

# Button Matrix - Documentation

Revision 1

## 1 Circuit Board

### 1.1 Schematic

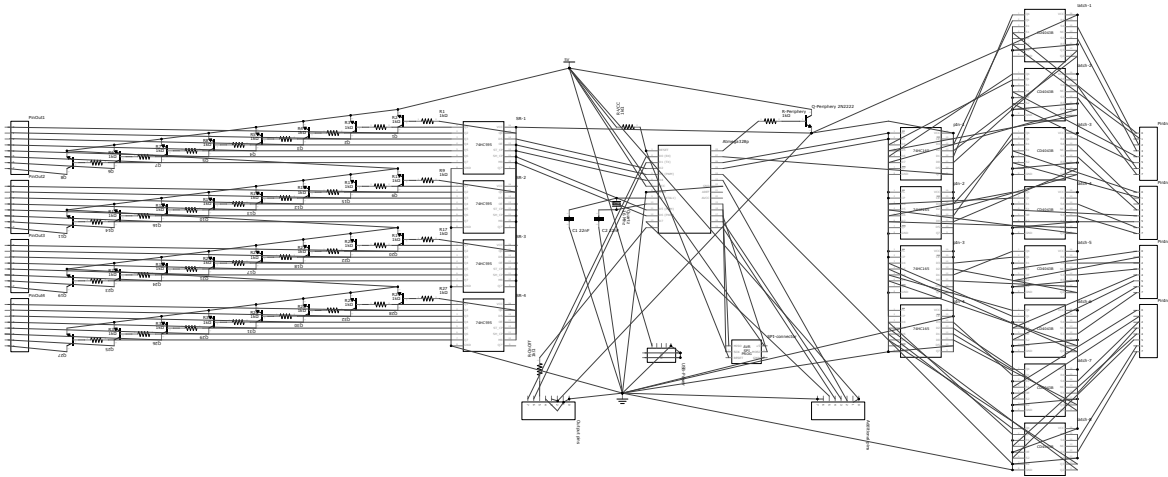


Figure 1: Schematic view of the circuit board design.

### 1.2 Layout - Top

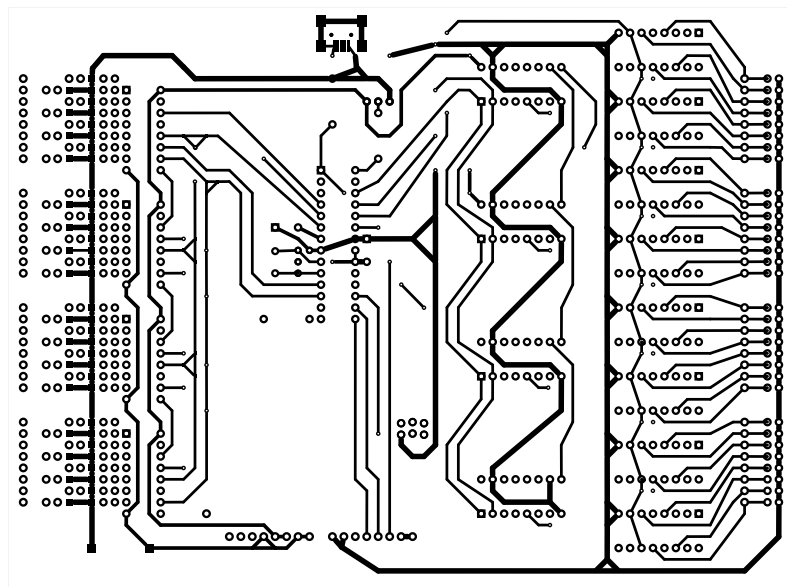


Figure 2: View of the circuit board top as seen from the top.

