Microprocessor systems EMISY

Integrated and external peripherals in microprocessor systems, part 1
Lecture 5

Semester 19L – Summer 2019

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Important remark

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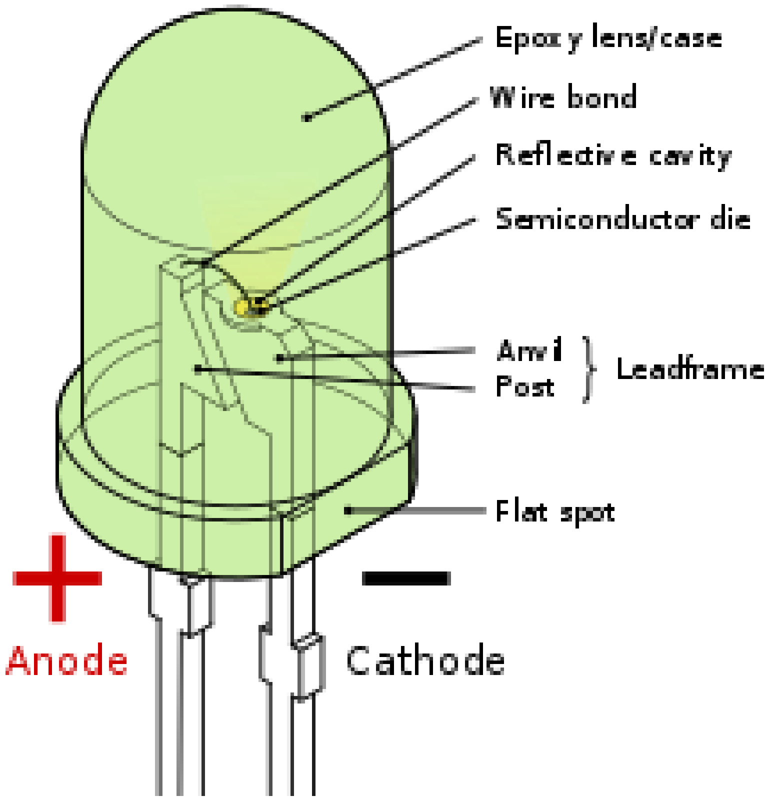
The most basic external peripheral – LED diode

LED (Light Emmiting Diode) is a semiconductor based light source, forced to emit light when current flows through it.



In some particular semiconductors the recombination of electrons is also a process that emits energy in the form of photons. The color of the light emited during the recombination proces is dependant on the band gap width of the semiconductor.

Infrared LEDs (Λ > 760 nm) are made of gallium arsenide (GaAs)
Red, orange, yellow and green LEDs are made of gallium phospide (GaP)
Blue, violet and ultraviolet LEDs are made of indium gallium nitride (InGaN)

LEDs are current-driven devices. It means it is required to force a proper current flow level through diode.

Usually low-power LEDs are powered with currents in range from 1 mA to 20 mA (older LEDs).

Voltage drop across forward-biased LED depends on semiconductor type and LED color.

Infrared LEDs voltage drop is less than 1.6V. Red LEDs have voltage drops up to 2.0 V, green and violet up to 4.0V. This means that not all LEDs (in means of color) can be supplied directly via microcontroller GPIO.

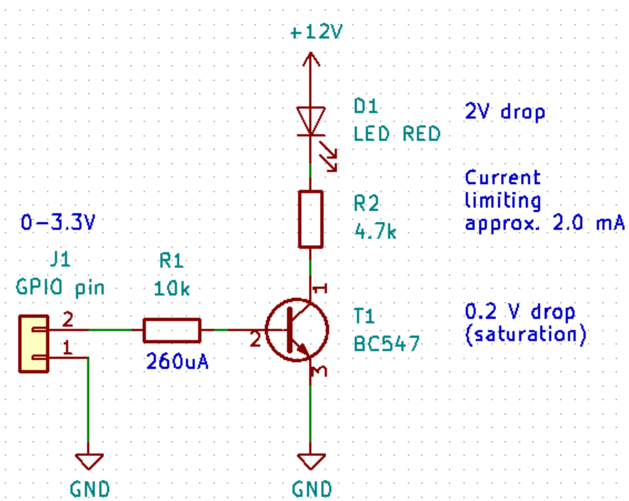
The most basic external peripheral – LED diode - interfacing

If the voltage drop on the forward biased LED is lower than microcontroller VCC voltage value and if the LED forward current is less than max. GPIO pin current then it is possible to connect the LED directly to the microcontroller pin with a series resistor. This resistor will limit the LED forward current.

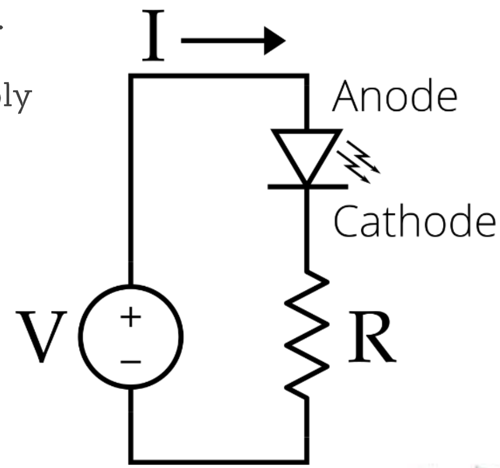
If any of upper conditions is not met then a special interfacing circuit is required. It can be either a simple transistor based current switch, or special LED driver chip, like for instance AL5801 (up to 350mA current)

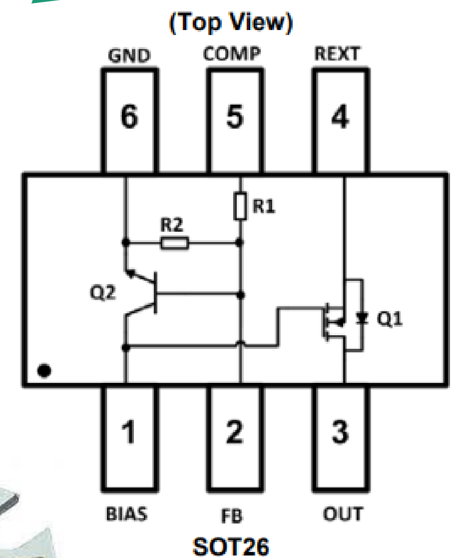
Special care must be taken during designing drivers for high power LEDs (max. current, power dissipation).

In many applications a separate switching power supply is required for high power LEDs



Calculation example...





High power LED on aluminium substrate

The most basic external peripheral – RGB diodes

By connecting three LEDs of different colors (red, green, blue) in parallel it is possible to create RGB LED. The final color will be a result of mixing red, green and blue. The intensity of each color can be adjusted with proper driving circuit, for instance PWM.

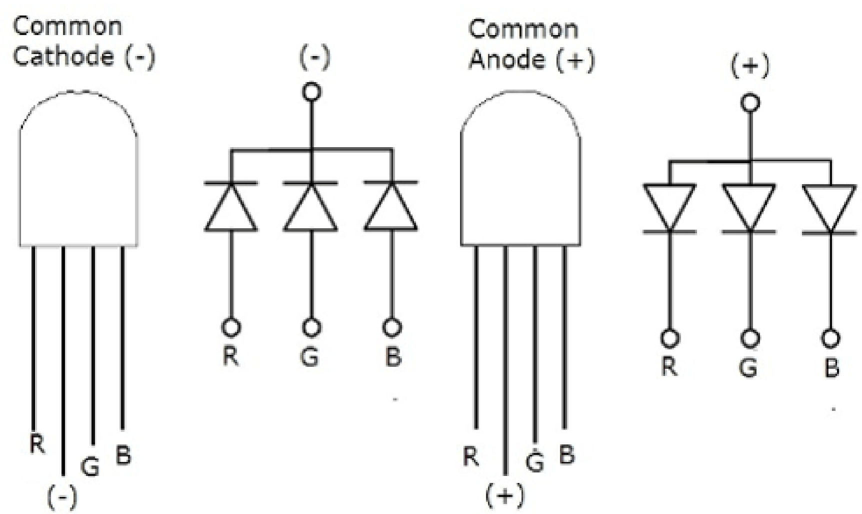
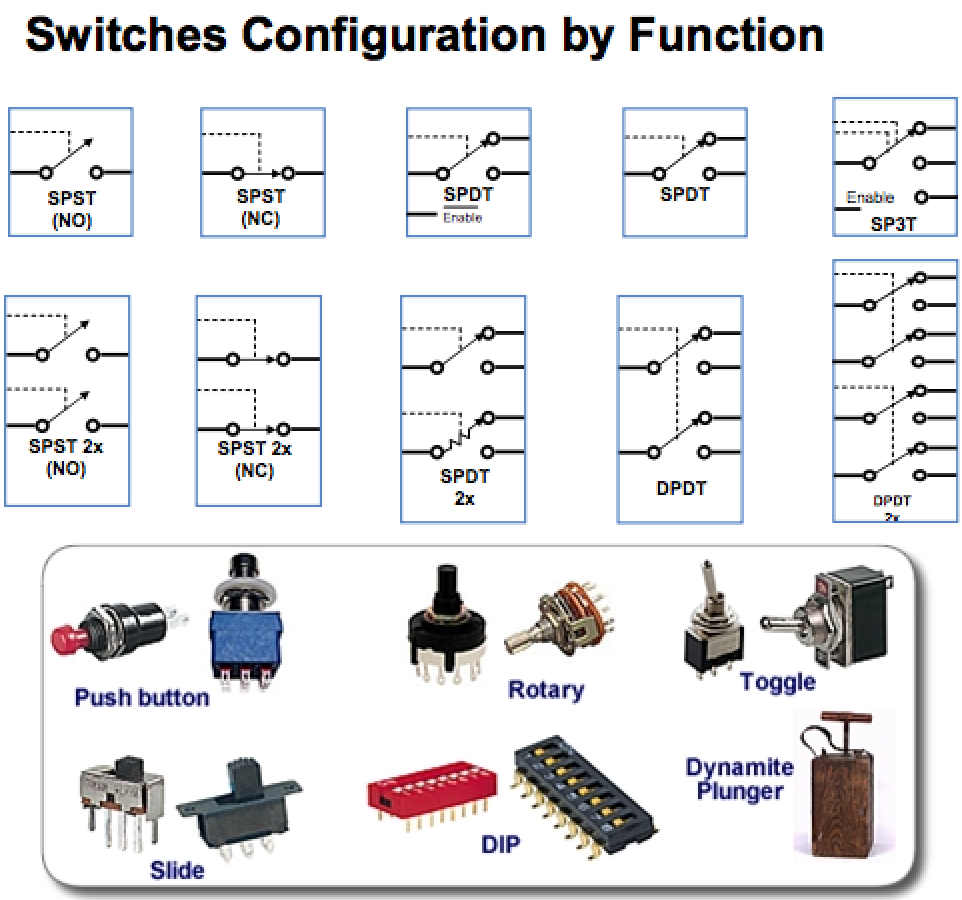


Image source: hackster.io

Connecting tact switches – introduction to keyboards

Switch is an electronic device that causes a short or break between two or more points in circuit...



