LED rojo y uno azul, tal como lo pide el enunciado, además, se añade una resistencia de 180Ω en cada uno de los LEDs, para disminuir la corriente que pasa a través de ellos, de esta forma se evita que se quemen. En este caso, tomando en cuenta que la tensión de umbral de un LED ronda, como mínimo, los 2V, se puede asumir que el máximo de corriente estaría dado por ley de ohm, con la resistencia de 180Ω y los 3V que corresponden a la caída de potencial en la resistencia. De este modo, la máxima corriente en el LED sería de: $\frac{3V}{180\Omega} \approx$ 16mA, lo cual se considera un valor aceptable para un LED, considerando que un valor de corriente ideal es de unos 20mA [5].

2.6.5. Sensor de humedad

Para este proyecto se necesita la implementación de un sensor de humedad, el cual sea capaz de medir la humedad relativa. Se elige un DHT11 para este objetivo, puede medir desde 20 % hasta 90 % de humedad relativa, utilizando una salida digital que lo convierte en un excelente componente por su precio. Cumple con los requerimientos del proyecto.

2.6.6. Pantalla LCD

La pantalla PCD8544 se escoge ya que es la requerida en el enunciado. Esta pantalla requiere alimentación de 3.3V, que puede ser provisto por el Arduino. Además, las señales deben ser de 3.3V, de lo que se encarga la librería Adafruit_PCD8544.

3. Análisis de Resultados

Para el desarrollo del laboratorio se utilizó el software de SimulIDE para crear el esquemático del circuito, el cual se muestra en la figura 6.

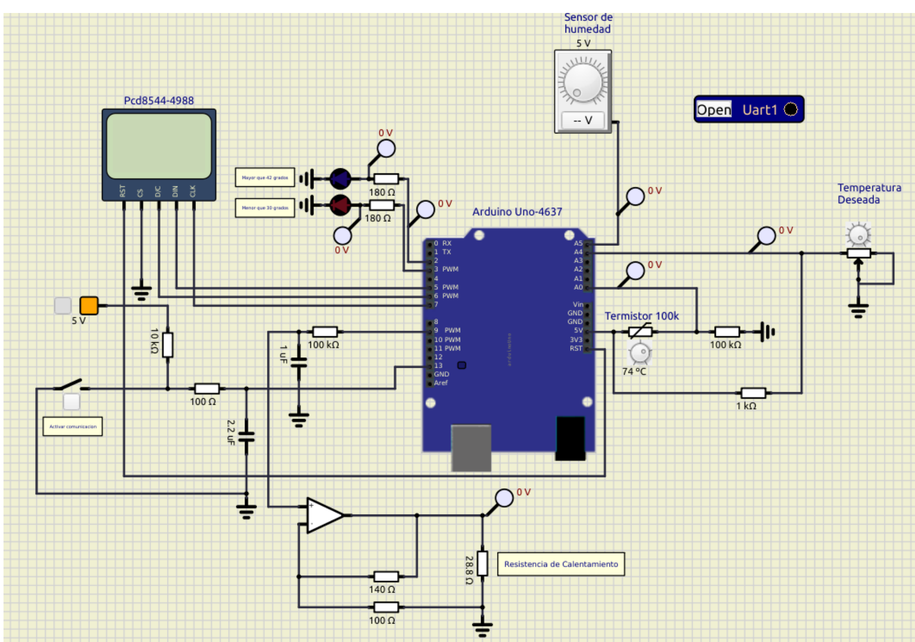


Figura 6: Circuito creado para la simulación [Elaboración propia]

Como se explicó anteriormente, este circuito consta de varias partes, las cuales se explican y se justifican en la sección anterior, estas trabajan en conjunto para realizar mediciones, controlar variables y darle una retroalimentación al usuario.

En la figura 7 se puede ver cómo luce el circuito en funcionamiento.

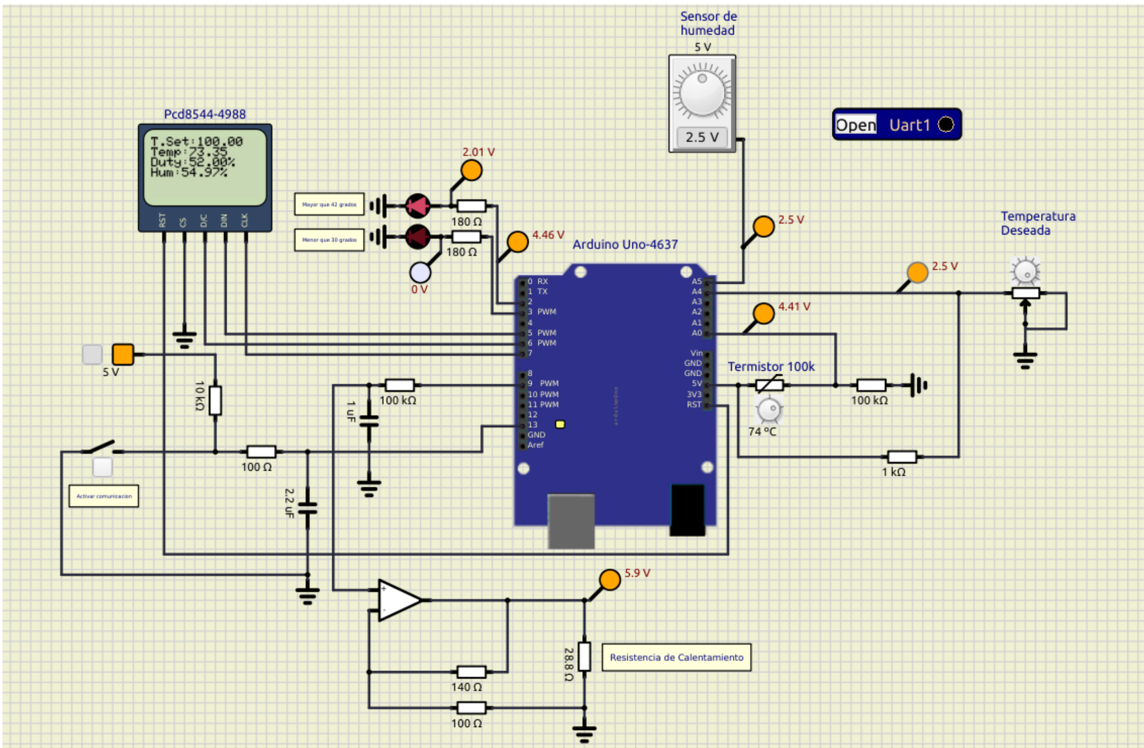


Figura 7: Circuito en funcionamiento [Elaboración propia]

Algunos de los detalles más importantes de la figura anterior son las sondas de voltaje para entender lo que está sucediendo con la alimentación del circuito y, además, la pantalla LCD, la cual muestra detalles bastante interesantes, como lo son la temperatura deseada, la temperatura actual, el *Duty Cicle* que representa el esfuerzo de control y por último, la humedad actual.

El control PID que se implementa se ve evidenciado en el funcionamiento del circuito. Como en no se provee una ecuación de planta, no es posible saber como varia la temperatura de la incubadora. Se debe por lo tanto asumir un sistema aislado sin perturbaciones. Aun así se implementan algunos controles de seguridad que serian útiles en una eventual implementación real de este circuito. Como la resistencia puede retener temperaturas bajas simplemente variando su tensión, se intenta cuando es posible mantener esta encendida a la temperatura deseada. En un sistema real, una resistencia en una incubadora aislada operando a una potencia particular va a seguir generando calor, aumentando la temperatura. Cuando se alcanza la temperatura deseada, un proceso lento que va a permitir fácilmente detectar cambios de temperatura en el orden de un grado, la resistencia se apagara. Esto permitirá que la incubadora baje de temperatura hasta alcanzar una temperatura menor, en cuyo momento se encenderá la resistencia para aumentar la temperatura de nuevo. Esta metodología permitirá que nunca se exceda, sin perturbaciones externas, la temperatura deseada que se digitó. Si se define una temperatura menor a la actual cuando esta operando el sistema, la resistencia simplemente se apagara para reducir la temperatura. Si se define una temperatura mayor a la deseada, se limita la resistencia a la temperatura máxima deseada, y se apaga si la temperatura sobrepasara el limite por cualquier razón. Similarmente si se define una temperatura deseada menor que la mínima especificada, la resistencia se encenderá a la temperatura mínima especificada. Debido a las limitaciones del simulador, no es posible simular este sistema tomando en cuenta una ecuación de planta de la incubadora, ni una resistencia emitiendo calor a cierta tasa, entonces variar la temperatura solo es posible de manera manual con un potenciómetro. Aun así, en teoría este sistema debería poder, una vez implementado en un escenario real, lidiar con las variaciones en temperatura y mantener los huevos dentro de un rango de temperaturas deseado.

Finalmente, la generación de datos a través del USART se logro de manera satisfactoria. El script de Python no se pudo probar directamente con los datos, pero la generación de CSV con otra entrada de datos se confirmo. Se verifica la funcionalidad del Arduino de enviar datos seriales a través de esta interfaz utilizando el monitor serial de SimulIDE:

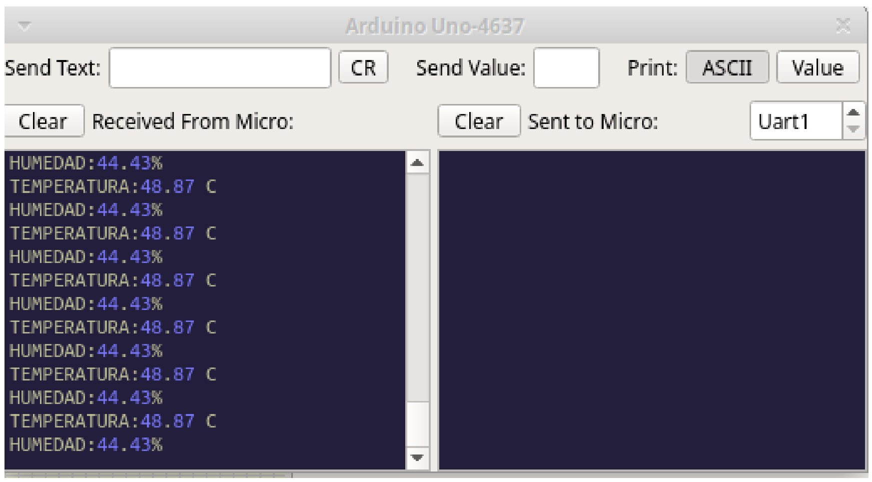


Figura 8: Funcionamiento de escritura serial

La razón que no se pudo verificar directamente la funcionalidad del script de Python es que no es posible leer y escribir de un mismo puerto serial al mismo tiempo. Como el Arduino de la simulación esta escribiendo datos al puerto, el script de Python no puede leer datos al mismo tiempo. Al pasar este código a un Arduino real, este podría mandar los datos a través de su interfaz serial, y una computadora corriendo el script de Python podría leer esta entrada.

4. Diagrama de bloques

Se utiliza el siguiente diagrama de flujo para entender el funcionamiento de la incubadora.

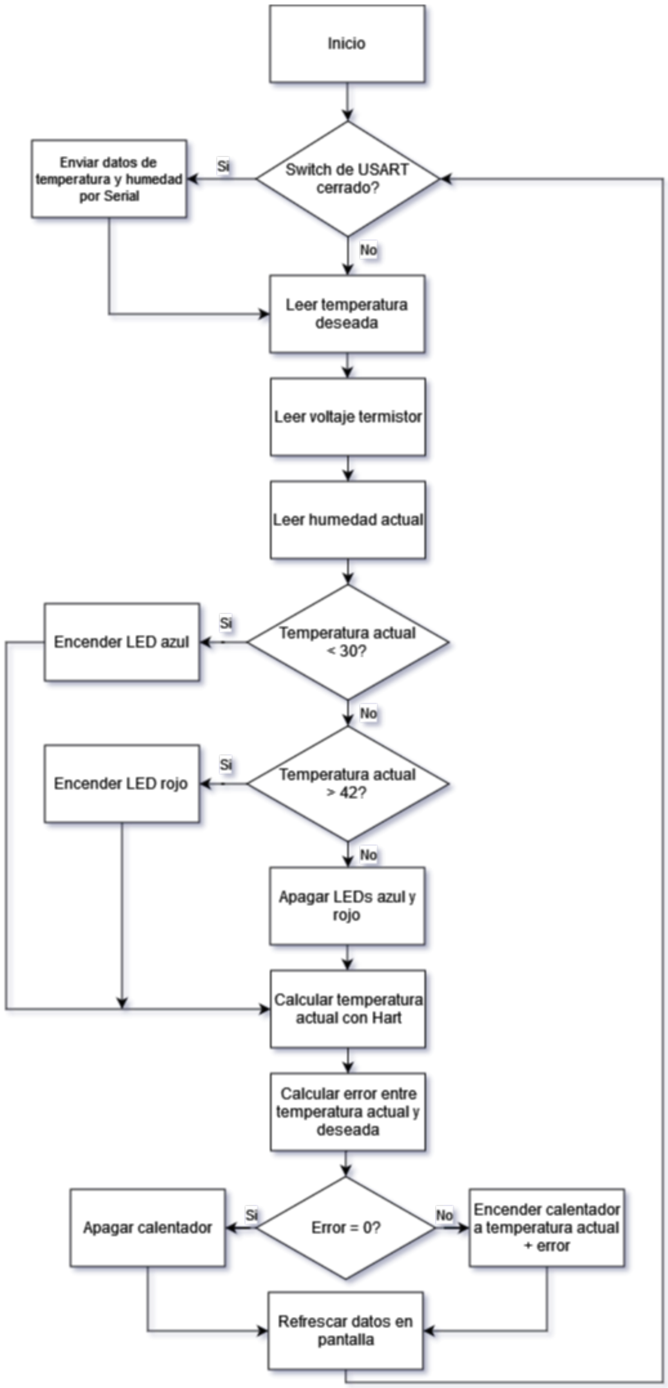


Figura 9: Diagrama de flujo del programa

5. Conclusiones y recomendaciones

- Se logró entender de una mejor forma el funcionamiento de los microprocesadores en tareas como lectura analógica y comunicación USART.
- Se comprendió la importancia que tienen plataformas como Arduino, las cuales, facilitan muchísimo el desarrollo de aplicaciones tecnológicas a través del uso de microcontroladores.
- Se logró comprender conceptos muy importantes para la utilización de los microcontroladores, tales como comunicación serial o ADC convirtiendo valores analógicos en un número de 10 bits, en el caso de Arduino UNO.

5.1. Recomendaciones

Durante el desarrollo del proyecto se pudo comprobar que el hecho de utilizar un simulador es muy limitante, por lo que una recomendación sería realizar este proyecto pero en su versión física, ya que de este modo, no se tendría limitaciones de componentes, tales como el caso del sensor de humedad el cual no existe en el simulador.

Referencias

[1] *Arduino Store*. Arduino CC. URL: `https://store-usa.arduino.cc/products/arduino-uno-rev3/`.

[2] *SRS Thermistor Calculator*. Stanford Research Systems Inc. URL: `https://www.thinksrs.com/downloads/programs/Therm%5C%20Calc/NTCCalibrator/NTCcalculator.htm`.

[3] *1.5A, 24V, 17MHz POWER OPERATIONAL AMPLIFIER*. Texas Instruments. 2011. URL: `https://www.ti.com/lit/ds/symlink/opa564.pdf?ts=1643678325920&ref_url=https%253A%252F%252Fwww.google.com%252F`.

[4] *Calentador de poliimida eléctrico con película de polietileno*. AliExpress.com. URL: `https://es.aliexpress.com/item/32653304442.html?gatewayAdapt=glo2esp`.

[5] *Conectar un led a tu Arduino*. Geek Factory. URL: `https://www.geekfactory.mx/tutoriales-arduino/conectar-un-led-a-tu-arduino/`.

6. Anexos

Como parte de los anexos se adjuntan las hojas de datos del termistor de 100kΩ, del sensor de humedad DHT100, del amplificador operacional OPA564, y la pantalla PCD8544.

6.1. Termistor

TDK Corporation
Piezo & Protection Device B. Grp.
3-9-1, Shibaura, Minato-ku, Tokyo,
108-0023, Japan
TEL. 03-6852-7300

NTCG

NTC Chip Thermistor

Temperature Sensing Device

PRODUCT:NTCG104EF104FTDSX

This product is compliant with the AEC-Q200 standard.

Dimensions and construction

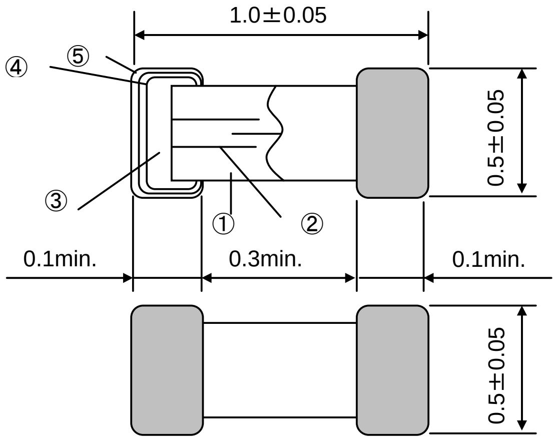


TABLE1. Parts List

	Part Name	Material
①	Element	Manganese, Nickel-oxide base Ceramics materials
②	Inner electrodes	Palladium
③	Terminal electrodes	Silver base
④		Nickel-plating
⑤		Tin-plating

Operating temperature range

-40 ~ +125°C

TABLE 2. Electric Performance:

Item	Symbol	Specification
Nominal resistance and tolerance	R25	100kΩ ± 1%
B value and tolerance	B25/50	4250K ± 1%
Maximum rated power (condition: PCB)	P25	100 mW / 25°C in still air

TABLE 3. Resistance - Temperature Characteristics (condition: chip in silicone oil)

Temp (°C)	Min (kΩ)	Nom (kΩ)	Max (kΩ)	Temp (°C)	Min (kΩ)	Nom (kΩ)	Max (kΩ)	Temp (°C)	Min (kΩ)	Nom (kΩ)	Max (kΩ)
-40.0	4054	4251	4458	20.0	125.5	127.0	128.6	80.0	10.24	10.58	10.92
-35.0	2875	3005	3140	25.0	99.00	100.0	101.0	85.0	8.587	8.887	9.195
-30.0	2063	2149	2238	30.0	78.26	79.23	80.21	90.0	7.235	7.500	7.774
-25.0	1497	1554	1613	35.0	62.26	63.18	64.10	95.0	6.122	6.357	6.600
-20.0	1097	1135	1175	40.0	49.84	50.68	51.54	100.0	5.202	5.410	5.626
-15.0	812.0	837.8	864.3	45.0	40.13	40.90	41.68	105.0	4.438	4.623	4.815
-10.0	606.6	624.1	642.0	50.0	32.50	33.19	33.90	110.0	3.801	3.966	4.137
-5.0	457.3	469.1	481.2	55.0	26.47	27.09	27.72	115.0	3.269	3.415	3.568
0.0	347.6	355.6	363.8	60.0	21.67	22.22	22.78	120.0	2.821	2.952	3.088
5.0	266.4	271.8	277.3	65.0	17.84	18.32	18.82	125.0	2.444	2.561	2.683
10.0	205.8	209.4	213.1	70.0	14.75	15.18	15.63				
15.0	160.1	162.5	164.9	75.0	12.26	12.64	13.04				

6.2. DHT11

DHT11 Humidity & Temperature Sensor

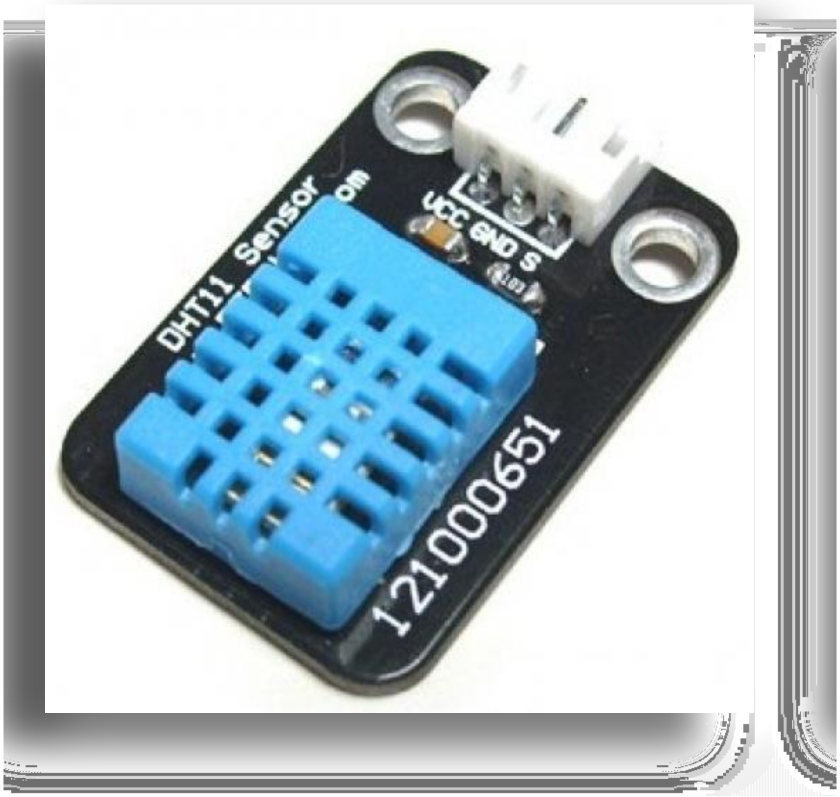
D-Robotics UK (www.droboticsonline.com)

DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output.

D-Robotics

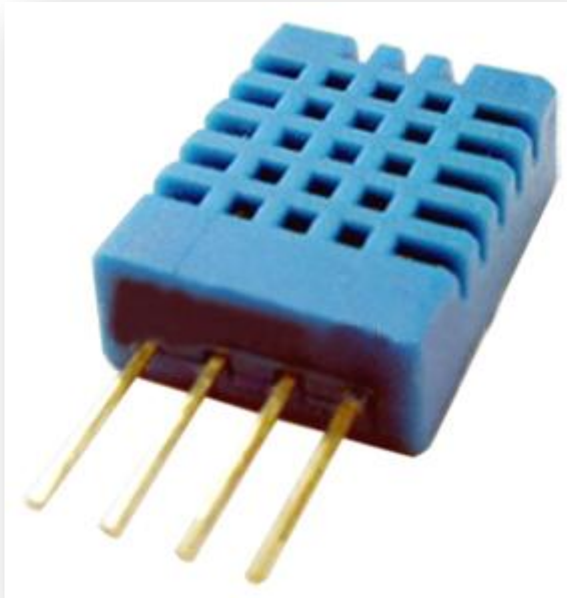
7/30/2010

DHT 11 Humidity & Temperature Sensor



1. Introduction

This DFRobot DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and temperature & humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability and cost-effectiveness.



Each DHT11 element is strictly calibrated in the laboratory that is extremely accurate on humidity calibration. The calibration coefficients are stored as programmes in the OTP memory, which are used by the sensor's internal signal detecting process. The single-wire serial interface makes system integration quick and easy. Its small size, low power consumption and up-to-20 meter signal transmission making it the best choice for various applications, including those most demanding ones. The component is 4-pin single row pin package. It is convenient to connect and special packages can be provided according to users' request.

2. Technical Specifications:

Overview:

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 ℃	±5%RH	±2℃	1	4 Pin Single Row

Detailed Specifications:

Parameters	Conditions	Minimum	Typical	Maximum
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			±1%RH	
Accuracy	25℃		±4%RH	
	0-50℃			±5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0℃	30%RH		90%RH
	25℃	20%RH		90%RH
	50℃	20%RH		80%RH
Response Time (Seconds)	1/e(63%)25℃，1m/s Air	6 S	10 S	15 S
Hysteresis			±1%RH	
Long-Term Stability	Typical		±1%RH/year	
Temperature				
Resolution		1℃	1℃	1℃
		8 Bit	8 Bit	8 Bit
Repeatability			±1℃	
Accuracy		±1℃		±2℃
Measurement Range		0℃		50℃
Response Time (Seconds)	1/e(63%)	6 S		30 S

3. Typical Application (Figure 1)

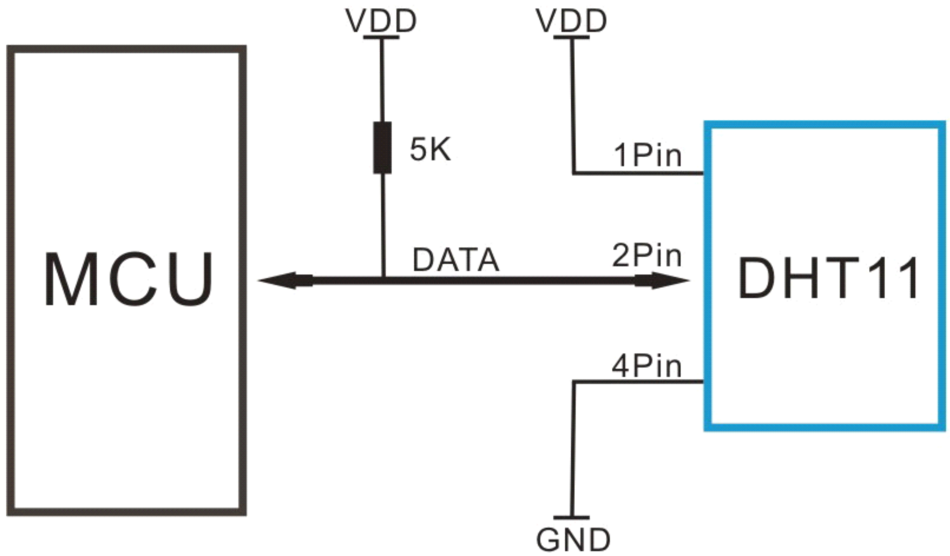


Figure 1 Typical Application

Note: 3Pin – Null; MCU = Micro-computer Unite or single chip Computer

When the connecting cable is shorter than 20 metres, a 5K pull-up resistor is recommended; when the connecting cable is longer than 20 metres, choose a appropriate pull-up resistor as needed.

4. Power and Pin

DHT11's power supply is 3-5.5V DC. When power is supplied to the sensor, do not send any instruction to the sensor in within one second in order to pass the unstable status. One capacitor valued 100nF can be added between VDD and GND for power filtering.

5. Communication Process: Serial Interface (Single-Wire Two-Way)

Single-bus data format is used for communication and synchronization between MCU and DHT11 sensor. One communication process is about 4ms.

Data consists of decimal and integral parts. A complete data transmission is **40bit**, and the sensor sends **higher data bit** first.

Data format: 8bit integral RH data + 8bit decimal RH data + 8bit integral T data + 8bit decimal T data + 8bit check sum. If the data transmission is right, the check-sum should be the last 8bit of "8bit integral RH data + 8bit decimal RH data + 8bit integral T data + 8bit decimal T data".

5.1 Overall Communication Process (Figure 2, below)

When MCU sends a start signal, DHT11 changes from the low-power-consumption mode to the running-mode, waiting for MCU completing the start signal. Once it is completed, DHT11 sends a response signal of 40-bit data that include the relative humidity and temperature information to MCU. Users can choose to collect (read) some data. Without the start signal from MCU, DHT11 will not give the response signal to MCU. Once data is collected, DHT11 will change to the low-power-consumption mode until it receives a start signal from MCU again.

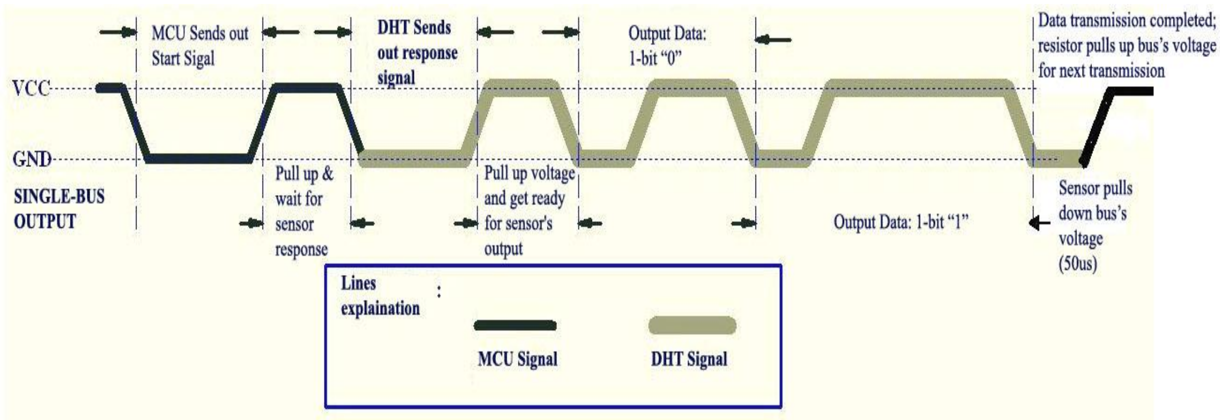


Figure 2 Overall Communication Process

5.2 MCU Sends out Start Signal to DHT (Figure 3, below)

Data Single-bus free status is at high voltage level. When the communication between MCU and DHT11 begins, the programme of MCU will set Data Single-bus voltage level from high to low and this process must take at least 18ms to ensure DHT's detection of MCU's signal, then MCU will pull up voltage and wait 20-40us for DHT's response.

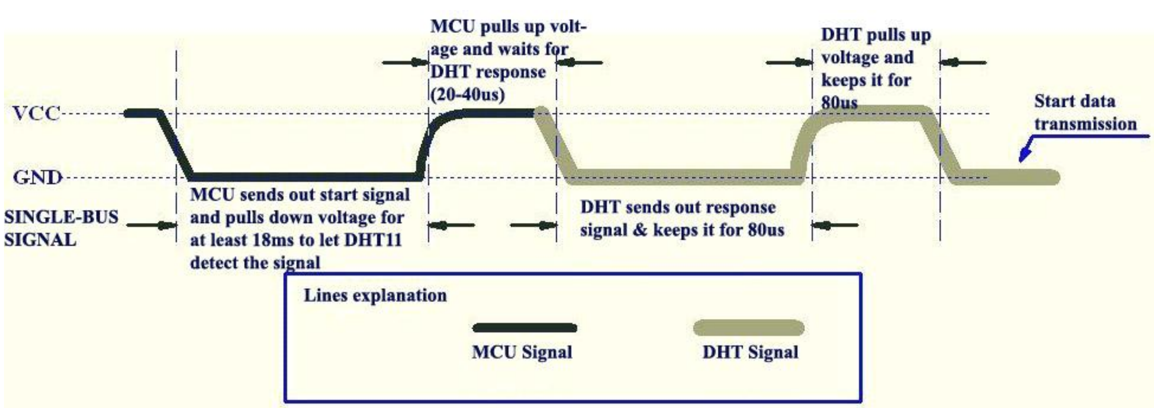


Figure 3 MCU Sends out Start Signal & DHT Responses

5.3 DHT Responses to MCU (Figure 3, above)

Once DHT detects the start signal, it will send out a low-voltage-level response signal, which lasts 80us. Then the programme of DHT sets Data Single-bus voltage level from low to high and keeps it for 80us for DHT's preparation for sending data.