### 1.3 Layout - Bottom

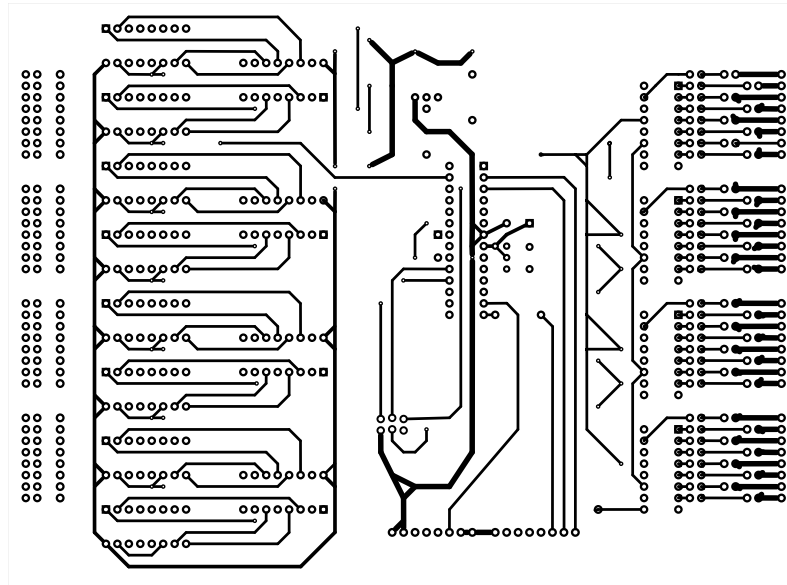


Figure 3: View of the circuit board bottom as seen from the bottom.

### 1.4 Layout - Hardware

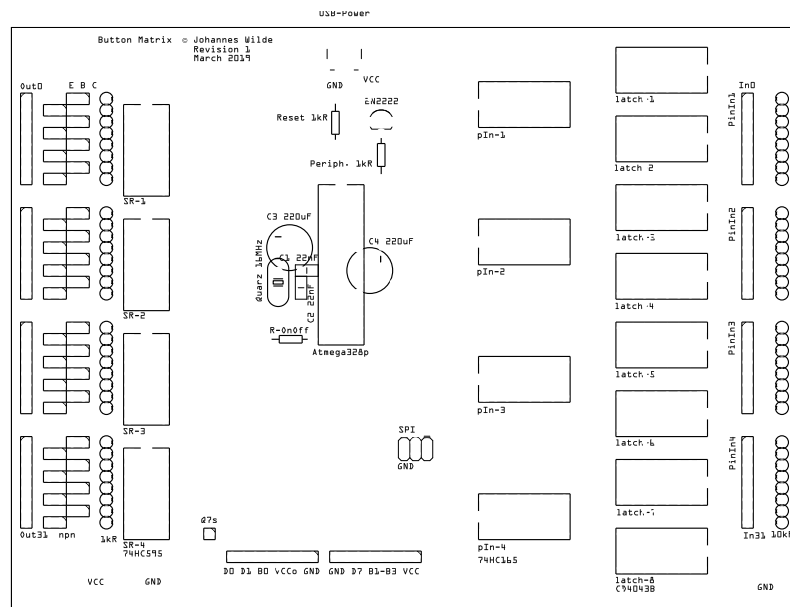


Figure 4: Positioning of the hardware as seen from the top.

## 1.5 Pin Connections

Table 1: Pins of the ATmega328P and their respective connections.

ATmega328P pin	connected to
VCC	VCC
GND	GND
AREF	VCC
AVCC	VCC
B0	connectorLeft - 5
B1	connectorRight - 4
B2	connectorRight - 3
B3	SPI - MOSI
B4	SPI - MISO
B5	SPI - CLK
B6	XTAL
B7	XTAL
C0	connectorRight - 2
C1	CD4043B - $R_i$
C2	74HC165 - CP
C3	74HC165 - $\overline{PL}$
C4	74HC165 - $d_7$
C5	VCCo enable
C6	$\overline{\text{Reset}}$
D0	connectorLeft - 7
D1	connectorLeft - 6
D2	74HC595 - SER
D3	74HC595 - $\overline{OE}$
D4	74HC595 - RCLK
D5	74HC595 - SRCLK
D6	74HC595 - $\overline{SRCLR}$
D7	connectorRight - 5

Table 2: Pins of the 74HC595 and their respective connections.