There are different types of switches:

SPST – Single Pole Single Throw – the most basic turn on/off switch, available in normally open and close versions
SPDT – Single Pole Dual Throw – three terminal switch, there are two positions available

SP3T, SP4T – SPDT variations with multiple ports

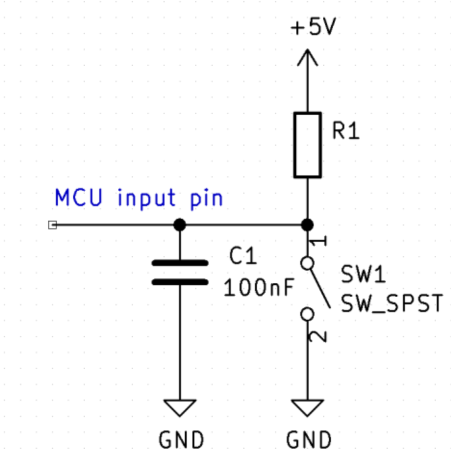
DPDT – Dual Pole Dual Throw – dual SPDT, can be used to turn on/off devices connected to 230V AC mains

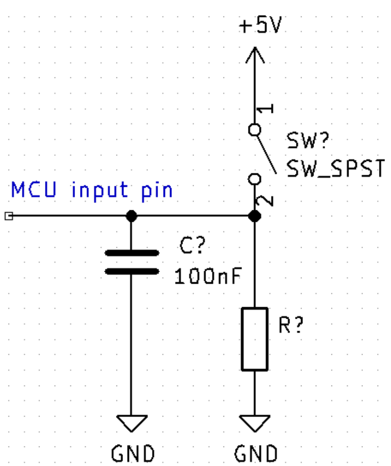
Push button switches – tact switches – they have one stable state (normally open or normally closed), they are used to create keyboards in microprocessor systems

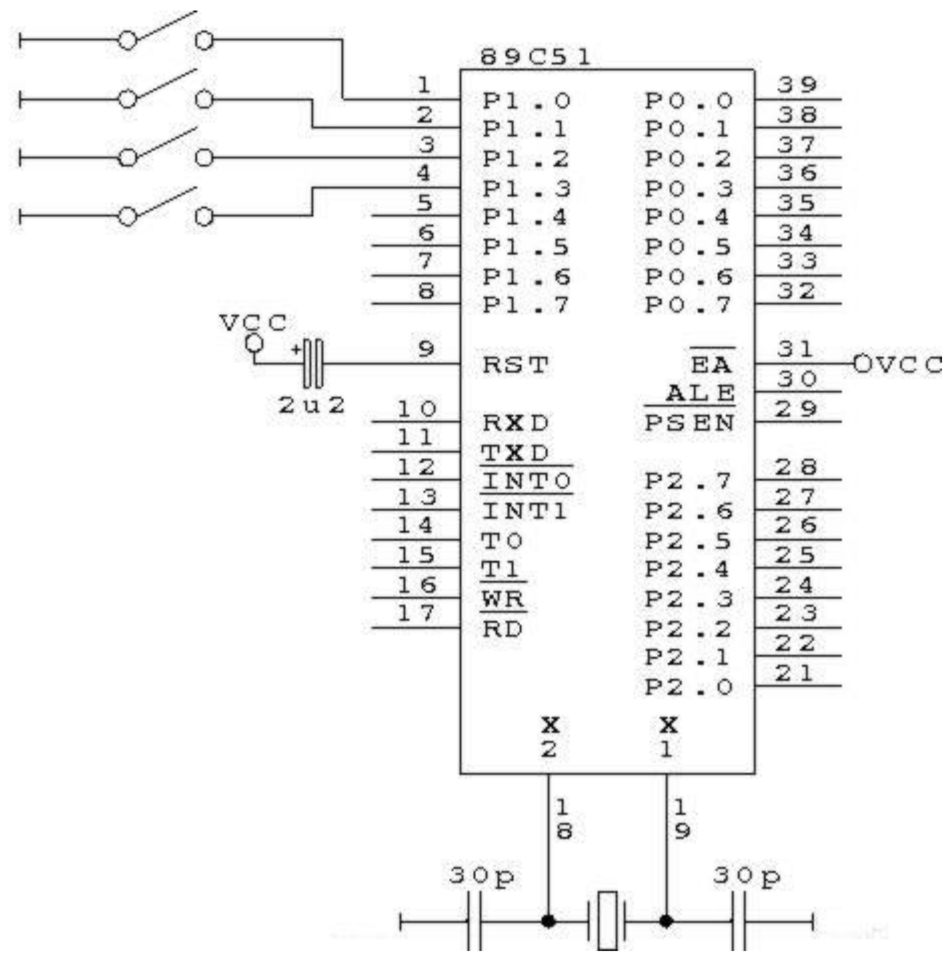
Image source: https://www.electronicshub.org/switches/

Connecting tact switches – pull-up or pull-down, the simplest keyboard

There are many ways to connect switches to microcontrollers, but it is a problem to think about – what should be the default state of the switch? Which type of pulling resistor should be used? Will there be any problems with signal integrity (long cables = inductance and oscillations) ?

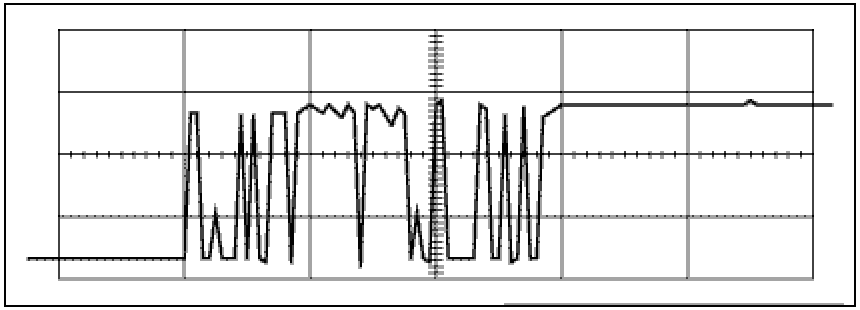






Connecting tact switches – debouncing

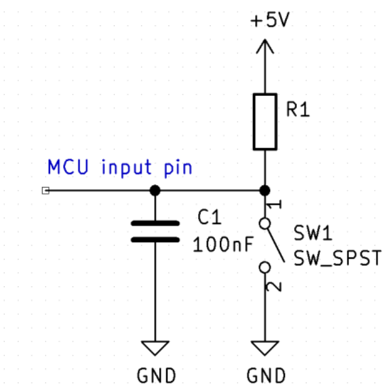
Problem with switches is that they can bounce several times during the switching process before they are locked in desired state. This may lead to software errors, when microcontroller counts more than one level change on its input pin.

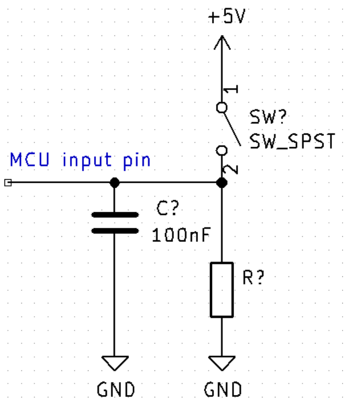


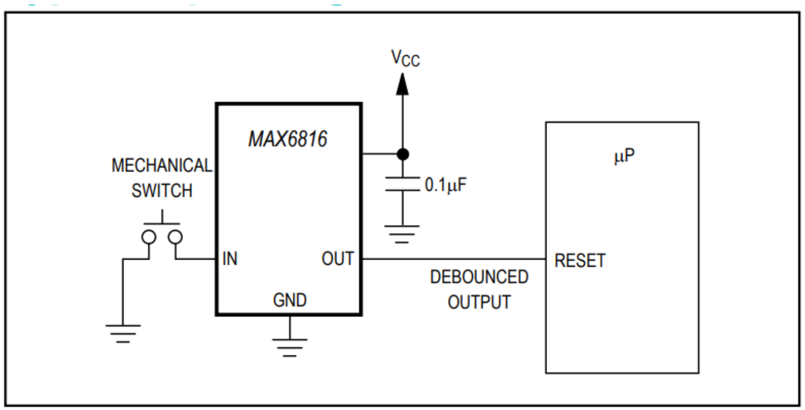
Time plot of switch voltage, showing bouncing effect

There are many ways to deal with the problem:

- Software way
  - Check the state of the pin after some time, like 50 ms, if still in the same state then the button/switch is pressed
- Hardware way
  - RC delay circuit
    - With/without Schmitt trigger buffer
  - Custom debouncing chip







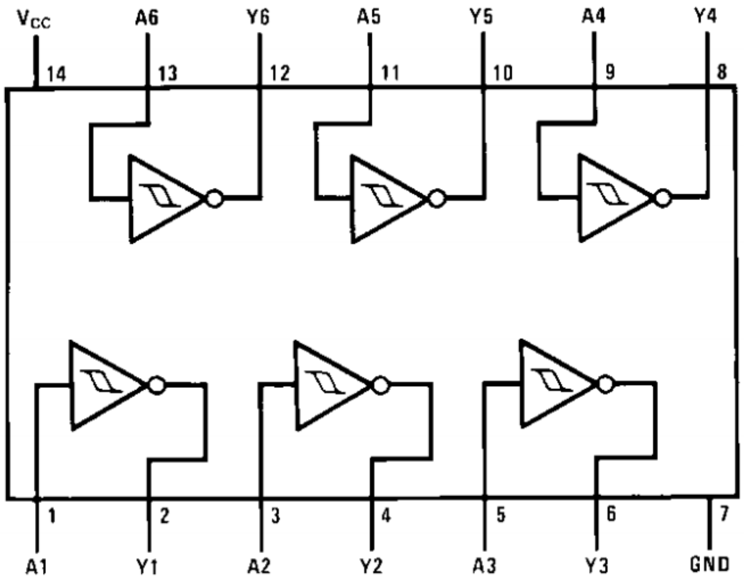
MAX6816 debouncer chip typical application.
It includes up to 15 kV ESD protection.

Debouncing solution must be applied to all types of keyboards and switches connected to microcontrollers.
The reliability of the entire system depends on it.

