Universidad de Costa Rica
Facultad de Ingeniería
Escuela de Ingeniería Eléctrica

IE-0624
Laboratorio de Microcontroladores

Laboratorio #3: GPIO, ADC, comunicaciones USART y SPI

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1. Resumen

En el siguiente laboratorio, se diseñó a través de un Arduino UNO un voltímetro que logra medir tensiones en AC y DC.

El foco central de este laboratorio fue poder captar tensiones que oscilan entre -24 V y 24 V, ya sea en corriente continua (DC) o alterna (AC). Luego, estas tensiones se muestran en una pantalla LCD PCD8544. Al mismo tiempo se logra una conexión con la computadora y mediante un *script* de *Python* se almacenan los valores recopilados en un archivo CSV.

Dicha conexión a la computadora se logra a través de un puerto serial utilizando el bloque llamado USART. Este bloque posibilita el almacenamiento de los datos obtenidos para su posterior análisis.

Se logró cumplir de manera satisfactoria el objetivo principal de la práctica sobre el manejo de GPIOs, comunicaciones y ADC, además que efectivamente con el diseño logrado se logra medir tensiones en AC y DC mediante el arduino y finalmente se logró controlar la comunicación mediante un switch.

Dirección del repositorio: `https://github.com/KrisKy02/IE0624-Laboratorio-de-microcontroladore` `git`

2. Nota Teórica

2.1. Arduino UNO

El *Arduino UNO* representa una placa de desarrollo esencial y versátil, ideal para adentrarse en el mundo de la electrónica y la codificación. Esta placa está equipada con los reconocidos microcontroladores *ATmega328P* y *ATMega 16U2*, sirviendo como una excelente introducción al universo de Arduino.

2.1.1. Características Principales

Procesador ATMega328P:

- CPU AVR que opera hasta 16 MHz.
- 32KB de Memoria Flash.
- 2KB de SRAM.
- 1KB de EEPROM.

Procesador ATMega16U2:

- Microcontrolador de 8 bits basado en RISC AVR®.
- 16 KB de Flash ISP.
- 512B de EEPROM.
- 512B de SRAM.

2.1.2. Seguridad y Gestión de Energía

- Reset al Encender (Power On Reset - POR).
- Detección de Bajo Voltaje (Brown Out Detection - BOD).
- Operable en un rango de voltaje de 2.7 a 5.5 volts.

2.1.3. Periféricos e Interfaces

- Timers/Contadores de 8 y 16 bits con registro de periodo dedicado.
- USART con generador de tasa de baudios fraccional.
- Interfaces SPI e I2C en modo controlador/periférico dual.
- Comparador Analógico (AC) con entrada de referencia escalable.

- Seis canales PWM.
- Interrupción y activación por cambio en pin.
- Watchdog Timer con oscilador independiente.

En la siguiente imagen se muestran los pines del Arduino

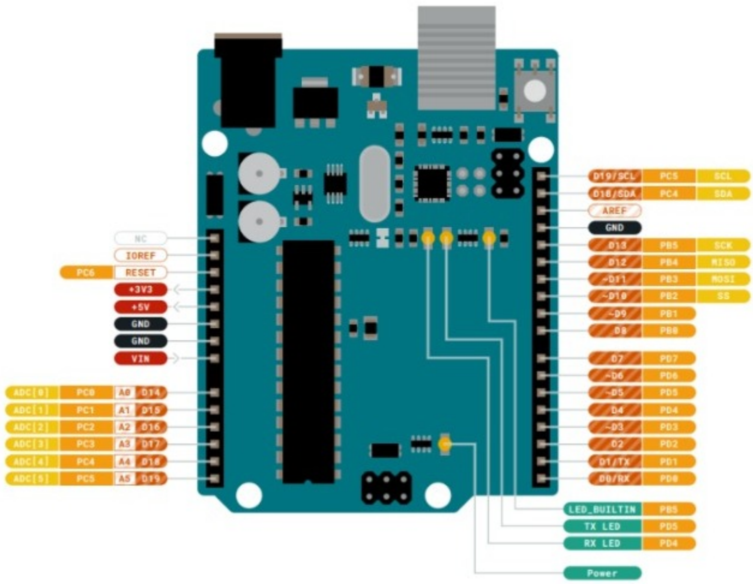


Figura 1: Diagrama de pines.

Y la descripción de cada pin se muestra a continuación

5.1 JANALOG

Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

Figura 2: Explicación de pines.

2.1.4. Debugging

- Interfaz debugWIRE para debugging y programación en chip.

Este hardware es de especial relevancia para los principiantes en Arduino, gracias a su diversidad de características y funcionalidades, permitiendo explorar un amplio espectro de proyectos y aplicaciones en electrónica y programación.

2.2. Microcontrolador ATmega328P

El microcontrolador ATmega328P de Microchip Technology Inc. es un controlador de 8 bits de baja potencia basado en la arquitectura AVR® RISC avanzada [1]. Este microcontrolador ha sido diseñado para otorgar un alto rendimiento y se encuentra optimizado para minimizar el consumo de energía frente a la velocidad de procesamiento, logrando una ejecución de instrucciones en un solo ciclo de reloj y, por tanto, una velocidad de procesamiento que se aproxima a un millón de instrucciones por segundo (MIPS) por megahercio.

2.2.1. Características del ATmega328P

El ATmega328P cuenta con 32 registros de propósito general de 8 bits y opera de forma totalmente estática, alcanzando hasta 20 MIPS a 20MHz[1]. Para el almacenamiento de datos y programas, dispone de diferentes segmentos de memoria no volátil de alta resistencia: Flash programable in-system de hasta 32KB, EEPROM de hasta 1KBytes, y SRAM interna de hasta 2KBytes.

En cuanto a las características de seguridad, posee reset por encendido y detección de bajada de tensión programable. Para la interacción con otros dispositivos y periféricos, el ATmega328P integra una variedad de características como USART serial programable, interfaz serial SPI maestro/esclavo, interfaz serial 2-wire orientada a bytes (compatible con Philips I^2C), temporizador/watchdog programable con oscilador en-chip y comparador analógico en-chip[1].

En términos de eficiencia energética, el ATmega328P ofrece seis modos de sueño: Idle, Reducción de ruido ADC, Ahorro de energía, Apagado, Standby y Standby extendido, permitiendo a los diseñadores de sistemas optimizar el consumo de energía en función de las necesidades de sus aplicaciones.

2.2.2. Aplicación en el Proyecto

En este proyecto, el microcontrolador ATmega328P es crucial ya que actúa como el cerebro del sistema, controlando y gestionando las diferentes partes del circuito, la adquisición de datos de los sensores y la comunicación con otros dispositivos y módulos.

Periféricos del Arduino Utilizados

1. **ADC (Conversor Analógico-Digital)**:
   - Los microcontroladores Arduino están equipados con periféricos ADC que convierten valores de voltaje analógico a valores digitales.
   - El ADC tiene una resolución de 10 bits en la plataforma Arduino UNO, lo que significa que los valores que puede representar oscilan entre 0 y 1023.
   - Estos valores digitales representan voltajes en el rango de 0V a la tensión de referencia (típicamente 5V en Arduino UNO).
   - En este proyecto, el ADC se emplea para leer tensiones a través de cuatro pines específicos (0, 1, 2, 3) y un pin adicional (`ACDC_PIN`) para decidir si las lecturas son en modo AC o DC.
2. **GPIO (General Purpose Input/Output)**:

- Los pines GPIO en el Arduino pueden ser configurados ya sea como entradas o salidas, y son empleados para interactuar con diversos componentes electrónicos.
- Se usa un pin GPIO configurado como salida (`LED_PIN`) para gestionar un LED. Este LED se activa cuando el voltaje leído supera cierto umbral.
- Un pin adicional (`SERIAL_ENABLE_PIN`) está configurado como entrada. Sirve como una señal para decidir si se deben enviar o no datos a través de la comunicación serial.

3. **Comunicación Serial**:
   - La comunicación serial permite que el Arduino envíe y reciba datos mediante UART (Transceptor Universal Asíncrono).
   - Se emplea en la transmisión de datos para diagnosticar o monitorear el comportamiento del sistema.
   - En este proyecto, la comunicación serial se utiliza para enviar valores de voltaje a una terminal serial cuando esté habilitado.
   - La velocidad de transmisión establecida es de 9600 baudios, común para la comunicación con dispositivos y computadoras.

2.3. Controlador y Driver LCD: PCD8544

El PCD8544 es un controlador y driver LCD de baja potencia en un solo chip, diseñado para manejar una pantalla gráfica de 48 filas y 84 columnas, ideal para equipos de telecomunicaciones. Todos los requerimientos para la operación del display están consolidados en un solo chip, lo que resulta en un mínimo de componentes externos y bajo consumo de energía[2].

2.3.1. Características Principales

- Controlador y Driver LCD en un solo chip.
- 48 filas, 84 columnas de salida.
- RAM de datos de Display de 48×84 bits.
- Generación de voltajes de bias y suministro LCD en-chip.
- Oscilador integrado.
- Interfaz serie de máximo 4,0 Mbits/s.
- Entradas compatibles con CMOS.
- Rango de voltajes de suministro lógico V_{DD} to V_{SS} : 2,7 to 3,3 V.
- Bajo consumo de energía, apto para sistemas operados por batería.