When DATA Single-Bus is at the low voltage level, this means that DHT is sending the response signal. Once DHT sent out the response signal, it pulls up voltage and keeps it for 80us and prepares for data transmission.

When DHT is sending data to MCU, every bit of data begins with the 50us low-voltage-level and the length of the following high-voltage-level signal determines whether data bit is "0" or "1" (see Figures 4 and 5 below).

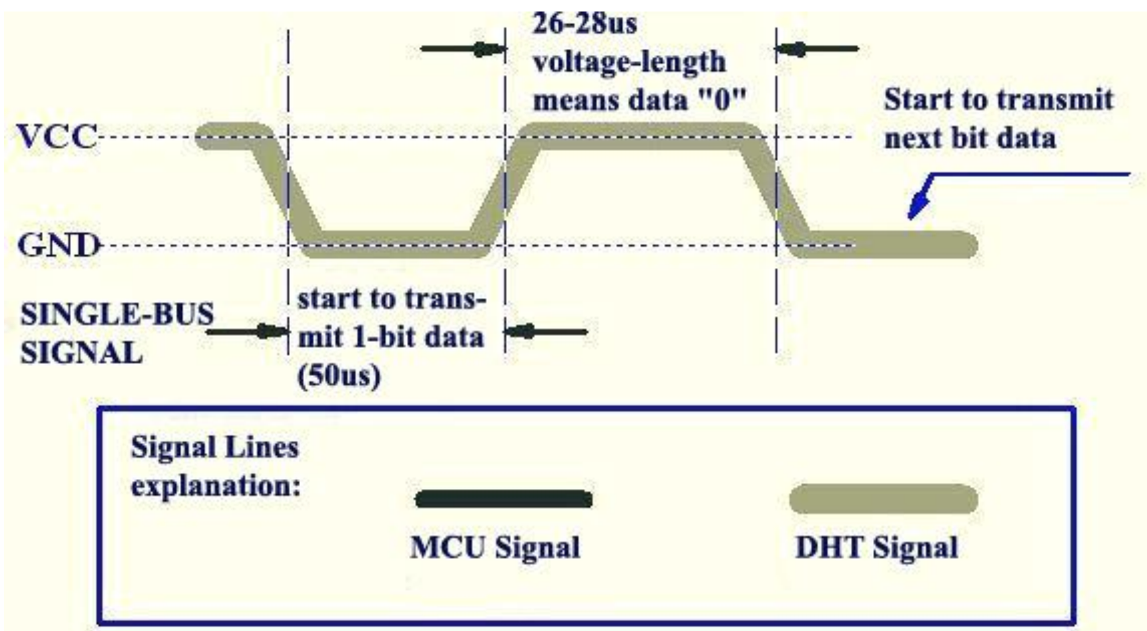


Figure 4 Data "0" Indication

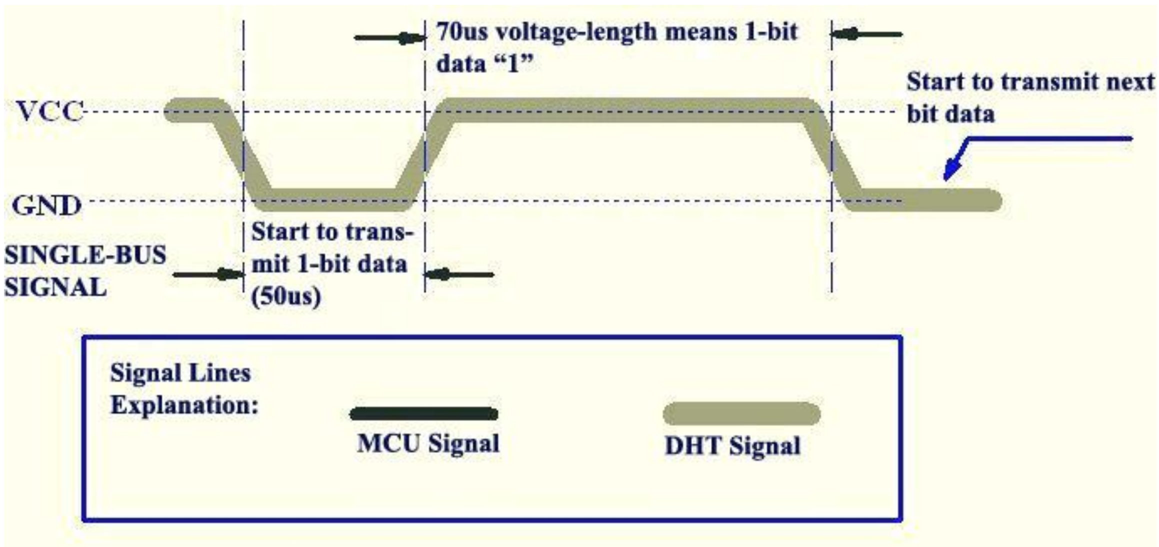


Figure 5 Data "1" Indication

If the response signal from DHT is always at high-voltage-level, it suggests that DHT is not responding properly and please check the connection. When the last bit data is transmitted, DHT11 pulls down the voltage level and keeps it for 50us. Then the Single-Bus voltage will be pulled up by the resistor to set it back to the free status.

6. Electrical Characteristics

VDD=5V, T = 25℃ (unless otherwise stated)

	Conditions	Minimum	Typical	Maximum
Power Supply	DC	3V	5V	5.5V
Current Supply	Measuring	0.5mA		2.5mA
	Average	0.2mA		1mA
	Standby	100uA		150uA
Sampling period	Second	1		

Note: Sampling period at intervals should be no less than 1 second.

7. Attentions of application

(1) Operating conditions

Applying the DHT11 sensor beyond its working range stated in this datasheet can result in 3%RH signal shift/discrepancy. The DHT11 sensor can recover to the calibrated status gradually when it gets back to the normal operating condition and works within its range. Please refer to (3) of this section to accelerate its recovery. Please be aware that operating the DHT11 sensor in the non-normal working conditions will accelerate sensor's aging process.

(2) Attention to chemical materials

Vapor from chemical materials may interfere with DHT's sensitive-elements and debase its sensitivity. A high degree of chemical contamination can permanently damage the sensor.

(3) Restoration process when (1) & (2) happen

Step one: Keep the DHT sensor at the condition of Temperature 50~60Celsius, humidity <10%RH for 2 hours;
Step two:K keep the DHT sensor at the condition of Temperature 20~30Celsius, humidity >70%RH for 5 hours.

(4) Temperature Affect

Relative humidity largely depends on temperature. Although temperature compensation technology is used to ensure accurate measurement of RH, it is still strongly advised to keep the humidity and temperature sensors working under the same temperature. DHT11 should be mounted at the place as far as possible from parts that may generate heat.

(5) Light Affect

Long time exposure to strong sunlight and ultraviolet may debase DHT's performance.

(6) Connection wires

The quality of connection wires will affect the quality and distance of communication and high quality shielding-wire is recommended.

(7) Other attentions

* Welding temperature should be bellow 260Celsius and contact should take less than 10 seconds.
* Avoid using the sensor under dew condition.
* Do not use this product in safety or emergency stop devices or any other occasion that failure of DHT11 may cause personal injury.
* Storage: Keep the sensor at temperature 10-40℃, humidity <60%RH.

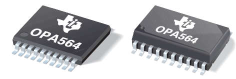
Declaim:

This datasheet is a translated version of the manufacturer's datasheet. Although the due care has been taken during the translation, D-Robotics is not responsible for the accuracy of the information contained in this document.

D-Robotics: www.droboticsonline.com

Email contact: d_robotics@hotmail.co.uk

6.3. OPA564



1.5A, 24V, 17MHz POWER OPERATIONAL AMPLIFIER

Check for Samples: OPA564

FEATURES

- HIGH OUTPUT CURRENT: 1.5A
- WIDE POWER-SUPPLY RANGE:
  – Single Supply: +7V to +24V
  – Dual Supply: ±3.5V to ±12V
- LARGE OUTPUT SWING: $20V_{PP}$ at 1.5A
- FULLY PROTECTED:
  – THERMAL SHUTDOWN
  – ADJUSTABLE CURRENT LIMIT
- DIAGNOSTIC FLAGS:
  – OVER-CURRENT
  – THERMAL SHUTDOWN
- OUTPUT ENABLE/$\overline{\text{SHUTDOWN}}$ CONTROL
- HIGH SPEED:
  – GAIN-BANDWIDTH PRODUCT: 17MHz
  – FULL-POWER BANDWIDTH AT $10V_{PP}$: 1.3MHz
  – SLEW RATE: 40V/μs
- DIODE FOR JUNCTION TEMPERATURE MONITORING
- HSOP-20 PowerPAD™ PACKAGE (Bottom- and Top-Side Thermal Pad Versions)

APPLICATIONS

- POWERLINE COMMUNICATIONS
- VALVE, ACTUATOR DRIVER
- V_{COM} DRIVER
- MOTOR DRIVER
- AUDIO POWER AMPLIFIER
- POWER-SUPPLY OUTPUT AMPLIFIER
- TEST EQUIPMENT AMPLIFIER
- TRANSDUCER EXCITATION
- LASER DIODE DRIVER
- GENERAL-PURPOSE LINEAR POWER BOOSTER

DESCRIPTION

The OPA564 is a low-cost, high-current operational amplifier that is ideal for driving up to 1.5A into reactive loads. The high slew rate provides 1.3MHz full-power bandwidth and excellent linearity. These monolithic integrated circuits provide high reliability in demanding powerline communications and motor control applications.

The OPA564 operates from a single supply of 7V to 24V, or dual power supplies of ±3.5V to ±12V. In single-supply operation, the input common-mode range extends to the negative supply. At maximum output current, a wide output swing provides a $20V_{PP}$ (I_{OUT} = 1.5A) capability with a nominal 24V supply.

The OPA564 is internally protected against over-temperature conditions and current overloads. It is designed to provide an accurate, user-selected current limit. Two flag outputs are provided; one indicates current limit and the second shows a thermal over-temperature condition. It also has an Enable/$\overline{\text{Shutdown}}$ pin that can be forced low to shut down the output, effectively disconnecting the load.

The OPA564 is housed in a thermally-enhanced, surface-mount PowerPAD™ package (HSOP-20) with the choice of the thermal pad on either the top side or the bottom side of the package. Operation for both versions is specified over the industrial temperature range, –40°C to +85°C.

OPA564 RELATED PRODUCTS

FEATURES	DEVICE
Zerø-Drift PGA with 2-Channel Input Mux and SPI	PGA112
Zerø-Drift Operational Amplifier, 50MHz, RRI/O, Single-Supply	OPA365
Quad Operational Amplifier, JFET Input , Low Noise	TL074
Power Operational Amplifier, 1.2A, 15V, 17MHz, 50V/μs	OPA561

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.

PACKAGE/ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
OPA564	HSOP-20 (PowerPAD on bottom)	DWP	OPA564
	HSOP-20 (PowerPAD on top)	DWD	OPA564

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS(1)

Over operating free-air temperature range (unless otherwise noted).

		OPA564	UNIT
Supply Voltage, V_S = (V+) – (V–)		+26	V
Signal Input Terminals	Voltage(2)	(V–)–0.4 to (V+)+0.4	V
	Current Through ESD Diodes(2)	±10	mA
	Maximum Differential Voltage Across Inputs(3)	0.5	V
Signal Output Terminals	Voltage	(V–)–0.4 to (V+)+0.4	V
	Current(4)	±10	mA
Output Short-Circuit(5)		Continuous	
Operating Junction Temperature, T_J		–40 to +125	°C
Storage Temperature, T_A		–55 to +150	°C
Junction Temperature, T_J		+150	°C
ESD Ratings	Human Body Model (HBM)	4000	V
	Charged Device Model (CDM)	1000	V
	Machine Model (MM)	200	V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.
(2) Input terminals are diode-clamped to the power-supply rails. Signals that can swing more than 0.4V beyond the supply rails should be current limited to 10mA or less.
(3) Refer to Figure 43 for information on input protection. See *Input Protection* section.
(4) Output terminals are diode-clamped to the power-supply rails. Input signals forcing the output terminal more than 0.4V beyond the supply rails should be current limited to 10mA or less.
(5) Short-circuit to ground within SOA. See *Power Dissipation and Safe Operating Area* for more information.

ELECTRICAL CHARACTERISTICS

Boldface limits apply over the specified temperature range: **T_A = –40°C to +85°C.**
At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

PARAMETERS		CONDITIONS	OPA564 MIN	OPA564 TYP	OPA564 MAX	UNIT
OFFSET VOLTAGE						
Input Offset Voltage	V_{OS}	V_{CM} = 0V		±2	±20	mV
vs Temperature	**dV_{OS}/dT**			**±10**		**μV/°C**
vs Power Supply	PSRR	V_{CM} = 0V, V_S = ±3.5V to ±13V		10	150	μV/V
INPUT BIAS CURRENT						
Input Bias Current(1)	I_B	V_{CM} = 0V		10	100	pA
vs Temperature			See Figure 10, Typical Characteristics			
Input Offset Current(1)	I_{OS}			10	100	pA
NOISE						
Input Voltage Noise Density	e_n	f = 1kHz		102.8		nV/√Hz
		f = 10kHz		20		nV/√Hz
		f = 100kHz		8		nV/√Hz
Input Current Noise	I_n	f = 1kHz		4		fA/√Hz
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range:	V_{CM}	Linear Operation	(V–)		(V+)–3	V
Common-Mode Rejection Ratio	CMRR	V_{CM} = (V–) to (V+)–3V	70	80		dB
vs Temperature			See Figure 9, Typical Characteristics			
INPUT IMPEDANCE						
Differential				10^{12} || 16		Ω || pF
Common-Mode				10^{12} || 9		Ω || pF
OPEN-LOOP GAIN						
Open-Loop Voltage Gain	A_{OL}	V_{OUT} = 20V_{PP}, R_{LOAD} = 1kΩ	80	108		dB
		V_{OUT} = 20V_{PP}, R_{LOAD} = 10Ω		93		dB
FREQUENCY RESPONSE						
Gain-Bandwidth Product(1)	GBW	R_{LOAD} = 5Ω		17		MHz
Slew Rate	SR	G = 1, 10V Step		40		V/μs
Full Power Bandwidth		G = +2, V_{OUT} = 10V_{PP}		1.3		MHz
Settling Time ±0.1%		G = +1, 10V Step, C_{LOAD} = 100pF		0.6		μs
±0.01%		G = +1, 10V Step, C_{LOAD} = 100pF		0.8		μs
Total Harmonic Distortion + Noise	THD+N	f = 1kHz, R_{LOAD} = 5Ω, G = +1, V_{OUT} = 5V_P		0.003		%
OUTPUT						
Voltage Output:	V_{OUT}					
Positive		I_{OUT} = 0.5A	(V+)–1	(V+)–0.4		V
Negative		I_{OUT} = –0.5A	(V–)+1	(V–)+0.3		V
Positive		I_{OUT} = 1.5A	(V+)–2	(V+)–1.5		V
Negative		I_{OUT} = –1.5A	(V–)+2	(V–)+1.1		V

(1) See Typical Characteristics.

ELECTRICAL CHARACTERISTICS (continued)

Boldface limits apply over the specified temperature range: **T_A = –40°C to +85°C.**
At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

PARAMETERS		CONDITIONS	OPA564 MIN	TYP	MAX	UNIT
OUTPUT, continued						
Maximum Continuous Current, dc	I_{OUT}			1.5(2)		A
Output Impedance, closed loop	R_O	f = 100kHz		10		Ω
Output Impedance, open loop	Z_O	G = +2, f = 100kHz	See Figure 24, Typical Characteristics			
Output Current Limit Range(3)				±0.4 to ±2.0		A
Current Limit Equation	I_{LIM}		$I_{LIM} \cong 20000 \times \left(\frac{1.2V}{5000 + R_{SET}}\right)$ (4) (5)			A
		Solved for R_{SET} (Current Limit)	$R_{SET} \cong (24k/I_{LIM}) - 5k\Omega$			Ω
Current Limit Accuracy		I_{LIM} = 1.5A		10		%
Current Limit Overshoot(6) (7)		V_{IN} = 5V Pulse (200ns t_r), G = +2		50		%
Output Shut Down						
Output Impedance(8)				6 || 120		GΩ || pF
Capacitive Load Drive	C_{LOAD}		See Figure 6, Typical Characteristics			
DIGITAL CONTROL						
Enable/$\overline{\text{Shutdown}}$ Mode INPUT		V_{DIG} = +3.3V to +5.5V referenced to V–				
$V_{E/\overline{S}}$ High (output enabled)		E/$\overline{S}$ Pin Open or Forced High	(V–)+2		(V–)+V_{DIG}	V
$V_{E/\overline{S}}$ Low (output shut down)		E/$\overline{S}$ Pin Forced Low	(V–)		(V–)+0.8	V
$I_{E/\overline{S}}$ High (output enabled)		E/$\overline{S}$ Pin Indicates High		10		μA
$I_{E/\overline{S}}$ Low (output shut down)		E/$\overline{S}$ Pin Indicates Low		1		μA
Output Shutdown Time				1		μs
Output Enable Time				3		μs
Current Limit Flag Output						
Normal Operation		Sinking 10μA		0	(V–)+0.8	V
Current-Limited		Sourcing 20μA	(V–)+2	V_{DIG}		V
Thermal Shutdown						
Normal Operation		Sinking 200μA		0	(V–)+0.8	V
Thermally Shutdown(9)		Sourcing 200μA	(V–)+2	V_{DIG}		V
Junction Temperature at Shutdown(10)				+140 to +157		°C
Hysteresis(10)				15 to 19		°C
T_{SENSE}						
Diode Ideality Factor	η			1.033		

(2) Under safe operating conditions. See *Power Dissipation and Safe Operating Area* for safe operating area (SOA) information.
(3) Minimum current limit is 0.4A. See *Adjustable Current Limit* in the *Applications* section.
(4) Quiescent current increases when the current limit is increased (see Typical Characteristics).
(5) R_{SET} (current limit) can range from 55kΩ (I_{OUT} = 400mA) to 10kΩ (I_{OUT} = 1.6A typ). See *Adjustable Current Limit* in the *Applications* section.
(6) See Typical Characteristics.
(7) Transient load transition time must be ≥ 200ns.
(8) See *Enable/Shutdown (E/S) Pin* in the *Applications* section.
(9) When sourcing, the V_{DIG} supply must be able to supply the current.
(10) Characterized, but not production tested.

ELECTRICAL CHARACTERISTICS (continued)

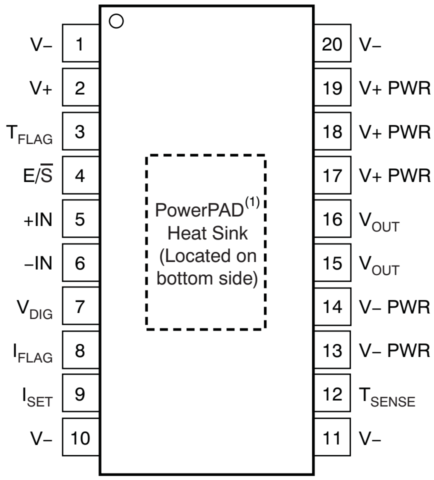
Boldface limits apply over the specified temperature range: **T_A = –40°C to +85°C.**
At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

PARAMETERS		CONDITIONS	OPA564 MIN	OPA564 TYP	OPA564 MAX	UNIT
POWER SUPPLY(11)						
Specified Voltage Range	V_S			±12		V
Operating Voltage Range			7		24	V
Quiescent Current(12)	I_Q	I_{OUT} = 0		39	50	mA
Over Temperature					**50**	**mA**
Quiescent Current in Shutdown Mode	I_{QSD}				5	mA
Specified Voltage for Digital	V_{DIG}		(V–) + 3.0		(V–) + 5.5	V
Digital Quiescent Current	I_{DIG}	V_{DIG} = 5V		43	100	μA
TEMPERATURE RANGE						
Specified Range			–40		+85	°C
Operating Range			–40		+125(13)	°C
Thermal Resistance						
HSOP-20 DWP PowerPAD (Pad Down)	θ_{JA}	High K Board		33		°C/W
	θ_{JC}			50		°C/W
	θ_{JP}			1.83		°C/W
	θ_{JB}			22		°C/W
HSOP-20 DWD PowerPAD (Pad Up)(14)	θ_{JA}	High K Board		45.5		°C/W
	θ_{JC}			6.3		°C/W
	θ_{JB}			22		°C/W

(11) Power-supply sequencing requirements must be observed. See *Power Supplies* section for more information.
(12) Quiescent current increases when the current limit is increased (see Typical Characteristics).
(13) The OPA564 typically goes into thermal shutdown at a junction temperature above +140°C.
(14) Thermal modeling of the DWD-20 package was done based on a 1-inch AAVID Thermalloy heatsink (Thermalloy part no. 65810).

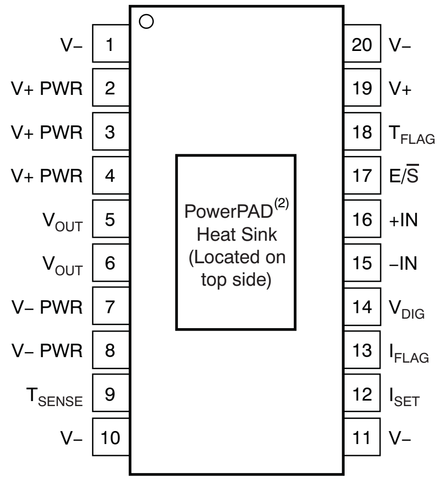
PIN CONFIGURATIONS

OPA564AIDWP
HSOP-20
PowerPAD on Bottom



(1) PowerPAD is internally connected to V–, Soldering the PowerPAD to the PCB is always required, even with applications that have low power dissipation.

OPA564AIDWD
HSOP-20
PowerPAD on Top

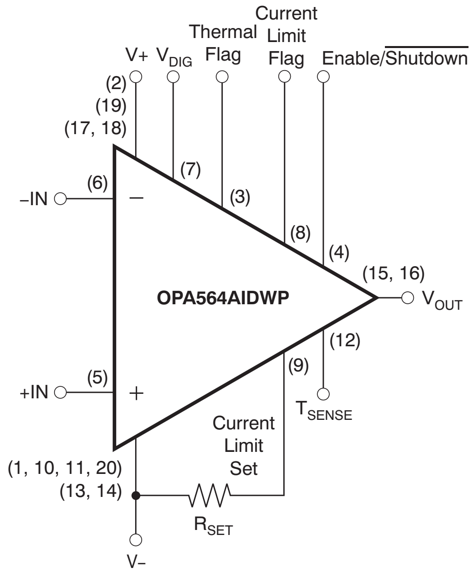


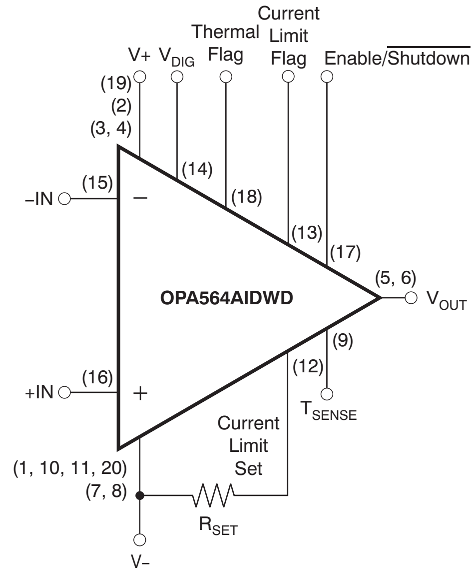
(2) PowerPAD is internally connected to V–.

PIN DESCRIPTIONS

OPA564AIDWP (PAD DOWN) PIN NO.	OPA564AIDWD (PAD UP) PIN NO.	NAME	DESCRIPTION
1, 10, 11, 20	1, 10, 11, 20	V–	–Supply for Amplifier, PWR Out, and Metal PowerPAD
2	19	V+	+Supply for Signal Amplifier
3	18	T_{FLAG}	Thermal Over Temperature Flag; flag is high when alarmed and device has gone into thermal shutdown.
4	17	$E/\overline{S}$	Enable/$\overline{\text{Shutdown}}$ Output Stage; take $E/\overline{S}$ low to shut down output
5	16	+IN	Noninverting Op Amp Input
6	15	–IN	Inverting Op Amp Input
7	14	V_{DIG}	+Supply for Digital Flag and $E/\overline{S}$ (referenced to V–). Valid Range is (V–) + 3.0V ≤ V_{DIG} ≤ (V–) + 5.5V.
8	13	I_{FLAG}	Current Limit Flag; Active High
9	12	I_{SET}	Current Limit Set (see *Applications* Section)
12	9	T_{SENSE}	Temperature Sense Pin for use with TMP411
13, 14	7, 8	V– PWR	–Supply for Power Output Stage
15, 16	5, 6	V_{OUT}	Output Voltage; R_O is high impedance when shut down
17, 18, 19	3, 4, 2	V+ PWR	+Supply for Power Output Stage

FUNCTIONAL PIN DIAGRAM





TYPICAL CHARACTERISTICS

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

QUIESCENT CURRENT vs SUPPLY VOLTAGE

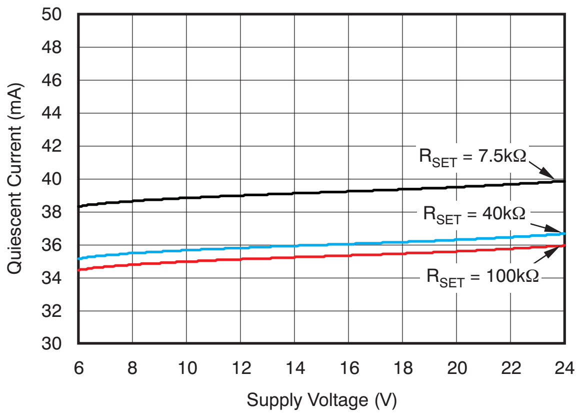


Figure 1.

OUTPUT VOLTAGE SWING vs OUTPUT CURRENT

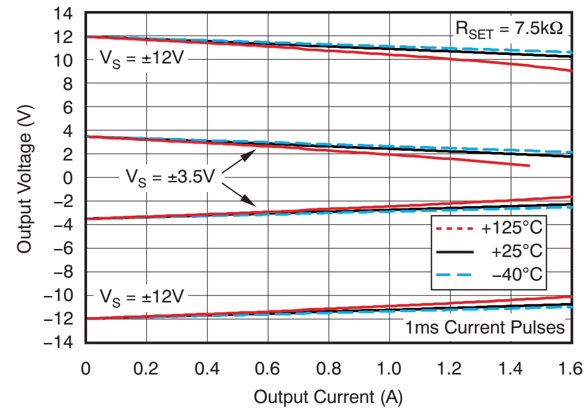


Figure 2.

LARGE−SIGNAL STEP RESPONSE, NO LOAD

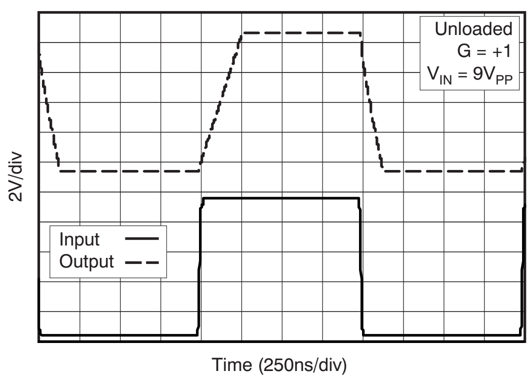


Figure 3.

LARGE−SIGNAL STEP RESPONSE

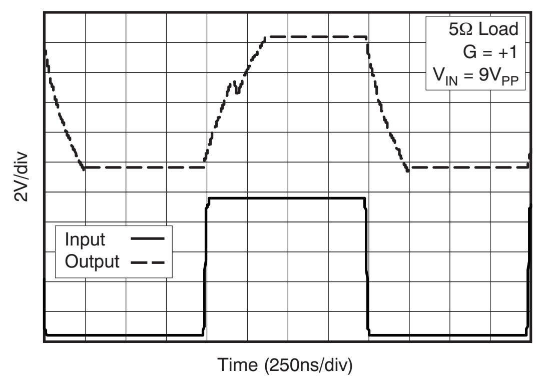


Figure 4.

SMALL−SIGNAL STEP RESPONSE

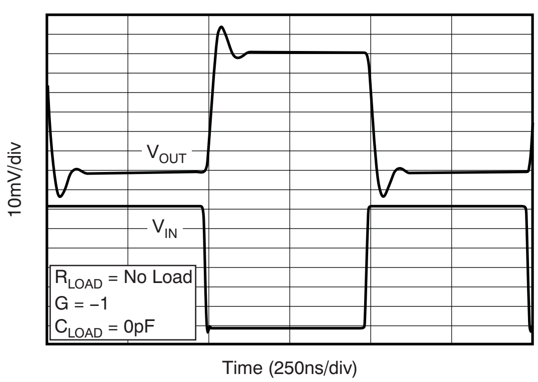


Figure 5.

SMALL−SIGNAL OVERSHOOT vs LOAD CAPACITANCE

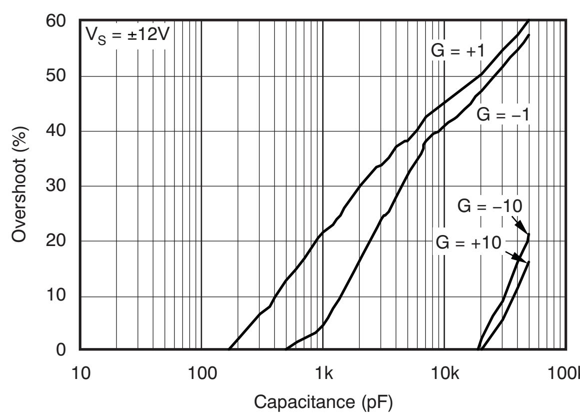


Figure 6.

TYPICAL CHARACTERISTICS (continued)

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

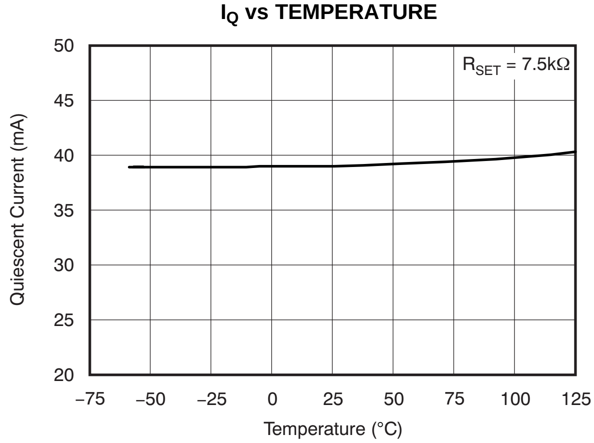


Figure 7.