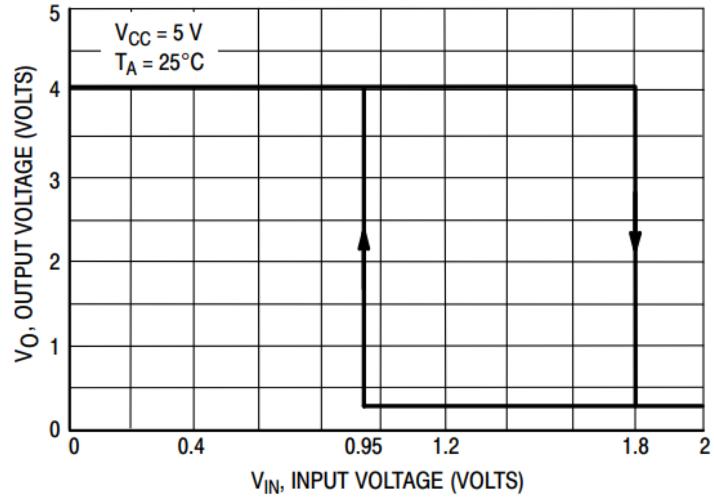
Image source: https://www.allaboutcircuits.com/technical-articles/switch-bounce-how-to-deal-with-it/
Maxim Integrated Application Note 287

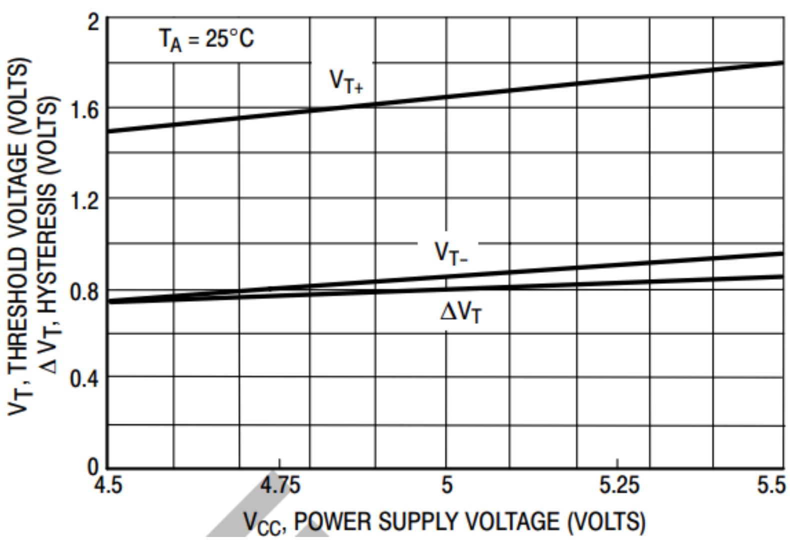
Connecting tact switches – debouncing – Schmitt trigger buffers

It is also possible to connect switches via Schmitt trigger buffers. Schmitt trigger logic gates have hysteresis, which means that threshold voltage for rising and falling edges of the input signal are different. This results in significant invulnerability to noise in circuit.



Gate diagram of classic 7414 Schmitt inverters chip.





Connecting tact switches – matrix keyboard

There is a problem. How to connect many switches to the microcontroller?
Driving each one with separate GPIO pin is very ineffective.

Let’s say we want to connect 16 button keyboard to the system we design. In standard approach we would need 16 GPIO pins, which is full occupation of two ports of 8051 microcontroller.

Instead, we can use only 8 GPIO pins and save the rest for other purposes.

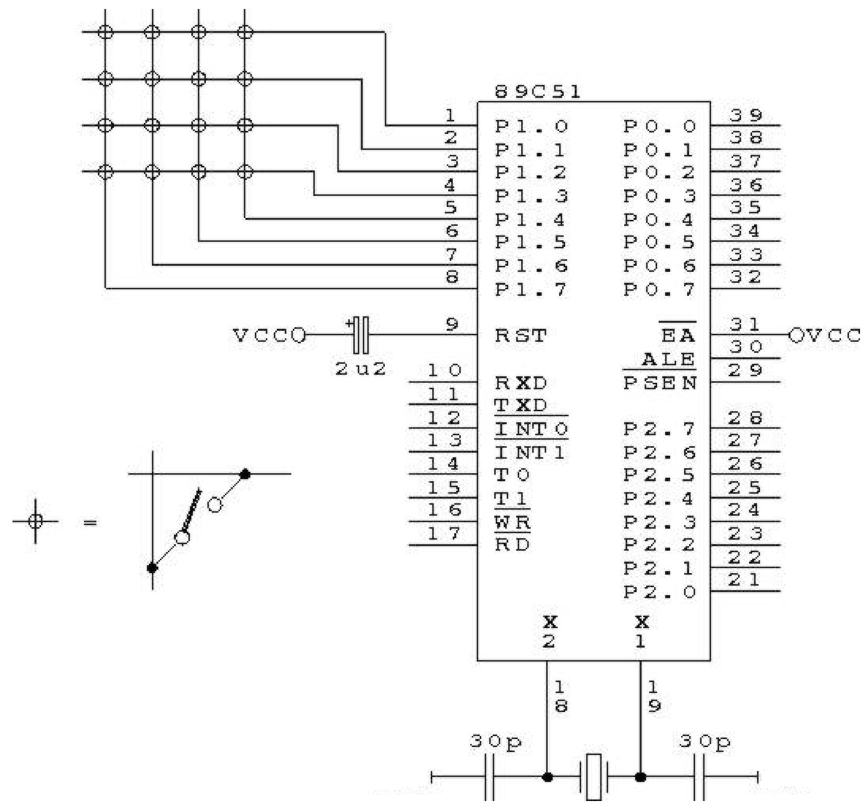
What we need is a matrix keyboard. To determine the state of each pin it is required to read the state of proper row pin and column pin.

For instance by reading pins P1.0 and P1.7 we can determine what is the state of upper left button.

All of the buttons should be fitted with pull-up resistors (internal or external).

What about debouncing?

There are also other ways to connect multi-button keyboards, for instance with using shift registers.

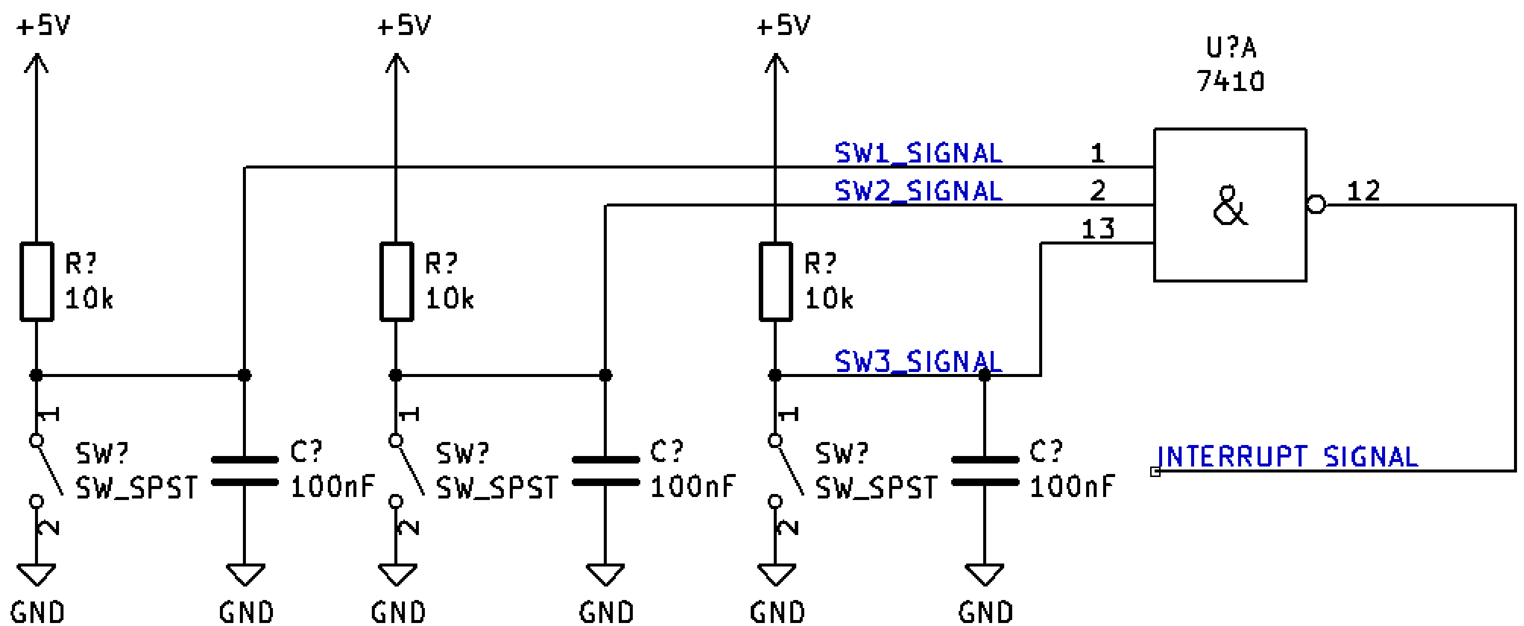


Connecting tact switches – interrupt based keyboard

To be able to determine if the button is pressed, microcontroller needs to constantly monitor the keyboard status. This is very ineffective and requires lots of resources of the MCU.

It is possible to connect keyboards using interrupts (coming up in next lectures). Microcontrollers usually have pins reserved as external interrupt source (for instance P3.2 and P3.3 in AT89S4051). These pins may be used to tell microcontroller that some button is pressed and it should immediately scan the keyboard. This approach allows to free the resources when buttons are not used.

7410 is triple input NAND gate. Default state of the NAND input is 111, so the output is 0. If any of the buttons is pressed, then the interrupt signal goes logic high, telling the MCU that it has to scan the keyboard.
All signals (SW1, SW2, SW3, INTERRUPT) have to be connected to microcontroller.



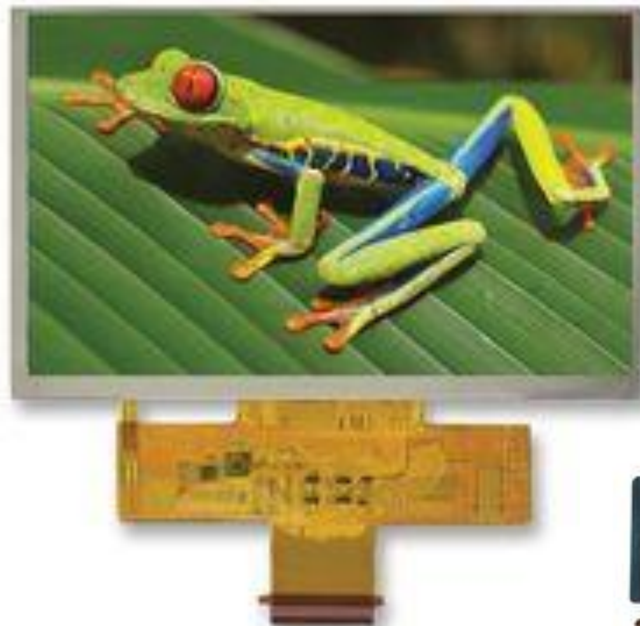
Outputting the data - displays

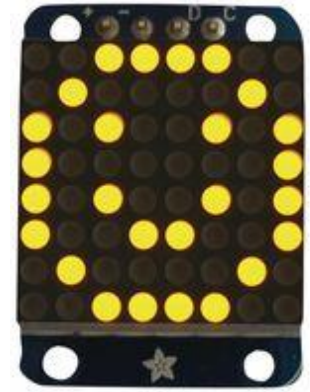
HMI (Human-Machine Interface) is one of the most commonly used and one of the most often embedded module of the electronic device. This interface allows for communication between machine and its user.

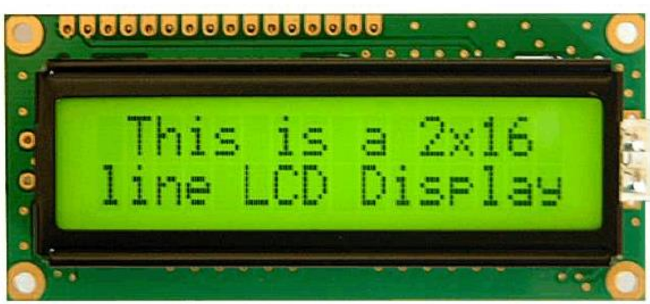
In many cases HMI is based on displays – electronic devices capable of showing information using optoelectronic components.