74HC595 pin	connected to
VCC	VCCo
GND	GND
SER	ATmega328P - D2 / 74HC595'' - $q_7$
$\overline{OE}$	ATmega328P - D3
RCLK	ATmega328P - D4
SRCLK	ATmega328P - D5
$\overline{SRCLR}$	ATmega328P - D6
$q_7$	74HC595' - SER / NC
$Q_i$	Out <sub>j</sub> -transistor base

Table 3: Pins of the 74HC165 and their respective connections.

74HC165 pin	connected to
VCC	VCCo
GND	GND
$\overline{\text{PL}}$	ATmega328P - C3
CP	ATmega328P - C2
d <sub>7</sub>	ATmega328P - C4 / 74HC165'' - SER
$\overline{\text{d}}_7$	NC
SER	74HC165' - d <sub>7</sub> / GND
$\overline{\text{CE}}$	GND
D <sub>i</sub>	CD4043B - Q <sub>i</sub>

Table 4: Pins of the CD4043B and their respective connections.

CD4043B pin	connected to
VCC	VCCo
GND	GND
Q <sub>i</sub>	74HC165 - D <sub>j</sub>
S <sub>i</sub>	In <sub>k</sub>
R <sub>i</sub>	ATmega328P - C1
OE	VCCo

Table 5: Pins of the connectorLeft and their respective connections.

connectorLeft pin	connected to
0	GND
1	GND
2	VCCo
3	VCCo
4	GND
5	ATmega328P-B0
6	ATmega328P-D1
7	ATmega328P-D0

Table 6: Pins of the connectorRight and their respective connections.

connectorRight pin	connected to
0	VCC
1	VCC
2	ATmega328P-C0
3	ATmega328P-B2
4	ATmega328P-B1
5	ATmega328P-D7
6	GND
7	GND

Above notations are held rather general - for the actual connections please refer to the schematic or board layouts above.

For better understandability however some general remarks:

1. The devices containing shiftregisters [74HC595, 74HC165] are concatenated with those of the same type, i.e. one device's output is connected to the next device's input [e.g. for 74HC595 it is  $q_7$  of the next one connected to SER of the previous one]. This is supposed to be inferred when using ' in above tables.
2. The last device in those concatenations is somewhat special, insofar as that for 74HC595  $q_7$  is NC and for 74HC165 SER is connected to GND.  
And for the first device 74HC595 SER is connected to ATmega328P - D2 and for 74HC165  $d_7$  is connected to ATmega328P - C4.
3. The connection of the 74HC595 to the Out is rather straightforward: the first output of the first shiftregister in the concatenation is connected to the first Out and the last output of the last shiftregister in the concatenation is connected to the last Out.
4. For In this is somewhat more complicated:

74HC165 pin	In pin
0	3
1	2
2	1
3	0
4	4
5	5
6	6
7	7

## 2 Hardware Description

### 2.1 ATmega328P

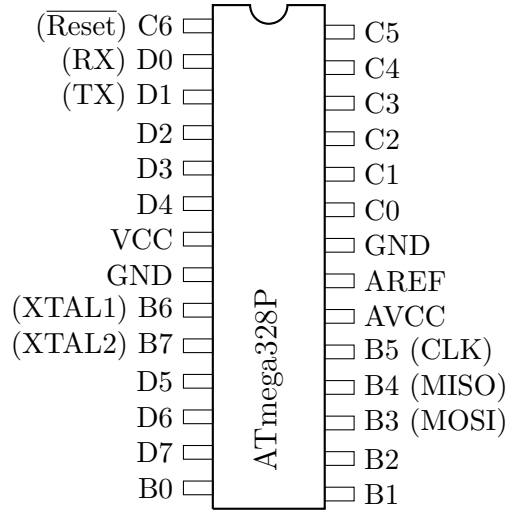


Figure 5: Schematic of the ATmega328P.