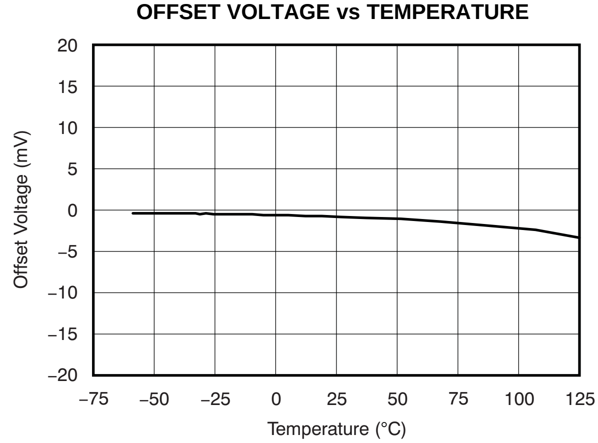


Figure 8.

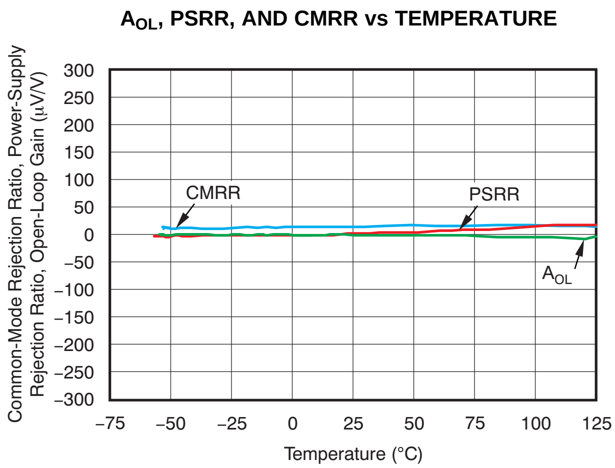


Figure 9.

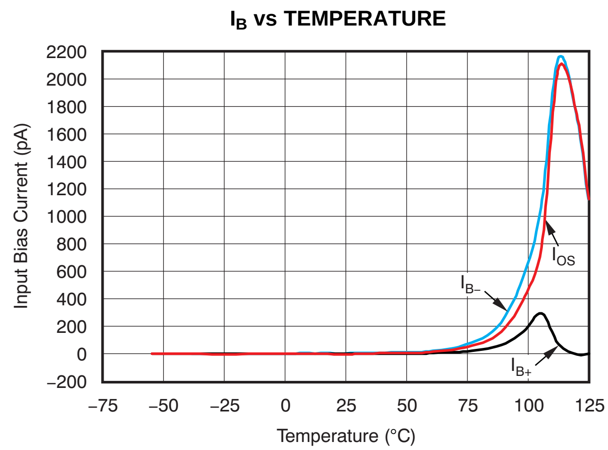


Figure 10.

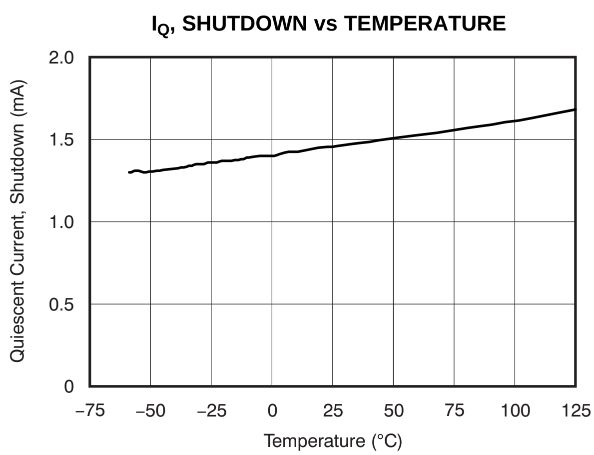


Figure 11.

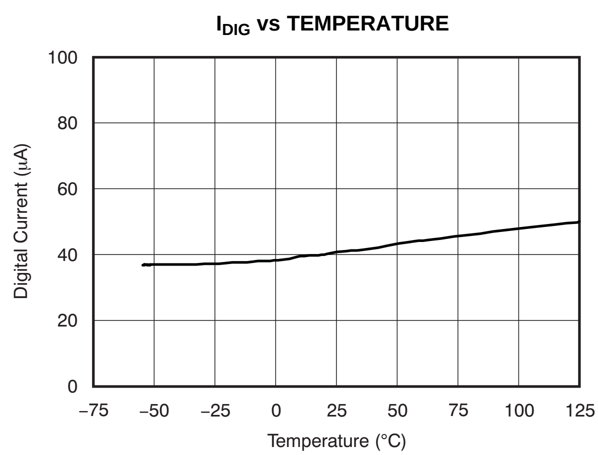


Figure 12.

TYPICAL CHARACTERISTICS (continued)

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

GAIN AND PHASE vs FREQUENCY

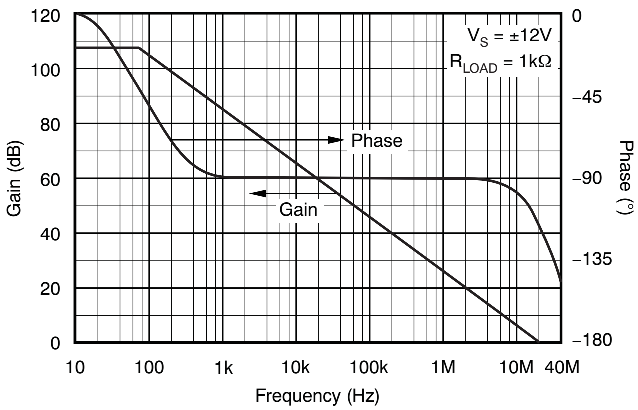


Figure 13.

COMMON-MODE REJECTION RATIO AND POWER-SUPPLY REJECTION RATIO vs FREQUENCY

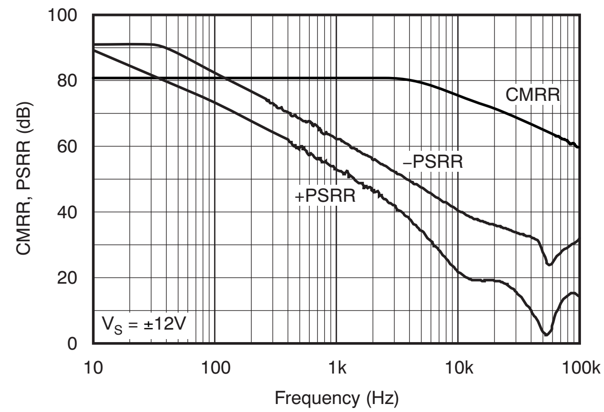


Figure 14.

OUTPUT VOLTAGE SWING vs FREQUENCY

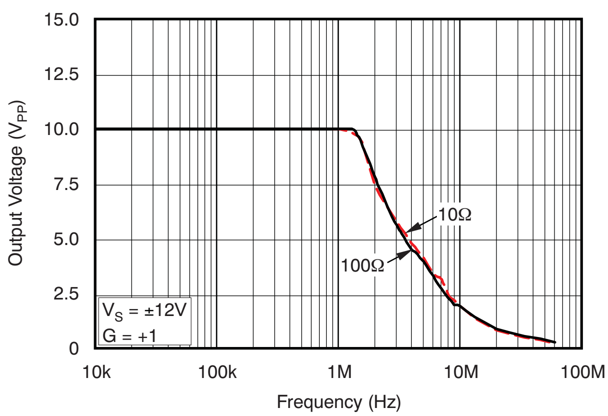


Figure 15.

OUTPUT VOLTAGE SWING vs FREQUENCY

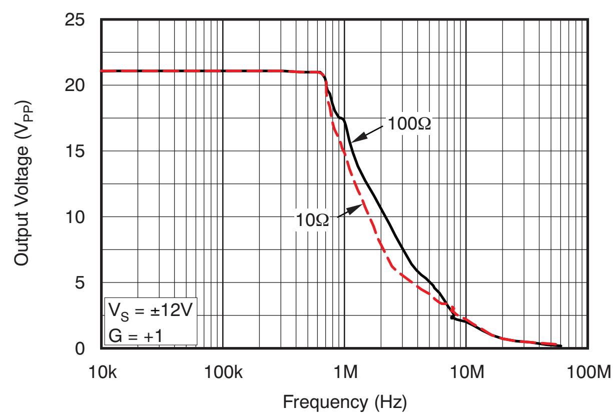


Figure 16.

TOTAL HARMONIC DISTORTION + NOISE vs AMPLITUDE

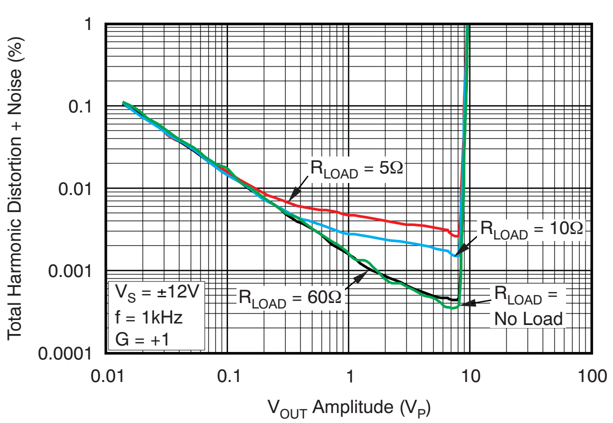


Figure 17.

TOTAL HARMONIC DISTORTION + NOISE vs AMPLITUDE

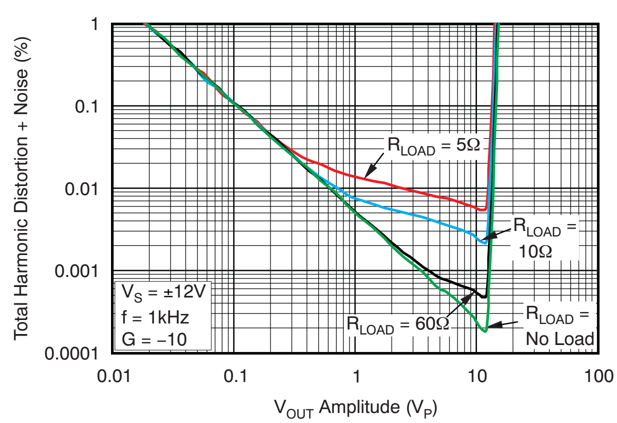


Figure 18.

TYPICAL CHARACTERISTICS (continued)

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

TOTAL HARMONIC DISTORTION + NOISE vs AMPLITUDE

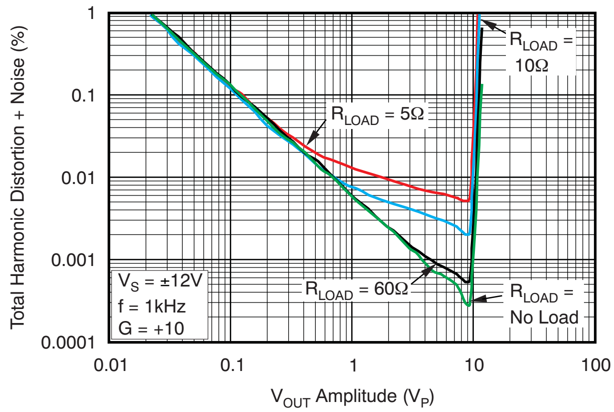


Figure 19.

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

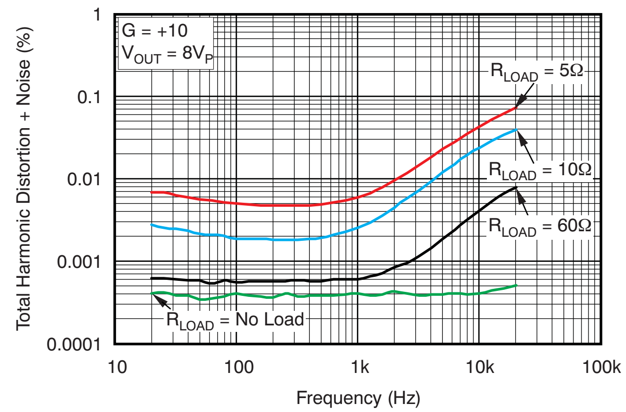


Figure 20.

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

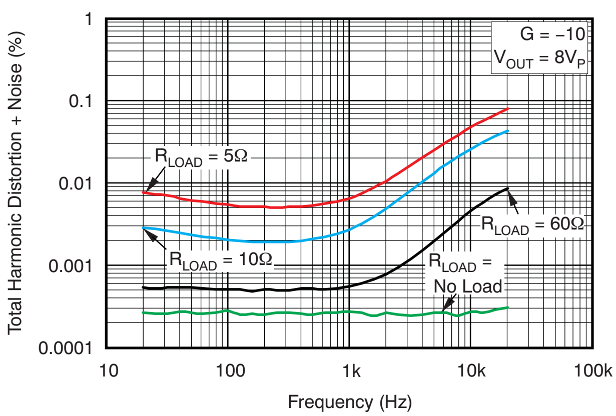


Figure 21.

TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

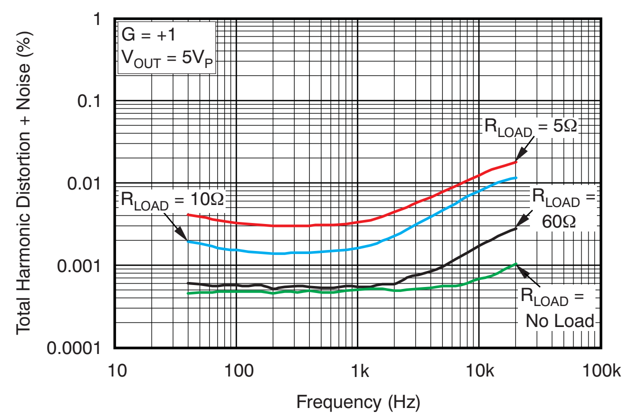


Figure 22.

INPUT VOLTAGE SPECTRAL NOISE AND CURRENT NOISE vs FREQUENCY

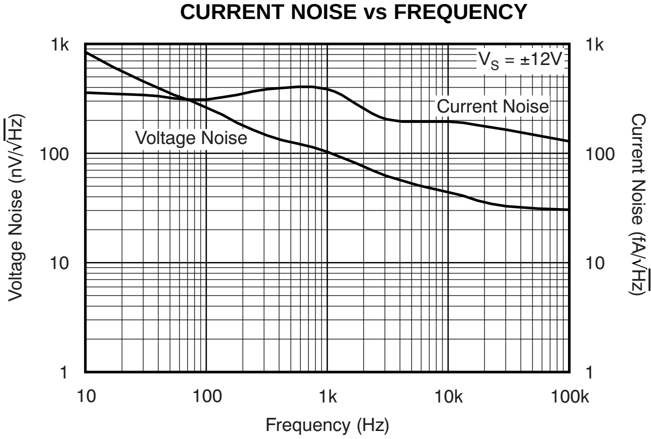


Figure 23.

OPEN-LOOP OUTPUT IMPEDANCE (No Load)

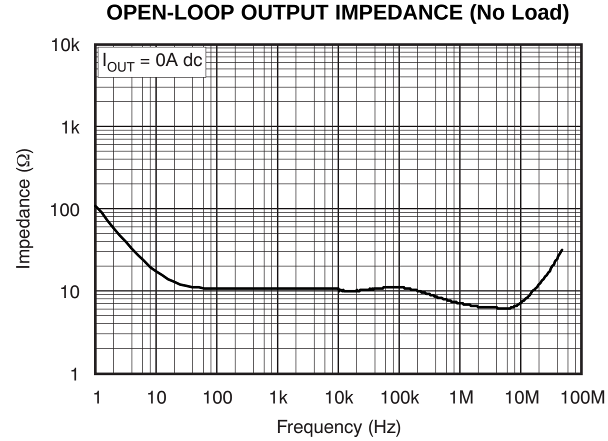


Figure 24.

TYPICAL CHARACTERISTICS (continued)

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

CLOSED-LOOP OUTPUT IMPEDANCE (No Load)

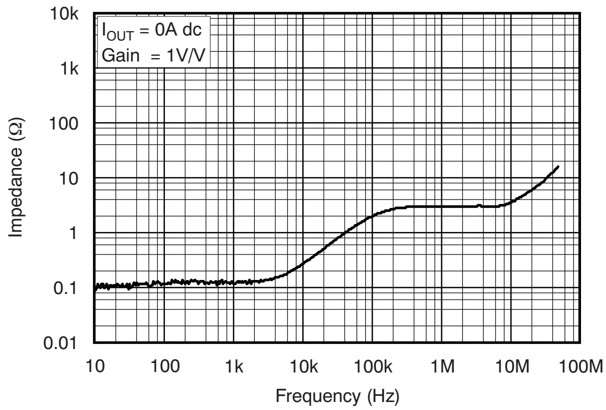


Figure 25.

INPUT BIAS CURRENT vs COMMON-MODE VOLTAGE

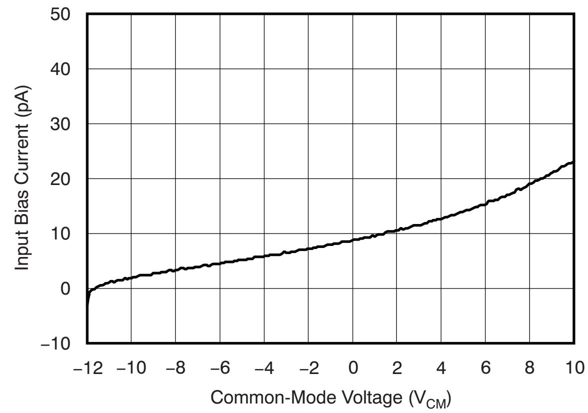


Figure 26.

ENABLE RESPONSE
R_{LOAD} = 100Ω

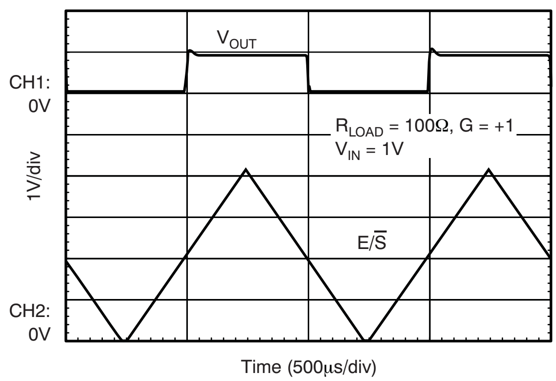


Figure 27.

SHUTDOWN TIME (INVERTING CONFIGURATION)

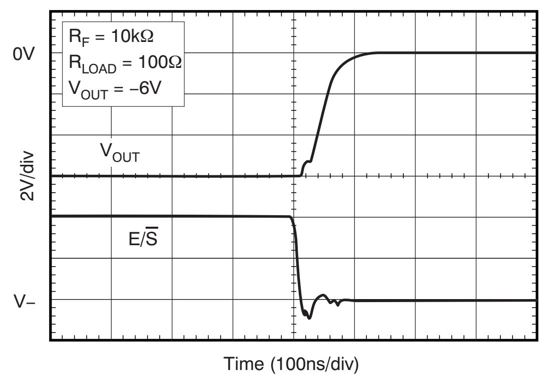


Figure 28.

ENABLE TIME (INVERTING CONFIGURATION)

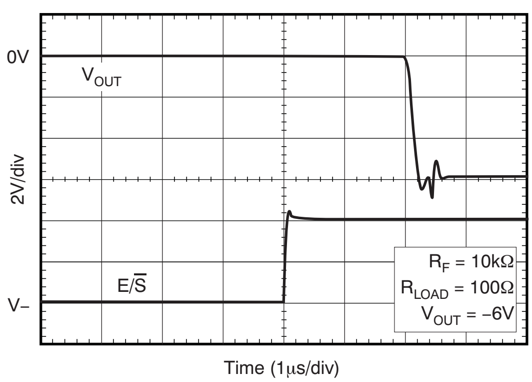


Figure 29.

CURRENT LIMIT PERCENT ERROR vs R_{SET}

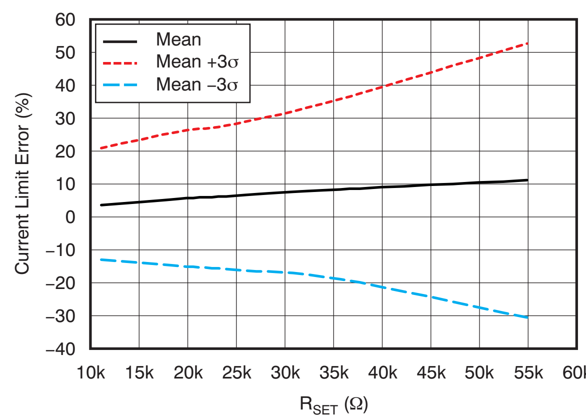


Figure 30.

TYPICAL CHARACTERISTICS (continued)

At T_{CASE} = +25°C, V_S = ±12V, R_{LOAD} = 20kΩ to GND, R_{SET} = 7.5kΩ, and E/$\overline{S}$ pin enabled, unless otherwise noted.

OUTPUT CURRENT LIMIT vs R_{SET} (SOURCING CURRENT)

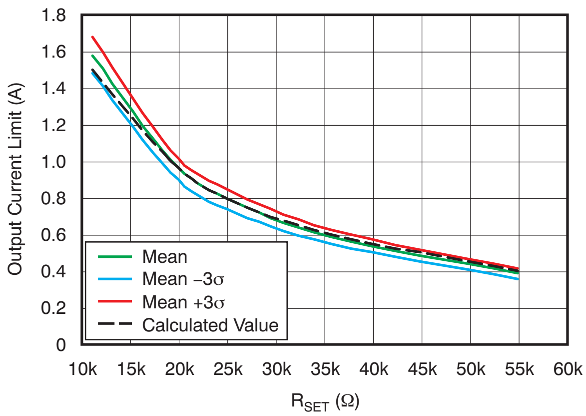


Figure 31.

OUTPUT CURRENT LIMIT vs R_{SET} (SINKING CURRENT)

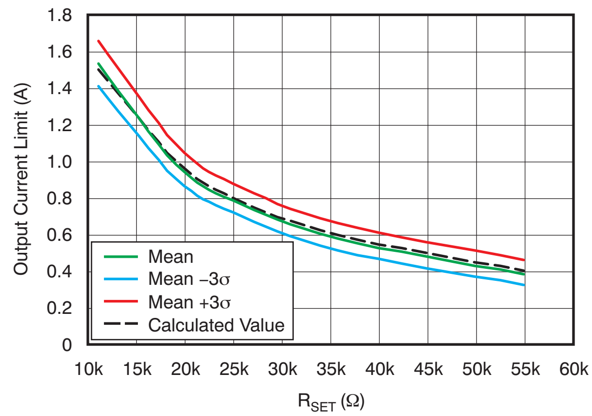


Figure 32.

QUIESCENT CURRENT INCREASE vs R_{SET}

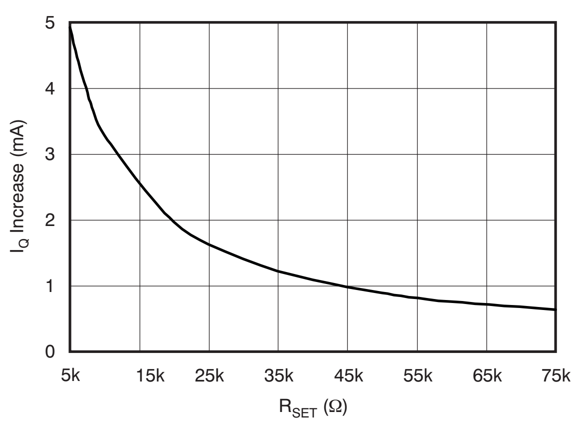


Figure 33.

OFFSET VOLTAGE PRODUCTION DISTRIBUTION

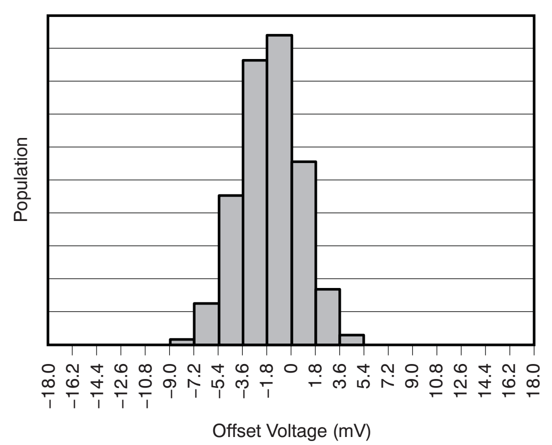


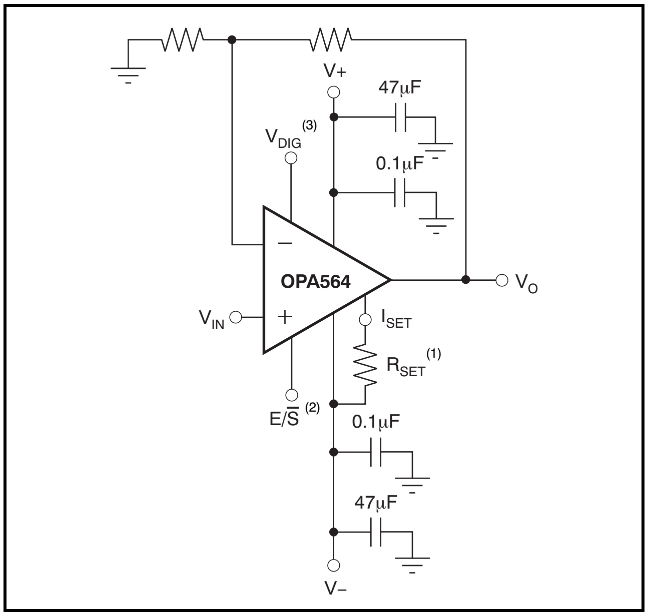
Figure 34.

APPLICATION INFORMATION

BASIC CONFIGURATION

Figure 35 shows the OPA564 connected as a basic noninverting amplifier. However, the OPA564 can be used in virtually any op amp configuration.

Power-supply terminals should be bypassed with low series impedance capacitors. The technique of using ceramic and tantalum capacitors in parallel is recommended. Power-supply wiring should have low series impedance.



(1) R_{SET} sets the current limit value from 0.4A to 1.5A.

(2) E/$\overline{S}$ pin forced low shuts down the output.

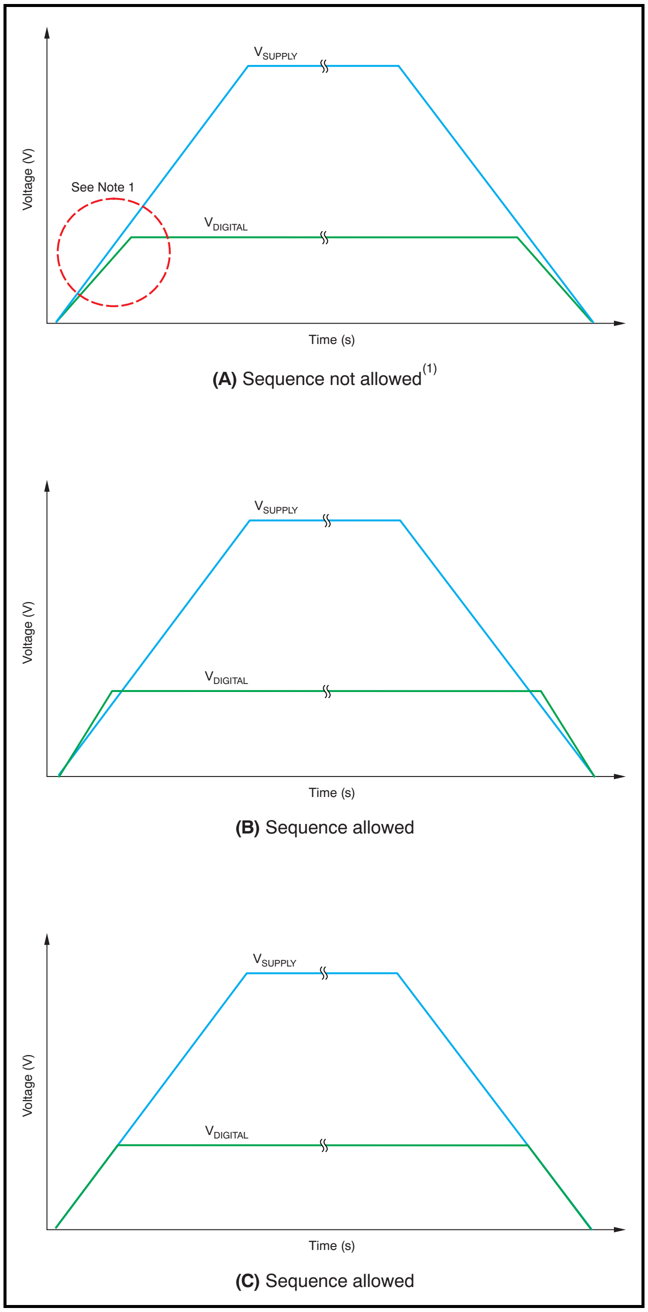
(3) V_{DIG} must not exceed (V–) + 5.5V; see Figure 56 for examples of generating a signal for V_{DIG}.

Figure 35. Basic Noninverting Amplifier

POWER SUPPLIES

The OPA564 operates with excellent performance from single (+7V to +24V) or dual (±3.5V to ±12V) analog supplies and a digital supply of +3.3V to +5.5V (referenced to the V– pin). Note that the analog power-supply voltages do not need to be symmetrical, as long as the total voltage remains below 24V. For example, the positive supply could be set to 14V with the negative supply at –10V. Most behaviors remain constant across the operating voltage range. Parameters that vary significantly with operating voltage are shown in the Typical Characteristics.

Sequencing of power supplies must assure that the digital supply voltage (V_{DIG}) be applied before the supply voltage to prevent damage to the OPA564. Figure 36 shows acceptable versus unacceptable power-supply sequencing.



(1) The power-supply sequence illustrated in (A) is not allowed. This power-supply sequence causes damage to the device.

Figure 36. Power-Supply Sequencing

ADJUSTABLE CURRENT LIMIT

The OPA564 provides over-current protection to the load through its accurate, user-adjustable current limit (I_{SET} pin). The current limit value, I_{LIM}, can be set from 0.4A to 1.5A by controlling the current through the I_{SET} pin. Setting the current limit does not require special power resistors. The output current does not flow through the I_{SET} pin.

A simple resistor to the negative rail is sufficient for a general, coarse limit of the output current. Figure 30 exhibits the percent of error in the transfer function between I_{SET} and I_{OUT} versus the current limit set resistor, R_{SET}; Figure 31 and Figure 32 show how this error translates to variation in I_{OUT} versus R_{SET}. The dotted line represents the ideal output current setting which is determined by the following equation:

$$I_{LIM} \cong 20000 \times \left[\frac{1.2V}{5000 + R_{SET}}\right] \tag{1}$$

The mismatch errors between the current limit set mirror and the output stage are primarily a result of variations in the ~1.2V bandgap reference, an internal 5kΩ resistor, the mismatch between the current limit and the output stage mirror, and the tolerance and temperature coefficient of the R_{SET} resistor referenced to the negative rail. Additionally, an increase in junction temperature can induce added mismatch in accuracy between the I_{SET} and I_{OUT} mirror. See Figure 53 for a method that can be used to dynamically change the current limit setting using a simple, zero drift current source. This approach simplifies the current limit equation to the following:

$$I_{LIM} \cong 20{,}000 \times I_{SET} \tag{2}$$

The current into the I_{SET} pin is determined by the NPN current source. Therefore, the errors contributed by the internal 1.2V bandgap reference and the 5kΩ resistor mismatch are eliminated, thus improving the overall accuracy of the transfer function. In this case, the primary source of error in I_{SET} is the R_{SET} resistor tolerance and the beta of the NPN transistor.