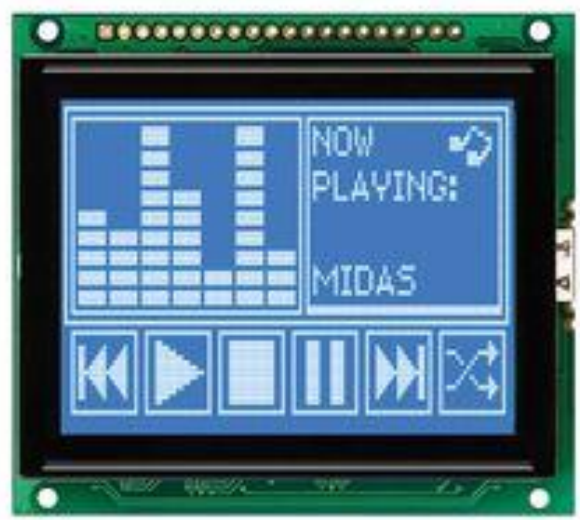
There are many different types of displays, like for example:

- LED displays – 7 segment, matrix displays, monochrome or RGB
- LCD displays – graphical or alphanumeric
- TFT displays – graphical color displays
- OLED displays
- E-ink displays – used in e-books
- VFD displays – nowadays rarely used



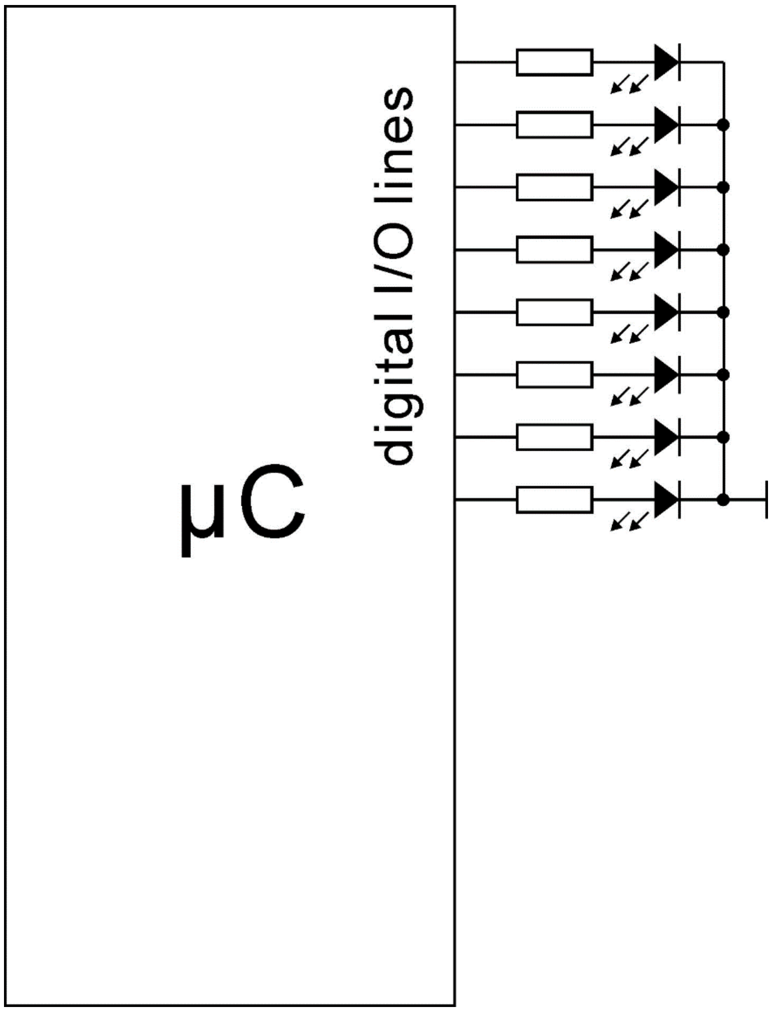


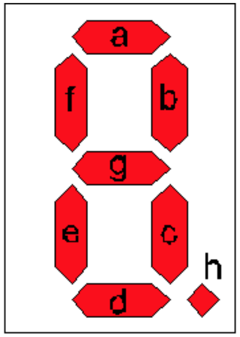


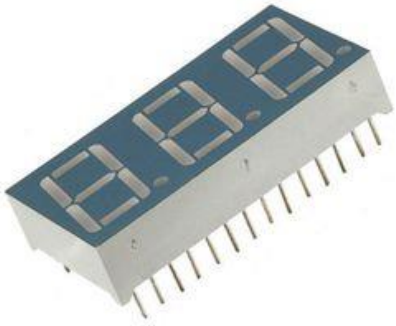


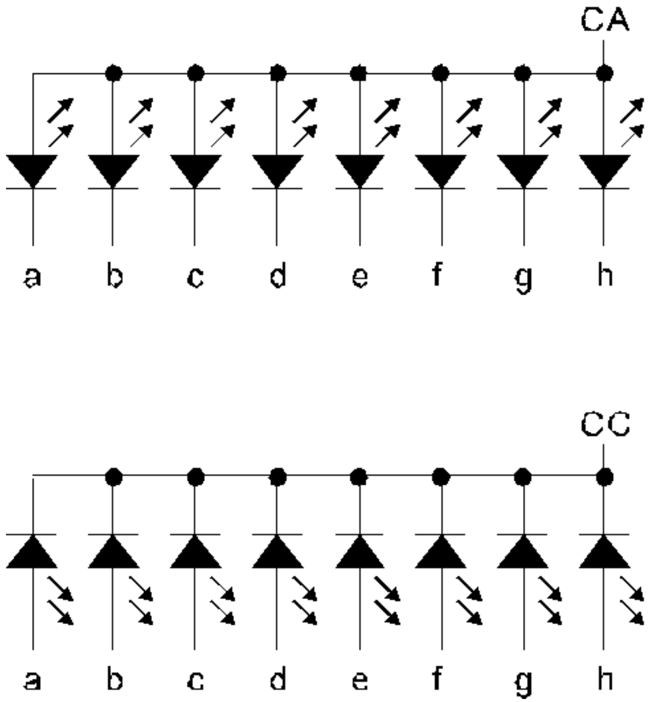
LED seven* segment display – common anode, common cathode, static driver