The bracketed names specify functionality assigned to the respective pins by the underlying hardware design. If one would want, these can be reconfigured for different use cases however.

### 2.2 74HC595 - 8-bit Shift Register

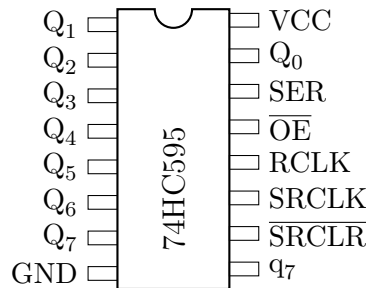


Figure 6: Schematic of the 8-bit shift register 74HC595.

Working principle:

The shiftregister has an internal  $[q_i, i \in [0, 7]]$  and an external  $[Q_i, i \in [0, 7]]$  8-bit register. On a rising edge on SRCLK the values  $q_i$  are shifted to  $q_{i+1}$  [ $i \in [0, 6]$ , higher  $i$  first] and SER to  $q_0$ .

On a rising edge on RCLK the values of  $q_i$  are copied to  $Q_i$  [ $i \in [0, 7]$ ]. These will only be visible externally if  $\overline{OE}$  is LOW [otherwise the outputs will be in a high impedance state].

A LOW on  $\overline{SRCLR}$  will set  $q_i$  [ $i \in [0, 7]$ ] LOW.

VCC and GND are required for the shift-register to work.

$q_7$  can be used to pass the out-shifted bits on to another shift-register, if  $q_7$  is connected to SER of the next shift-register [which will have to be clocked accordingly].

$Q_i$  - Output  $i$ ; GND - Ground;  $q_7$  - Serial output;  $\overline{\text{SRCLR}}$  - Clear internal shift-register on LOW; RCLK - Copy internal to external shift-register; SRCLK - shift in SER on rising edge;  $\overline{\text{OE}}$  - Output Enable; SER - Serial input; VCC - Supply Voltage.

### 2.3 74HC165 - 8-bit parallel in, serial out register

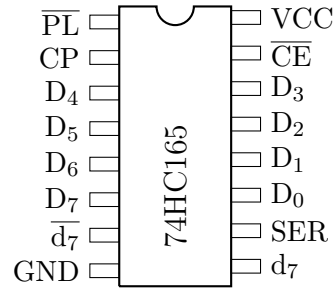


Figure 7: Schematic of the parallel in, serial out IC 74HC165.

Working principle:

The parallel load, serial out IC has an internal  $[d_i, i \in [0, 7]]$  and an external  $[D_i, i \in [0, 7]]$  8-bit register.

When  $\overline{\text{PL}}$  is LOW the  $D_i$  are copied to the  $d_i$   $[i \in [0, 7]]$  asynchronously, i.e. without the need for a clock.

When  $\overline{\text{PL}}$  is HIGH the 74HC165 will function as a shift-register: on a positive edge on CP [if  $\overline{\text{CE}}$  is low] the values  $d_i$  are shifted to  $d_{i+1}$   $[i \in [0, 6], \text{ higher } i \text{ first}]$  and SER to  $d_0$ . Additionally the complementary signal of the new  $d_7$  will be visible on  $\overline{d_7}$ .

VCC and GND are required for the 74HC165 to work.

$d_7$  can be used to pass the out-shifted bits on to another 74HC165, if  $d_7$  is connected to SER of the next 74HC165 [which will need to have  $\overline{\text{PL}}$  low,  $\overline{\text{CE}}$  low and be clocked accordingly].

$\overline{\text{PL}}$  - Not Parallel Load; CP - Clock;  $D_i$  - Parallel Data In;  $d_7$  - Serial Output;  $\overline{d_7}$  - Not Serial Output; GND - Ground; SER - Serial In;  $\overline{\text{CE}}$  - Not Clock Enable; VCC - Supply Voltage.