It is important to note that the primary intent of the current limit on the OPA564 is coarse protection of the output stage; therefore, the user should exercise caution when attempting to control the output current by dynamically toggling the current limit setting. Predictable performance is better achieved by controlling the output voltage through the feedback loop of the OPA564.

Setting the Current Limit

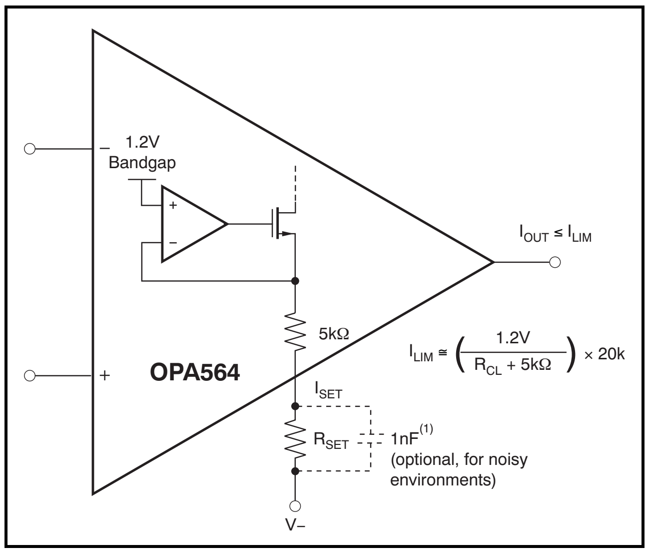
Leaving the I_{SET} pin unconnected damages the device. Connecting I_{SET} directly to V– is not recommended because it programs the current limit far beyond the 1.5A capability of the device and causes excess power dissipation. The minimum recommended value for R_{SET} is 7.5kΩ, which programs the maximum current limit to approximately 1.9A. The maximum value for R_{SET} is 55kΩ, which programs the minimum current limit to approximately 0.4A. The simplest method for adjusting the current limit (I_{LIM}) uses a resistor or potentiometer connected between the I_{SET} pin and V–, according to Equation 1.

If I_{LIM} has been defined, R_{SET} can be solved by rearranging Equation 1 into Equation 3:

$$R_{SET} \cong \left[\frac{24k\Omega}{I_{LIM}}\right] - 5k\Omega \tag{3}$$

R_{SET} in combination with a 5kΩ internal resistor determines the magnitude of a small current that sets the desired output current limit.

Figure 37 shows a simplified schematic of the OPA564 current limit architecture.



(1) At power-on, this capacitor is not charged. Therefore, the OPA564 is programmed for maximum output current. Capacitor values > 1nF are not recommended.

Figure 37. Adjustable Current Limit

ENABLE/SHUTDOWN (E/S) PIN

The output of the OPA564 shuts down when the E/S pin is forced low. For normal operation (output enabled), the E/S pin must be pulled high (at least 2V above V–). To enable the OPA564 permanently, the E/S pin can be left unconnected. The E/S pin has an internal 100kΩ pull-up resistor. When the output is shut down, the output impedance of the OPA564 is 6GΩ || 120pF. The output shutdown output voltage versus output current is shown in Figure 42. Although the output is high-impedance when shut down, there is still a path through the feedback network into the input stage to ground; see Figure 43. To prevent damage to the OPA564, ensure that the voltage across the input terminals +IN and –IN does not exceed 0.5V, and that the current flowing through the input terminals does not exceed 10mA when operated beyond the supply rails, V– and V+. Refer to the *Input Protection* section.

Input Protection

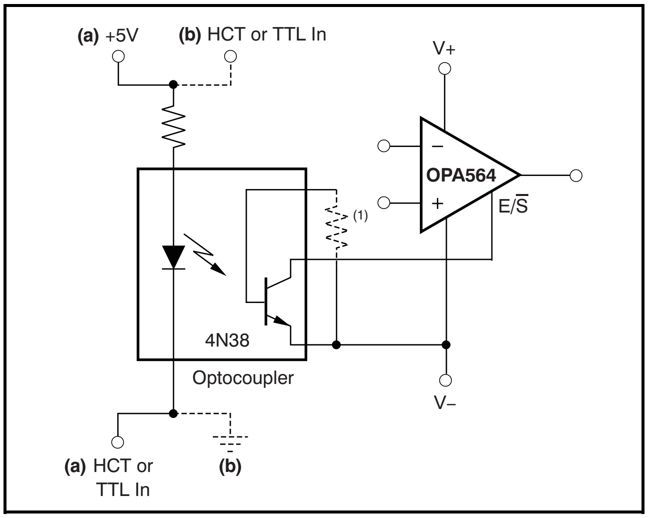
Electrostatic discharge (ESD) protection followed by back-to-back diodes and input resistors (see Figure 43) are used for input protection on the OPA564. Exceeding the turn-on threshold of these diodes, as in a pulse condition, can cause current to flow through the input protection diodes because of the finite slew rate of the amplifier. If the input current is not limited, the back-to-back diodes and the input devices can be destroyed. Sources of high input current can also cause subtle damage to the amplifier. Although the unit may still be functional, important parameters such as input offset voltage, drift, and noise may shift.

When using the OPA564 as a unity-gain buffer (follower), as an inverting amplifier, or in shutdown mode, the input voltage between the input terminals (+IN and –IN) must be limited so that the voltage does not exceed 0.5V. This condition must be maintained across the entire common-mode range from V– to V+. If the inputs are taken above either supply rail, the current must be limited to 10mA through the ESD protection diodes. During excursions past the rails, it is still necessary to limit the voltage across the input terminals. If necessary, external back-to-back diodes should be added between +IN and –IN to maintain the 0.5V requirement between these connections.

Output Shutdown

The shutdown pin (E/S) is referenced to the negative supply (V–). Therefore, shutdown operation is slightly different in single-supply and dual-supply applications. In single-supply operation, V– typically equals common ground. Therefore, the shutdown logic signal and the OPA564 shutdown pin are referenced to the same potential. In this configuration, the logic pin and the OPA564 enable can simply be connected together. Shutdown occurs for voltage levels of less than 0.8V. The OPA564 is enabled at logic levels greater than 2V. In dual-supply operation, the logic pin remains referenced to a logic ground. However, the shutdown pin of the OPA564 continues to be referenced to V–.

Thus, in a dual-supply system, to shut down the OPA564 the voltage level of the logic signal must be level-shifted by some means. One way to shift the logic signal voltage level is by using an optocoupler, as Figure 38 shows.



(1) Optional; may be required to limit leakage current of optocoupler at high temperatures.

Figure 38. Shutdown Configuration for Dual Supplies (Using Optocoupler)

To shut down the output, the E/S pin is pulled low, no greater than 0.8V above V–. This function can be used to conserve power during idle periods. To return the output to an enabled state, the E/S pin should be pulled to at least 2.0V above V–. Figure 27 shows the typical enable and shutdown response times. It should be noted that the E/S pin does not affect the internal thermal shutdown.

When the OPA564 will be used in applications where the device shuts down, special care should be taken with respect to input protection. Consider the following two examples.

Figure 39 shows the amplifier in a follower configuration. The load is connected midway between the supplies, V+ and V–.

When the device shuts down in this situation, the load pulls V_{OUT} to ground. Little or no current then flows through the input of the OPA564.

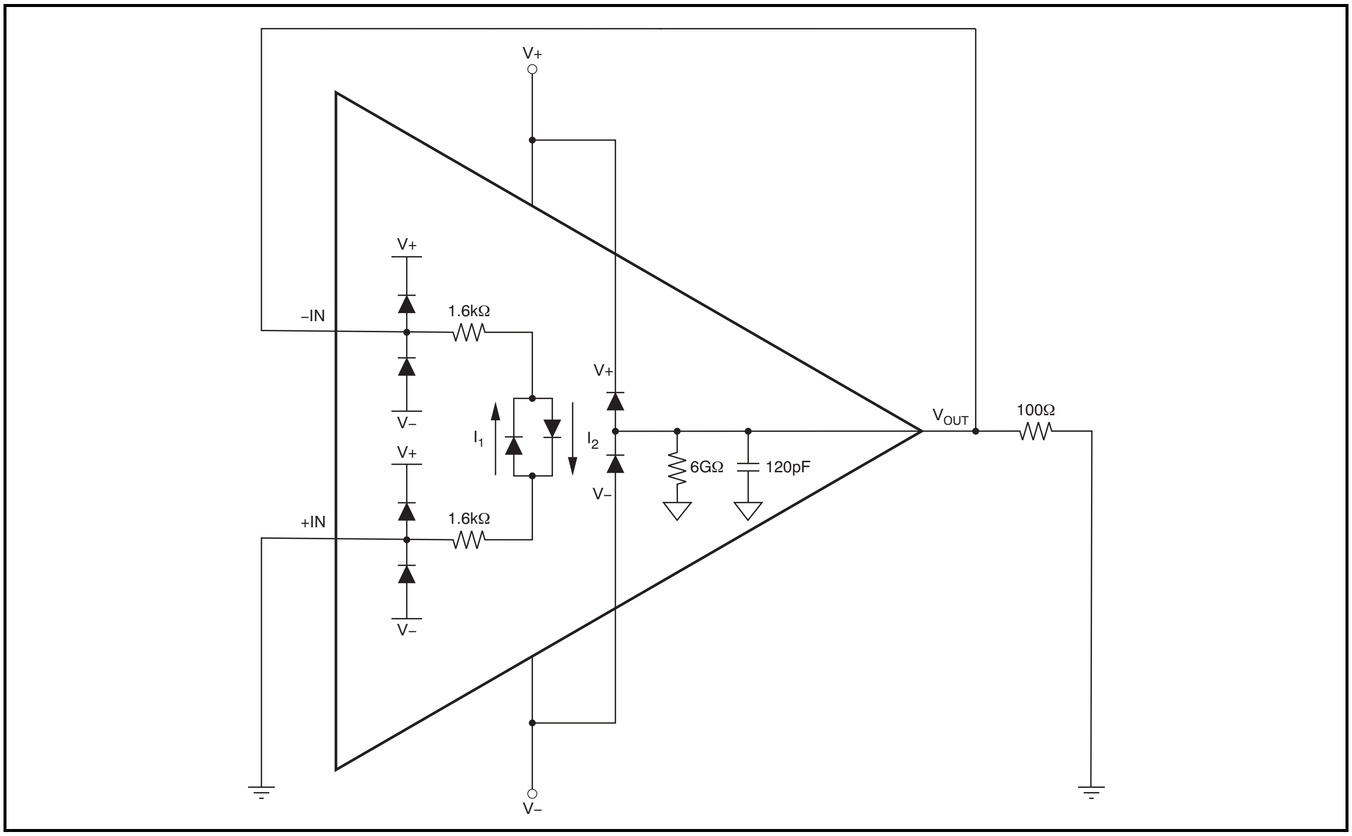


Figure 39. Shutdown Equivalent Circuit with Load Connected Midway Between Supplies

Now consider Figure 40. Here, the load is connected to V–. When the device shuts down, current flows from the positive input +IN through the first 1.6kΩ resistor through an input protection diode, then through the second 1.6kΩ resistor, and finally through the 100Ω resistor to V–.

This current flow produces a voltage across the inputs which is much greater than 0.5V, which damages the OPA564. A similar problem would occur if the load is connected to the positive supply.

CAUTION

This configuration damages the device.

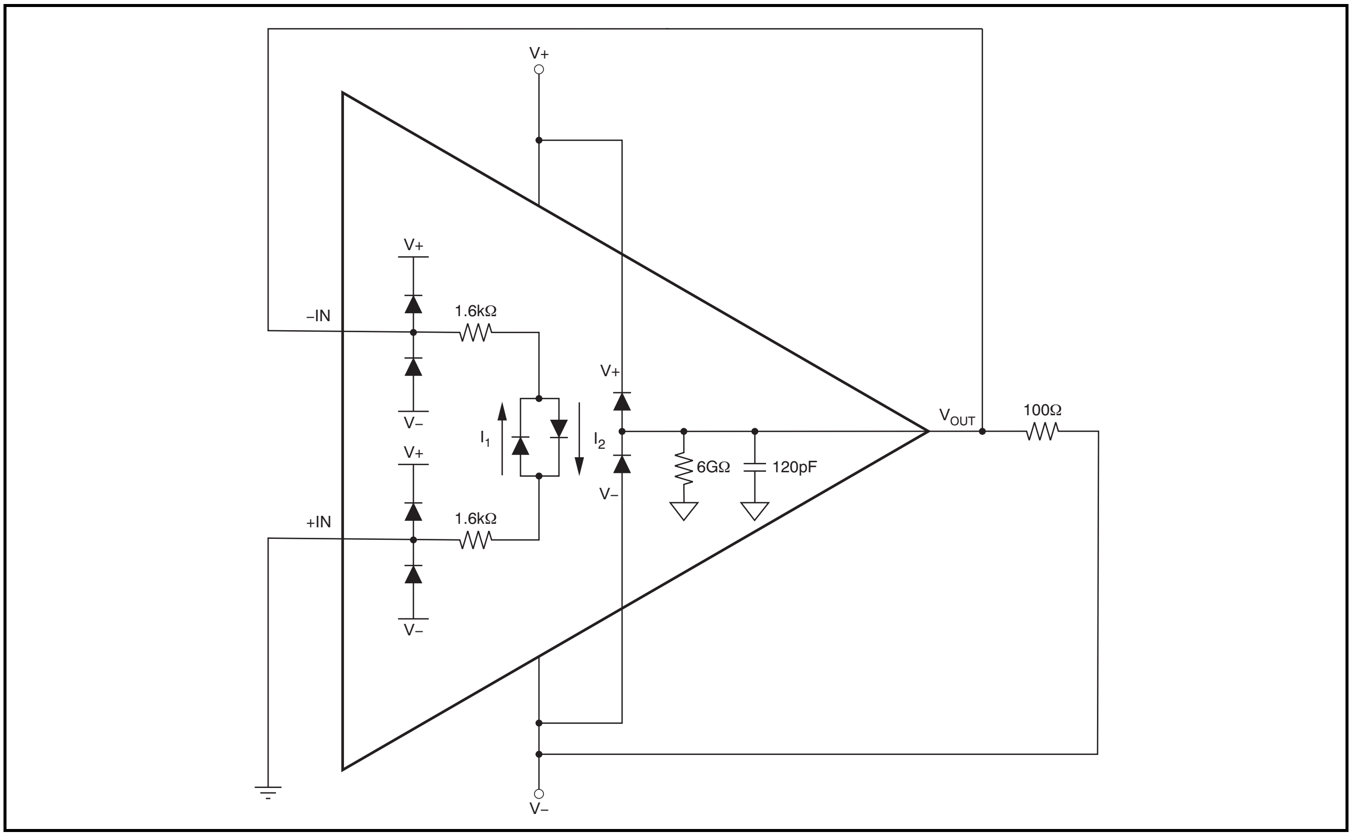


Figure 40. Shutdown Equivalent Circuit with Load Connected to V–: Voltage Across Inputs During DIsable Exceeds Input Requirements

The solution is to place external protection diodes across the OPA564 input. Figure 41 illustrates this configuration.

NOTE

This configuration protects the input during shutdown.

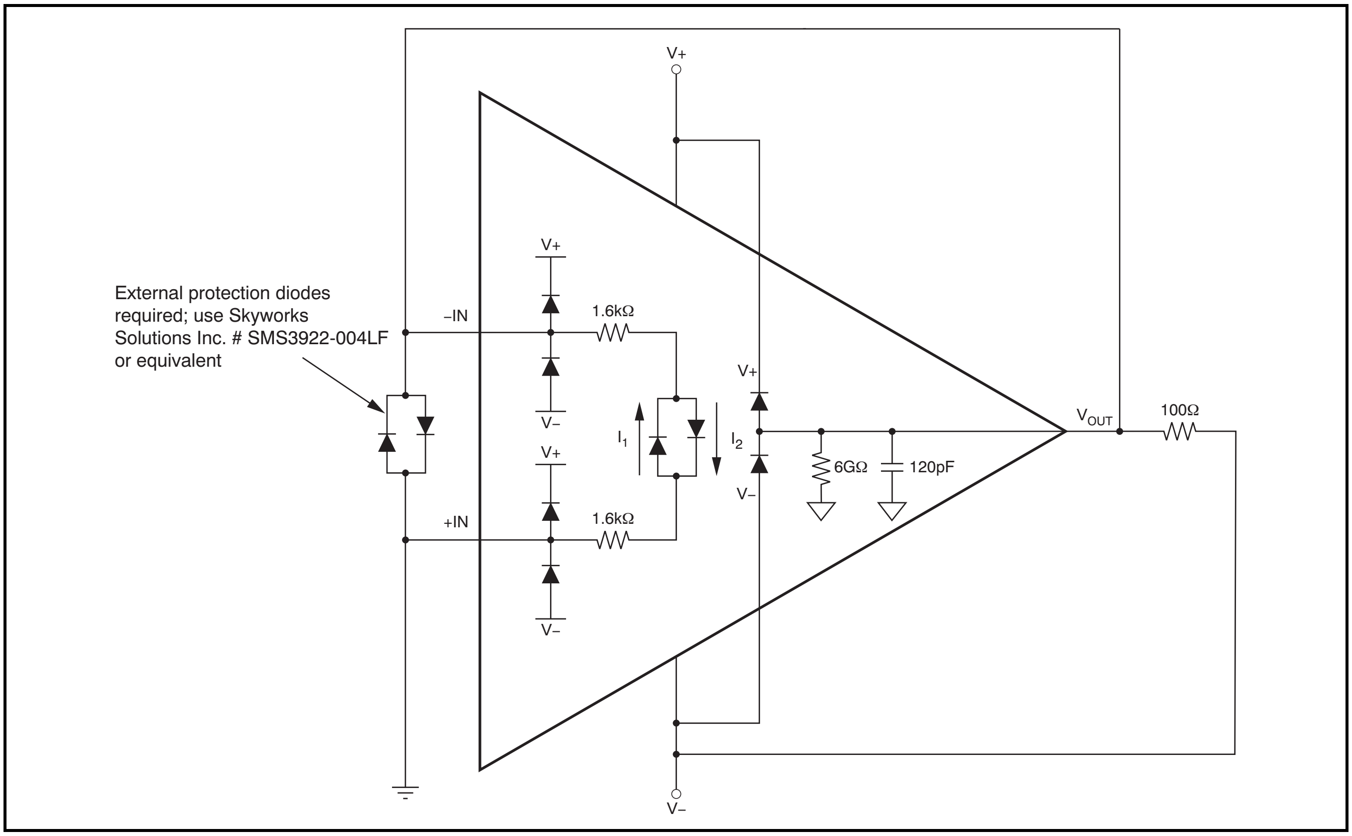


Figure 41. Shutdown Equivalent Circuit with Load Connected to V–: Protected Input Configuration

Ensuring Microcontroller Compatibility

Not all microcontrollers output the same logic state after power-up or reset. 8051-type microcontrollers, for example, output logic high levels while other models power up with logic low levels after reset. In the configuration of Figure 38**(a)**, the shutdown signal is applied on the cathode side of the photodiode within the optocoupler. A high logic level causes the OPA564 to be enabled, and a low logic level shuts the OPA564 down. In the configuration of Figure 38**(b)**, with the logic signal applied on the anode side, a high level causes the OPA564 to shut down, and a low level enables the op amp.

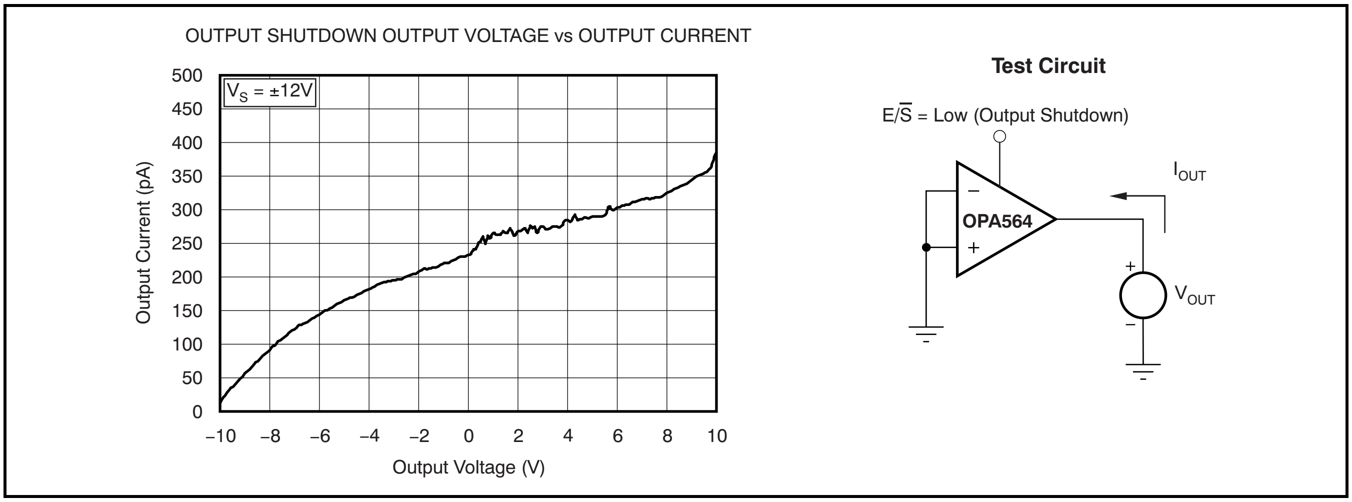


Figure 42. Output Shutdown Output Impedance

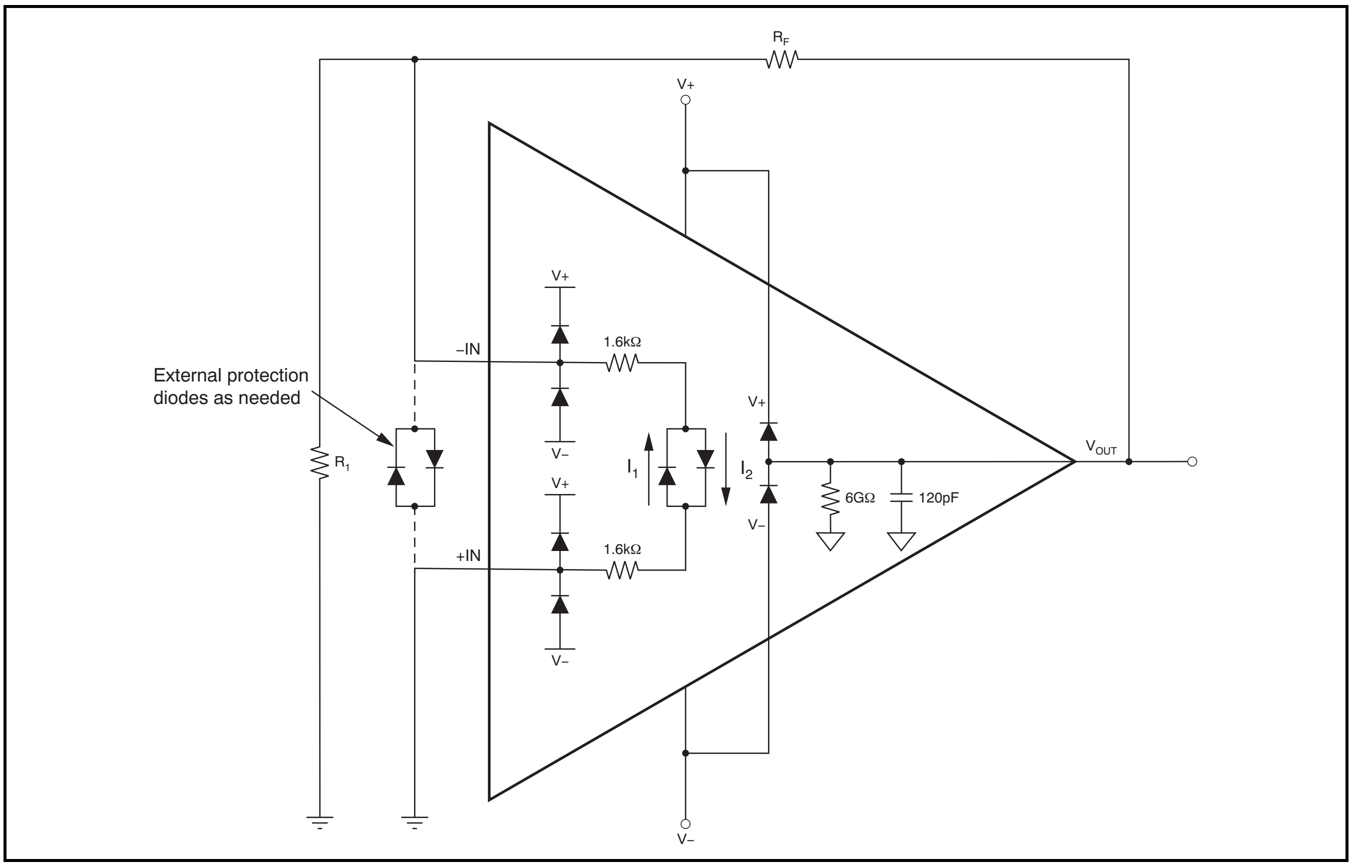


Figure 43. OPA564: Output Shutdown Equivalent Circuit (with External Feedback)

CURRENT LIMIT FLAG

The OPA564 features a current limit flag (I_{FLAG}) that can be monitored to determine if the load current is operating within or exceeding the current limit set by the user. The output signal of I_{FLAG} is compatible with standard CMOS logic and is referenced to the negative supply pin (V–). A voltage level of + 0.8V or less with respect to V– indicates that the amplifier is operating within the limits set by the user. A voltage level of +2.0V or greater with respect to V– indicates that the OPA564 is operating above (exceeds) the current limit set by the user. See *Setting the Current Limit* for proper current limit operation.

OUTPUT STAGE COMPENSATION

The complex load impedances common in power op amp applications can cause output stage instability. For normal operation, output compensation circuitry is typically not required. However, if the OPA564 is intended to be driven into current limit, an R/C network (snubber) may be required. A snubber circuit such as the one shown in Figure 54 may also enhance stability when driving large capacitive loads (greater than 1000pF) or inductive loads (for example, motors or loads separated from the amplifier by long cables). Typically, 3Ω to 10Ω in series with 0.01μF to 0.1μF is adequate. Some variations in circuit value may be required with certain loads.

OUTPUT PROTECTION

The output structure of the OPA564 includes ESD diodes (see Figure 43). Voltage at the OPA564 output must not be allowed to go more than 0.4V beyond either supply rail to avoid damaging the device. Reactive and electromagnetic field (EMF)-generation loads can return load current to the amplifier, causing the output voltage to exceed the power-supply voltage. This damaging condition can be avoided with clamping diodes from the output terminal to the power supplies, as Figure 54 and Figure 55 illustrate. Schottky rectifier diodes with a 3A or greater continuous rating are recommended.

THERMAL PROTECTION

The OPA564 has thermal sensing circuitry that helps protect the amplifier from exceeding temperature limits. Power dissipated in the OPA564 causes the junction temperature to rise. Internal thermal shutdown circuitry disables the output when the die temperature reaches the thermal shutdown temperature limit. The OPA564 output remains shut down until the die has cooled sufficiently; see the Electrical Characteristics, *Thermal Shutdown* section.

Depending on load and signal conditions, the thermal protection circuit may cycle on and off. This cycling limits the amplifier dissipation, but may have undesirable effects on the load. Any tendency to activate the thermal protection circuit indicates excessive power dissipation or an inadequate heatsink. For reliable, long-term, continuous operation, with I_{OUT} at the maximum output of 1.5A, the junction temperature should be limited to +85°C maximum. Figure 44 shows the maximum output current versus junction temperature for dc and RMS signal outputs. To estimate the margin of safety in a complete design (including heatsink), increase the ambient temperature until the thermal protection triggers. Use worst-case loading and signal conditions. For good, long-term reliability, thermal protection should trigger more than 35°C above the maximum expected ambient condition of the application.

The internal protection circuitry of the OPA564 was designed to protect against overload conditions; it was not intended to replace proper heatsinking. Continuously running the OPA564 into thermal shutdown degrades reliability.

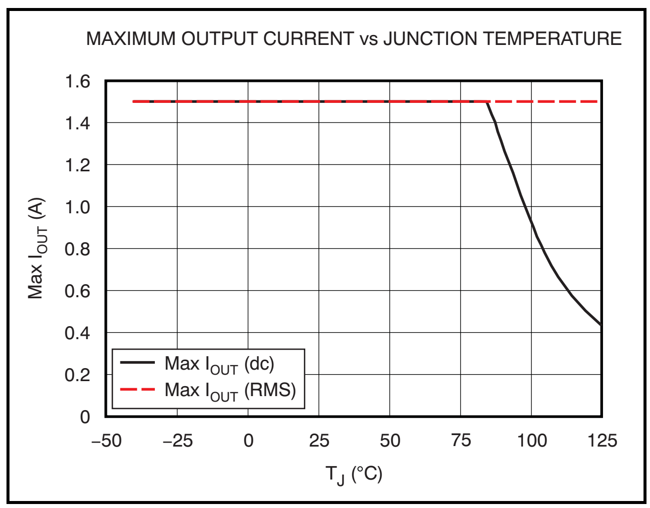


Figure 44. Maximum Output Current vs Junction Temperature

USING T_{SENSE} FOR MEASURING JUNCTION TEMPERATURE

The OPA564 includes an internal diode for junction temperature monitoring. The η-factor of this diode is 1.033. Measuring the OPA564 junction temperature can be accomplished by connecting the T_{SENSE} pin to a remote-junction temperature sensor, such as the TMP411 (see Figure 57).

POWER DISSIPATION AND SAFE OPERATING AREA

Power dissipation depends on power supply, signal, and load conditions. For dc signals, power dissipation is equal to the product of output current (I_{OUT}) and the voltage across the conducting output transistor [(V+) – V_{OUT} when sourcing; V_{OUT} – (V–) when sinking]. Dissipation with ac signals is lower. Application Bulletin AB-039, *Power Amplifier Stress and Power Handling Limitations* (SBOA022, available for download from www.ti.com) explains how to calculate or measure power dissipation with unusual signals and loads.

Figure 45 shows the safe operating area at room temperature with various heatsinking efforts. Note that the safe output current decreases as (V+) – V_{OUT} or V_{OUT} – (V–) increases. Figure 46 shows the safe operating area at various temperatures with the PowerPAD being soldered to a 2oz copper pad.

The power that can be safely dissipated in the package is related to the ambient temperature and the heatsink design. The PowerPAD package was specifically designed to provide excellent power dissipation, but board layout greatly influences the heat dissipation of the package. Refer to the *Thermally-Enhanced PowerPAD Package* section for further details.