* They can be made of less or more LED segments







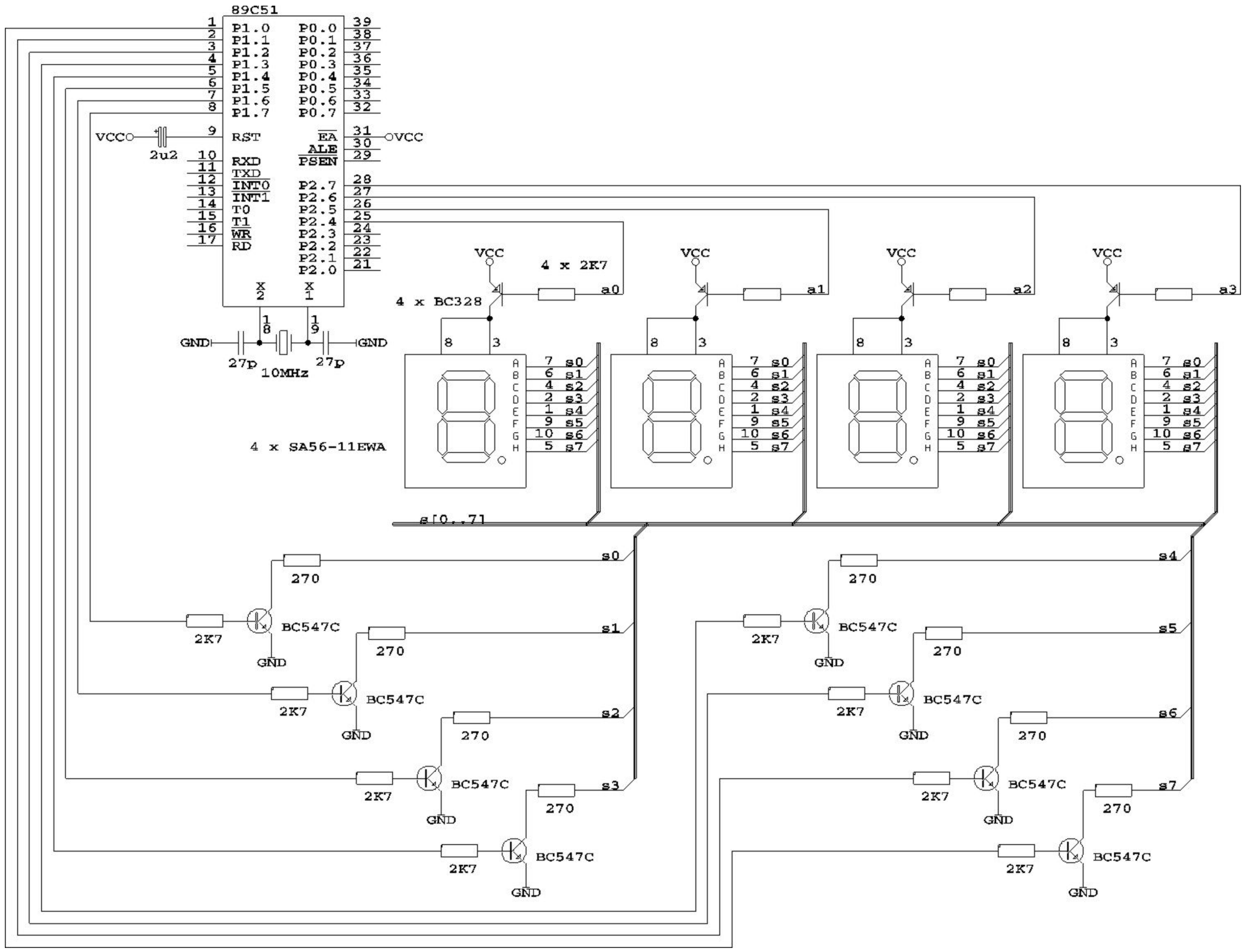


Direct interface between LED display and microcontroller

Common anode and common cathode diagrams

LED seven* segment display – multiplexing

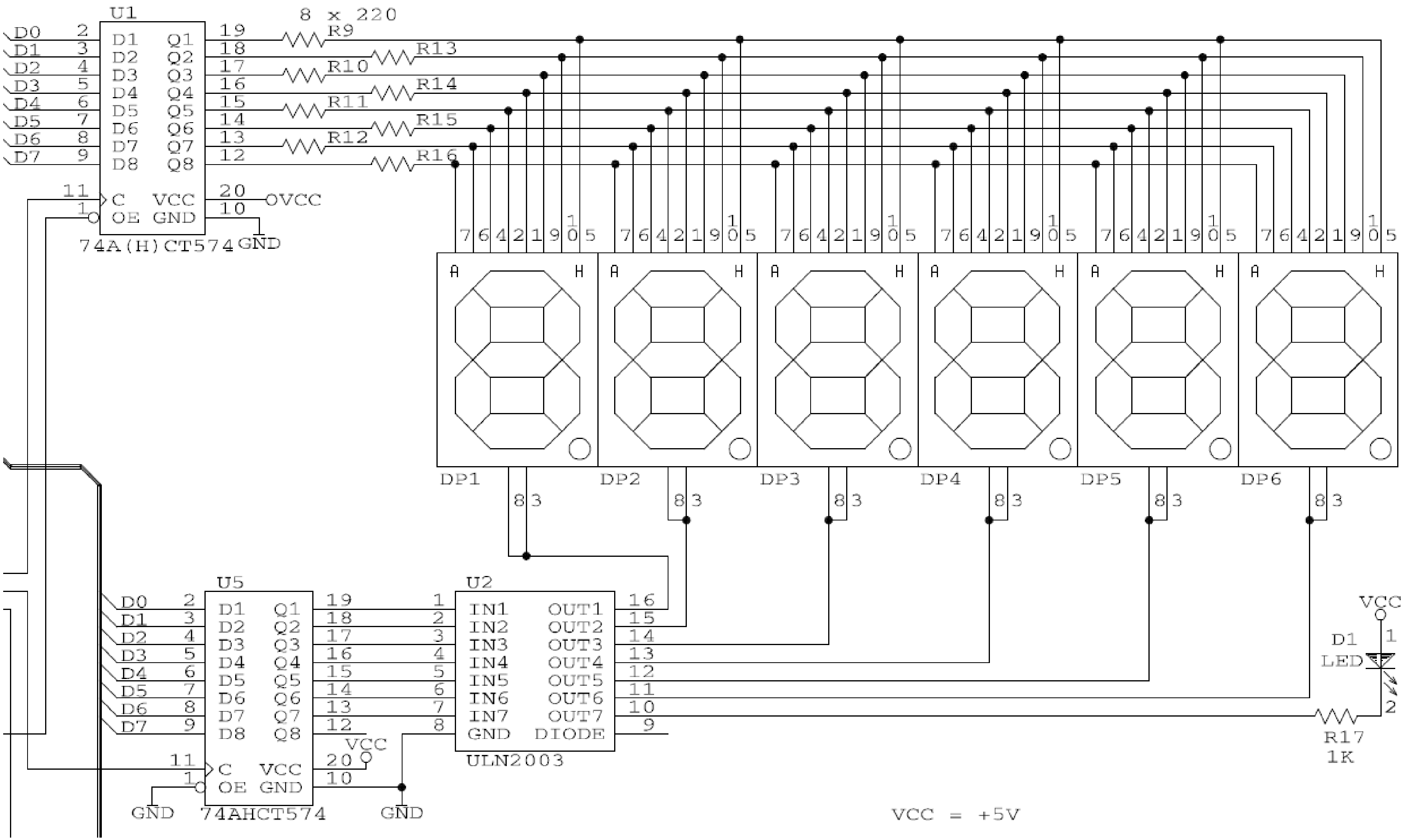
* They can be made of less or more LED segments



Multiplexing of LED displays using transistor current switches

LED seven* segment display – laboratory multiplexing

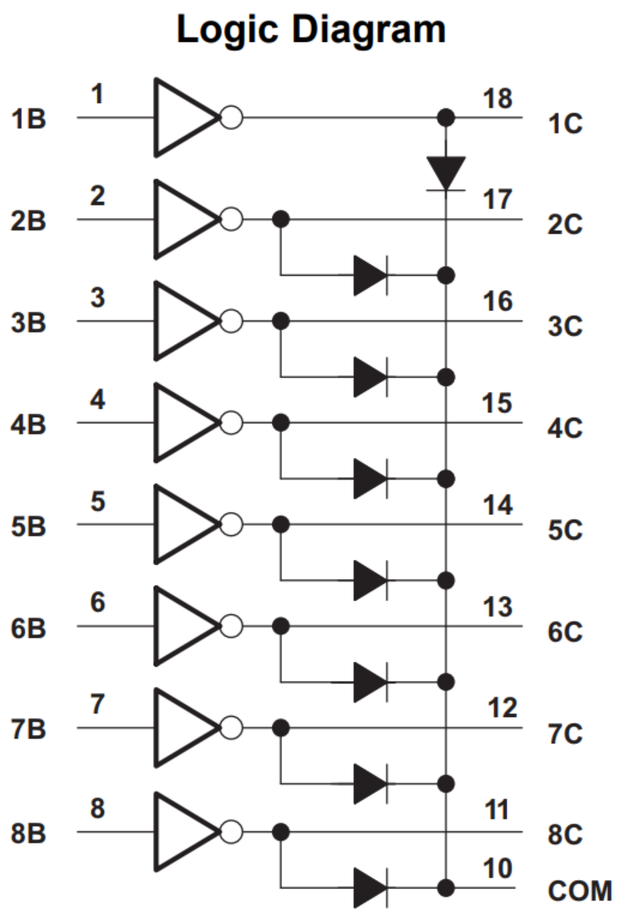
* They can be made of less or more LED segments



Multiplexing of LED displays using ULN2803 current buffer. This circuit will be used during Lab 2.

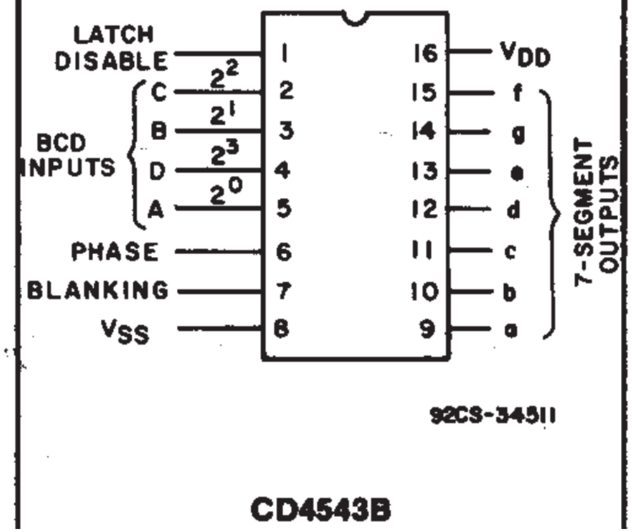
LED seven* segment display – digital display drivers

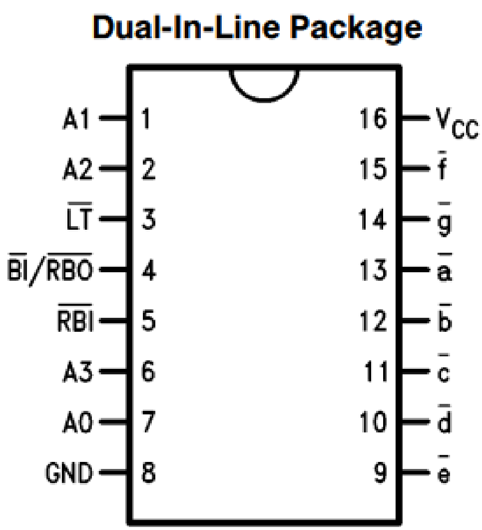
* They can be made of less or more LED segments



Logic diagram of ULN2803

CD4543 BCD to 7 segment driver





74LS247 BCD to 7 segment driver

Image source: https://components101.com/cd4511-7-segment-driver-ic

Alphanumeric LCD display – HD44780 driver based and clones

HD44780 LCD driver chip from Hitachi is currently one of the most popular driver for alphanumeric LCD displays. There are lots of different types of LCD displays based on this driver or its clones.

The way it is connected with the microprocessor system (via 8 bit Motorola 6800 based parallel or 4 bit interface) is a standard in electronics.

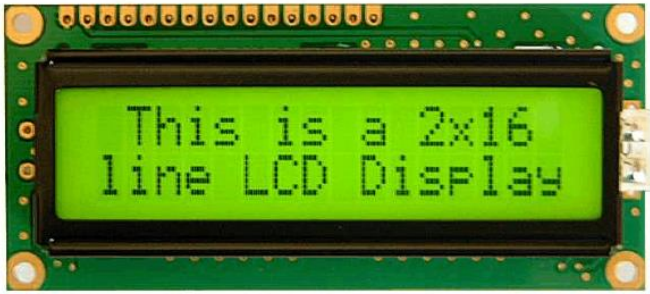
HD447800 is compatible with following clones:
HD66712, KS0066, KS0073, KS0076, LC7985, NT3881, S6A0069, SED1278, ST7066

Typically these type of displays are connected with 16 pin connector. Pin 1 is GND. Pin 2 is driver VCC, pin 3 is for contrast regulatic

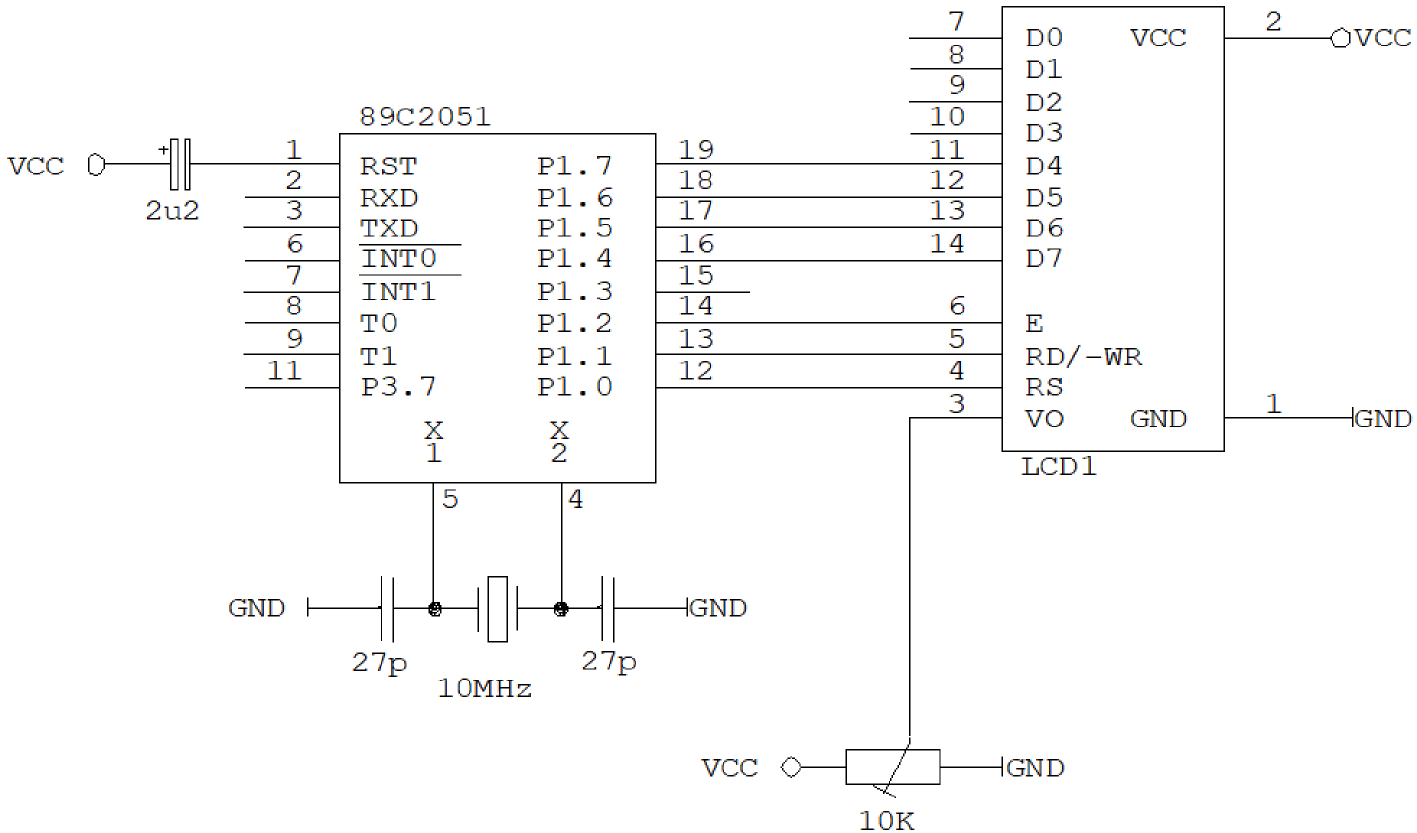
Pin 4 is RS (command or data pin), then pin 5 is R/W (read or write – in many applications shorted to GND for write-only). In most cases HD44780 should be supplied with +5V DC, thus direct interfacing it with 3.3V logic is not always possible.

