Why ULUs?

Universal Logic Units are modular digital building blocks. See it as digital Lego. I have created ULUs because I wanted to play with digital logic, like playing with Lego. When you have an idea, you just grab your ULUs, connect them to each other and build something. It is that easy. Show your children or family how digital technology works. Sensor based systems, logic experiments, a 4-bit computer or a Turing machine can be built with ULUs.

There are several advantages of using building blocks. First, everything you build is fully recyclable. No old experiments laying in the drawer somewhere. Secondly when more or new functions are needed, just build extra ULUs. You are not limited by anything. Third, you can build the most ULUs in one or two evenings. It is very rewarding to see progress that easy and have in a short amount of time something working in your hands. And finally, they look need.

ULUs are fully constructed with standard, of the shelf available, components. No 3D printed parts of custom PCBs are needed. Construction is easy and only hand-tools and a soldering iron are required for fabrication.

History of ULUs

It must be somewhere in the 1970's that I experimented with Fischertechnik electronic building blocks. That became increasingly frustrating: I was always short on certain building blocks, while others laying around unused. Buying additional ones, was extremely expensive. So, I designed a cheap building block (Figure 1, second from left). Furthermore, Fischertechnik designed a separate block for every gate type. I found that so in contradiction to the generic usability of the other Fischertechnik materials, that I want to solve that.

It stayed at the back of my mind and in 2018 I finally found a solution and designed a uniform gate building block (Figure 1, third from left). In 2020 I improved it, it was the start of the current ULUs.

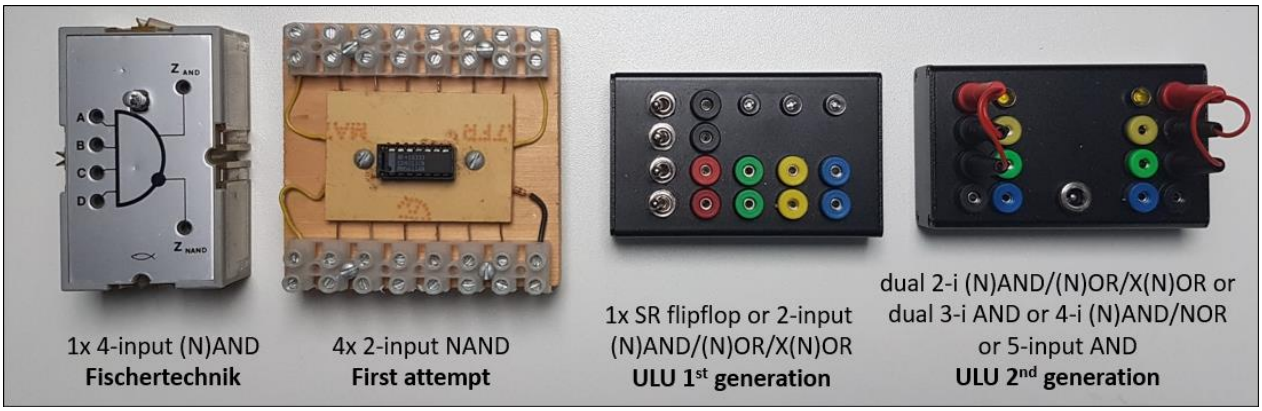

Figure 1 – My earlier attempts to build logic bricks

The high prices combined with the limited functionality made me decide to design and build my own logic bricks: ULUs. I wanted it to be a fail-safe, easy to use and easy to make brick. That is why I chose positive logic (+5V is a logical 1), separate power plugs (to prevent short-circuiting), a 4-bit data bus plug (easy to plug and less surface area), standard boxes (no 3-d printing) and prototyping board (simple PCB's that can be built without ordering). These are unique and powerful features that, together with the powerful functionality, ensure you can build beautiful experiments. Today over 30 ULUs are specified and build.

Other logic bricks

The idea of logic bricks was first introduced in the early 1970's in Germany. Several systems where developed and mainly used for education. Nowadays logic bricks can still be bought. However, they have two major disadvantages: 1. They are expensive and 2. The functionality is limited to mostly gates and flip-flops. If you want to build something interesting, you need a lot of bricks.