The relationship between thermal resistance and power dissipation can be expressed as:

$T_J = T_A + T_{JA}$

$T_{JA} = P_D \times \theta_{JA}$

Combining these equations produces:

$T_J = T_A + P_D \times \theta_{JA}$

where:

T_J = Junction temperature (°C)

T_A = Ambient temperature (°C)

θ_{JA} = Junction-to-ambient thermal resistance (°C/W)

P_D = Power dissipation (W)

To determine the required heatsink area, required power dissipation should be calculated and the relationship between power dissipation and thermal resistance should be considered to minimize shutdown conditions and allow for proper long-term operation (junction temperature of +85°C or less).

Once the heatsink area has been selected, worst-case load conditions should be tested to ensure proper thermal protection.

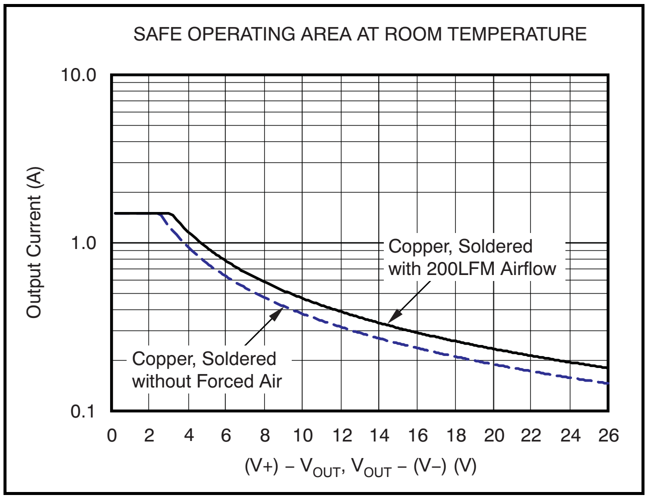
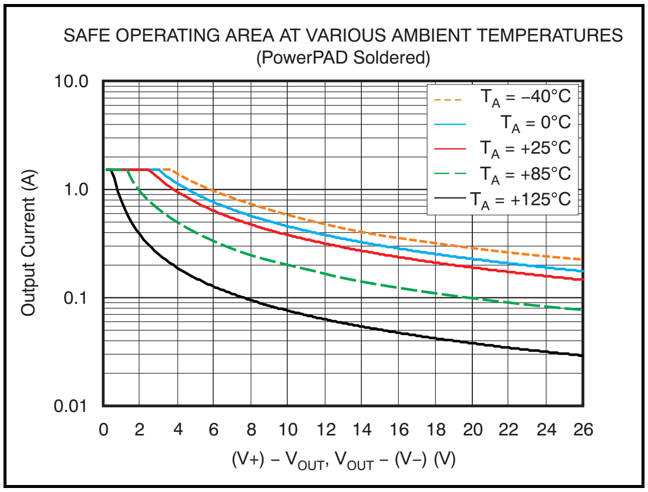


Figure 45. Safe Operating Area at Room Temperature



PowerPAD soldered to a 2oz copper pad.

Figure 46. Safe Operating Area at Various Ambient Temperatures

For applications with limited board size, refer to Figure 47 for the approximate thermal resistance relative to heatsink area. Increasing heatsink area beyond $2in^2$ provides little improvement in thermal resistance. To achieve the 33°C/W shown in the Electrical Characteristics, a 2oz copper plane size of $9in^2$ was used. The PowerPAD package is well-suited for continuous power levels from 2W to 4W, depending on ambient temperature and heatsink area. The addition of airflow also influences maximum power dissipation, as Figure 48 illustrates. Higher power levels may be achieved in applications with a low on/off duty cycle, such as remote meter reading.

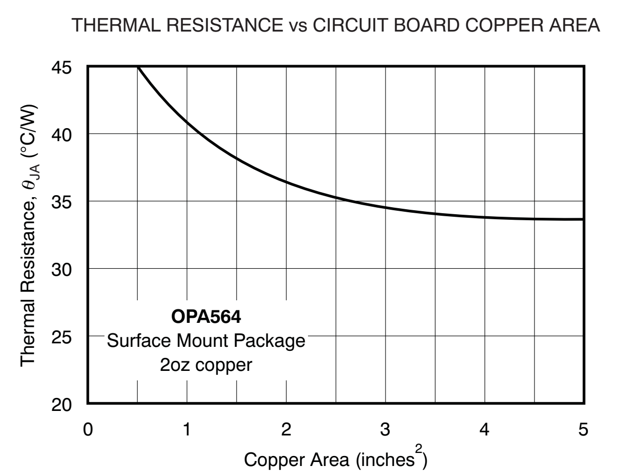


Figure 47. Thermal Resistance vs Circuit Board Copper Area

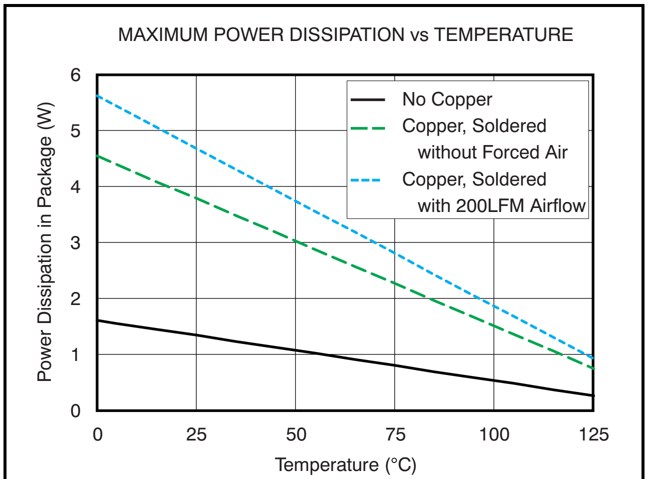


Figure 48. Maximum Power Dissipation vs Temperature

THERMALLY-ENHANCED PowerPAD PACKAGE

The OPA564 uses the HSOP-20 PowerPAD DWP and DWD packages, which are thermally-enhanced, standard size IC packages. These packages enhance power dissipation capability significantly and can be easily mounted using standard printed circuit board (PCB) assembly techniques, and can be removed and replaced using standard repair procedures.

The DWP PowerPAD package is designed so that the leadframe die pad (or thermal pad) is exposed on the bottom of the IC, as shown in Figure 49**a**; the DWD PowerPAD package has the exposed pad on the top side of the package, as shown in Figure 49**b**. The thermal pad provides an extremely low thermal resistance (θ_{JC}) path between the die and the exterior of the package.

PowerPAD packages with exposed pad down are designed to be soldered directly to the PCB, using the PCB as a heatsink. Texas Instruments does not recommend the use of the of a PowerPAD package without soldering it to the PCB because of the risk of lower thermal performance and mechanical integrity. In addition, through the use of thermal vias, the bottom-side thermal pad can be directly connected to a power plane or special heatsink structure designed into the PCB. The PowerPAD should be at the same voltage potential as V–. Soldering the bottom-side PowerPAD to the PCB is always required, even with applications that have low power dissipation. It provides the necessary thermal and mechanical connection between the leadframe die and the PCB.

Pad-up PowerPAD packages should have appropriately designed heatsinks attached. Because of the variation and flexible nature of this type of heat sink, additional details should come from the specific manufacturer of the heatsink.

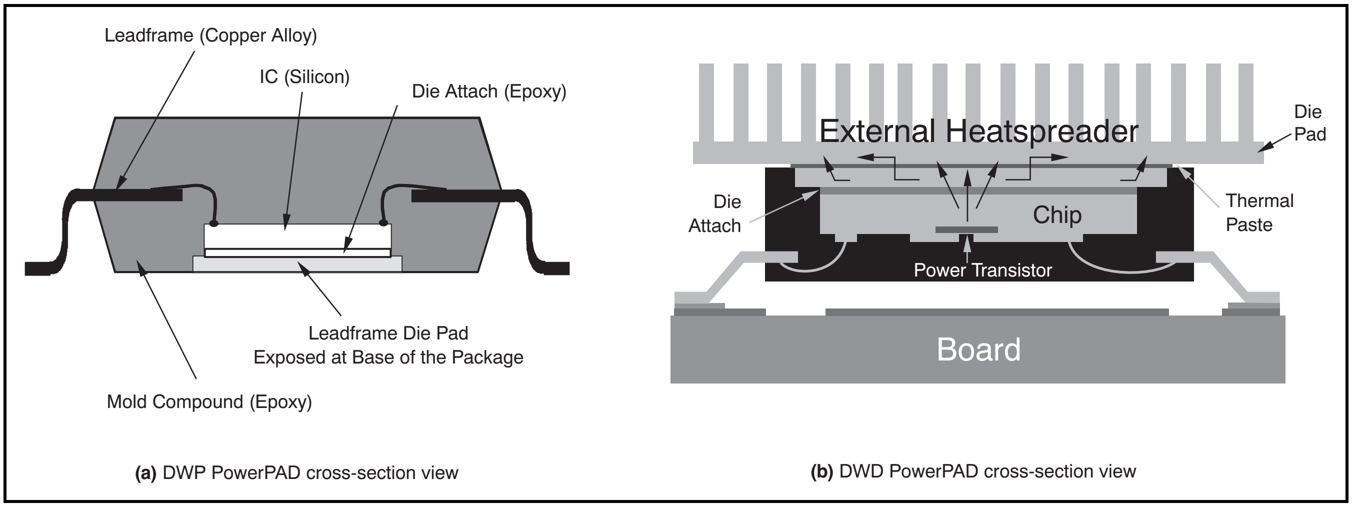


Figure 49. Cross-Section Views

Bottom-Side PowerPAD Assembly Process

1. The PowerPAD must be connected to the most negative supply of the device, V–.
2. Prepare the PCB with a top side etch pattern, as shown in the attached thermal land pattern mechanical drawing. There should be etch for the leads as well as etch for the thermal land.
3. Place the recommended number of holes (or thermal vias) in the area of the thermal pad, as seen in the attached thermal land pattern mechanical drawing. These holes should be 13mils (.013in, or 330.2μm) in diameter. They are kept small so that solder wicking through the holes is not a problem during reflow.
4. It is recommended, but not required, to place a small number of the holes under the package and outside the thermal pad area. These holes provide an additional heat path between the copper land and ground plane and are 25mils (.025in, or 635μm) in diameter. They may be larger because they are not in the area to be soldered, so wicking is not a problem. This configuration is illustrated in the attached thermal land pattern mechanical drawing.
5. Connect all holes, including those within the thermal pad area and outside the pad area, to the internal plane that is at the same voltage potential as V–.
6. When connecting these holes to the internal plane, do not use the typical web or spoke via connection methodology (as Figure 50 shows). Web connections have a high thermal resistance connection that is useful for slowing the heat transfer during soldering operations. This configuration makes the soldering of vias that have plane connections easier. However, in this application, low thermal resistance is desired for the most efficient heat transfer. Therefore, the holes under the PowerPAD package should be connected to the internal plane with a complete connection around the entire circumference of the plated through-hole.
7. The top-side solder mask should leave exposed the terminals of the package and the thermal pad area. The thermal pad area should leave the 13mil holes exposed. The larger 25mil holes outside the thermal pad area should be covered with solder mask.
8. Apply solder paste to the exposed thermal pad area and all of the package terminals.
9. With these preparatory steps completed, the PowerPAD IC is simply placed in position and run through the solder reflow operation as any standard surface-mount component. This processing results in a part that is properly installed.

For detailed information on the PowerPAD package including thermal modeling considerations and repair procedures, see Technical Brief SLMA002, *PowerPAD Thermally Enhanced Package*, available at www.ti.com.

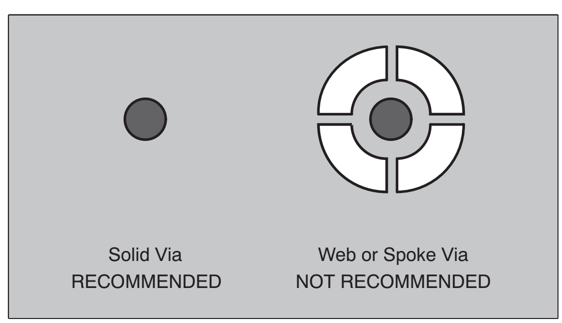
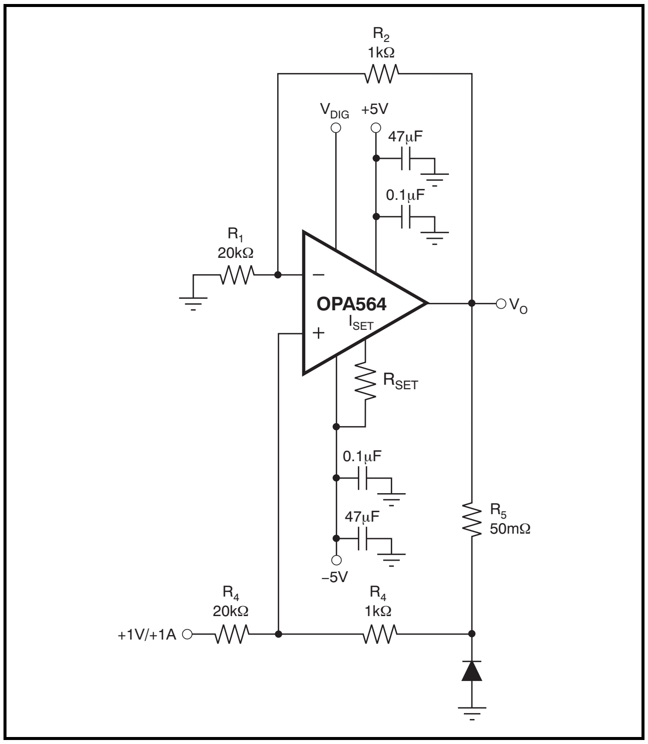


Figure 50. Via Connection Methods



(1) See Figure 35 for an example of a basic noninverting amplifier with V_{DIG} not exceeding 5.5V.

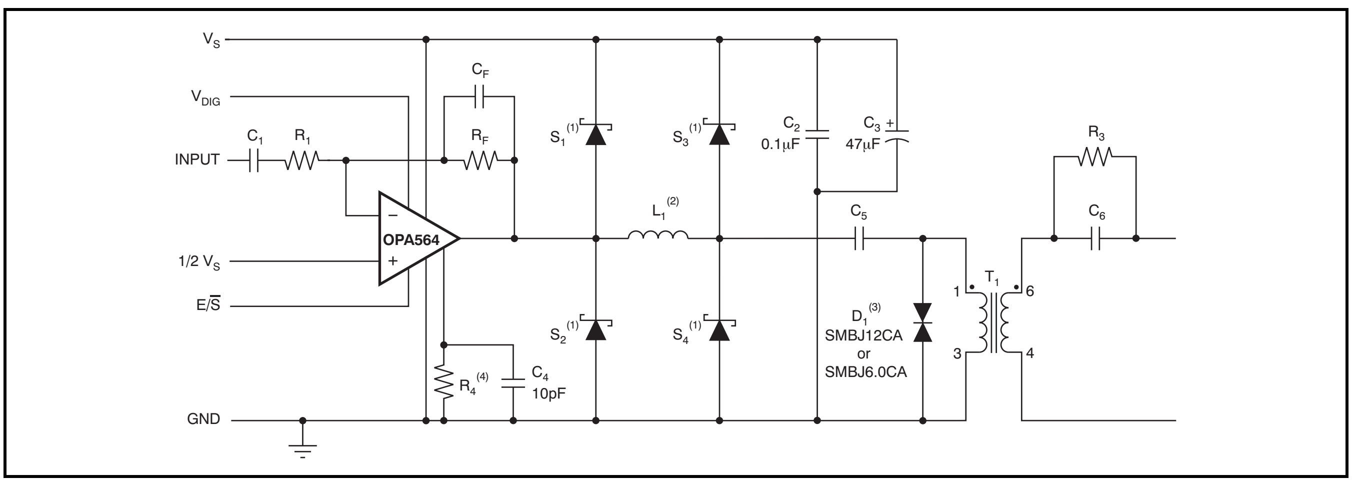
Figure 51. Improved Howland Current Pump

APPLICATIONS CIRCUITS

The high output current and low supply of the OPA564 make it a good candidate for driving laser diodes and thermoelectric coolers. Figure 51 shows an improved Howland current pump circuit.

POWERLINE COMMUNICATION

Powerline communication (PLC) applications require some form of signal transmission over an existing ac power line. A common technique used to couple these modulated signals to the line is through a signal transformer. A power amplifier is often needed to provide adequate levels of current and voltage to drive the varying loads that exist on today's powerlines. One such application is shown in Figure 52. The OPA564 is used to drive signals used in frequency modulation schemes such as FSK (Frequency-Shift Keying) or OFDM (Orthogonal Frequency-Division Multiplexing) to transmit digital information over the powerline. The power output capabilities of the OPA564 are needed to drive the current requirements of the transformer that is shown in the figure, coupled to the ac power line via a coupling capacitor. Circuit protection is often needed or required to prevent excessive line voltages or current surges from damaging the active circuitry in the power amplifier and application circuitry.



(1) S_1, S_2, S_3, and S_4 are Schottky diodes. S_1 and S_2 are B350 or equivalent. S_3 and S_4 are BAV99T or equivalent.

(2) L_1 should be small enough so that it does not interfere with the bandwidth of interest but large enough to suppress transients that could damage the OPA564.

(3) D_1 is a transient suppression diode. For 24V supplies, use SMBJ12CA. For 12V supplies, use SMBJ6.0CA. Voltage rating of transient voltage suppressor should be half the supply rating or less.

(4) The minimum recommended value for R_4 is 7.5kΩ.

Figure 52. Powerline Communication Line Coupling

PROGRAMMABLE POWER SUPPLY

Figure 53 shows the OPA333 used to control I_{SET} in order to adjust the current limit of the OPA564.

Figure 54 shows a basic motor speed driver but does not include any control over the motor speed. For applications where good control of the speed of the motor is desired, but the precision of a tachometer control is not required, the circuit in Figure 55 provides control by using feedback of the current consumption to adjust the motor drive.

For more information on this circuit, see the Application Bulletin *DC Motor Speed Controller: Control a DC Motor without Tachometer Feedback* (SBOA043), available for download at the TI web site.

Figure 56 shows two examples of generating the signal for V_{DIG}. Figure 56**a** uses an 1N4732A zener to bias the V_{DIG} to precisely 4.7V above V–. Figure 56**b** uses a high-voltage subregulator to derive the V_{DIG} voltage. Figure 58 illustrates a detailed powerline communication circuit.

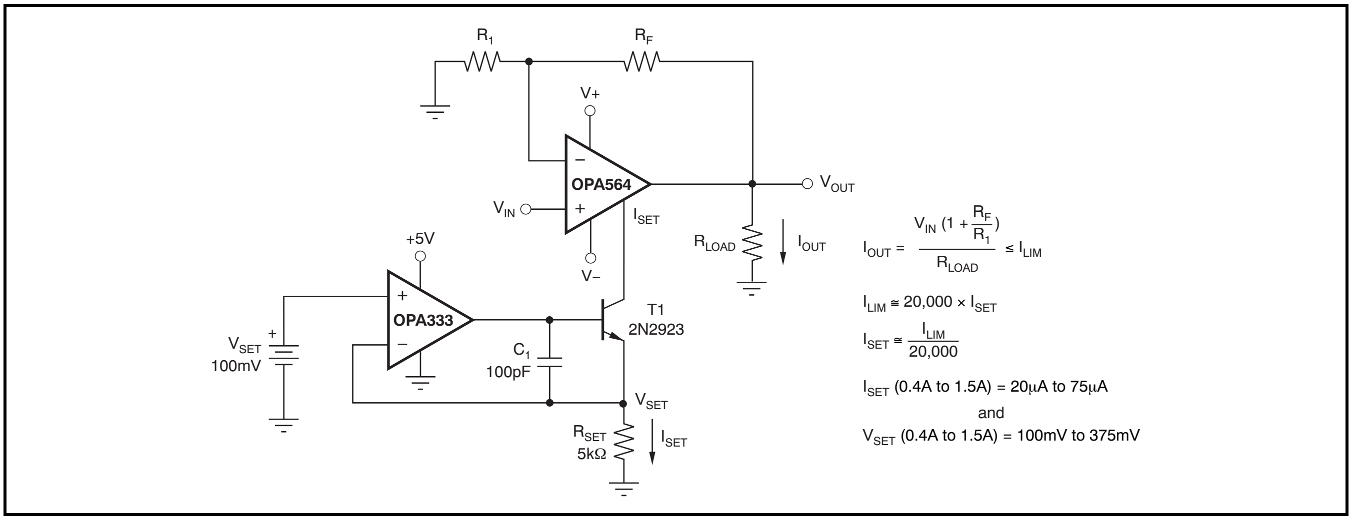
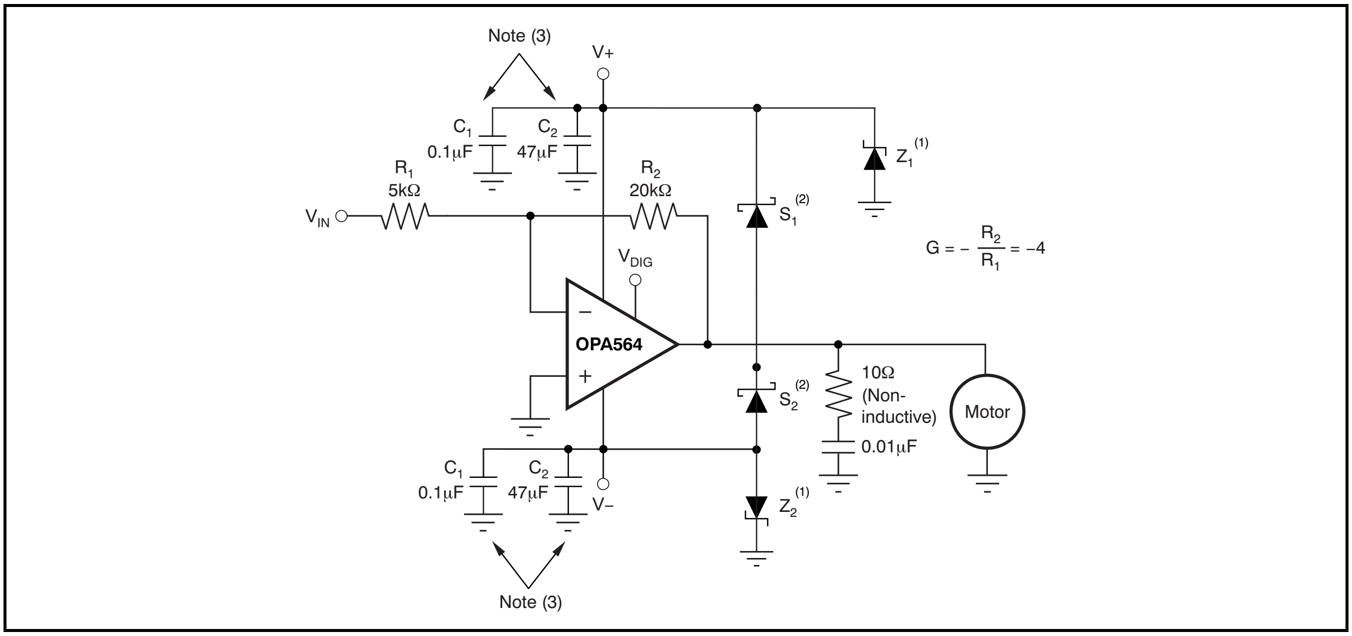


Figure 53. Programmable Current Limit Option

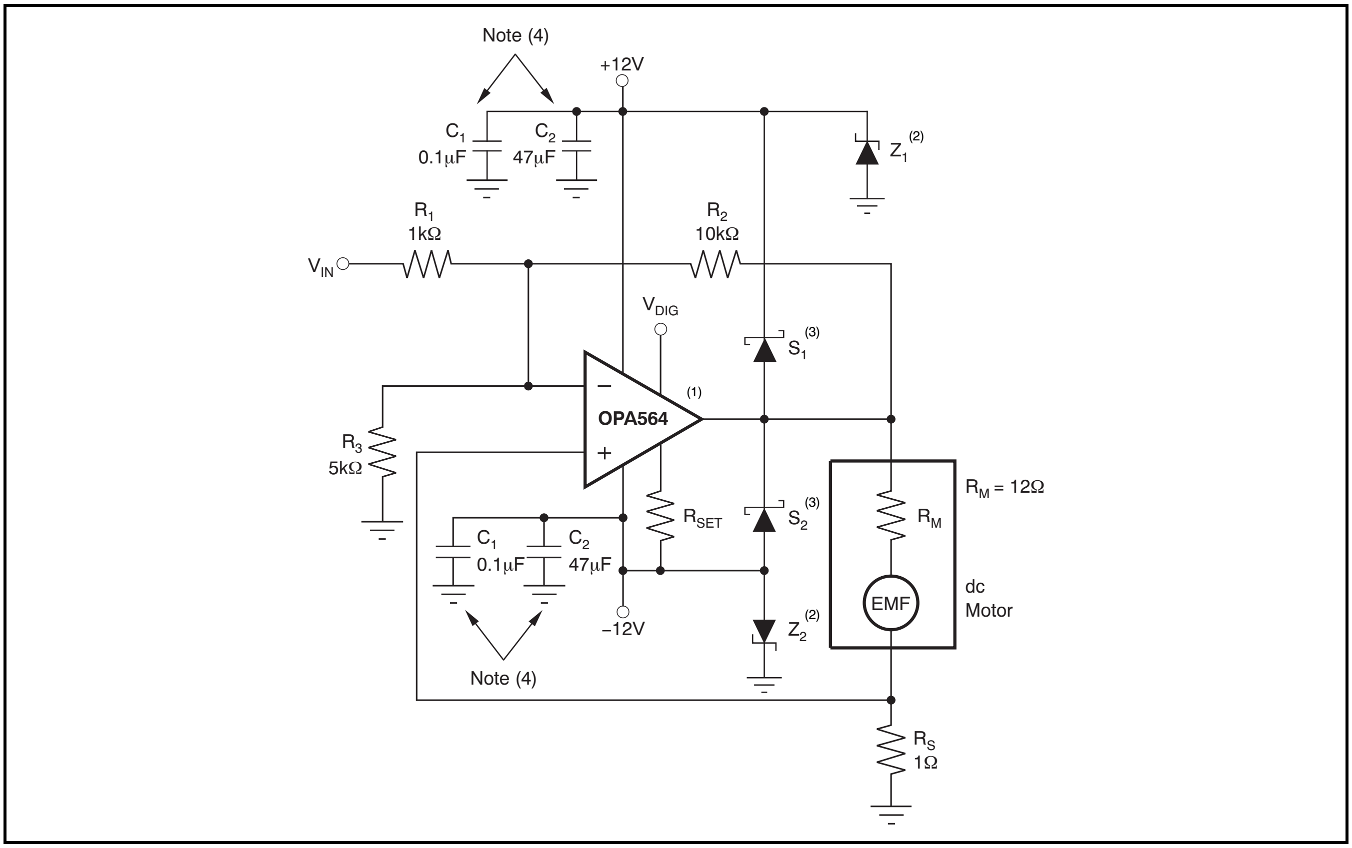


(1) Z_1, Z_2 = zener diodes (IN5246 or equivalent). Select Z_1 and Z_2 diodes that are capable of the maximum anticipated surge current.

(2) S_1, S_2 = Schottky diodes (STPS1L40 or equivalent).

(3) C_1 = high-frequency bypass capacitors; C_2 = low-frequency bypass capacitors (minimum of 10µF for every 1A peak current)

Figure 54. Motor Drive Circuit



(1) I_{FLAG} and T_{FLAG} connections are not shown.

(2) Z_1, Z_2 = zener diodes (IN5246 or equivalent). Select Z_1 and Z_2 diodes that are capable of the maximum anticipated surge current.

(3) S_1, S_2 = Schottky diodes (STPS1L40 or equivalent).

(4) C_1 = high-frequency bypass capacitors; C_2 = low-frequency bypass capacitors (minimum of 10μF for every 1A peak current).