- Compensación de temperatura de V_{LCD}.
- Rango de temperatura de operación: $25\,\text{to} + 70\,°C$.

2.3.2. Descripción General

Este componente es fabricado en tecnología CMOS n-well e interfaces con microcontroladores a través de una interfaz de bus serie, proporcionando todas las funciones necesarias para el display en un solo chip y permitiendo la generación de voltajes de suministro y bias LCD en-chip, lo que se traduce en una reducción significativa de componentes externos y de consumo de energía[2].

2.3.3. Aplicaciones

Este controlador y driver LCD es especialmente adecuado para equipos de telecomunicaciones, dada su capacidad de manejar displays gráficos de dimensiones específicas y su versatilidad en la integración con otros componentes y sistemas[2].

2.4. Diodos

Un **diodo** es un componente electrónico fundamental en la electrónica moderna. Es un dispositivo semiconductor que opera fundamentalmente como un interruptor unidireccional para el flujo de corriente, permitiendo la circulación en una dirección y bloqueándola en la dirección contraria [3]. Estos dispositivos, debido a su capacidad para rectificar, son esenciales en la conversión de corriente alterna (CA) a corriente continua (CC) pulsante. Los diodos vienen en diferentes clasificaciones basadas en su tipo, voltaje, y capacidad de corriente.

La polaridad del diodo se define por dos terminales: el ánodo, que es positivo, y el cátodo, que es negativo. La corriente se permite pasar solo cuando hay una tensión positiva aplicada al ánodo [3]. Curiosamente, el símbolo del diodo tiene una flecha que apunta en la dirección opuesta al flujo real de electrones, ya que la convención adoptada muestra la corriente fluyendo desde el lado positivo al negativo [3].

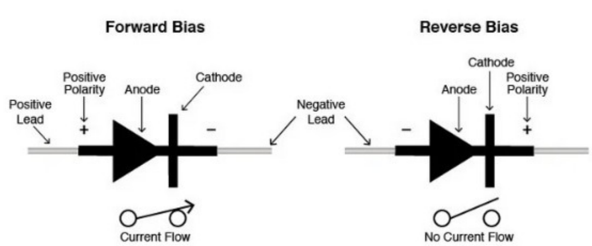


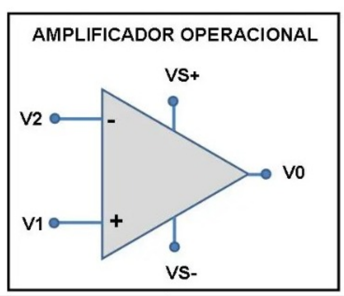
Figura 3: Diodo.[3]

2.5. Amplificador operacional

El **amplificador operacional**, a menudo referido como OPAMP, es un circuito integrado que facilita la implementación de numerosas aplicaciones electrónicas, tales como comparadores de voltaje, amplificadores de señal, realización de operaciones aritméticas y filtrado de señales [4]. Internamente, los OPAMPs están formados por un conjunto de transistores que controlan corrientes y tensiones para otorgarle sus propiedades eléctricas características. Uno de los modelos más conocidos en la historia de los amplificadores operacionales es el circuito integrado 741, siendo uno de los primeros en surgir. Este IC en particular alberga un único OPAMP en su interior, no obstante, los modelos más modernos pueden contener hasta 2 o 4 amplificadores operacionales en total [4].

En cuanto a su estructura, un amplificador operacional presenta dos entradas y una salida, además de conexiones para alimentación positiva y negativa. La configuración de estas entradas determina el comportamiento global del circuito. En un OPAMP ideal se asumen ciertas condiciones:

- La impedancia entre las entradas inversora y no inversora es infinita, por lo que no hay flujo de corriente entre ellas.
- La diferencia de potencial (voltaje) entre las terminales inversora y no inversora debe ser nula.
- No circula corriente a través de las patas inversora y no inversora [4].



Terminal	Descripción
- input	Entrada Inversora
+ input	Entrada no inversora
Output	Salida
+Vss	Alimentación Positiva
-Vss	Alimentación Negativa

Figura 4: Amplificador operacional.[3]

2.6. Precios de los componentes

A continuación se muestran la lista de precios de los componentes utilizados

Componente	**Precio (Colones)**
Arduino UNO	16 000
Amp Op	400
Capacitor	280
Resistencias	70
Diodo LED	299
Botón	120

Tabla 1: Precio de los componentes

3. Desarrollo

3.1. Diseño

3.1.1. Conversión de voltajes a valores positivos

Dado que el Arduino sólo es capaz de interpretar entradas con valores positivos, es necesario implementar un offset a las señales de entrada. Para esto, se emplea un amplificador operacional (OpAmp) configurado como sumador no inversor. La metodología y las ecuaciones empleadas para el diseño y análisis de este amplificador sumador no inversor se fundamentan en el trabajo de Wilaeba Electronica [5].

Cada entrada tiene su propia resistencia, denominada como R_1, R_2, etc., y la resistencia de realimentación, denotada como R_f, será calculada para balancear el circuito.

Análisis del Circuito

La salida del circuito, V_0, se calcula según la siguiente ecuación:

$$V_0 = R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) \tag{1}$$

Donde cada término dentro del paréntesis representa el efecto de cada entrada en la salida, y R_f es la resistencia de realimentación.

Para balancear el circuito y minimizar el error por corriente de bias, se debe seleccionar una resistencia adicional, R_x, de acuerdo a la siguiente ecuación:

$$R_x = \frac{R_P \cdot R_f}{R_P - R_f} \tag{2}$$

Donde R_P es el paralelo de todas las resistencias de entrada. Si el resultado para R_x es negativo, la resistencia se coloca entre el pin inversor y tierra. Si el resultado es positivo, se coloca entre el pin no inversor y tierra.

Para la ecuación (1), se toman valores de $R_1 = R_2 = 1k\Omega$ y se despeja para R_f obteniendo un valor de $1k\Omega$ y para con esto, se obtiene el valor de R_x que al sustituir en (2) se obteniendo un valor de $1k\Omega$. Por lo que el circuito para esta etapa se vería de la siguiente manera:

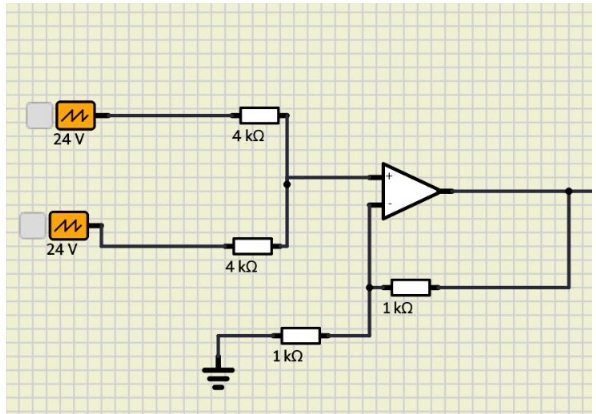


Figura 5: Circuito con Offset

La salida del sumador será la señal de entrada incrementada en 24V. Este procedimiento se aplica de la misma forma tanto para señales DC como AC, resultando así en una señal modificada que se encuentra en un rango de 0V a 48V. En este contexto, un valor de 0V en la señal modificada corresponde a un valor de -24V en la señal de entrada, mientras que un valor de 48V en la señal modificada corresponde a un valor de 24V en la señal de entrada.

3.1.2. Conversión AC/DC

Ya que el Arduino solo lee valores en DC, para medir el voltaje en AC se reuqiere hacer una conversión a DC, por lo tanto se realiza un convertidor con un puente de diodos para la etapa de rectificado y un capacitor para la etapa de rizado, como se muestra a continuación:

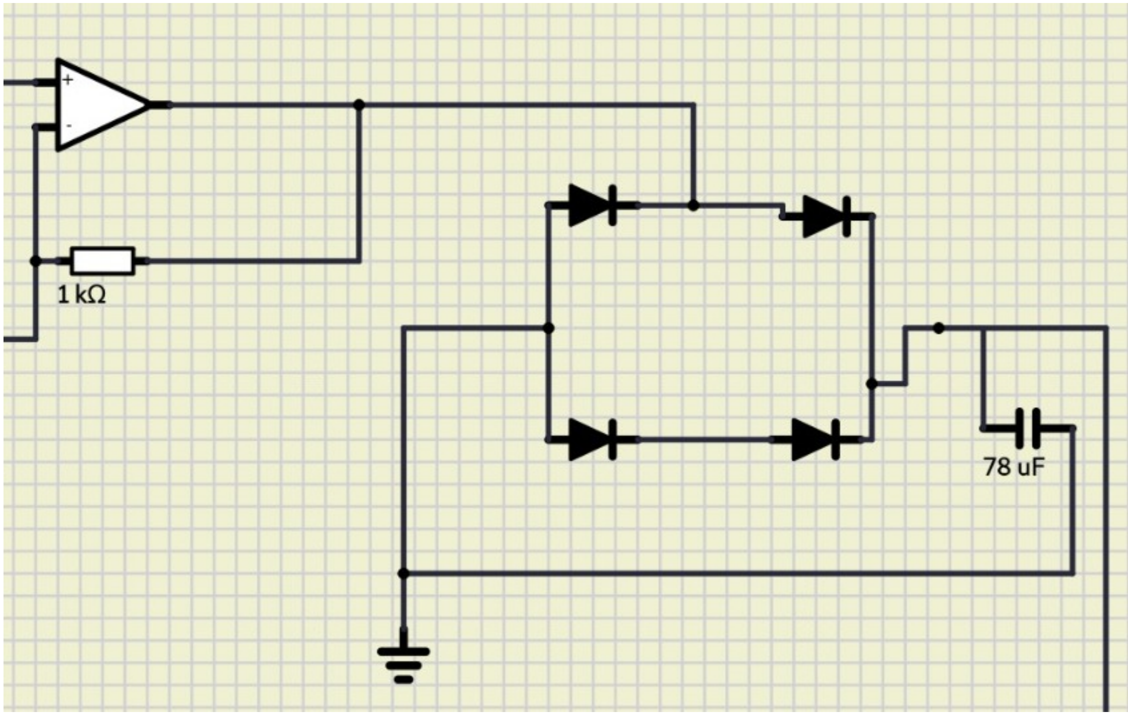


Figura 6: Convertidor AC/DC

3.1.3. Divisor de Tensión

Tras adaptar convertir la señal AC a una DC para el Arduino, se debe adecuar los niveles de voltaje a un rango que el Arduino pueda leer, entre 0 V y 5 V. Por ende, implementamos un divisor de tensión. Este se diseñó considerando un voltaje de entrada máximo de 48 V y un voltaje de salida máximo de 5 V.

La relación entre el voltaje de entrada, el voltaje de salida y las resistencias del divisor de tensión se describe por la ecuación:

$$V_{\text{out}} = \frac{V_{\text{in}} \cdot R_1}{R_1 + R_2} \tag{3}$$

Donde: V_{out} es el voltaje de salida deseado (5 V), V_{in} es el voltaje de entrada máximo (48 V), R_1 y R_2 son las resistencias del divisor de tensión.

Asumiendo un valor de $R_1 = 10\,\text{k}\Omega$, y sustituyendo los valores conocidos en la ecuación, se tiene:

$$5\,\text{V} = \frac{48\,\text{V} \cdot 10\,\text{k}\Omega}{10\,\text{k}\Omega + R_2} \tag{4}$$

Resolviendo para R_2, se encuentra un valor de aproximadamente 86 kΩ.

3.1.4. Manejo de rebotes

El manejo de rebotes, o “debounce”, se puede realizar mediante técnicas de hardware. La implementación por hardware del debounce posee la ventaja de preservar el rendimiento del código al no incrementar su tiempo de ejecución. Sin embargo, introduce la desventaja de hacer más complicada la configuración del circuito.

Un método simple de lograr un debounce por hardware es mediante la conexión de un capacitor en paralelo al dispositivo en cuestión, ya sea un interruptor, botón, sensor, etc. En términos generales, un condensador de valor cercano a 1uF es adecuado para eliminar la mayor parte del ruido y las perturbaciones no deseadas. [6]. En nuestro circuito, esto se ve de la siguiente manera:

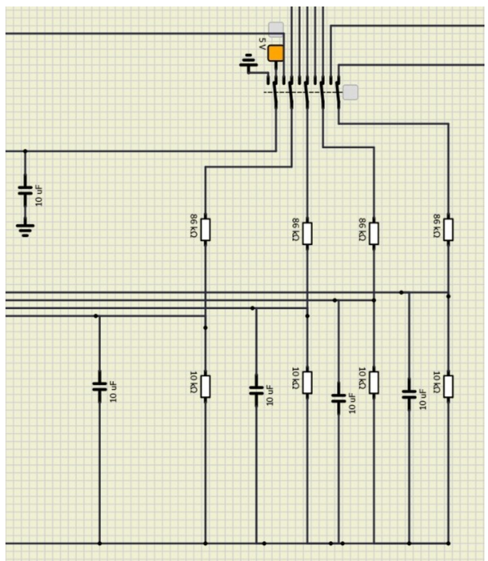


Figura 7: Control de rebotes mediante hardware.

3.1.5. Diseño de Resistencia para LED de Advertencia

Para encender el LED de advertencia cuando se supera un voltaje de 20V, primero debemos tener en cuenta las especificaciones del LED:

- Tensión de funcionamiento: 2,4V

La resistencia se utilizará para limitar la corriente que pasa a través del LED. La fórmula general para calcular la resistencia necesaria para un LED es:

$$R = \frac{V_{source} - V_{LED}}{I_{LED}}$$

donde:

- R es la resistencia necesaria.
- V_{source} es el voltaje de la fuente, en este caso 5V.
- V_{LED} es la tensión de funcionamiento del LED.
- I_{LED} es la corriente deseada a través del LED.

Insertando los valores en la fórmula:

$$R = \frac{5\text{V} - 2{,}4\text{V}}{0{,}03\text{A}}$$

Resolviendo para R, obtenemos:

$$R = 86,67\Omega$$

Por lo tanto, se debe utilizar una resistencia de aproximadamente 91Ω (valor comercial más cercano) para limitar la corriente a través del LED a 30mA.

3.1.6. Control de transmisión serial

Para gestionar la comunicación serial en nuestro proyecto Arduino, se incorporó un switch. Al activar esta entrada, el Arduino permite la transmisión de datos por el puerto serial. Para garantizar una detección fiable del estado del switch, se conectó con una resistencia pull-up. Además, para manejar posibles rebotes del switch, se añadió un capacitor en paralelo.

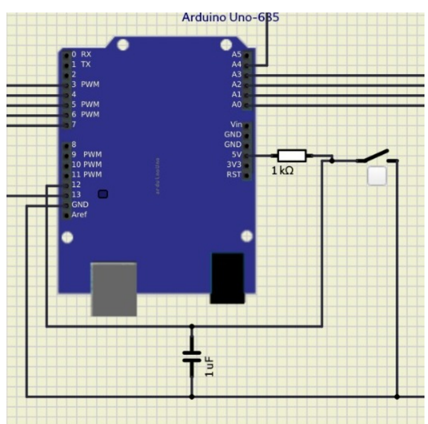


Figura 8: Control de transmisión serial.

3.2. Funcionalidad de Hardware

Al poner en marcha el circuito, se evidencia que la configuración sumadora es efectiva en proporcionar un offset a la señal de entrada. Esta configuración permite la conversión de voltajes a valores positivos. La figura 9 muestra claramente los voltajes de salida derivados de esta configuración sumadora.

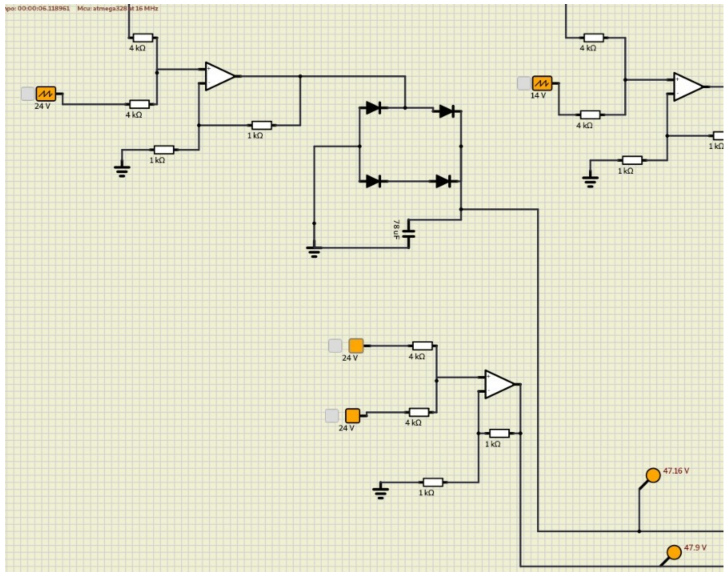


Figura 9: Voltajes de salida del sumador.

Posteriormente, se observa el comportamiento del otro segmento del circuito, como se presenta en la figura 10.

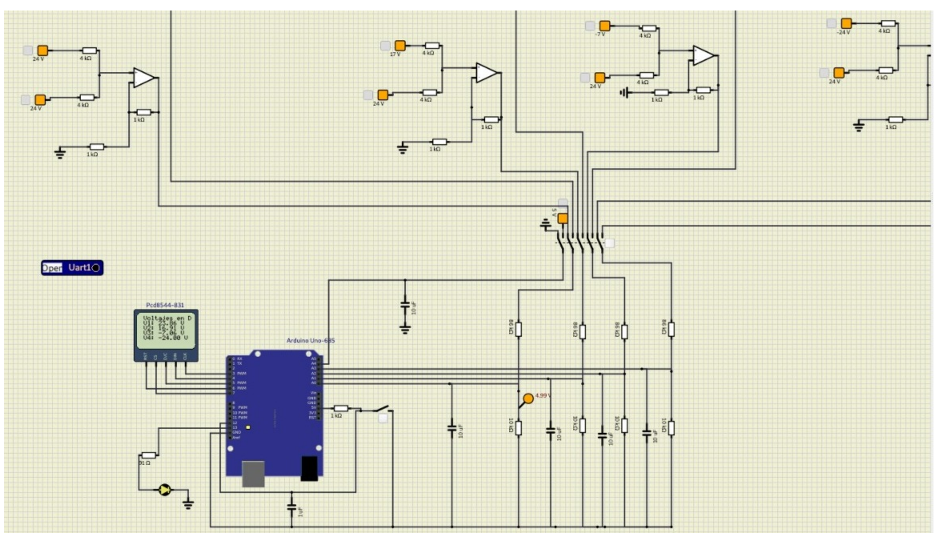


Figura 10: Resultados obtenidos en el segmento subsiguiente del circuito.