Pin 6 is EN (enable) pin. Pins 7 to 14 are for 8 bit data bus. The remaining two pins are usually used for backlight.

HD44780 has two types of internal memories:
- DDRAM (Display Data Ram) – it stores currently displayed signs, this memory should be 80 bytes long (in standard HD44780)
- CGROM (Character Generator ROM) – this memory stores the information about how to display signs on the display. First 64 bytes of CGROM can be written (RAM block of CGROM), the re is read-only.

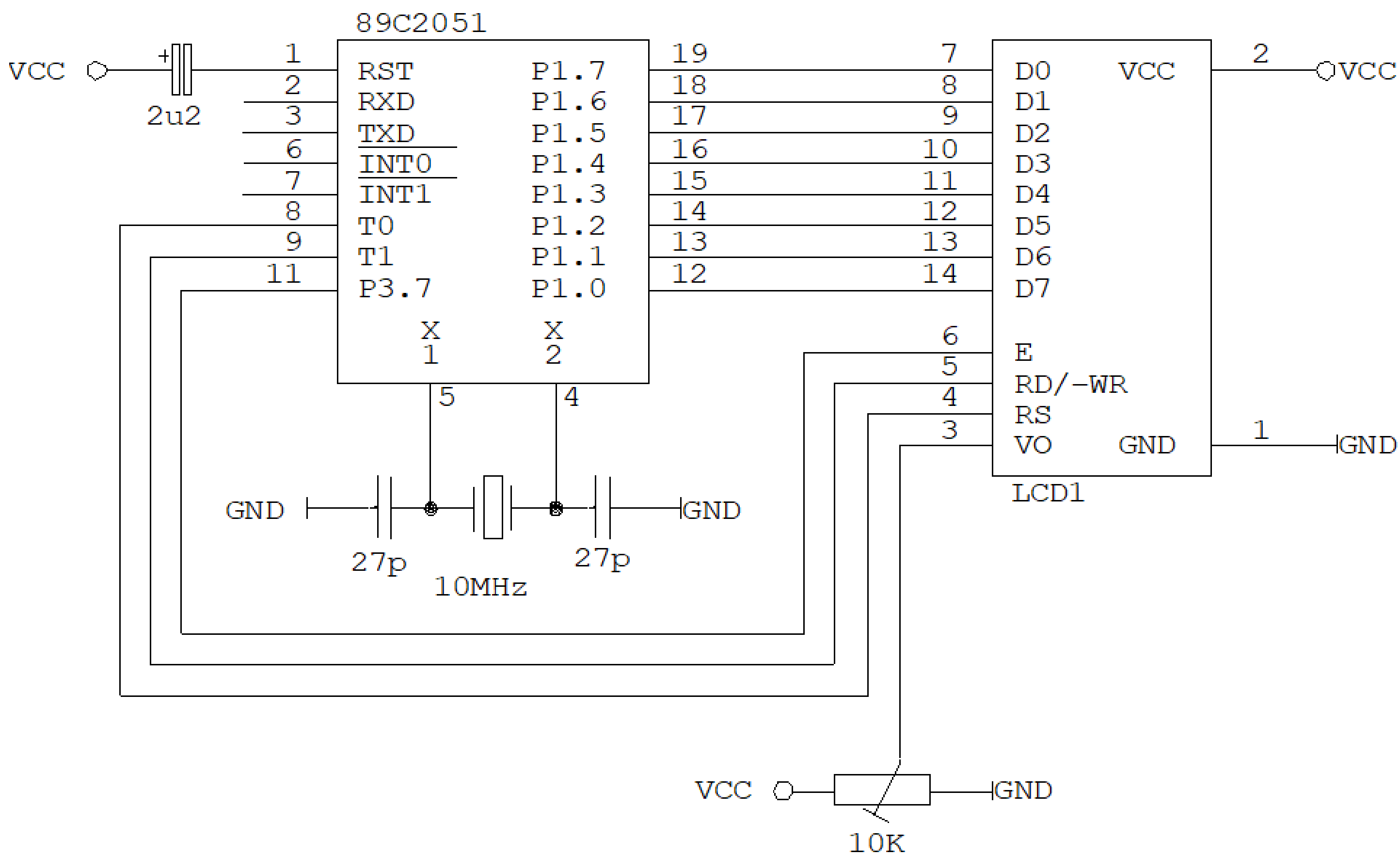


HD44780 – 2x16 display interfacing



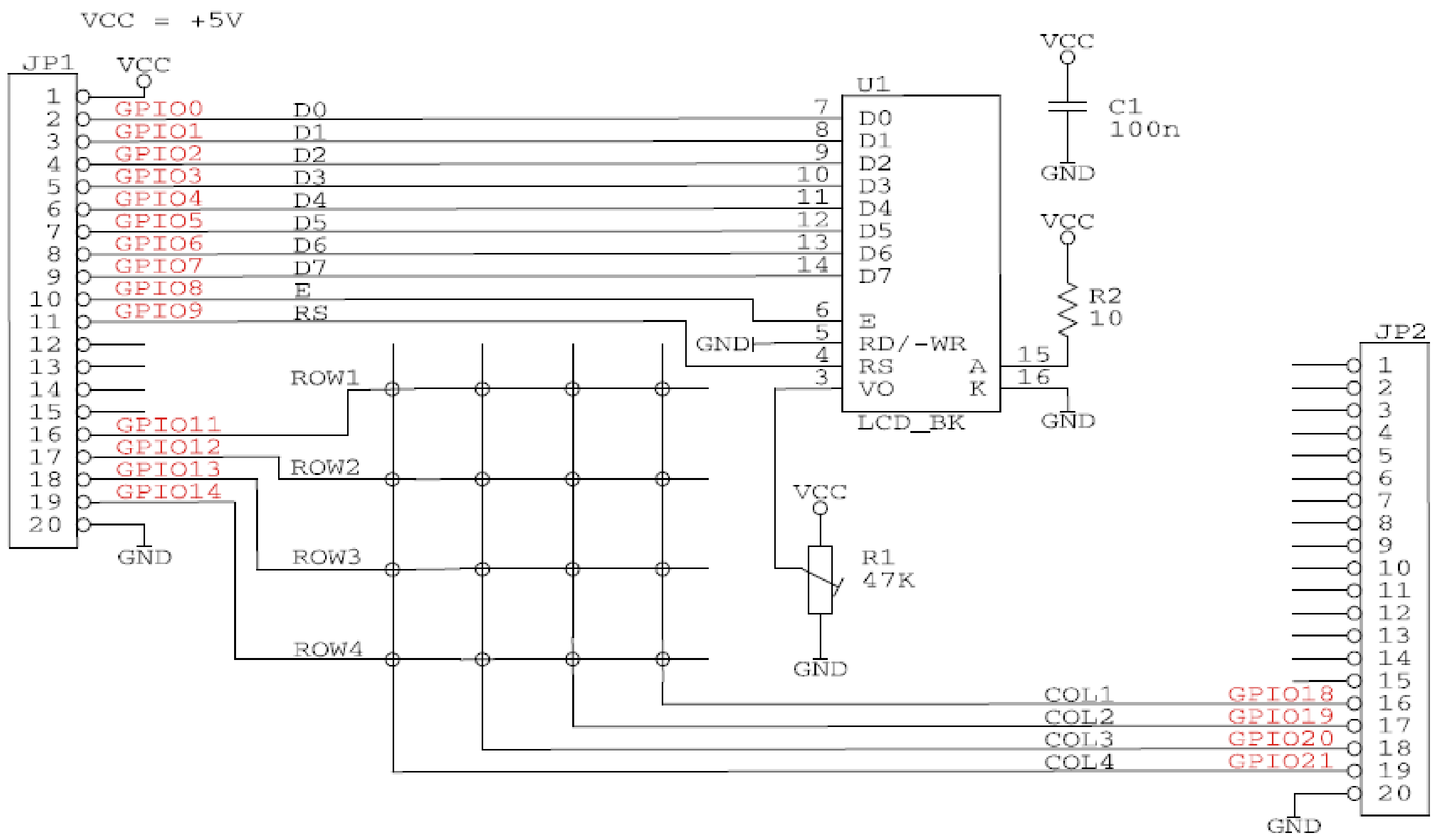
4 bit interface for HD44780 based display