Figure 55. DC Motor Speed Controller (without Tachometer)

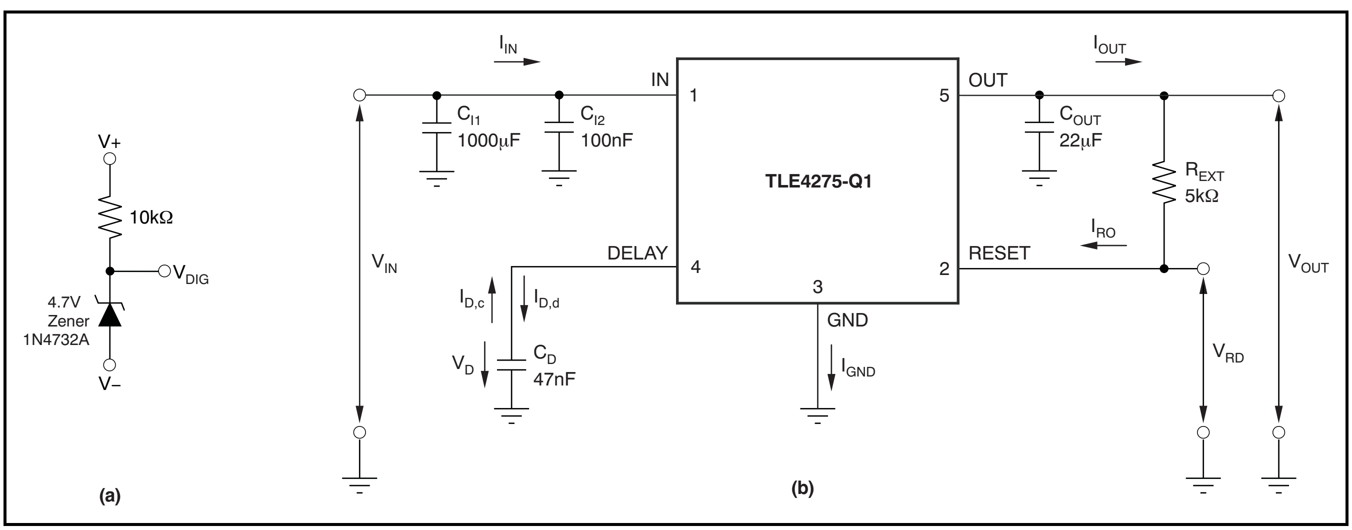


Figure 56. Circuits for Generating V_{DIG}

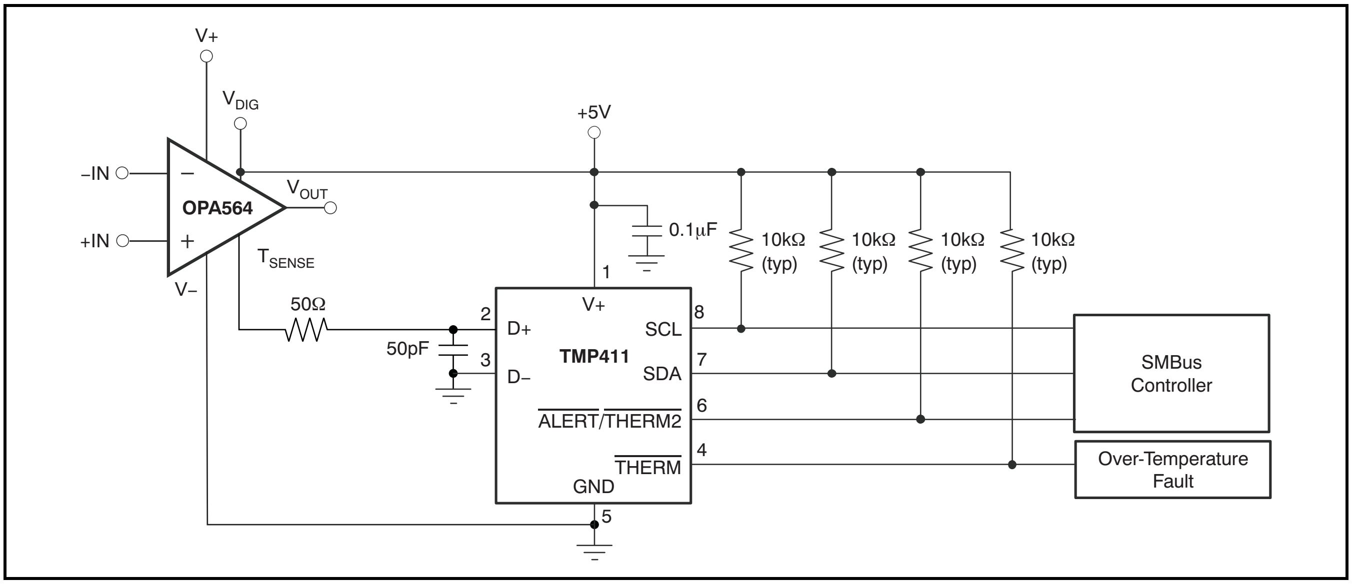


Figure 57. Temperature Measurement Using T_{SENSE} and TMP411

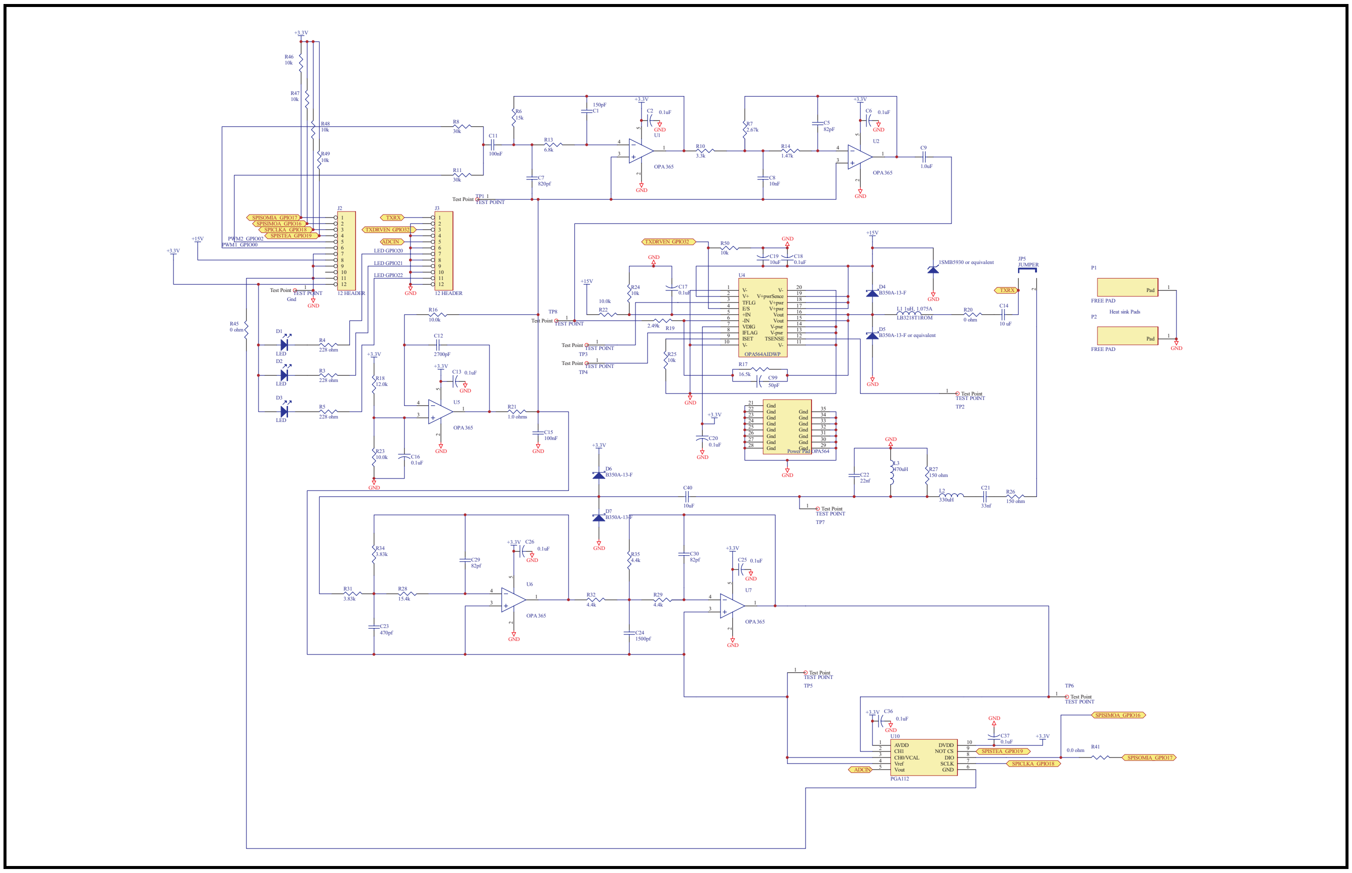


Figure 58. Detailed Powerline Communication Circuit

REVISION HISTORY

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision D (November, 2010) to Revision E **Page**

Changes from Revision C (November, 2009) to Revision D **Page**

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
OPA564AIDWD	ACTIVE	HSOP	DWD	20	25	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 85	OPA564	Samples
OPA564AIDWDR	ACTIVE	HSOP	DWD	20	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 85	OPA564	Samples
OPA564AIDWP	ACTIVE	SO PowerPAD	DWP	20	25	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 85	OPA564	Samples
OPA564AIDWPR	ACTIVE	SO PowerPAD	DWP	20	2000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 85	OPA564	Samples

[1] 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.

[2] **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

[3] MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

[4] There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

[6] Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF OPA564 :

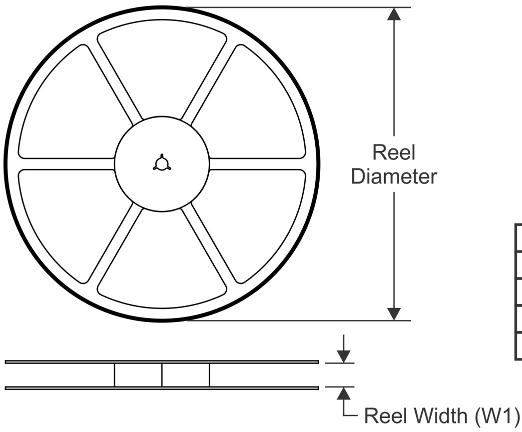
- Automotive: OPA564-Q1

NOTE: Qualified Version Definitions:

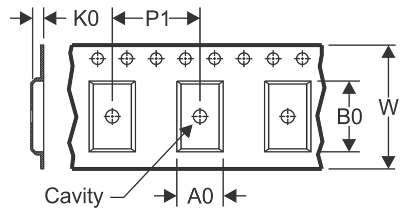
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

REEL DIMENSIONS

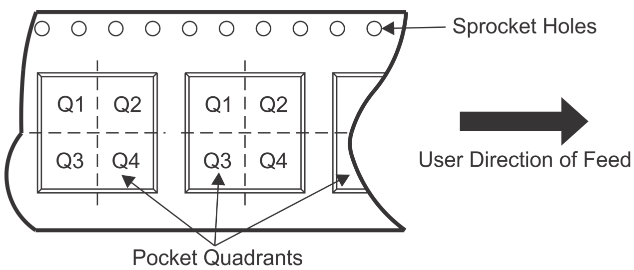


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

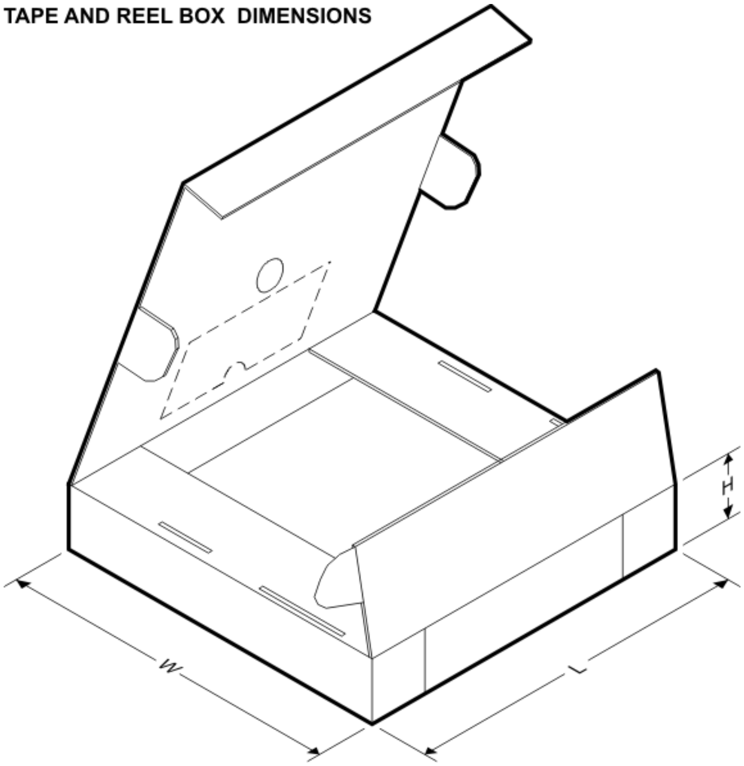
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
OPA564AIDWDR	HSOP	DWD	20	2000	330.0	24.4	10.8	13.3	2.7	12.0	24.0	Q1
OPA564AIDWPR	SO Power PAD	DWP	20	2000	330.0	24.4	10.8	13.3	2.7	12.0	24.0	Q1

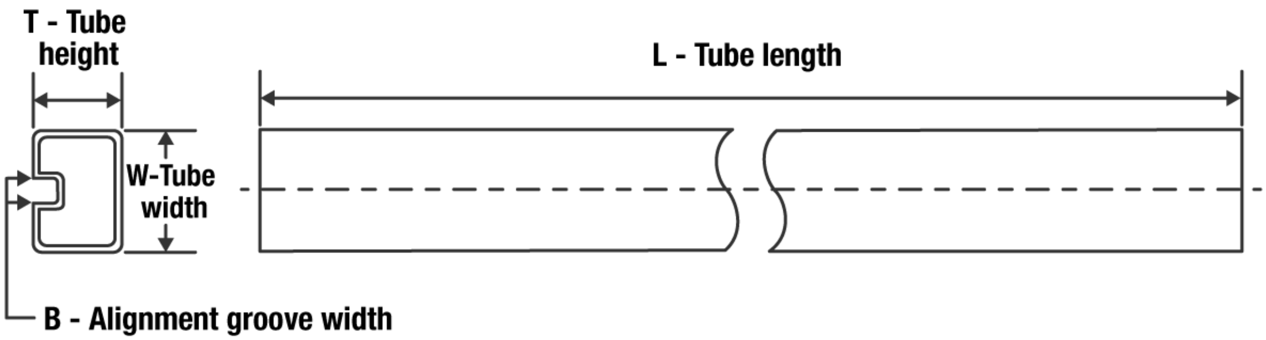
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA564AIDWDR	HSOP	DWD	20	2000	350.0	350.0	43.0
OPA564AIDWPR	SO PowerPAD	DWP	20	2000	350.0	350.0	43.0

TUBE

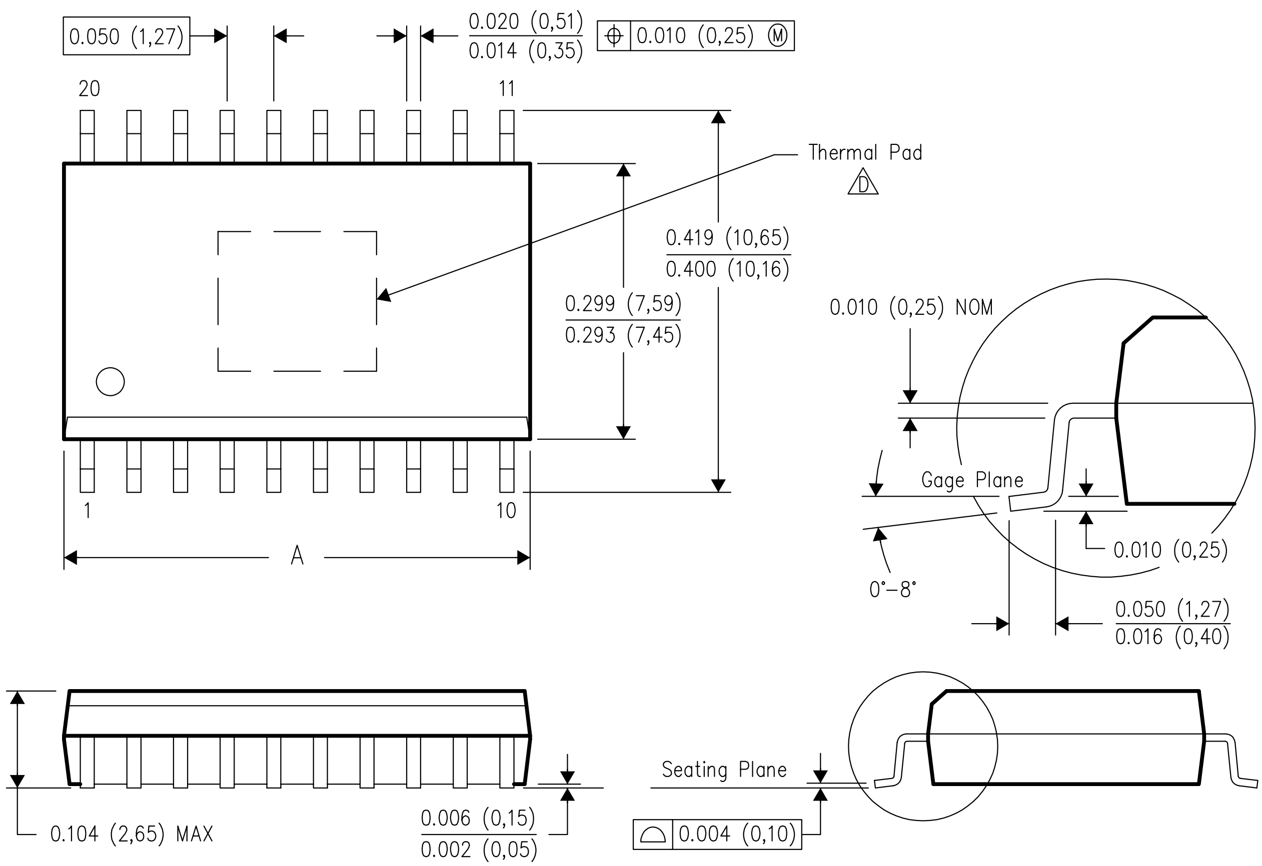


*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (µm)	B (mm)
OPA564AIDWD	DWD	HSOIC	20	25	506.98	12.7	4826	6.6
OPA564AIDWP	DWP	HSOIC	20	25	506.98	12.7	4826	6.6

DWP (R-PDSO-G**) PowerPAD™ PLASTIC SMALL-OUTLINE PACKAGE

20 PINS SHOWN



DIM \ PINS **	16	20	24	28
A MAX	0.410 (10,41)	0.510 (12,95)	0.610 (15,49)	0.710 (18,03)
A MIN	0.400 (10,16)	0.500 (12,70)	0.600 (15,24)	0.700 (17,78)

4147575/C 02/05

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http: //www.ti.com>. See the product data sheet for details regarding the exposed thermal pad dimensions.

PowerPAD is a trademark of Texas Instruments.

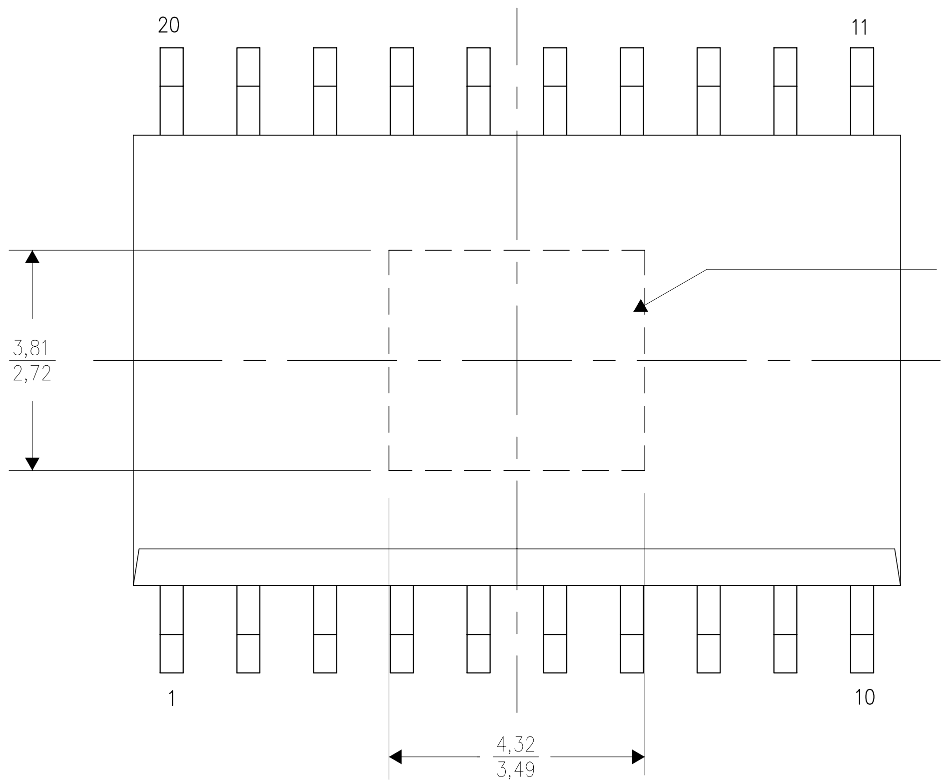
DWP (R-PDSO-G20) PowerPAD™ PLASTIC SMALL OUTLINE

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Top View

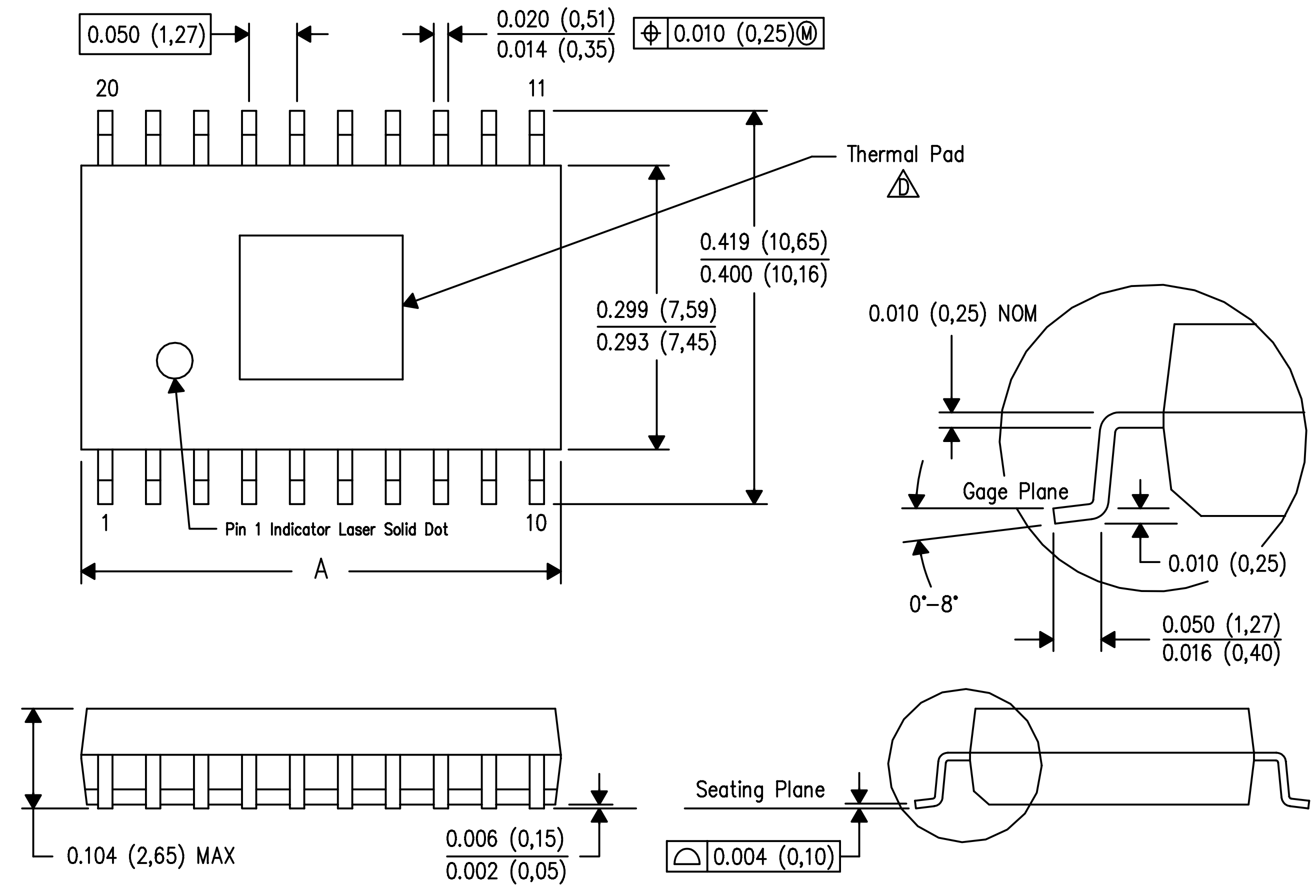
Exposed Thermal Pad Dimensions

4206325-2/E 12/10

NOTE: A. All linear dimensions are in millimeters

DWD (R-PDSO-G**) PowerPAD™ PLASTIC SMALL-OUTLINE (DIE DOWN)

20 PINS SHOWN



PINS ** / DIM	16	20	24	28
A MAX	0.410 (10,41)	0.510 (12,95)	0.610 (15,49)	0.710 (18,03)
A MIN	0.400 (10,16)	0.500 (12,70)	0.600 (15,24)	0.700 (17,78)

4147576/D 01/09

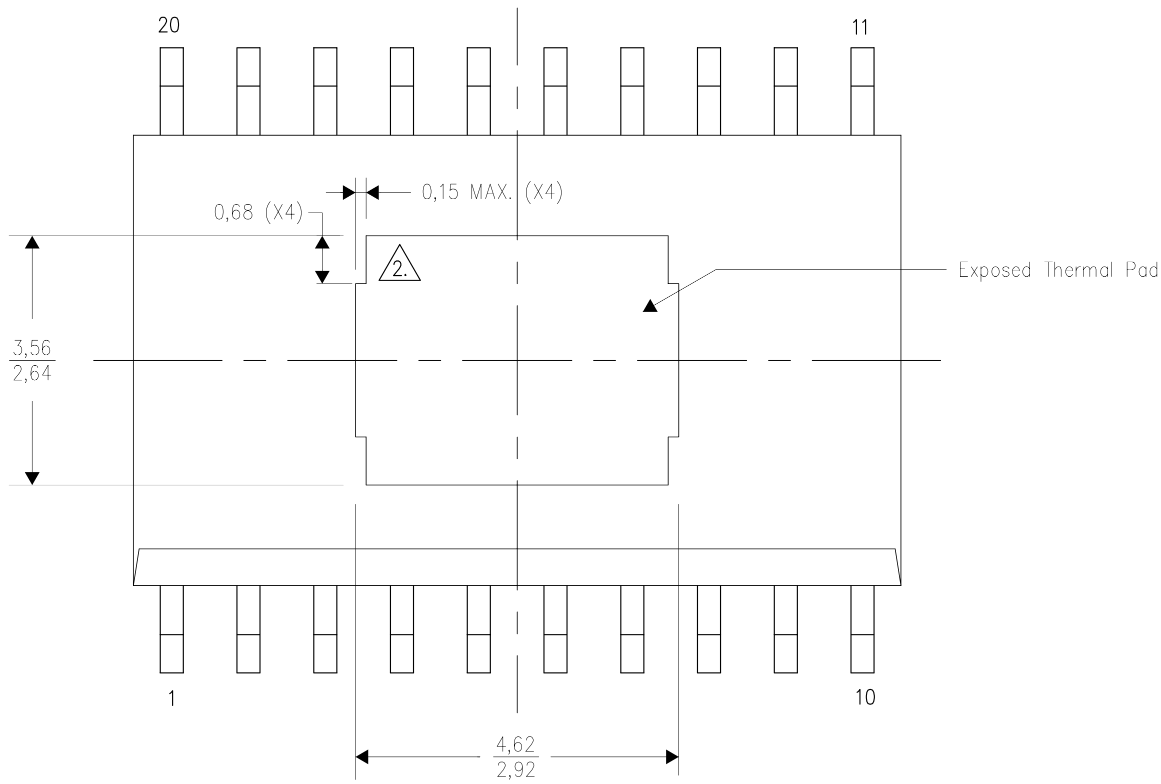
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http: //www.ti.com>. See the product data sheet for details regarding the exposed thermal pad dimensions.

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Top View

NOTES: 1. All linear dimensions are in millimeters
2. Corner notches may not be present.

Exposed Thermal Pad Dimensions

6.4. PCD8544

DATA SHEET

PCD8544
48 × 84 pixels matrix LCD controller/driver

Product specification
File under Integrated Circuits, IC17

1999 Apr 12

Philips
Semiconductors

PHILIPS

CONTENTS

1 FEATURES

- Single chip LCD controller/driver
- 48 row, 84 column outputs
- Display data RAM 48 × 84 bits
- On-chip:
  - Generation of LCD supply voltage (external supply also possible)
  - Generation of intermediate LCD bias voltages
  - Oscillator requires no external components (external clock also possible).
- External $\overline{RES}$ (reset) input pin
- Serial interface maximum 4.0 Mbits/s
- CMOS compatible inputs
- Mux rate: 48
- Logic supply voltage range V_{DD} to V_{SS}: 2.7 to 3.3 V
- Display supply voltage range V_{LCD} to V_{SS}
  - 6.0 to 8.5 V with LCD voltage internally generated (voltage generator enabled)
  - 6.0 to 9.0 V with LCD voltage externally supplied (voltage generator switched-off).
- Low power consumption, suitable for battery operated systems
- Temperature compensation of V_{LCD}
- Temperature range: –25 to +70 °C.

2 GENERAL DESCRIPTION

The PCD8544 is a low power CMOS LCD controller/driver, designed to drive a graphic display of 48 rows and 84 columns. All necessary functions for the display are provided in a single chip, including on-chip generation of LCD supply and bias voltages, resulting in a minimum of external components and low power consumption.

The PCD8544 interfaces to microcontrollers through a serial bus interface.

The PCD8544 is manufactured in n-well CMOS technology.

3 APPLICATIONS

- Telecommunications equipment.

4 ORDERING INFORMATION

TYPE NUMBER	PACKAGE		
	NAME	DESCRIPTION	VERSION
PCD8544U	–	chip with bumps in tray; 168 bonding pads + 4 dummy pads	–

5 BLOCK DIAGRAM

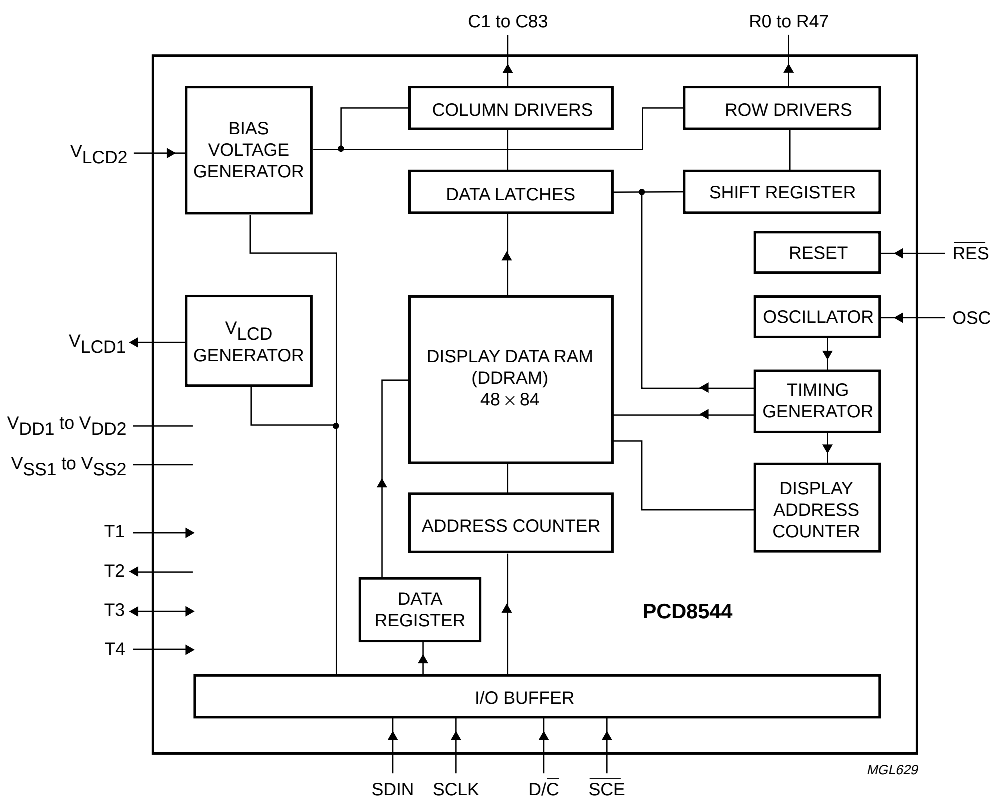


Fig.1 Block diagram.

6 PINNING

SYMBOL	DESCRIPTION
R0 to R47	LCD row driver outputs
C0 to C83	LCD column driver outputs
V_{SS1}, V_{SS2}	ground
V_{DD1}, V_{DD2}	supply voltage
V_{LCD1}, V_{LCD2}	LCD supply voltage
T1	test 1 input
T2	test 2 output
T3	test 3 input/output
T4	test 4 input
SDIN	serial data input
SCLK	serial clock input
D/$\overline{C}$	data/$\overline{\text{command}}$
$\overline{SCE}$	chip enable
OSC	oscillator
$\overline{RES}$	external reset input
dummy1, 2, 3, 4	not connected

Note

1. For further details, see Fig.18 and Table 7.

6.1 Pin functions

6.1.1 R0 TO R47 ROW DRIVER OUTPUTS

These pads output the row signals.