En la imagen, se observa el adecuado funcionamiento del divisor de tensión. Se muestra la transición de una tensión de aproximadamente 48V a una cercana a 5V. Asimismo, se evidencia que el software y hardware interactúan de manera correcta. Al procesar la señal a través del Arduino, la pantalla LCD despliega los valores de entrada iniciales. Adicionalmente, se observa que el LED se ilumina, indicando la detección de valores que exceden los 20V o que son inferiores a -20V.

3.3. Funcionalidad de Software

El software desarrollado para el Arduino se encarga de leer y procesar las tensiones desde distintos puntos de muestreo, mostrar los resultados en un LCD, controlar un LED basado en ciertos criterios y también proporcionar una salida de datos por el puerto serial.

Al principio, se declaran y definen constantes y variables para los pines utilizados, valores de resistencias y configuraciones iniciales. Se hace uso de la biblioteca `PCD8544.h` para controlar el LCD.

En la función `setup()`, se inicializa el LCD, se configura la comunicación serial y se establecen las configuraciones de entrada/salida para varios pines. Esta función se ejecuta una vez al iniciar el Arduino.

La función `loop()`, que se ejecuta continuamente, empieza leyendo el estado del pin `ACDC_PIN` para determinar si los valores que se deben mostrar son en corriente continua (DC) o alterna (AC). Dependiendo de esta lectura, llama a la función `displayAndLogVoltage()` con el etiquetado correspondiente y una función de conversión que, en el caso de AC, convierte la tensión a su valor RMS.

La función `displayAndLogVoltage()` es el corazón del programa. Esta función lee los valores analógicos de los pines de voltaje definidos, los convierte a valores de voltaje reales considerando un divisor de tensión, los ajusta según las resistencias especificadas y finalmente los muestra en el LCD. Además, si cualquier valor leído supera los 20V (en valor absoluto), enciende un LED. Después de un retardo de 1 segundo, si la comunicación serial está habilitada, esta misma función también envía los valores leídos a través del puerto serial.

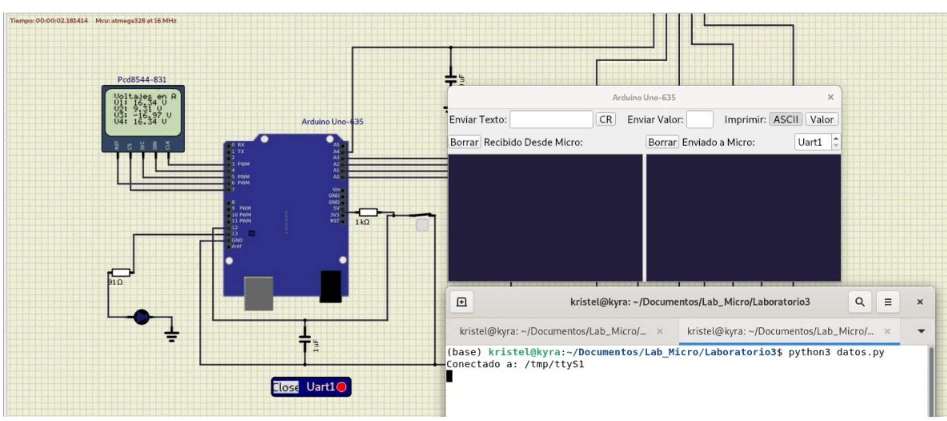


Figura 11: Resultados en la terminal con la comunicación serial deshabilitada.

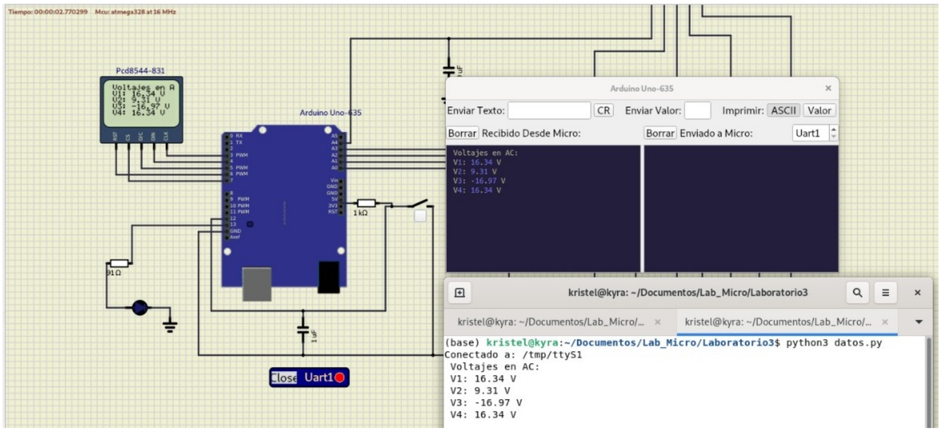


Figura 12: Resultados en la terminal con la comunicación serial habilitada.

Las Figuras 11 y 12 muestran los resultados obtenidos en la terminal cuando la comunicación serial está deshabilitada y habilitada, respectivamente.

En la Figura 11, se puede apreciar que cuando el switch de habilitación se encuentra en posición 0 (deshabilitado), la comunicación serial no se establece. Esto se refleja en la ausencia de datos en la terminal donde se ejecuta el script de Python, corroborando así el comportamiento esperado del código al detectar este estado del switch.

Por otro lado, en la Figura 12, con el switch de habilitación en posición 1 (habilitado), se observa que la comunicación serial se activa con éxito. Los datos de voltaje son mostrados no solo en el monitor serial del Arduino, sino también en la terminal donde se ejecuta el script de Python, evidenciando así la correcta transmisión y recepción de datos entre el Arduino y la terminal.

4. Conclusiones y Recomendaciones

4.1. Conclusiones

- Se logró cumplir de manera satisfactoria el objetivo principal de la práctica sobre el manejo de GPIOs, comunicaciones y ADC
- Se logró medir de manera satisfactoria las tensiones en DC y AC mediante el arduino UNO. Cabe destacar que las tensiones fueron positivas y negativas.
- Se logró de manera satifactoria el uso de los cables USART para poder conectar el Arduino con la PC y así mediante un script de Python guardar los datos registrados en un archivo csv.
- Se logró de manera correcta utilizar y aprender sobre los Arduinos y aplicar conocimientos previos en el lenguaje programación C para el desarrollo.

4.2. Recomendaciones

- Examinar las bibliotecas necesarias para identificar comandos útiles en la elaboración del código.
- Implementar un interruptor multipolar que visualice la tensión DC o AC según su posición.
- Buscar la mejor manera de optimizar el diseño ya que al tener gran cantidad de componentes puede llegar a convertirse de gran tamaño

Referencias

[1] M. T. Inc., *ATmega48A/PA/88A/PA/168A/PA/328/P Data Sheet*, 2020, dS40002061B. [Online]. Available: http://www.microchip.com/

[2] P. Semiconductors, *PCD8544 Product Specification*, Apr 12 1999, file under Integrated Circuits, IC17. [Online]. Available: https://www.alldatasheet.com/view.jsp?Searchword=Pcd8544&gad_source=1&gclid=CjwKCAjw69moBhBgEiwAUFCx2NDXXXOaQIaP3gxh3yjSjhYW3GLYFfABbkcHyT40S_fb__93wuadjxoCvSgQAvD_BwE

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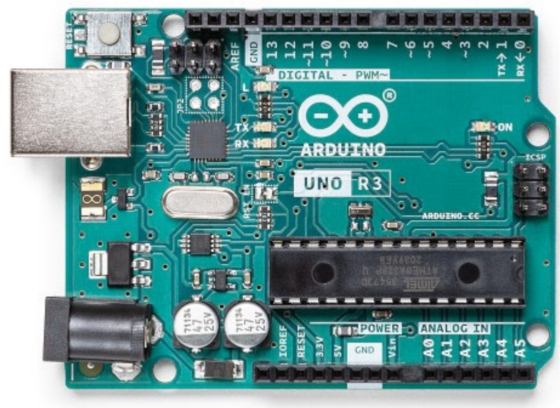
[6] L. Llamas. (2016) Debounce e interrupciones con arduino. Consultado el: [29 de septiembre del 2023]. [Online]. Available: https://www.luisllamas.es/debounce-interrupciones-arduino/

5. Apéndices

Product Reference Manual
SKU: A000066



Description

The Arduino UNO R3 is the perfect board to get familiar with electronics and coding. This versatile development board is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.
This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32KB Flash
    - 2KB SRAM
    - 1KB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 KB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts

CONTENTS

1 The Board

1.1 Application Examples

The UNO board is the flagship product of Arduino. Regardless if you are new to the world of electronics or will use the UNO as a tool for education purposes or industry-related tasks, the UNO is likely to meet your needs.