HD44780 – 2x16 display interfacing



8 bit interface for HD44780 based display

HD44780 – 2x16 display interfacing

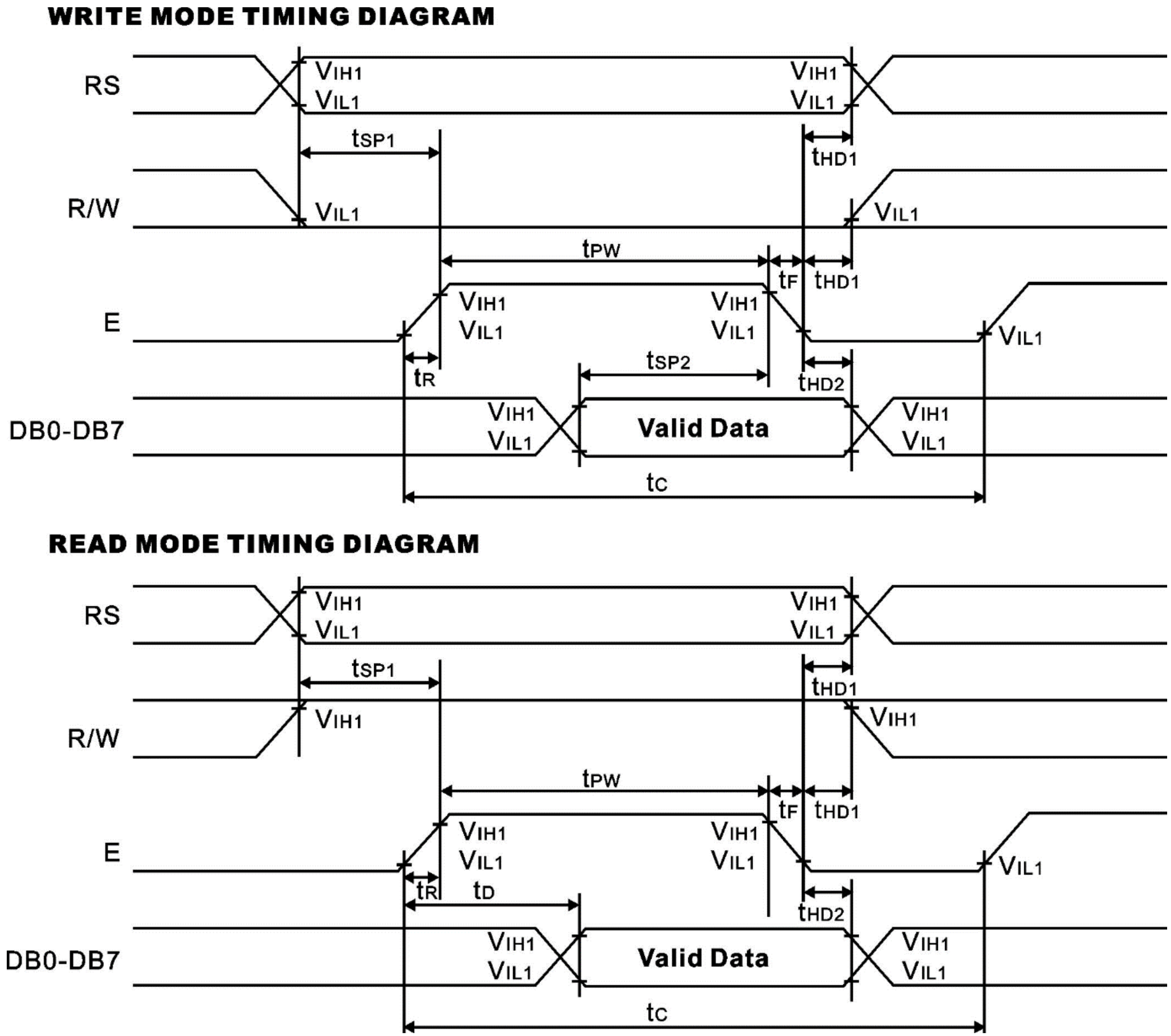


8 bit interface for HD44780 based display, schematic of Lab 1 and Lab 3 adapter board

HD44780 – 2x16 display timing

Mode	Characteristic	Symbol	Min.	Typ.	Max.	Unit
Write Mode (Refer to Fig-6)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu1	40	-	-	
	R/W and RS Hold Time	t_{H1}	10	-	-	
	Data Setup Time	tsu2	80	-	-	
	Data Hold Time	t_{H2}	10	-	-	
Read Mode (Refer to Fig-7)	E Cycle Time	tc	500	-	-	ns
	E Rise / Fall Time	t_R,t_F	-	-	20	
	E Pulse Width (High, Low)	tw	230	-	-	
	R/W and RS Setup Time	tsu	40	-	-	
	R/W and RS Hold Time	t_H	10	-	-	
	Data Output Delay Time	t_D	-	-	120	
	Data Hold Time	t_{DH}	5	-	-	

HD44780 – 2x16 display timing



Timing compatible with Motorola 6800 standard.

For write operation R/W must be tied low.

Data on bus DB0-DB7 are acknowledged with falling edge of enable (E) signal.

During read operation R/W must be tied high. Data on bus DB0-DB7 is acknowledged on rising edge of enable signal.

HD44780 – 2x16 display initialization

Power on

↓

Wait for more than 30 ms after VDD rises to 4.5 v

↓

Function set									
RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	1	1	N	F	X	X

↓

Wait for more than 39 µs

↓

Display ON/OFF Control									
RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	0	0	1	D	C	B

↓

Wait for more than 39 µs

↓

Display Clear									
RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	0	0	0	0	0	1

↓

Wait for more than 1.53 ms

↓

Entry Mode Set									
RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	0	0	0	1	I/D	SH

↓

Initialization end

N	0	1-line mode
	1	2-line mode

F	0	display off
	1	display on

D	0	display off
	1	display on

C	0	cursor off
	1	cursor on

B	0	blink off
	1	blink on

I/D	0	decrement mode
	1	increment mode

SH	0	entire shift off
	1	entire shift on

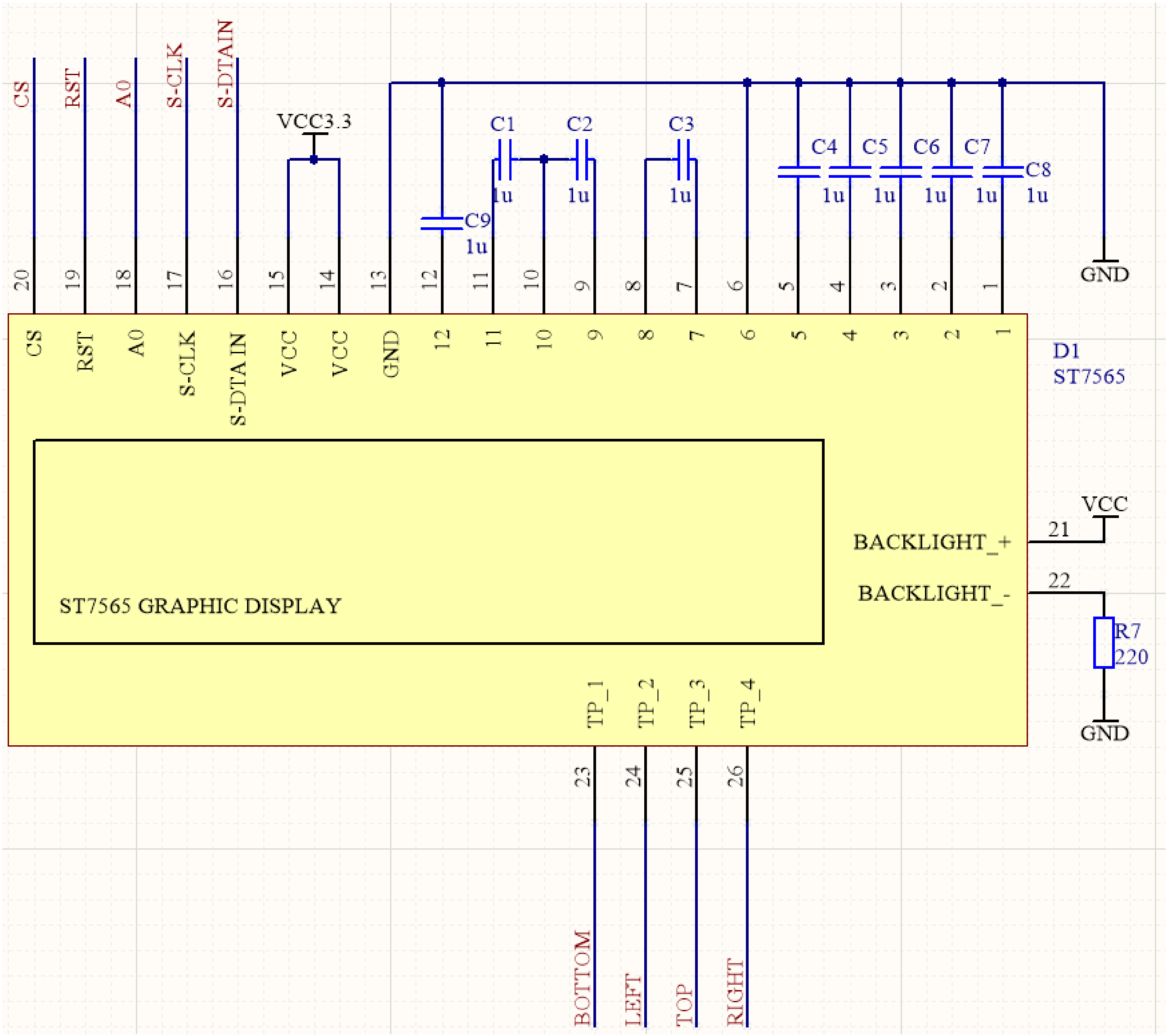
LCD graphical displays

Graphical display drivers are usually working with pixel matrices and allow to display any graphics (usually in monochrome). More sophisticated drivers may have embedded sign generator that can be very useful when displaying text.

Among many popular display drivers the following should be mentioned:

- KS0108/7B - one of the most popular display drivers by Samsung. It drives up to 64x64 displays and is driven via 8 bit Motorola 6800 parallel interface. It does not have sign generator
- T6963C – one of the most popular display drivers with sign generator, manufactured by Toshiba. It works with up to 128x256 pixel display. Internal sign generator can store up to 256 user custom signs. It is controlled via 8 bit Intel 8080 interface
- ST7565R – quite popular display driver, used in COG (Chip on Glass) and DOGM series displays. These displays are working with 3.3V logic and communicate with microprocessor system via SPI write-only interface – only microcontroller sends data ,there is no reading from the display. For proper operation it requires additional capacitors for internal charge pump regulators. It does not have sign generator.
- UC1601 – very similar to ST7565R

LCD graphical displays – ST7565R driver based, interfacing



NIXIE tubes – pretty popular relic of the past

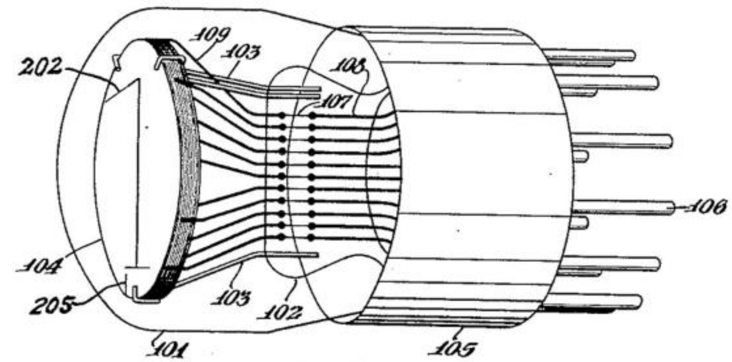


Fig: 1

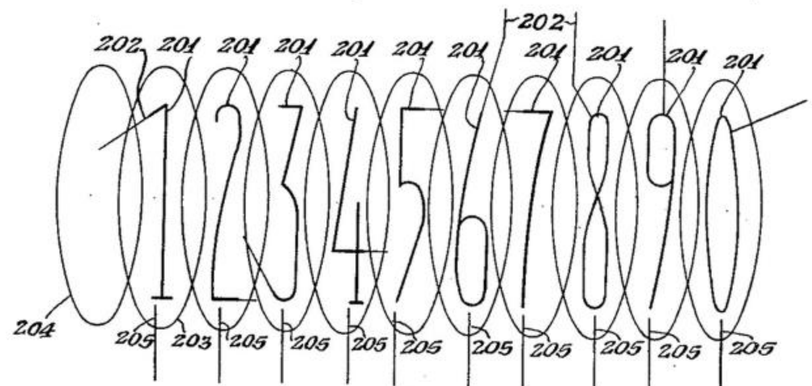


Fig: 2

Why should we talk about them at all?

- Because they are awesome ☺
- Because they are vintage and still quite popular
- Because they show how to drive high voltage circuits safely

Presented circuits are powered with very high DC voltage, exceeding 100V. This voltage level is very dangerous for people and potential shock may lead to serious injury or can be even lethal!