6.1.2 C0 TO C83 COLUMN DRIVER OUTPUTS

These pads output the column signals.

6.1.3 V_{SS1}, V_{SS2}: NEGATIVE POWER SUPPLY RAILS

Supply rails V_{SS1} and V_{SS2} must be connected together.

6.1.4 V_{DD1}, V_{DD2}: POSITIVE POWER SUPPLY RAILS

Supply rails V_{DD1} and V_{DD2} must be connected together.

6.1.5 V_{LCD1}, V_{LCD2}: LCD POWER SUPPLY

Positive power supply for the liquid crystal display. Supply rails V_{LCD1} and V_{LCD2} must be connected together.

6.1.6 T1, T2, T3 AND T4: TEST PADS

T1, T3 and T4 must be connected to V_{SS}, T2 is to be left open. Not accessible to user.

6.1.7 SDIN: SERIAL DATA LINE

Input for the data line.

6.1.8 SCLK: SERIAL CLOCK LINE

Input for the clock signal: 0.0 to 4.0 Mbits/s.

6.1.9 D/$\overline{C}$: MODE SELECT

Input to select either command/address or data input.

6.1.10 $\overline{SCE}$: CHIP ENABLE

The enable pin allows data to be clocked in. The signal is active LOW.

6.1.11 OSC: OSCILLATOR

When the on-chip oscillator is used, this input must be connected to V_{DD}. An external clock signal, if used, is connected to this input. If the oscillator and external clock are both inhibited by connecting the OSC pin to V_{SS}, the display is not clocked and may be left in a DC state.
To avoid this, the chip should always be put into Power-down mode before stopping the clock.

6.1.12 $\overline{RES}$: RESET

This signal will reset the device and must be applied to properly initialize the chip. The signal is active LOW.

7 FUNCTIONAL DESCRIPTION

7.1 Oscillator

The on-chip oscillator provides the clock signal for the display system. No external components are required and the OSC input must be connected to V_{DD}. An external clock signal, if used, is connected to this input.

7.2 Address Counter (AC)

The address counter assigns addresses to the display data RAM for writing. The X-address X_6 to X_0 and the Y-address Y_2 to Y_0 are set separately. After a write operation, the address counter is automatically incremented by 1, according to the V flag.

7.3 Display Data RAM (DDRAM)

The DDRAM is a 48 × 84 bit static RAM which stores the display data. The RAM is divided into six banks of 84 bytes (6 × 8 × 84 bits). During RAM access, data is transferred to the RAM through the serial interface. There is a direct correspondence between the X-address and the column output number.

7.4 Timing generator

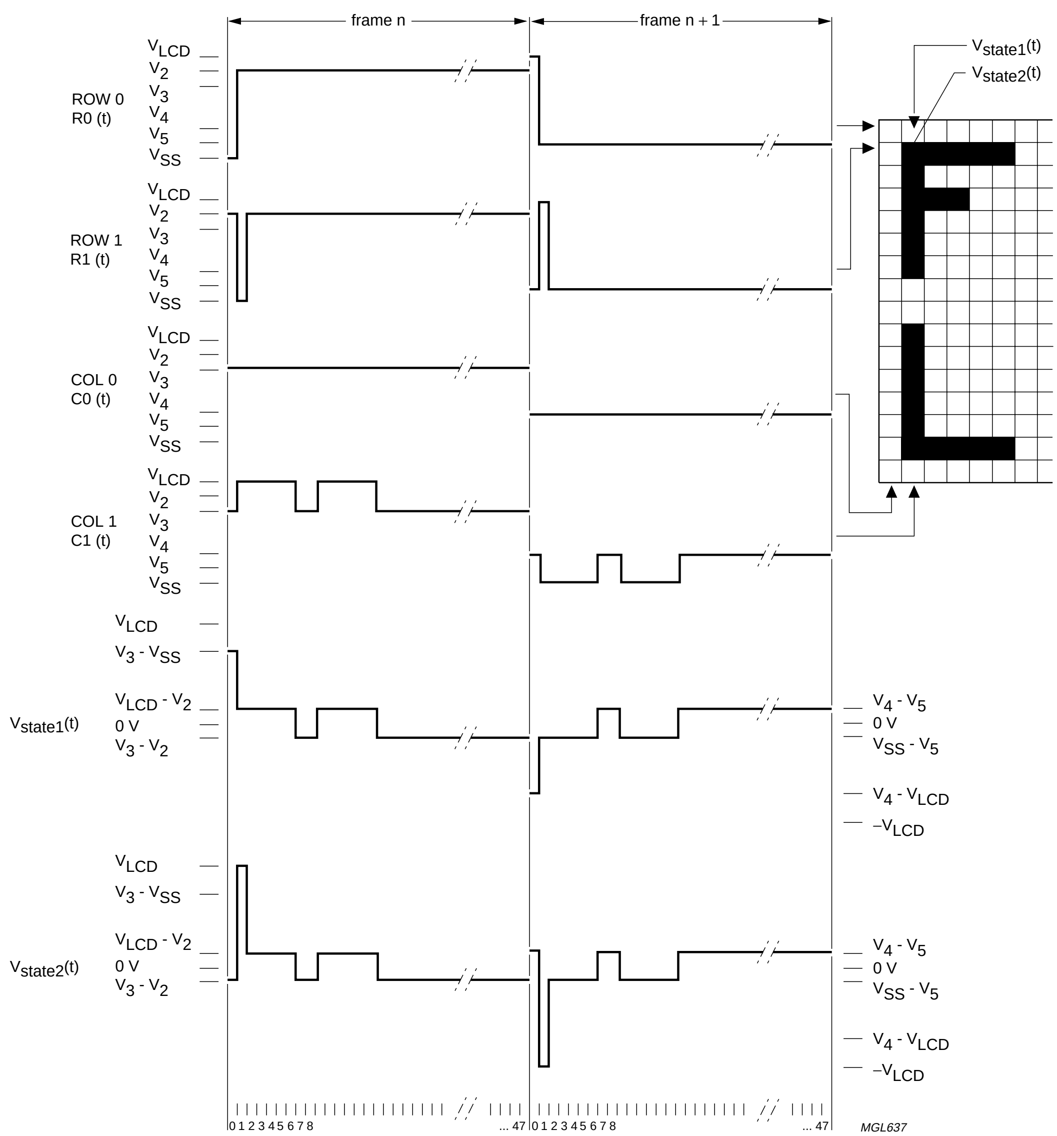
The timing generator produces the various signals required to drive the internal circuits. Internal chip operation is not affected by operations on the data buses.

7.5 Display address counter

The display is generated by continuously shifting rows of RAM data to the dot matrix LCD through the column outputs. The display status (all dots on/off and normal/inverse video) is set by bits E and D in the ‘display control’ command.

7.6 LCD row and column drivers

The PCD8544 contains 48 row and 84 column drivers, which connect the appropriate LCD bias voltages in sequence to the display in accordance with the data to be displayed. Figure 2 shows typical waveforms. Unused outputs should be left unconnected.



$V_{state1}(t) = C1(t) - R0(t)$.
$V_{state2}(t) = C1(t) - R1(t)$.

Fig.2 Typical LCD driver waveforms.

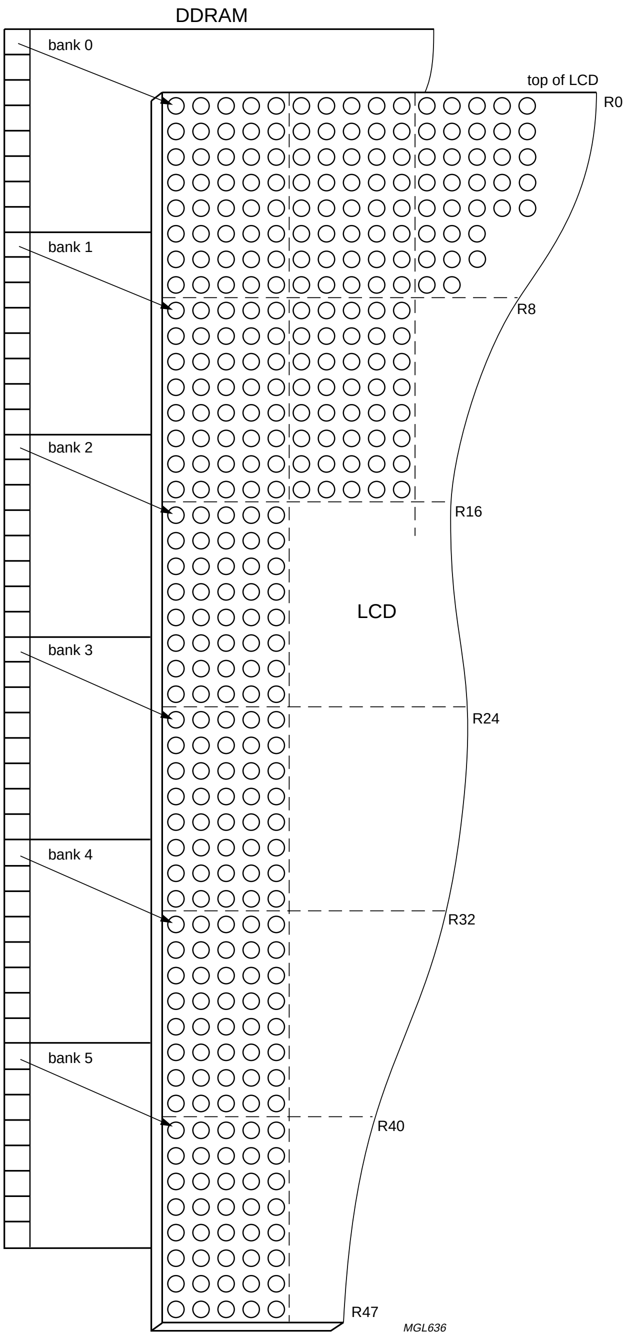


Fig.3 DDRAM to display mapping.

7.7 Addressing

Data is downloaded in bytes into the 48 by 84 bits RAM data display matrix of PCD8544, as indicated in Figs. 3, 4, 5 and 6. The columns are addressed by the address pointer. The address ranges are: X 0 to 83 (1010011), Y 0 to 5 (101). Addresses outside these ranges are not allowed. In the vertical addressing mode (V = 1), the Y address increments after each byte (see Fig.5). After the last Y address (Y = 5), Y wraps around to 0 and X increments to address the next column. In the horizontal addressing mode (V = 0), the X address increments after each byte (see Fig.6). After the last X address (X = 83), X wraps around to 0 and Y increments to address the next row. After the very last address (X = 83 and Y = 5), the address pointers wrap around to address (X = 0 and Y = 0).

7.7.1 DATA STRUCTURE

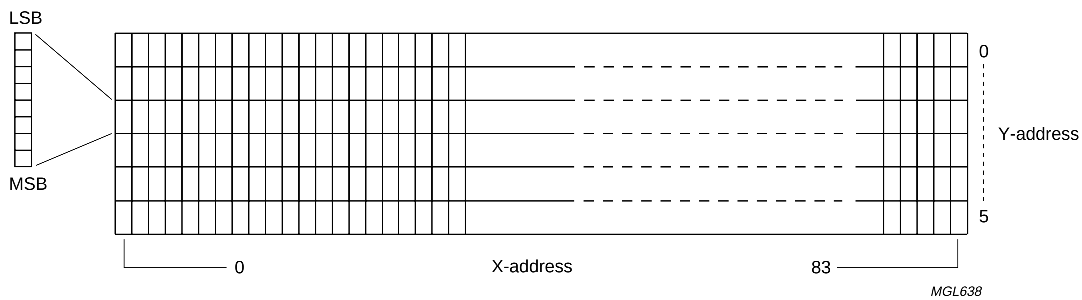


Fig.4 RAM format, addressing.

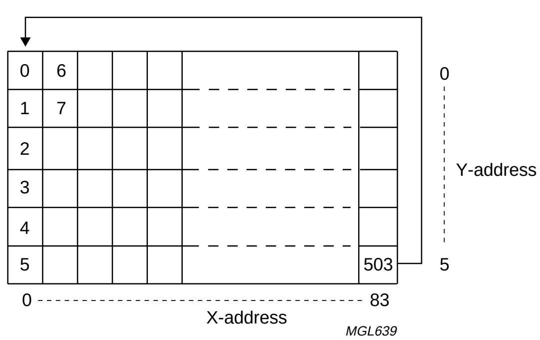


Fig.5 Sequence of writing data bytes into RAM with vertical addressing (V = 1).

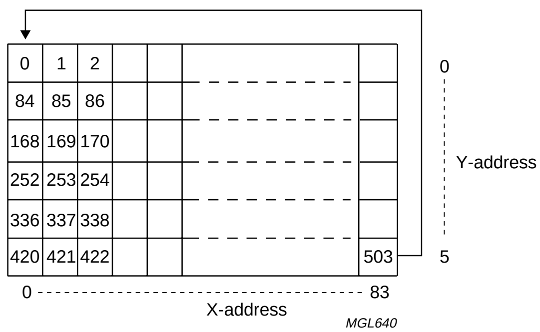
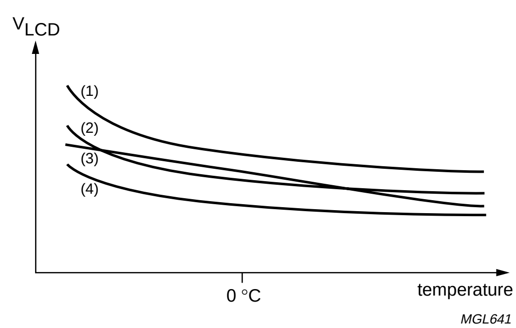


Fig.6 Sequence of writing data bytes into RAM with horizontal addressing (V = 0).

7.8 Temperature compensation

Due to the temperature dependency of the liquid crystals' viscosity, the LCD controlling voltage V_{LCD} must be increased at lower temperatures to maintain optimum contrast. Figure 7 shows V_{LCD} for high multiplex rates. In the PCD8544, the temperature coefficient of V_{LCD}, can be selected from four values (see Table 2) by setting bits TC_1 and TC_0.



(1) Upper limit.
(2) Typical curve.
(3) Temperature coefficient of IC.
(4) Lower limit.

Fig.7 V_{LCD} as function of liquid crystal temperature (typical values).

8 INSTRUCTIONS

The instruction format is divided into two modes: If D/$\overline{C}$ (mode select) is set LOW, the current byte is interpreted as command byte (see Table 1). Figure 8 shows an example of a serial data stream for initializing the chip. If D/$\overline{C}$ is set HIGH, the following bytes are stored in the display data RAM. After every data byte, the address counter is incremented automatically.

The level of the D/$\overline{C}$ signal is read during the last bit of data byte.

Each instruction can be sent in any order to the PCD8544. The MSB of a byte is transmitted first. Figure 9 shows one possible command stream, used to set up the LCD driver.

The serial interface is initialized when $\overline{SCE}$ is HIGH. In this state, SCLK clock pulses have no effect and no power is consumed by the serial interface. A negative edge on $\overline{SCE}$ enables the serial interface and indicates the start of a data transmission.

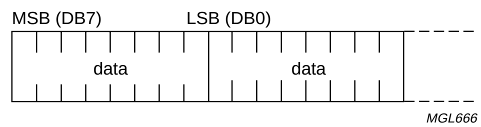


Fig.8 General format of data stream.

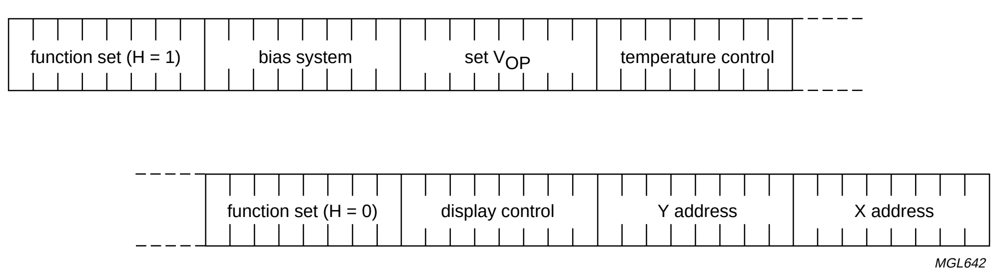


Fig.9 Serial data stream, example.

Figures 10 and 11 show the serial bus protocol.

- When $\overline{SCE}$ is HIGH, SCLK clock signals are ignored; during the HIGH time of $\overline{SCE}$, the serial interface is initialized (see Fig.12)
- SDIN is sampled at the positive edge of SCLK
- D/$\overline{C}$ indicates whether the byte is a command (D/$\overline{C}$ = 0) or RAM data (D/$\overline{C}$ = 1); it is read with the eighth SCLK pulse
- If $\overline{SCE}$ stays LOW after the last bit of a command/data byte, the serial interface expects bit 7 of the next byte at the next positive edge of SCLK (see Fig.12)
- A reset pulse with $\overline{RES}$ interrupts the transmission. No data is written into the RAM. The registers are cleared. If $\overline{SCE}$ is LOW after the positive edge of $\overline{RES}$, the serial interface is ready to receive bit 7 of a command/data byte (see Fig.13).

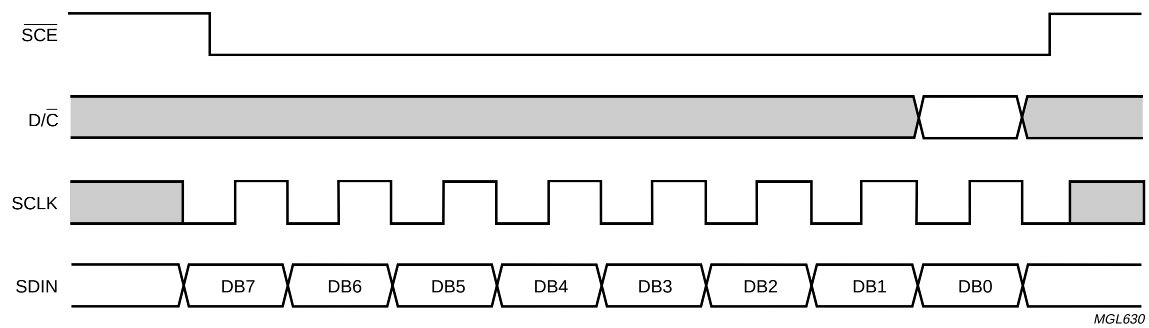


Fig.10 Serial bus protocol - transmission of one byte.

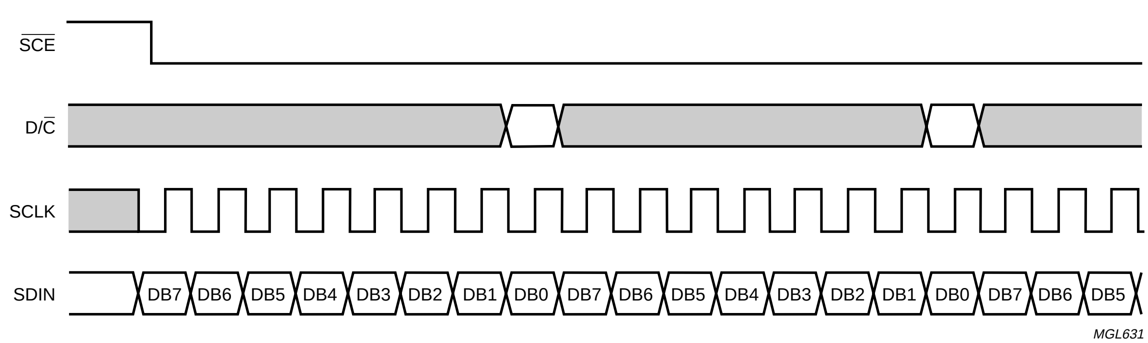


Fig.11 Serial bus protocol - transmission of several bytes.

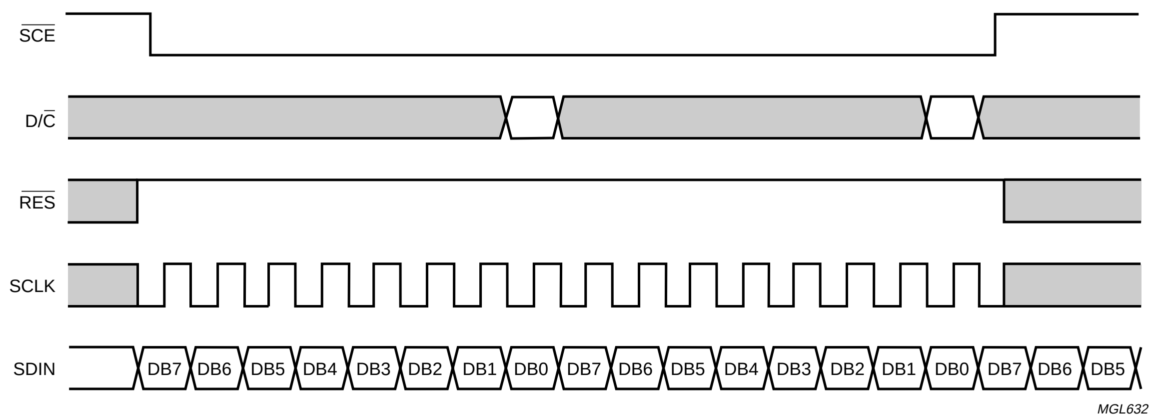


Fig.12 Serial bus reset function ($\overline{SCE}$).

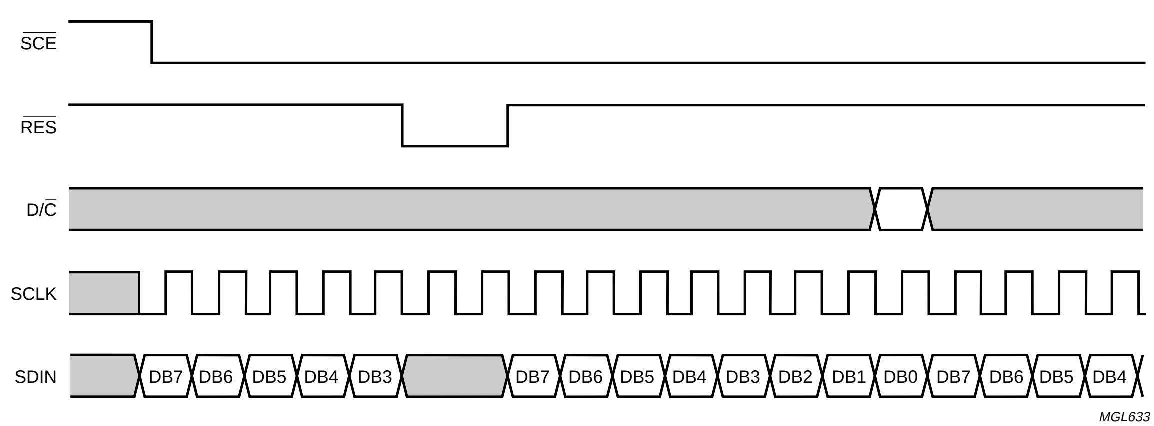


Fig.13 Serial bus reset function ($\overline{RES}$).

Table 1 Instruction set

INSTRUCTION	D/$\overline{C}$	COMMAND BYTE								DESCRIPTION
		DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	
(H = 0 or 1)										
NOP	0	0	0	0	0	0	0	0	0	no operation
Function set	0	0	0	1	0	0	PD	V	H	power down control; entry mode; extended instruction set control (H)
Write data	1	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	writes data to display RAM
(H = 0)										
Reserved	0	0	0	0	0	0	1	X	X	do not use
Display control	0	0	0	0	0	1	D	0	E	sets display configuration
Reserved	0	0	0	0	1	X	X	X	X	do not use
Set Y address of RAM	0	0	1	0	0	0	Y_2	Y_1	Y_0	sets Y-address of RAM; $0 \leq Y \leq 5$
Set X address of RAM	0	1	X_6	X_5	X_4	X_3	X_2	X_1	X_0	sets X-address part of RAM; $0 \leq X \leq 83$
(H = 1)										
Reserved	0	0	0	0	0	0	0	0	1	do not use
	0	0	0	0	0	0	0	1	X	do not use
Temperature control	0	0	0	0	0	0	1	TC_1	TC_0	set Temperature Coefficient (TC_x)
Reserved	0	0	0	0	0	1	X	X	X	do not use
Bias system	0	0	0	0	1	0	BS_2	BS_1	BS_0	set Bias System (BS_x)
Reserved	0	0	1	X	X	X	X	X	X	do not use
Set V_{OP}	0	1	V_{OP6}	V_{OP5}	V_{OP4}	V_{OP3}	V_{OP2}	V_{OP1}	V_{OP0}	write V_{OP} to register

Table 2 Explanations of symbols in Table 1

BIT	0	1
PD	chip is active	chip is in Power-down mode
V	horizontal addressing	vertical addressing
H	use basic instruction set	use extended instruction set
D and E		
00	display blank	
10	normal mode	
01	all display segments on	
11	inverse video mode	
TC_1 and TC_0		
00	V_{LCD} temperature coefficient 0	
01	V_{LCD} temperature coefficient 1	
10	V_{LCD} temperature coefficient 2	
11	V_{LCD} temperature coefficient 3	

8.1 Initialization

Immediately following power-on, the contents of all internal registers and of the RAM are undefined. **A $\overline{\text{RES}}$ pulse must be applied**. Attention should be paid to the possibility that the **device may be damaged** if not properly reset.

All internal registers are reset by applying an external $\overline{\text{RES}}$ pulse (active LOW) at pad 31, within the specified time. However, the RAM contents are still undefined. The state after reset is described in Section 8.2.

The $\overline{\text{RES}}$ input must be $\leq 0.3V_{DD}$ when V_{DD} reaches V_{DDmin} (or higher) within a maximum time of 100 ms after V_{DD} goes HIGH (see Fig.16).

8.2 Reset function

After reset, the LCD driver has the following state:

- Power-down mode (bit PD = 1)
- Horizontal addressing (bit V = 0) normal instruction set (bit H = 0)
- Display blank (bit E = D = 0)
- Address counter X_6 to X_0 = 0; Y_2 to Y_0 = 0
- Temperature control mode (TC_1 TC_0 = 0)
- Bias system (BS_2 to BS_0 = 0)
- V_{LCD} is equal to 0, the HV generator is switched off (V_{OP6} to V_{OP0} = 0)
- After power-on, the RAM contents are undefined.

8.3 Function set

8.3.1 BIT PD

- All LCD outputs at V_{SS} (display off)
- Bias generator and V_{LCD} generator off, V_{LCD} can be disconnected
- Oscillator off (external clock possible)
- Serial bus, command, etc. function
- Before entering Power-down mode, the RAM needs to be filled with ‘0’s to ensure the specified current consumption.

8.3.2 BIT V

When V = 0, the horizontal addressing is selected. The data is written into the DDRAM as shown in Fig.6. When V = 1, the vertical addressing is selected. The data is written into the DDRAM, as shown in Fig.5.

8.3.3 BIT H

When H = 0 the commands ‘display control’, ‘set Y address’ and ‘set X address’ can be performed; when H = 1, the others can be executed. The ‘write data’ and ‘function set’ commands can be executed in both cases.

8.4 Display control

8.4.1 BITS D AND E

Bits D and E select the display mode (see Table 2).

8.5 Set Y address of RAM

Y_n defines the Y vector addressing of the display RAM.

Table 3 Y vector addressing

Y_2	Y_1	Y_0	BANK
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5

8.6 Set X address of RAM

The X address points to the columns. The range of X is 0 to 83 (53H).

8.7 Temperature control

The temperature coefficient of V_{LCD} is selected by bits TC_1 and TC_0.

8.8 Bias value

The bias voltage levels are set in the ratio of R - R - nR - R - R, giving a 1/(n + 4) bias system. Different multiplex rates require different factors n (see Table 4). This is programmed by BS_2 to BS_0. For Mux 1 : 48, the optimum bias value n, resulting in 1/8 bias, is given by:

$$n = \sqrt{48} - 3 = 3.928 = 4 \quad (1)$$

Table 4 Programming the required bias system

BS_2	BS_1	BS_0	n	RECOMMENDED MUX RATE
0	0	0	7	1 : 100
0	0	1	6	1 : 80
0	1	0	5	1 : 65/1 : 65
0	1	1	4	1 : 48
1	0	0	3	1 : 40/1 : 34
1	0	1	2	1 : 24
1	1	0	1	1 : 18/1 : 16
1	1	1	0	1 : 10/1 : 9/1 : 8

Table 5 LCD bias voltage

SYMBOL	BIAS VOLTAGES	BIAS VOLTAGE FOR $\frac{1}{8}$ BIAS
V1	V_{LCD}	V_{LCD}
V2	(n + 3)/(n + 4)	$\frac{7}{8} \times V_{LCD}$
V3	(n + 2)/(n + 4)	$\frac{6}{8} \times V_{LCD}$
V4	2/(n + 4)	$\frac{2}{8} \times V_{LCD}$
V5	1/(n + 4)	$\frac{1}{8} \times V_{LCD}$
V6	V_{SS}	V_{SS}

8.9 Set V_{OP} value

The operation voltage V_{LCD} can be set by software. The values are dependent on the liquid crystal selected. V_{LCD} = a + (V_{OP6} to V_{OP0}) × b [V]. In the PCD8544, a = 3.06 and b = 0.06 giving a program range of 3.00 to 10.68 at room temperature.

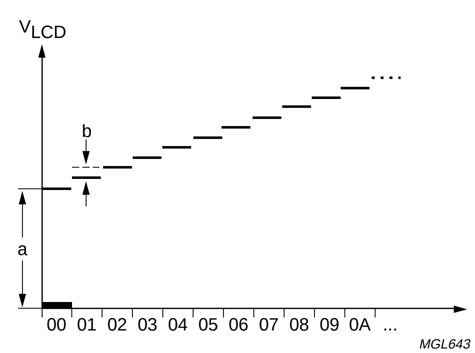
Note that the charge pump is turned off if V_{OP6} to V_{OP0} is set to zero.

For Mux 1 : 48, the optimum operation voltage of the liquid can be calculated as:

$$V_{LCD} = \frac{1 + \sqrt{48}}{\sqrt{2 \cdot \left(1 - \frac{1}{\sqrt{48}}\right)}} \cdot V_{th} = 6.06 \cdot V_{th} \qquad (2)$$

where V_{th} is the threshold voltage of the liquid crystal material used.

Caution, as V_{OP} increases with lower temperatures, care must be taken not to set a V_{OP} that will exceed the maximum of 8.5 V when operating at −25 °C.



a = 3.06.
b = 0.06.
V_{OP6} to V_{OP0} (programmed) [00 to 7FH].

Fig.14 V_{OP} programming.