First entry to electronics: If this is your first project within coding and electronics, get started with our most used and documented board; Arduino UNO. It is equipped with the well-known ATmega328P processor, 14 digital input/output pins, 6 analog inputs, USB connections, ICSP header and reset button. This board includes everything you will need for a great first experience with Arduino.

Industry-standard development board: Using the Arduino UNO R3 board in industries, there are a range of companies using the UNO board as the brain for their PLC's.

Education purposes: Although the UNO R3 board has been with us for about ten years, it is still widely used for various education purposes and scientific projects. The board's high standard and top quality performance makes it a great resource to capture real time from sensors and to trigger complex laboratory equipment to mention a few examples.

1.2 Related Products

- Starter Kit
- Arduino UNO R4 Minima
- Arduino UNO R4 WiFi
- Tinkerkit Braccio Robot

2 Ratings

2.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (-40°F)	85 °C (185°F)

NOTE: In extreme temperatures, EEPROM, voltage regulator, and the crystal oscillator, might not work as expected.

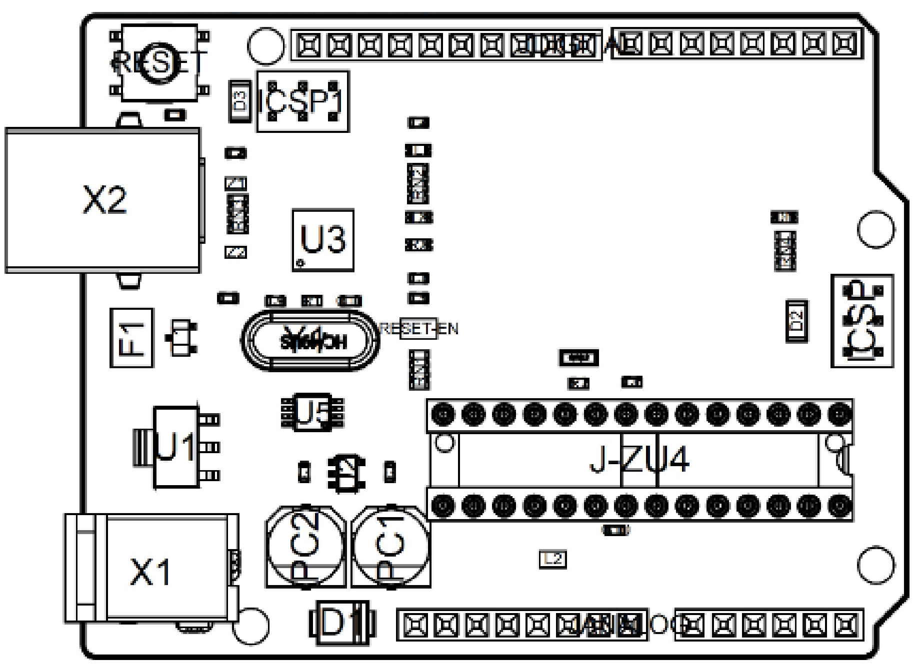
2.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
VINMax	Maximum input voltage from VIN pad	6	-	20	V
VUSBMax	Maximum input voltage from USB connector		-	5.5	V
PMax	Maximum Power Consumption	-	-	xx	mA

3 Functional Overview

3.1 Board Topology

Top view



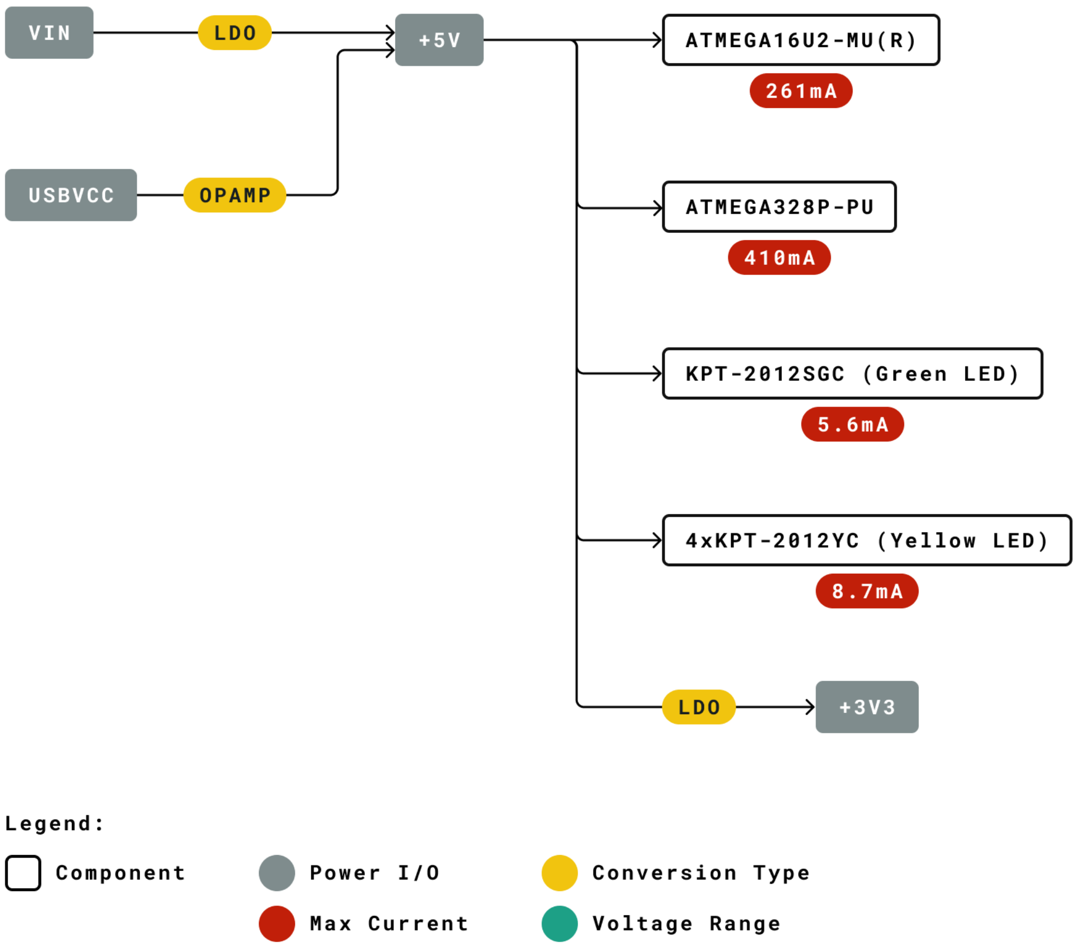
Board topology

Ref.	Description	Ref.	Description
X1	Power jack 2.1x5.5mm	U1	SPX1117M3-L-5 Regulator
X2	USB B Connector	U3	ATMEGA16U2 Module
PC1	EEE-1EA470WP 25V SMD Capacitor	U5	LMV358LIST-A.9 IC
PC2	EEE-1EA470WP 25V SMD Capacitor	F1	Chip Capacitor, High Density
D1	CGRA4007-G Rectifier	ICSP	Pin header connector (through hole 6)
J-ZU4	ATMEGA328P Module	ICSP1	Pin header connector (through hole 6)
Y1	ECS-160-20-4X-DU Oscillator		

3.2 Processor

The Main Processor is a ATmega328P running at up to 20 MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the USB Bridge coprocessor.

3.3 Power Tree



Power tree

4 Board Operation

4.1 Getting Started - IDE

If you want to program your Arduino UNO R3 while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino UNO to your computer, you'll need a USB-B cable. This also provides power to the board, as indicated by the LED.