### 2.4 CD4043B - CMOS Quad 3-State R/S-Latches [NOR]

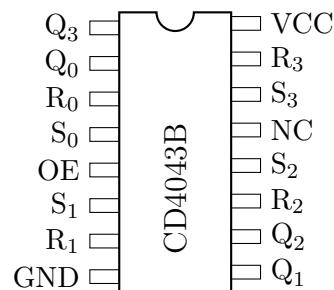


Figure 8: Schematic of the quad 3-state R/S Latch CD4043B.

Table 7: Functional states of the quad 3-state R/S Latch CD4043B [ $i \in [0, 3]$ ].

$S_i$	$R_i$	OE	$Q_i$
X	X	LOW	high impedance
LOW	LOW	HIGH	unchanged
HIGH	LOW	HIGH	HIGH
LOW	HIGH	HIGH	LOW
HIGH	HIGH	HIGH	HIGH

Working principle:

OE controls whether the outputs  $Q_i$  [ $i \in [0, 3]$ ] are connected [OE is HIGH] or in a high-impedance state [like an open circuit; OE is LOW].

Each separate output  $Q_i$  [ $i \in [0, 3]$ ] can be set to HIGH [ $S_i$  HIGH] or reset to LOW [ $R$  HIGH] separately and asynchronously.

In case  $S_i$  and  $R_i$  are HIGH simultaneously, the respective output  $Q_i$  will read HIGH.

NC is not connected internally.

$Q_i$  - Output  $i$ ;  $R_i$  - Reset  $i$ ;  $S_i$  - Set  $i$ ; OE - Output Enable; GND - Ground; NC - Not Connected; VCC - Supply Voltage.

## 2.5 LED

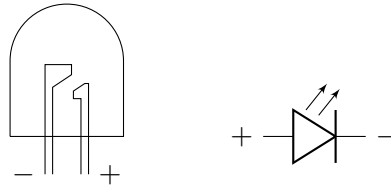


Figure 9: Schematic view of a LED and its representation in circuit diagrams.

## 2.6 npn-Transistor

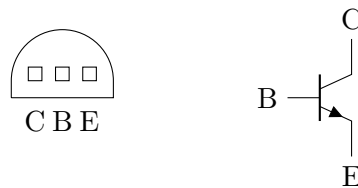


Figure 10: Schematic top view onto a npn-transistor and its representation in circuit diagrams.

## 2.7 Periphery

## 3 SPI-Programming

The ATmega328P can be programmed using the serial peripheral interface [SPI].



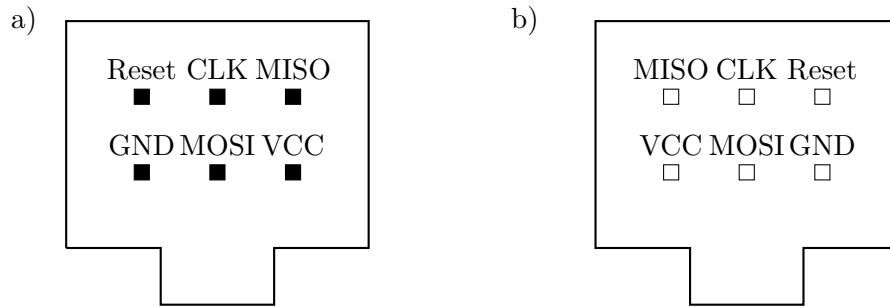


Figure 11: SPI connectors - a) connector, b) cable.

I used an Arduino Uno programmed with the “Arduino ISP” sketch [under Examples in the Arduino IDE] to program my separate ATmega328P.

In order for that to work one will have to keep the Reset pin of the programming Arduino Uno HIGH with a capacitor and connect the Reset pin of the device to be programmed with the pin as specified in the “Arduino ISP” sketch via `#define RESET 10` [this being pin D10 per default].

Other than that each pin of the programmer will have to be connected with the pin of the same name of the programme [i.e. e.g. MOSI-programmer → MOSI-programmee].