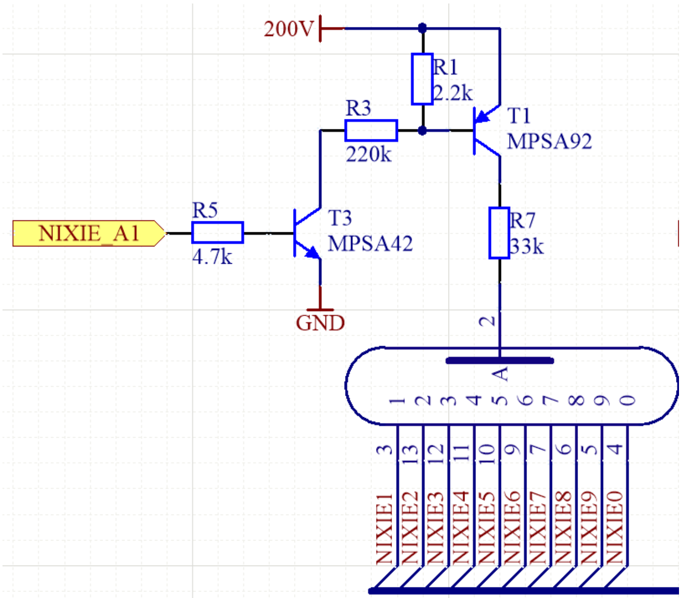
The author takes no responsibility for the usage of this material and any potential losses this usage can lead to.

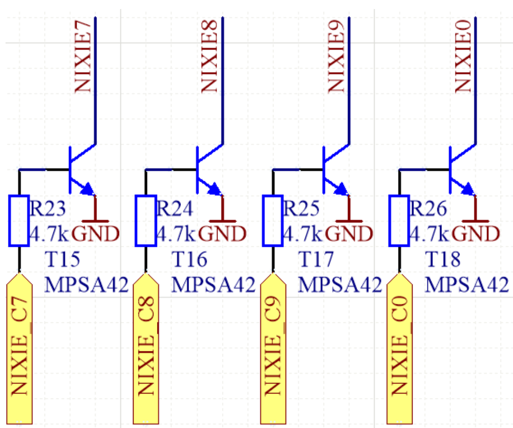
Do not attempt to reproduce these circuits unless you are really aware of what you are doing or if you do not have any qualified personnel for help and guidance.

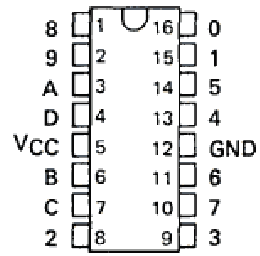
You have been warned!

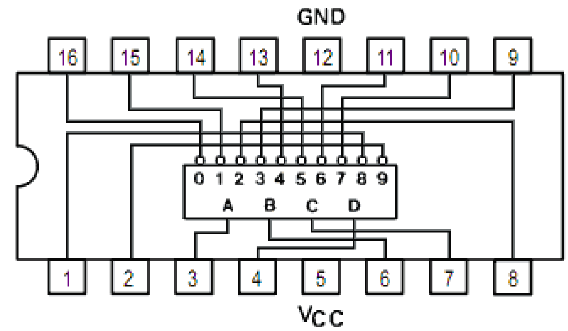
Image source: https://www.displays2go.com/P-38864/Electrical-Hazard-Industrial-Warning-Sticker-High-Voltage-Safety-Message

NIXIE tubes – interfacing









INPUTS				OUTPUTS									
A	B	C	D	0	1	2	3	4	5	6	7	8	9
L	L	L	L	L	H	H	H	H	H	H	H	H	H
H	L	L	L	H	L	H	H	H	H	H	H	H	H
L	H	L	L	H	H	L	H	H	H	H	H	H	H
H	H	L	L	H	H	H	L	H	H	H	H	H	H
L	L	H	L	H	H	H	H	L	H	H	H	H	H
H	L	H	L	H	H	H	H	H	L	H	H	H	H
L	H	H	L	H	H	H	H	H	H	L	H	H	H
H	H	H	L	H	H	H	H	H	H	H	L	H	H
L	L	L	H	H	H	H	H	H	H	H	H	L	H
H	L	L	H	H	H	H	H	H	H	H	H	H	L
L	H	L	H	H	H	H	H	H	H	H	H	H	H
H	H	L	H	H	H	H	H	H	H	H	H	H	H
L	L	H	H	H	H	H	H	H	H	H	H	H	H
H	L	H	H	H	H	H	H	H	H	H	H	H	H
L	H	H	H	H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H	H	H	H	H

NIXIE tubes – how to generate HV for the tubes?

The answer is simple – step up switching converter!
There are many different circuits available, including dedicated chips, or using universal ones, like NE555. It is even possible (and often preffered) to use PWM signal from the microcontroller to drive the switching regulator.

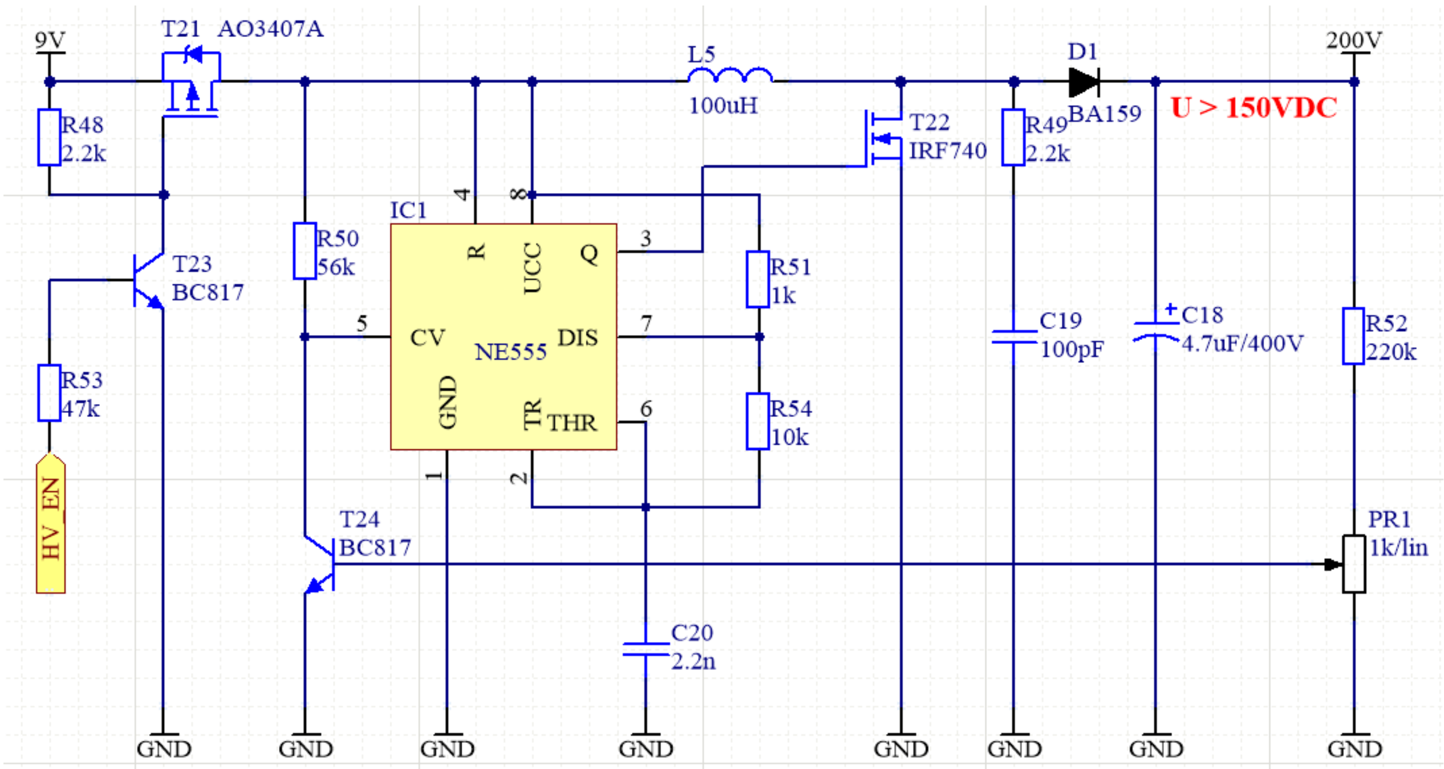
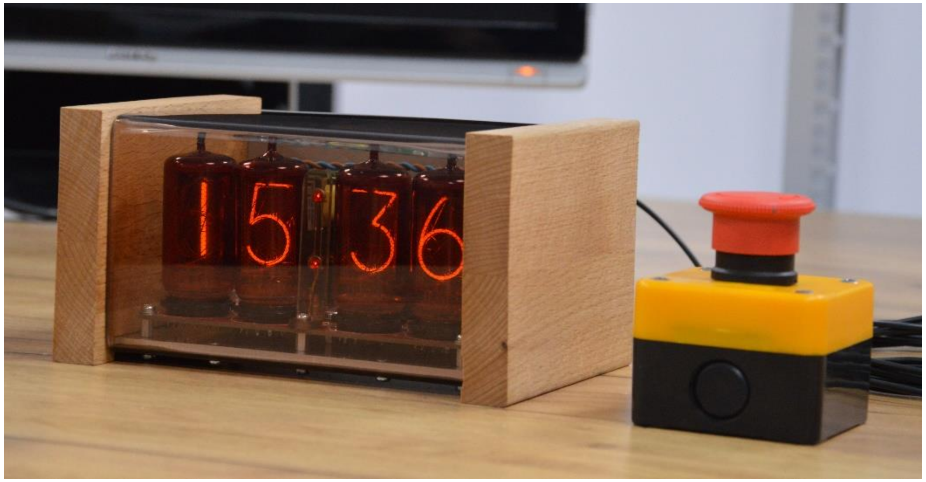


Image source: http://romanworkshop.blutu.pl/elec/cats/gfxh/t141.htm

NIXIE tubes – sample projects, mostly clocks



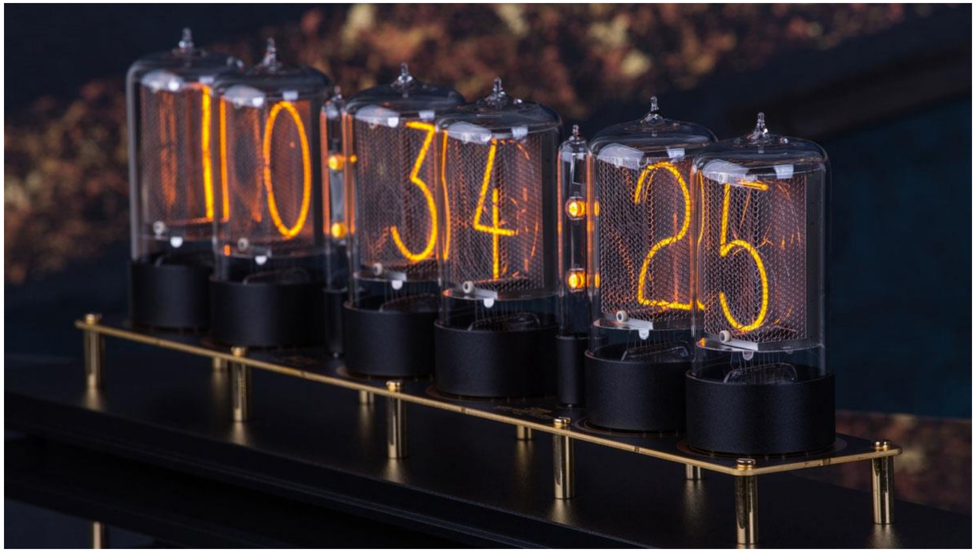


Image source: https://www.etsy.com/market/nixie_tube_clock
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