4.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

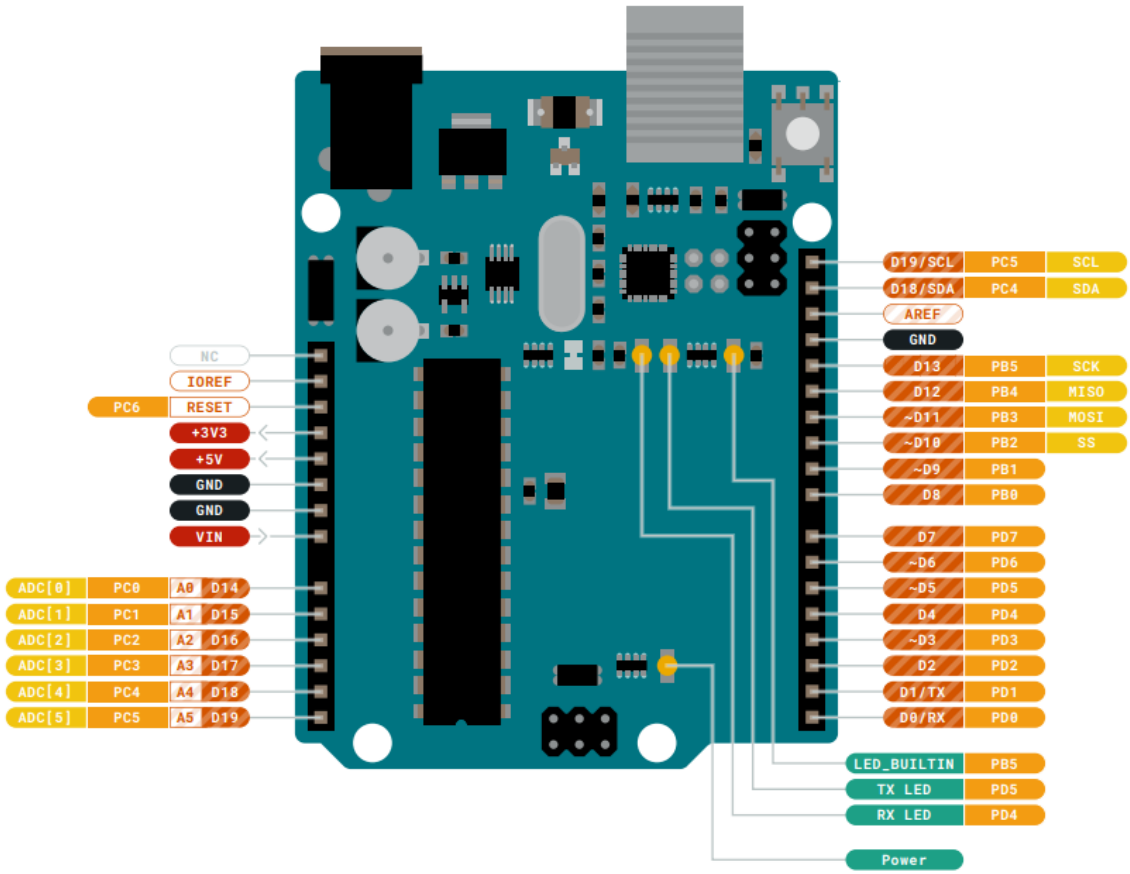
4.3 Sample Sketches

Sample sketches for the Arduino UNO R3 can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino website [4]

4.4 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on Arduino Project Hub **[5]**, the Arduino Library Reference **[6]** and the online Arduino store **[7]** where you will be able to complement your board with sensors, actuators and more.

5 Connector Pinouts



Pinout

5.1 JANALOG

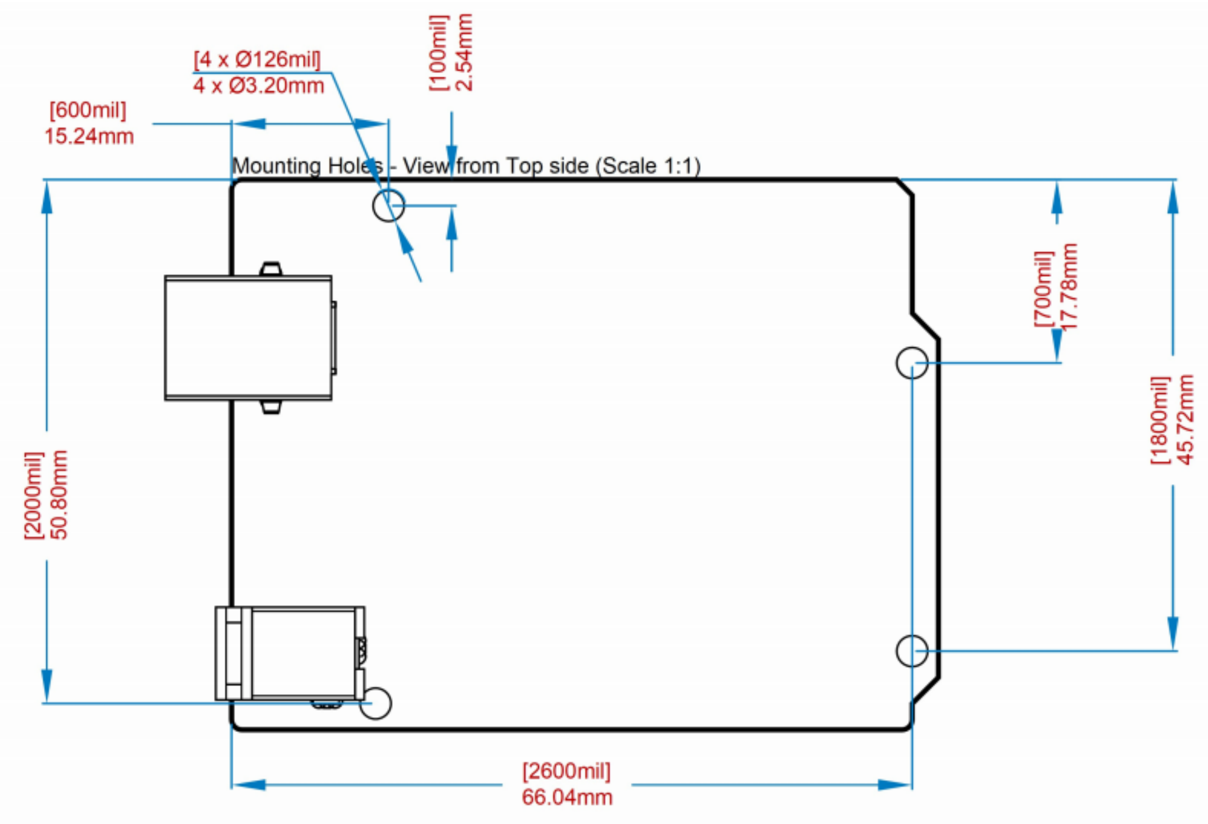
Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO
13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

5.2 JDIGITAL

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 1/GPIO
3	D2	Digital/GPIO	Digital pin 2/GPIO
4	D3	Digital/GPIO	Digital pin 3/GPIO
5	D4	Digital/GPIO	Digital pin 4/GPIO
6	D5	Digital/GPIO	Digital pin 5/GPIO
7	D6	Digital/GPIO	Digital pin 6/GPIO
8	D7	Digital/GPIO	Digital pin 7/GPIO
9	D8	Digital/GPIO	Digital pin 8/GPIO
10	D9	Digital/GPIO	Digital pin 9/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

5.3 Mechanical Information

5.4 Board Outline & Mounting Holes



Board outline

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

ROHS 2 Directive 2011/65/EU	
Conforms to:	EN50581:2012
Directive 2014/35/EU. (LVD)	
Conforms to:	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/AC:2011
Directive 2004/40/EC & 2008/46/EC & 2013/35/EU, EMF	
Conforms to:	EN 62311:2008

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions: No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List" (Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l’ installation et de l’ exploitation de ce dispositif, la distance entre le radiateur et le corps est d ’au moins 20 cm.

Important: The operating temperature of the EUT can’t exceed 85℃ and shouldn’t be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/Main/Software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Arduino Website	https://www.arduino.cc/
Project Hub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/
Online Store	https://store.arduino.cc/

10 Revision History

Date	Revision	Changes
26/07/2023	2	General Update
06/2021	1	Datasheet release

INTEGRATED CIRCUITS

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

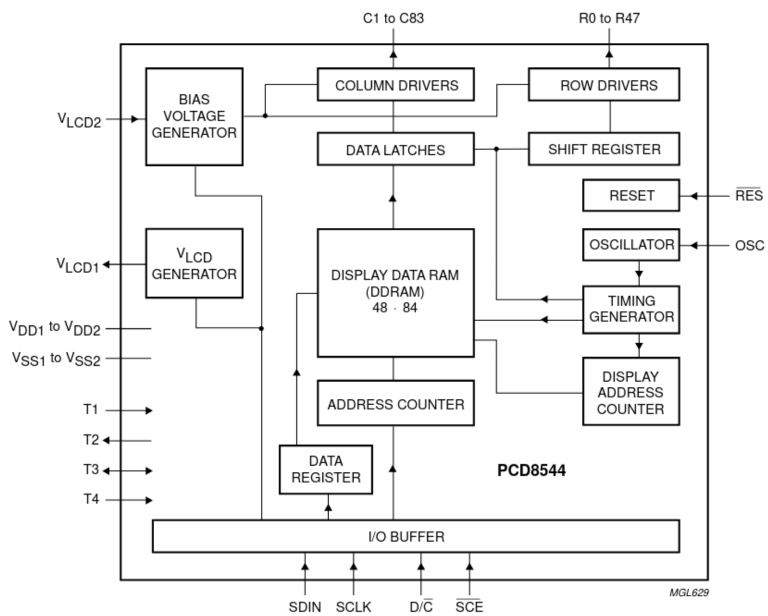


Fig.1 Block diagram.