9 LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134); see notes 1 and 2.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{DD}	supply voltage	note 3	–0.5	+7	V
V_{LCD}	supply voltage LCD	note 4	–0.5	+10	V
V_i	all input voltages		–0.5	V_{DD} + 0.5	V
I_{SS}	ground supply current		–50	+50	mA
I_I, I_O	DC input or output current		–10	+10	mA
P_{tot}	total power dissipation		–	300	mW
P_O	power dissipation per output		–	30	mW
T_{amb}	operating ambient temperature		–25	+70	°C
T_j	operating junction temperature		–65	+150	°C
T_{stg}	storage temperature		–65	+150	°C

Notes

1. Stresses above those listed under limiting values may cause permanent damage to the device.
2. Parameters are valid over operating temperature range unless otherwise specified. All voltages are with respect to V_{SS} unless otherwise noted.
3. With external LCD supply voltage externally supplied (voltage generator disabled). V_{DDmax} = 5 V if LCD supply voltage is internally generated (voltage generator enabled).
4. When setting V_{LCD} by software, take care not to set a V_{OP} that will exceed the maximum of 8.5 V when operating at –25 °C, see Caution in Section 8.9.

10 HANDLING

Inputs and outputs are protected against electrostatic discharge in normal handling. However, to be totally safe, it is desirable to take normal precautions appropriate to handling MOS devices (see *“Handling MOS devices”*).

11 DC CHARACTERISTICS

V_{DD} = 2.7 to 3.3 V; V_{SS} = 0 V; V_{LCD} = 6.0 to 9.0 V; T_{amb} = –25 to +70 °C; unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
V_{DD1}	supply voltage 1	LCD voltage externally supplied (voltage generator disabled)	2.7	–	3.3	V
V_{DD2}	supply voltage 2	LCD voltage internally generated (voltage generator enabled)	2.7	–	3.3	V
V_{LCD1}	LCD supply voltage	LCD voltage externally supplied (voltage generator disabled)	6.0	–	9.0	V
V_{LCD2}	LCD supply voltage	LCD voltage internally generated (voltage generator enabled); note 1	6.0	–	8.5	V
I_{DD1}	supply current 1 (normal mode) for internal V_{LCD}	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; T_{amb} = 25 °C; display load = 10 μA; note 2	–	240	300	μA
I_{DD2}	supply current 2 (normal mode) for internal V_{LCD}	V_{DD} = 2.70 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; T_{amb} = 25 °C; display load = 10 μA; note 2	–	–	320	μA
I_{DD3}	supply current 3 (Power-down mode)	with internal or external LCD supply voltage; note 3	–	1.5	–	μA
I_{DD4}	supply current external V_{LCD}	V_{DD} = 2.85 V; V_{LCD} = 9.0 V; f_{SCLK} = 0; notes 2 and 4	–	25	–	μA
I_{LCD}	supply current external V_{LCD}	V_{DD} = 2.7 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; T = 25 °C; display load = 10 μA; notes 2 and 4	–	42	–	μA
Logic						
V_{IL}	LOW level input voltage		V_{SS}	–	$0.3V_{DD}$	V
V_{IH}	HIGH level input voltage		$0.7V_{DD}$	–	V_{DD}	V
I_L	leakage current	$V_I = V_{DD}$ or V_{SS}	–1	–	+1	μA
Column and row outputs						
$R_{o(C)}$	column output resistance C0 to C83		–	12	20	kΩ
$R_{o(R)}$	row output resistance R0 to R47		–	12	20	kΩ
$V_{bias(tol)}$	bias voltage tolerance on C0 to C83 and R0 to R47		–100	0	+100	mV

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
LCD supply voltage generator						
V_{LCD}	V_{LCD} tolerance internally generated	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; display load = 10 µA; note 5	–	0	300	mV
TC0	V_{LCD} temperature coefficient 0	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; display load = 10 µA	–	1	–	mV/K
TC1	V_{LCD} temperature coefficient 1	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; display load = 10 µA	–	9	–	mV/K
TC2	V_{LCD} temperature coefficient 2	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; display load = 10 µA	–	17	–	mV/K
TC3	V_{LCD} temperature coefficient 3	V_{DD} = 2.85 V; V_{LCD} = 7.0 V; f_{SCLK} = 0; display load = 10 µA	–	24	–	mV/K

Notes

1. The maximum possible V_{LCD} voltage that may be generated is dependent on voltage, temperature and (display) load.
2. Internal clock.
3. RAM contents equal ‘0’. During power-down, all static currents are switched off.
4. If external V_{LCD}, the display load current is not transmitted to I_{DD}.
5. Tolerance depends on the temperature (typically zero at 27 °C, maximum tolerance values are measured at the temperate range limit).

12 AC CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
f_{OSC}	oscillator frequency		20	34	65	kHz
$f_{clk(ext)}$	external clock frequency		10	32	100	kHz
f_{frame}	frame frequency	f_{OSC} or $f_{clk(ext)}$ = 32 kHz; note 1	–	67	–	Hz
t_{VHRL}	V_{DD} to $\overline{RES}$ LOW	Fig.16	0[2]	–	30	ms
$t_{WL(RES)}$	$\overline{RES}$ LOW pulse width	Fig.16	100	–	–	ns
Serial bus timing characteristics						
f_{SCLK}	clock frequency	V_{DD} = 3.0 V ±10%	0	–	4.00	MHz
T_{cy}	clock cycle SCLK	All signal timing is based on 20% to 80% of V_{DD} and maximum rise and fall times of 10 ns	250	–	–	ns
t_{WH1}	SCLK pulse width HIGH		100	–	–	ns
t_{WL1}	SCLK pulse width LOW		100	–	–	ns
t_{su2}	$\overline{SCE}$ set-up time		60	–	–	ns
t_{h2}	$\overline{SCE}$ hold time		100	–	–	ns
t_{WH2}	$\overline{SCE}$ min. HIGH time		100	–	–	ns
t_{h5}	$\overline{SCE}$ start hold time; note 3		100	–	–	ns
t_{su3}	D/$\overline{C}$ set-up time		100	–	–	ns
t_{h3}	D/$\overline{C}$ hold time		100	–	–	ns
t_{su4}	SDIN set-up time		100	–	–	ns
t_{h4}	SDIN hold time		100	–	–	ns

Notes

1. $T_{frame} = \frac{f_{clk(ext)}}{480}$
2. $\overline{RES}$ may be LOW before V_{DD} goes HIGH.
3. t_{h5} is the time from the previous SCLK positive edge (irrespective of the state of $\overline{SCE}$) to the negative edge of $\overline{SCE}$ (see Fig.15).

12.1 Serial interface

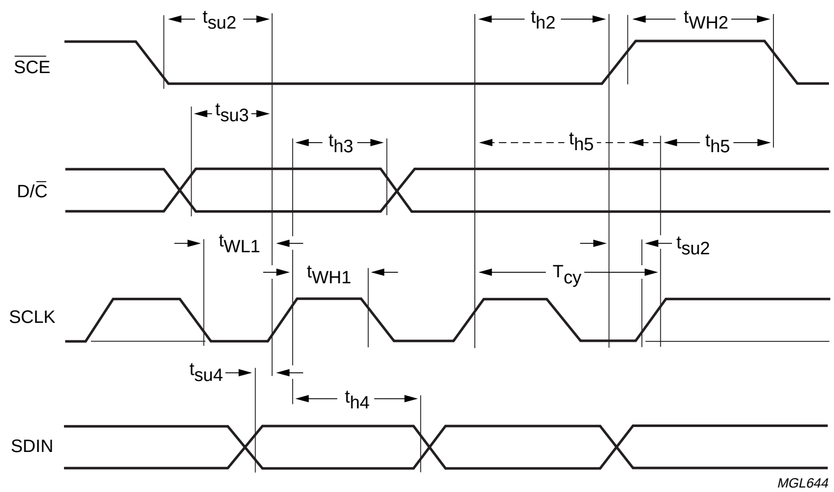


Fig.15 Serial interface timing.

12.2 Reset

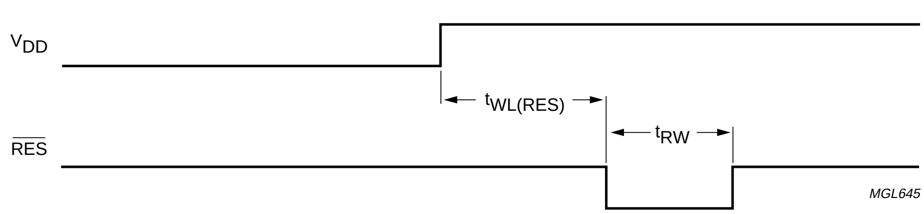
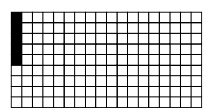
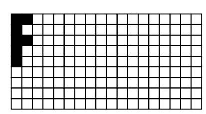
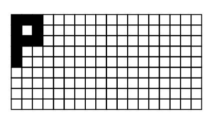
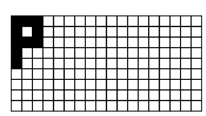
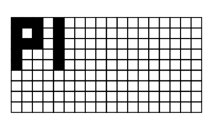
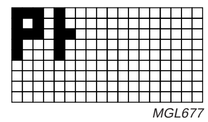
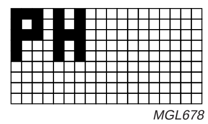
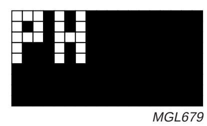
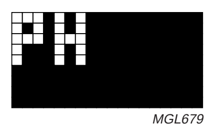
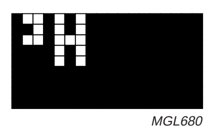


Fig.16 Reset timing.

13 APPLICATION INFORMATION

Table 6 Programming example

STEP	SERIAL BUS BYTE									DISPLAY	OPERATION
	D/$\overline{C}$	**DB7**	**DB6**	**DB5**	**DB4**	**DB3**	**DB2**	**DB1**	**DB0**		
1	start										$\overline{SCE}$ is going LOW
2	0	0	0	1	0	0	0	0	1		function set PD = 0 and V = 0, select extended instruction set (H = 1 mode)
3	0	1	0	0	1	0	0	0	0		set V_{OP}; V_{OP} is set to a $+16 \times b$ [V]
4	0	0	0	1	0	0	0	0	0		function set PD = 0 and V = 0, select normal instruction set (H = 0 mode)
5	0	0	0	0	0	1	1	0	0		display control set normal mode (D = 1 and E = 0)
6	1	0	0	0	1	1	1	1	1	 MGL673	data write Y and X are initialized to 0 by default, so they are not set here
7	1	0	0	0	0	0	1	0	1	 MGL674	data write
8	1	0	0	0	0	0	1	1	1	 MGL675	data write
9	1	0	0	0	0	0	0	0	0	 MGL675	data write
10	1	0	0	0	1	1	1	1	1	 MGL676	data write

STEP	SERIAL BUS BYTE									DISPLAY	OPERATION
	D/$\overline{C}$	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0		
11	1	0	0	0	0	0	1	0	0		data write
12	1	0	0	0	1	1	1	1	1		data write
13	0	0	0	0	0	1	1	0	1		display control; set inverse video mode (D = 1 and E = 1)
14	0	1	0	0	0	0	0	0	0		set X address of RAM; set address to ‘0000000’
15	1	0	0	0	0	0	0	0	0		data write

The pinning is optimized for single plane wiring e.g. for chip-on-glass display modules. Display size: 48 × 84 pixels.

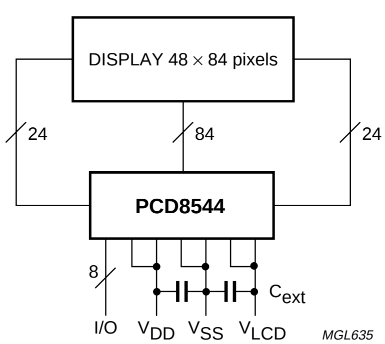


Fig.17 Application diagram.

The required minimum value for the external capacitors is: C_{ext} = 1.0 µF.

Higher capacitor values are recommended for ripple reduction.

14 BONDING PAD LOCATIONS

14.1 Bonding pad information (see Fig.18)

PARAMETER	SIZE
Pad pitch	min. 100 µm
Pad size, aluminium	80 × 100 µm
Bump dimensions	59 × 89 × 17.5 (±5) µm
Wafer thickness	max. 380 µm

14.2 Bonding pad location

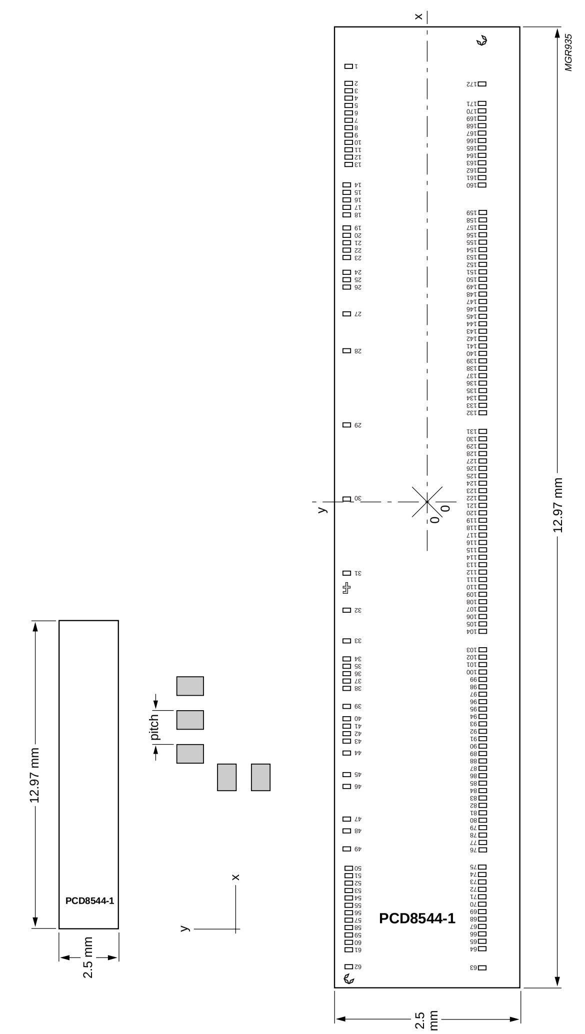


Fig.18 Bonding pad locations.

Table 7 Bonding pad locations (dimensions in µm). All X/Y coordinates are referenced to the centre of chip (see Fig.18)

PAD	PAD NAME	x	y
1	dummy1	+5932	+1060
2	R36	+5704	+1060
3	R37	+5604	+1060
4	R38	+5504	+1060
5	R39	+5404	+1060
6	R40	+5304	+1060
7	R41	+5204	+1060
8	R42	+5104	+1060
9	R43	+5004	+1060
10	R44	+4904	+1060
11	R45	+4804	+1060
12	R46	+4704	+1060
13	R47	+4604	+1060
14	V_{DD1}	+4330	+1085
15	V_{DD1}	+4230	+1085
16	V_{DD1}	+4130	+1085
17	V_{DD1}	+4030	+1085
18	V_{DD1}	+3930	+1085
19	V_{DD2}	+3750	+1085
20	V_{DD2}	+3650	+1085
21	V_{DD2}	+3550	+1085
22	V_{DD2}	+3450	+1085
23	V_{DD2}	+3350	+1085
24	V_{DD2}	+3250	+1085
25	V_{DD2}	+3150	+1085
26	V_{DD2}	+3050	+1085
27	SCLK	+2590	+1085
28	SDIN	+2090	+1085
29	D/$\overline{C}$	+1090	+1085
30	$\overline{SCE}$	+90	+1085
31	$\overline{RES}$	–910	+1085
32	OSC	–1410	+1085
33	T3	–1826	+1085
34	V_{SS2}	–2068	+1085
35	V_{SS2}	–2168	+1085
36	V_{SS2}	–2268	+1085
37	V_{SS2}	–2368	+1085
38	V_{SS2}	–2468	+1085
39	T4	–2709	+1085
40	V_{SS1}	–2876	+1085
41	V_{SS1}	–2976	+1085
42	V_{SS1}	–3076	+1085
43	V_{SS1}	–3176	+1085
44	T1	–3337	+1085
45	V_{LCD2}	–3629	+1085
46	V_{LCD2}	–3789	+1085
47	V_{LCD1}	–4231	+1085
48	V_{LCD1}	–4391	+1085
49	T2	–4633	+1085
50	R23	–4894	+1060
51	R22	–4994	+1060
52	R21	–5094	+1060
53	R20	–5194	+1060
54	R19	–5294	+1060
55	R18	–5394	+1060
56	R17	–5494	+1060
57	R16	–5594	+1060
58	R15	–5694	+1060
59	R14	–5794	+1060
60	R13	–5894	+1060
61	R12	–5994	+1060
62	dummy2	–6222	+1060
63	dummy3	–6238	–738
64	R0	–5979	–738
65	R1	–5879	–738
66	R2	–5779	–738
67	R3	–5679	–738
68	R4	–5579	–738
69	R5	–5479	–738
70	R6	–5379	–738
71	R7	–5279	–738
72	R8	–5179	–738
73	R9	–5079	–738
74	R10	–4979	–738
75	R11	–4879	–738
76	C0	–4646	–746

PAD	PAD NAME	x	y
77	C1	–4546	–746
78	C2	–4446	–746
79	C3	–4346	–746
80	C4	–4246	–746
81	C5	–4146	–746
82	C6	–4046	–746
83	C7	–3946	–746
84	C8	–3846	–746
85	C9	–3746	–746
86	C10	–3646	–746
87	C11	–3546	–746
88	C12	–3446	–746
89	C13	–3346	–746
90	C14	–3246	–746
91	C15	–3146	–746
92	C16	–3046	–746
93	C17	–2946	–746
94	C18	–2846	–746
95	C19	–2746	–746
96	C20	–2646	–746
97	C21	–2546	–746
98	C22	–2446	–746
99	C23	–2346	–746
100	C24	–2246	–746
101	C25	–2146	–746
102	C26	–2046	–746
103	C27	–1946	–746
104	C28	–1696	–746
105	C29	–1596	–746
106	C30	–1496	–746
107	C31	–1396	–746
108	C32	–1296	–746
109	C33	–1196	–746
110	C34	–1096	–746
111	C35	–996	–746
112	C36	–896	–746
113	C37	–796	–746
114	C38	–696	–746
115	C39	–596	–746
116	C40	–496	–746
117	C41	–396	–746

PAD	PAD NAME	x	y
118	C42	–296	–746
119	C43	–196	–746
120	C44	–96	–746
121	C45	+4	–746
122	C46	+104	–746
123	C47	+204	–746
124	C48	+304	–746
125	C49	+404	–746
126	C50	+504	–746
127	C51	+604	–746
128	C52	+704	–746
139	C53	+804	–746
130	C54	+904	–746
131	C55	+1004	–746
132	C56	+1254	–746
133	C57	+1354	–746
134	C58	+1454	–746
135	C59	+1554	–746
136	C60	+1654	–746
137	C61	+1754	–746
138	C62	+1854	–746
139	C63	+1954	–746
140	C64	+2054	–746
141	C65	+2154	–746
142	C66	+2254	–746
143	C67	+2354	–746
144	C68	+2454	–746
145	C69	+2554	–746
146	C70	+2654	–746
147	C71	+2754	–746
148	C72	+2854	–746
149	C73	+2954	–746
150	C74	+3054	–746
151	C75	+3154	–746
152	C76	+3254	–746
153	C77	+3354	–746
154	C78	+3454	–746
155	C79	+3554	–746
156	C80	+3654	–746
157	C81	+3754	–746
158	C82	+3854	–746

PAD	PAD NAME	x	y
159	C83	+3954	–746
160	R35	+4328	–738
161	R34	+4428	–738
162	R33	+4528	–738
163	R32	+4628	–738
164	R31	+4728	–738
165	R30	+4828	–738
166	R29	+4928	–738
167	R28	+5028	–738
168	R27	+5128	–738
169	R26	+5228	–738
170	R25	+5328	–738
171	R24	+5428	–738
172	dummy4	+5694	–738

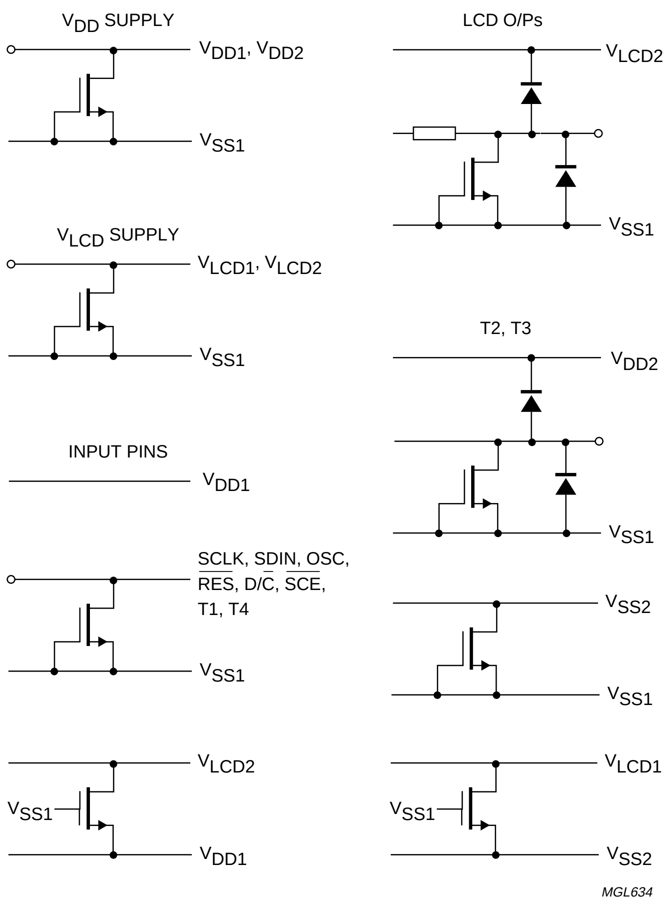
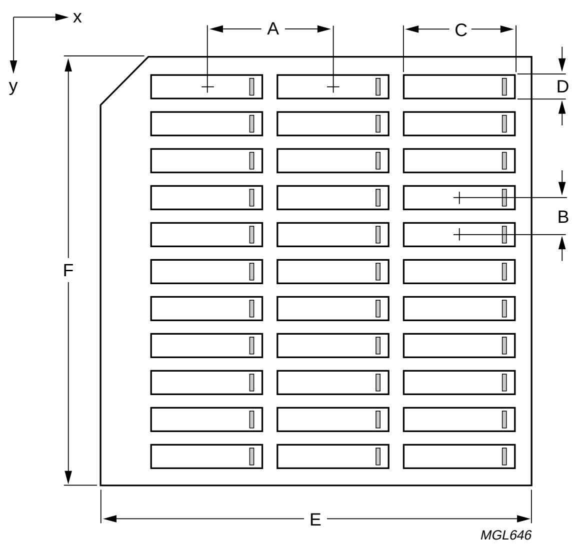


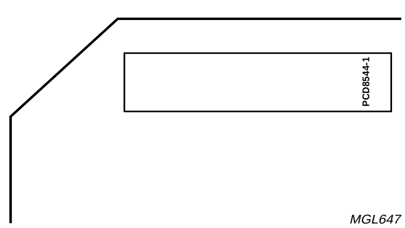
Fig.19 Device protection diagram.

15 TRAY INFORMATION



For the dimensions of x, y and A to F, see Table 8.

Fig.20 Tray details.



The orientation of the IC in a pocket is indicated by the position of the IC type name on the die surface with respect to the chamfer on the upper left corner of the tray. Refer to the bonding pad location diagram for the orientation and position of the type name on the die surface.

Fig.21 Tray alignment.

Table 8 Dimensions

DIM.	DESCRIPTION	VALUE
A	pocket pitch, in the x direction	14.82 mm
B	pocket pitch, in the y direction	4.39 mm
C	pocket width, in the x direction	13.27 mm
D	pocket width, in the y direction	2.8 mm
E	tray width, in the x direction	50.67 mm
F	tray width, in the y direction	50.67 mm
x	no. of pockets in the x direction	3
y	no. of pockets in the y direction	11

16 DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

17 LIFE SUPPORT APPLICATIONS

These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such improper use or sale.

NOTES

Philips Semiconductors – a worldwide company

Argentina: see South America

Australia: 34 Waterloo Road, NORTH RYDE, NSW 2113, Tel. +61 2 9805 4455, Fax. +61 2 9805 4466

Austria: Computerstr. 6, A-1101 WIEN, P.O. Box 213, Tel. +43 1 60 101 1248, Fax. +43 1 60 101 1210

Belarus: Hotel Minsk Business Center, Bld. 3, r. 1211, Volodarski Str. 6, 220050 MINSK, Tel. +375 172 20 0733, Fax. +375 172 20 0773

Belgium: see The Netherlands

Brazil: see South America

Bulgaria: Philips Bulgaria Ltd., Energoproject, 15th floor, 51 James Bourchier Blvd., 1407 SOFIA, Tel. +359 2 68 9211, Fax. +359 2 68 9102

Canada: PHILIPS SEMICONDUCTORS/COMPONENTS, Tel. +1 800 234 7381, Fax. +1 800 943 0087

China/Hong Kong: 501 Hong Kong Industrial Technology Centre, 72 Tat Chee Avenue, Kowloon Tong, HONG KONG, Tel. +852 2319 7888, Fax. +852 2319 7700

Colombia: see South America

Czech Republic: see Austria

Denmark: Sydhavnsgade 23, 1780 COPENHAGEN V, Tel. +45 33 29 3333, Fax. +45 33 29 3905

Finland: Sinikalliontie 3, FIN-02630 ESPOO, Tel. +358 9 615 800, Fax. +358 9 6158 0920

France: 51 Rue Carnot, BP317, 92156 SURESNES Cedex, Tel. +33 1 4099 6161, Fax. +33 1 4099 6427

Germany: Hammerbrookstraße 69, D-20097 HAMBURG, Tel. +49 40 2353 60, Fax. +49 40 2353 6300

Hungary: see Austria

India: Philips INDIA Ltd, Band Box Building, 2nd floor, 254-D, Dr. Annie Besant Road, Worli, MUMBAI 400 025, Tel. +91 22 493 8541, Fax. +91 22 493 0966

Indonesia: PT Philips Development Corporation, Semiconductors Division, Gedung Philips, Jl. Buncit Raya Kav.99-100, JAKARTA 12510, Tel. +62 21 794 0040 ext. 2501, Fax. +62 21 794 0080

Ireland: Newstead, Clonskeagh, DUBLIN 14, Tel. +353 1 7640 000, Fax. +353 1 7640 200

Israel: RAPAC Electronics, 7 Kehilat Saloniki St, PO Box 18053, TEL AVIV 61180, Tel. +972 3 645 0444, Fax. +972 3 649 1007

Italy: PHILIPS SEMICONDUCTORS, Piazza IV Novembre 3, 20124 MILANO, Tel. +39 2 6752 2531, Fax. +39 2 6752 2557

Japan: Philips Bldg 13-37, Kohnan 2-chome, Minato-ku, TOKYO 108-8507, Tel. +81 3 3740 5130, Fax. +81 3 3740 5077

Korea: Philips House, 260-199 Itaewon-dong, Yongsan-ku, SEOUL, Tel. +82 2 709 1412, Fax. +82 2 709 1415

Malaysia: No. 76 Jalan Universiti, 46200 PETALING JAYA, SELANGOR, Tel. +60 3 750 5214, Fax. +60 3 757 4880

Mexico: 5900 Gateway East, Suite 200, EL PASO, TEXAS 79905, Tel. +9-5 800 234 7381, Fax +9-5 800 943 0087

Middle East: see Italy

Netherlands: Postbus 90050, 5600 PB EINDHOVEN, Bldg. VB, Tel. +31 40 27 82785, Fax. +31 40 27 88399

New Zealand: 2 Wagener Place, C.P.O. Box 1041, AUCKLAND, Tel. +64 9 849 4160, Fax. +64 9 849 7811

Norway: Box 1, Manglerud 0612, OSLO, Tel. +47 22 74 8000, Fax. +47 22 74 8341

Pakistan: see Singapore

Philippines: Philips Semiconductors Philippines Inc., 106 Valero St. Salcedo Village, P.O. Box 2108 MCC, MAKATI, Metro MANILA, Tel. +63 2 816 6380, Fax. +63 2 817 3474

Poland: Ul. Lukiska 10, PL 04-123 WARSZAWA, Tel. +48 22 612 2831, Fax. +48 22 612 2327

Portugal: see Spain

Romania: see Italy

Russia: Philips Russia, Ul. Usatcheva 35A, 119048 MOSCOW, Tel. +7 095 755 6918, Fax. +7 095 755 6919

Singapore: Lorong 1, Toa Payoh, SINGAPORE 319762, Tel. +65 350 2538, Fax. +65 251 6500

Slovakia: see Austria

Slovenia: see Italy

South Africa: S.A. PHILIPS Pty Ltd., 195-215 Main Road Martindale, 2092 JOHANNESBURG, P.O. Box 7430 Johannesburg 2000, Tel. +27 11 470 5911, Fax. +27 11 470 5494

South America: Al. Vicente Pinzon, 173, 6th floor, 04547-130 SÃO PAULO, SP, Brazil, Tel. +55 11 821 2333, Fax. +55 11 821 2382

Spain: Balmes 22, 08007 BARCELONA, Tel. +34 93 301 6312, Fax. +34 93 301 4107

Sweden: Kottbygatan 7, Akalla, S-16485 STOCKHOLM, Tel. +46 8 5985 2000, Fax. +46 8 5985 2745

Switzerland: Allmendstrasse 140, CH-8027 ZÜRICH, Tel. +41 1 488 2741 Fax. +41 1 488 3263

Taiwan: Philips Semiconductors, 6F, No. 96, Chien Kuo N. Rd., Sec. 1, TAIPEI, Taiwan Tel. +886 2 2134 2886, Fax. +886 2 2134 2874

Thailand: PHILIPS ELECTRONICS (THAILAND) Ltd., 209/2 Sanpavuth-Bangna Road Prakanong, BANGKOK 10260, Tel. +66 2 745 4090, Fax. +66 2 398 0793

Turkey: Talatpasa Cad. No. 5, 80640 GÜLTEPE/ISTANBUL, Tel. +90 212 279 2770, Fax. +90 212 282 6707

Ukraine: PHILIPS UKRAINE, 4 Patrice Lumumba str., Building B, Floor 7, 252042 KIEV, Tel. +380 44 264 2776, Fax. +380 44 268 0461

United Kingdom: Philips Semiconductors Ltd., 276 Bath Road, Hayes, MIDDLESEX UB3 5BX, Tel. +44 181 730 5000, Fax. +44 181 754 8421

United States: 811 East Arques Avenue, SUNNYVALE, CA 94088-3409, Tel. +1 800 234 7381, Fax. +1 800 943 0087

Uruguay: see South America

Vietnam: see Singapore

Yugoslavia: PHILIPS, Trg N. Pasica 5/v, 11000 BEOGRAD, Tel. +381 11 62 5344, Fax.+381 11 63 5777

For all other countries apply to: Philips Semiconductors, International Marketing & Sales Communications, Building BE-p, P.O. Box 218, 5600 MD EINDHOVEN, The Netherlands, Fax. +31 40 27 24825

Internet: http://www.semiconductors.philips.com

Printed in The Netherlands 465008/750/01/pp32 Date of release: 1999 Apr 12 Document order number: 9397 750 05024