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

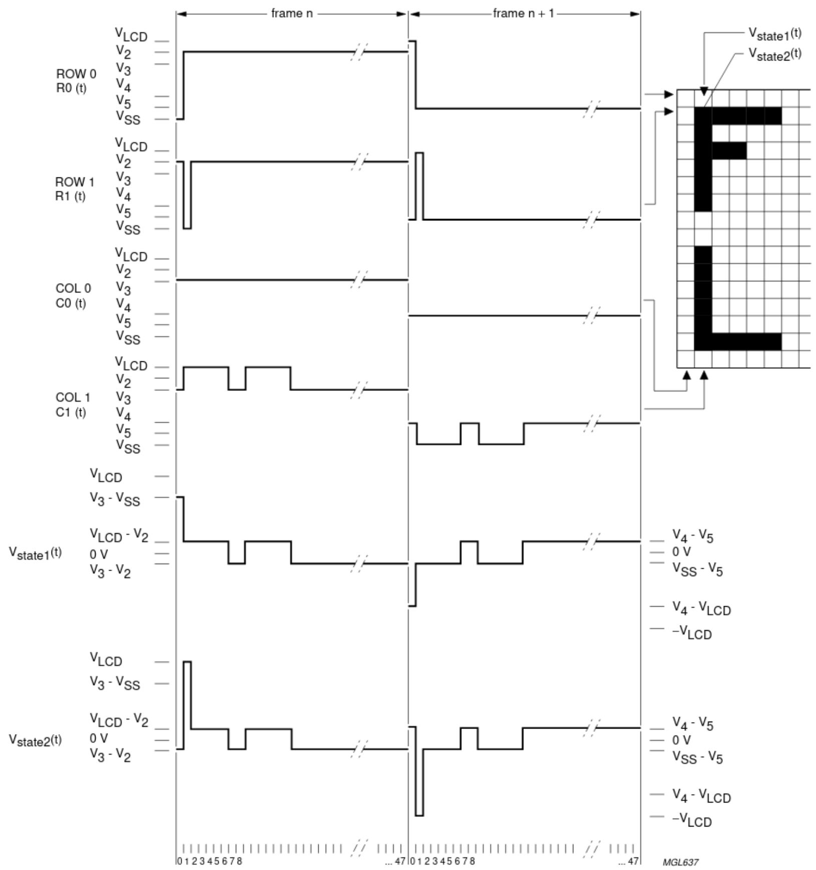
The timing generator produces the various signals required to drive the internal circuits. Internal chip operation is not affected by operations on the data buses.

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.

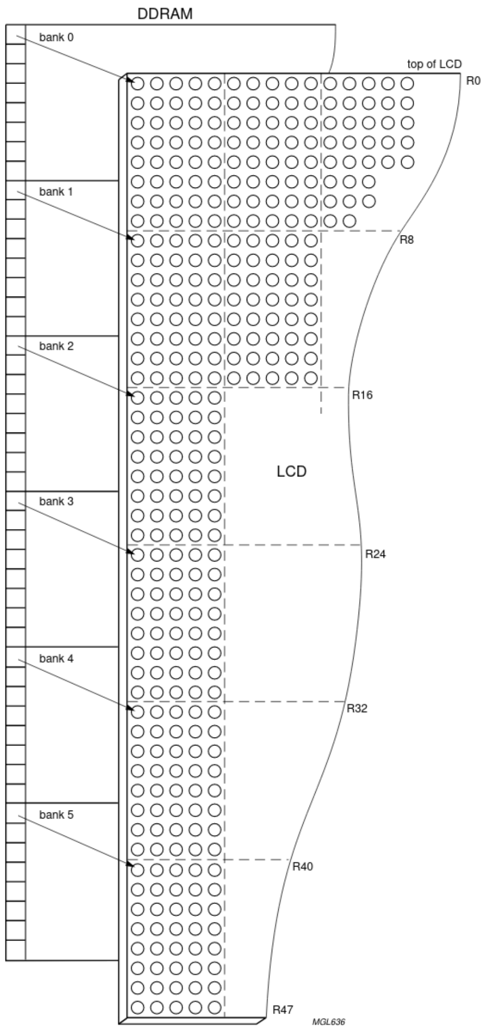


Fig.3 DDRAM to display mapping.

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

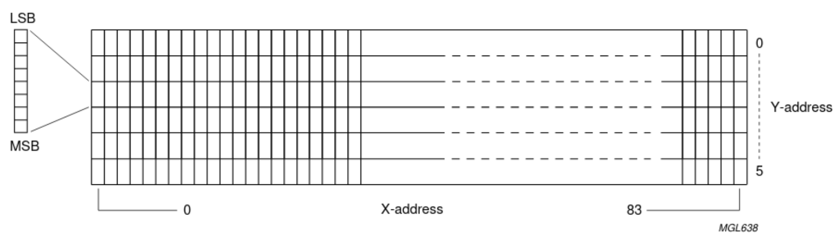


Fig.4 RAM format, addressing.

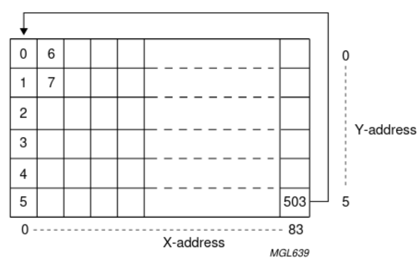


Fig.5 Sequence of writing data bytes into RAM with vertical addressing (V = 1).

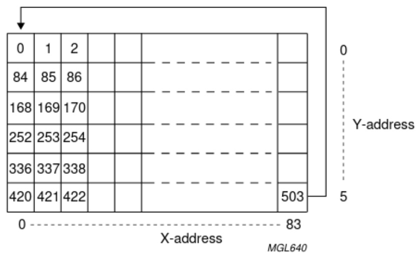
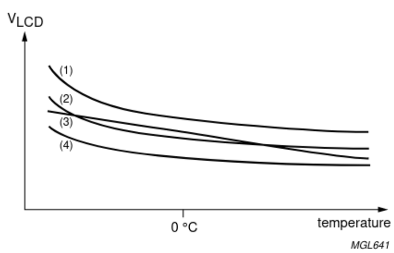


Fig.6 Sequence of writing data bytes into RAM with horizontal addressing (V = 0).

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.

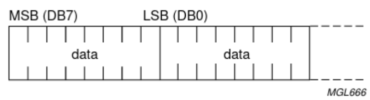


Fig.8 General format of data stream.

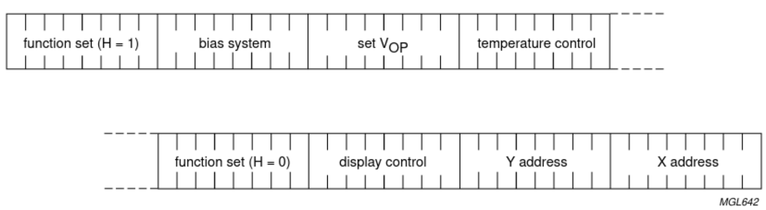


Fig.9 Serial data stream, example.

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).

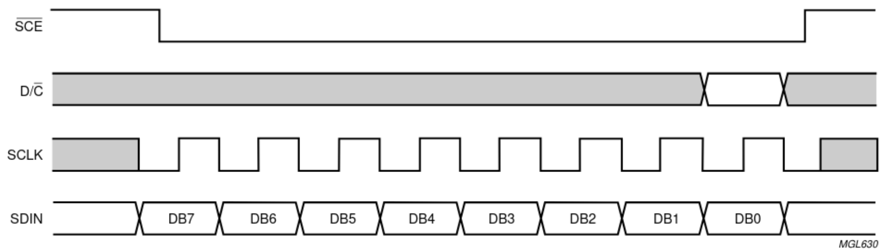


Fig.10 Serial bus protocol - transmission of one byte.

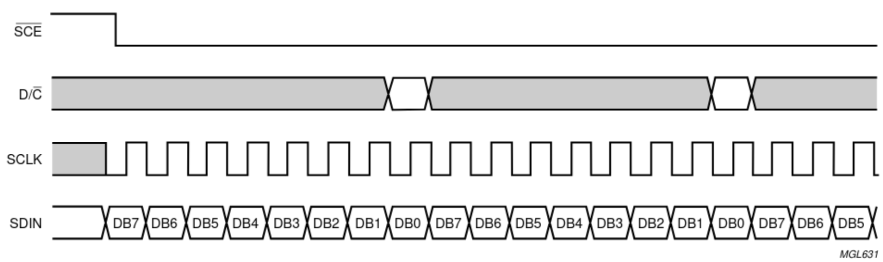


Fig.11 Serial bus protocol - transmission of several bytes.

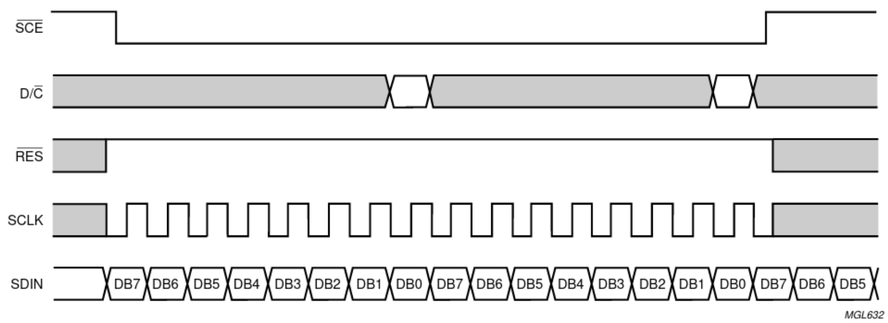


Fig.12 Serial bus reset function ($\overline{\text{SCE}}$).

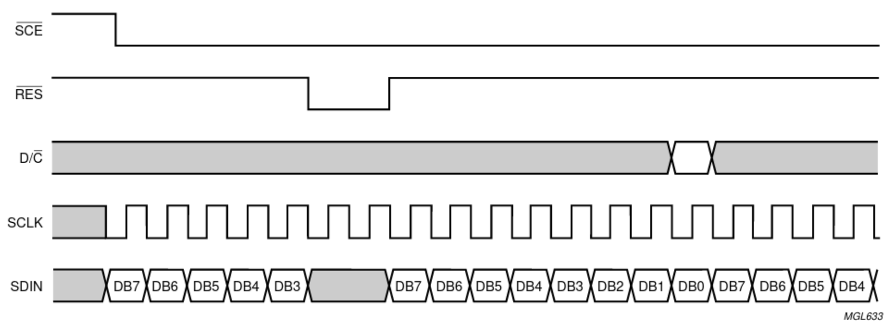


Fig.13 Serial bus reset function ($\overline{\text{RES}}$).

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 $\overline{RES}$ 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 $\overline{RES}$ 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 $\overline{RES}$ 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:

$$n = \sqrt{48} - 3 = 3.928 = 4 \tag{1}$$

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)	$\frac{7}{8} \cdot V_{LCD}$
V3	(n + 2)/(n + 4)	$\frac{6}{8} \cdot V_{LCD}$
V4	2/(n + 4)	$\frac{2}{8} \cdot V_{LCD}$
V5	1/(n + 4)	$\frac{1}{8} \cdot V_{LCD}$
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 $V_{OP0}) \cdot b$ [V]. In the PCD8544, a = 3.06 and b = 0.06 giving a program range of 3.00 to 10.68 at room temperature.

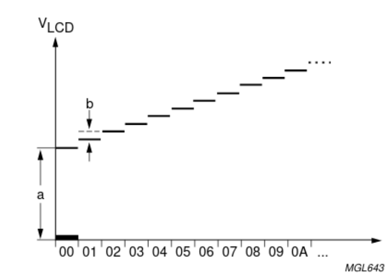
Note that the charge pump is turned off if V_{OP6} to V_{OP0} is set to zero.

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 ∝A; note 2	–	240	300	∝A
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 ∝A; note 2	–	–	320	∝A
I_{DD3}	supply current 3 (Power-down mode)	with internal or external LCD supply voltage; note 3	–	1.5	–	∝A
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	–	∝A
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 ∝A; notes 2 and 4	–	42	–	∝A
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	∝A
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 ∝A; 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 ∝A	–	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 ∝A	–	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 ∝A	–	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 ∝A	–	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

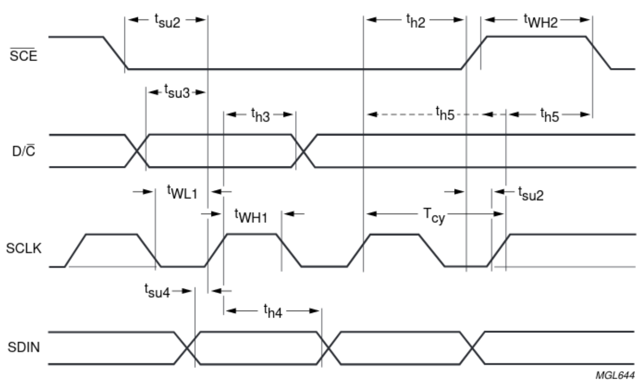


Fig.15 Serial interface timing.

12.2 Reset

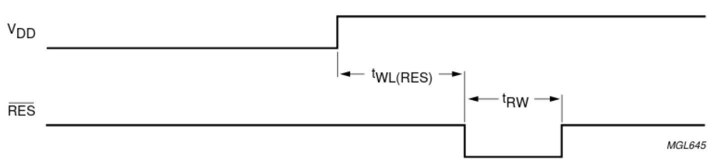
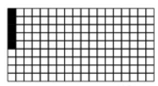
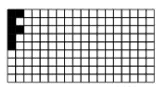
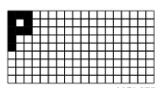
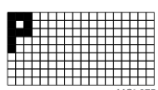
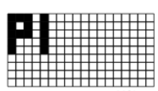
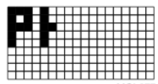
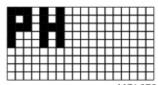
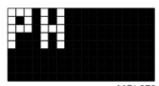
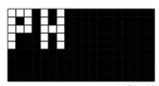
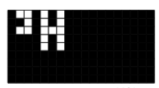


Fig.16 Reset timing.

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 · 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	 MGL677	data write
12	1	0	0	0	1	1	1	1	1	 MGL678	data write
13	0	0	0	0	0	1	1	0	1	 MGL679	display control; set inverse video mode (D = 1 and E = 1)
14	0	1	0	0	0	0	0	0	0	 MGL679	set X address of RAM; set address to ‘0000000’
15	1	0	0	0	0	0	0	0	0	 MGL680	data write

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

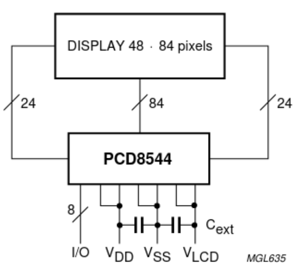


Fig.17 Application diagram.

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

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 ∝m
Pad size, aluminium	80 · 100 ∝m
Bump dimensions	59 · 89 · 17.5 (±5) ∝m
Wafer thickness	max. 380 ∝m

14.2 Bonding pad location

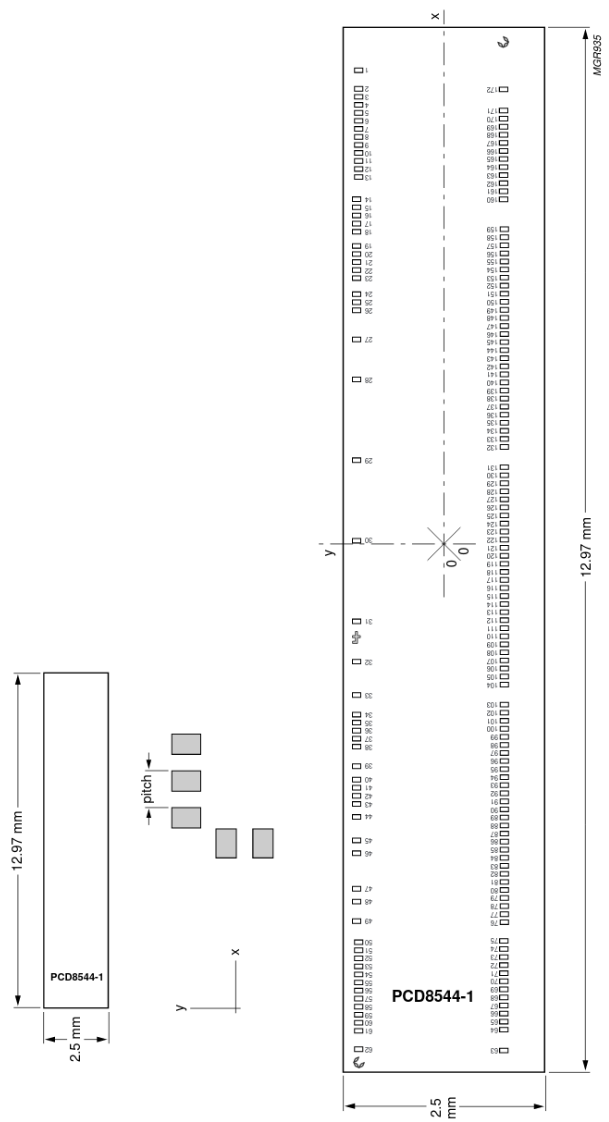


Fig.18 Bonding pad locations.

Table 7 Bonding pad locations (dimensions in ∝m). 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

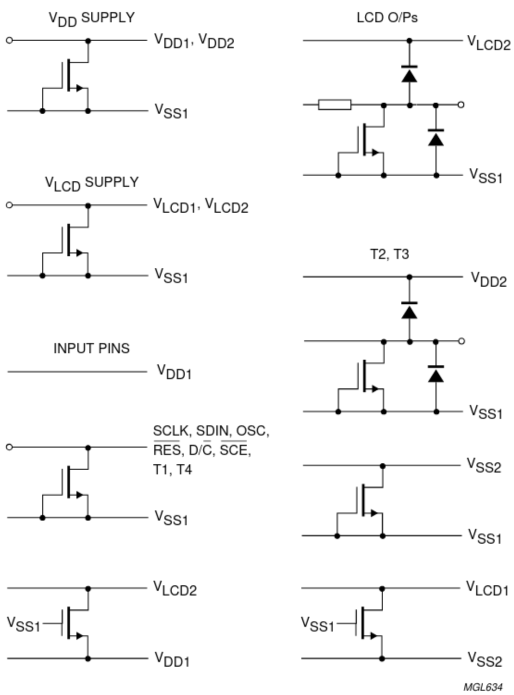
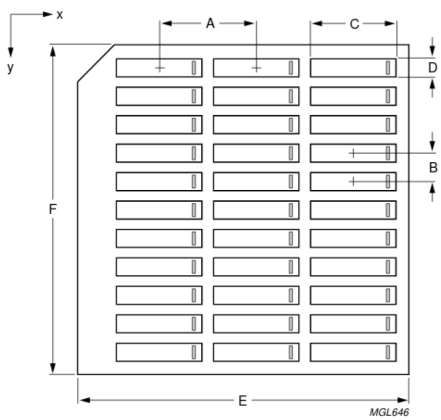


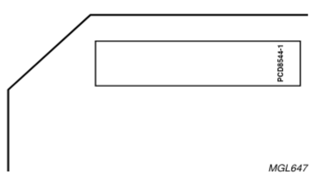
Fig.19 Device protection diagram.

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.	

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