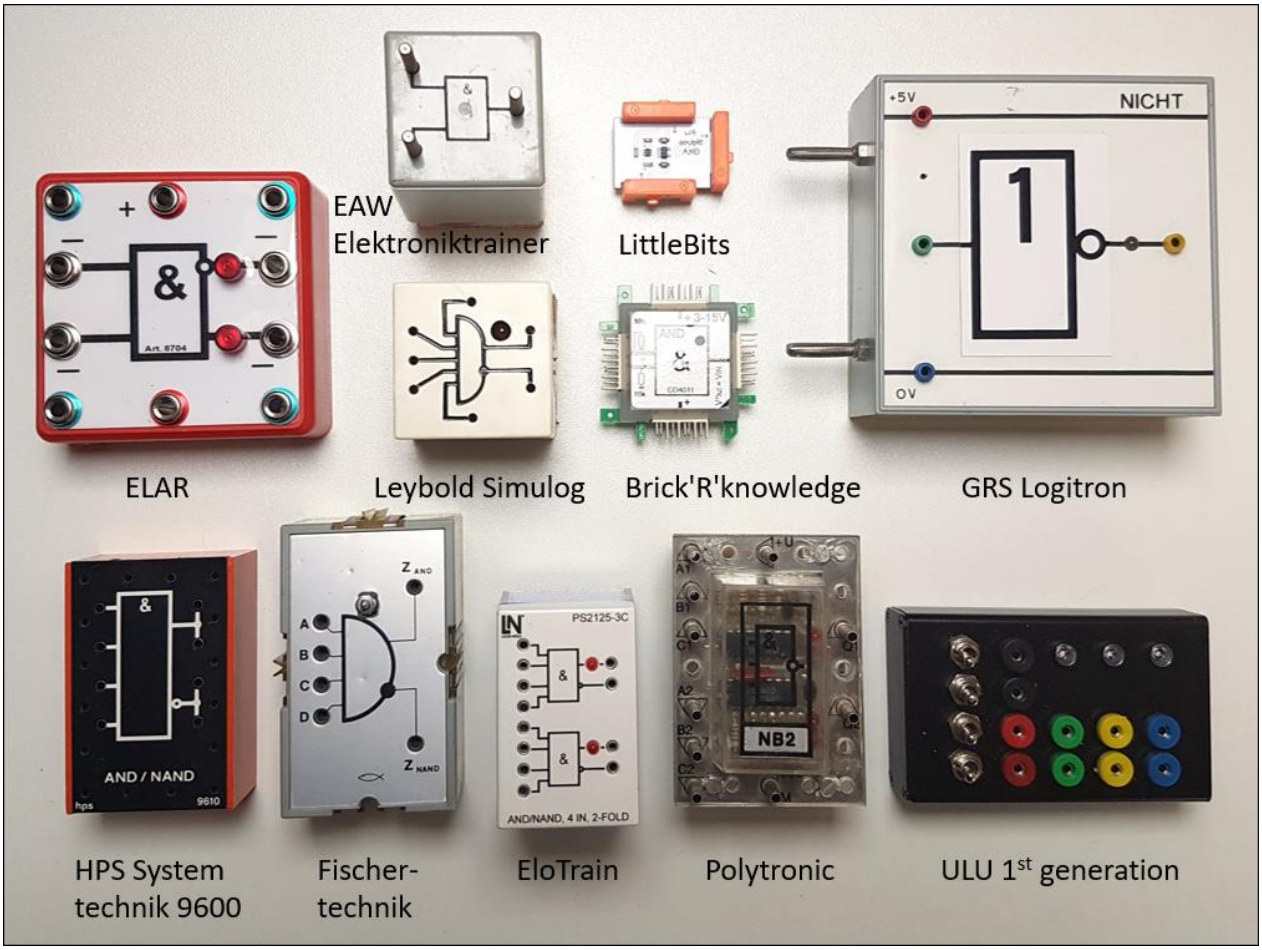

Figure 2 – Old and recent logic bricks (collection from the author)

Specifications

An ULU (universal Logic Unit) contains one or more logical components or functions. Distinction can be made between ULUs with contain components (relay, gate or flip-flop) and ULUs that contain functions (adder, register or memory). An ULU is designed as universal as possible.

Every ULU:

1. Has a unique name and number. This number has no meaning other than uniquely identify the ULU. If the functionality an ULU is modified, it will get a new number and possible a new name.
2. Is always a black enclosure (preferable 50*80*20mm with a drill grid with 28 positions).
3. Works on 5V (voltage limits: 3.8V – 5.5V).
4. Recognizes a logical 1 that is 3.8 – 5.5V, and a logical 0 that is a not connected input.
5. Can deliver 1A output current, to avoid current limitations. That implicates that Arduino outputs must be buffered (with a relay).
6. Uses a well-defined I/O interface, implemented with standard connectors:
   a. 2mm banana plug for the digital signal;
   b. 4-pole 3.5mm jack plug for the 4-bit data bus;

c. 5.5*2.1mm power connector for the 5V power supply;
d. Other plug(s) as required, to avoid signal confusion.

7. That uses a data bus, has a bus with enabled output. If the "enable" signal is false, the ULU passes a high impedance signal, which effectively disconnects data output from the circuit.
8. That uses one or more toggle switches, the switch(es) are “on” when set upwards and “off” when downwards.

Furthermore:

9. Everything that can be solved in the cabling is not solved in the ULU-box, that keeps the box simple.
10. No switching or processing speeds are specified. Since (± 10ms switching) relays are used, the maximum switching speed will be around 50Hz.
11. Preferable input colors are: black, green, blue and output colors are: white, yellow & red.
12. LED logic value indicators are placed preferably on the digital outputs and not the inputs.

Enclosures

Every ULU has a paper drill template: adjust the size to the right dimensions, print this template on your home printer, temporary glue the printout to the enclosure and use a center punch to mark the positions. After that, it is not very difficult to drill the necessary holes at the right positions.

Standard enclosure (80*50*20mm)

Most ULU’s will fit in a standard enclosure. The required size of an enclosure is determined by the combination of the required:

1. surface area for the sockets;
2. empty internal space for the electronics.

When there is not sufficient space, one of the larger enclosures will be used. In principle every enclosure is just large enough to facilitate its functionality and not larger.

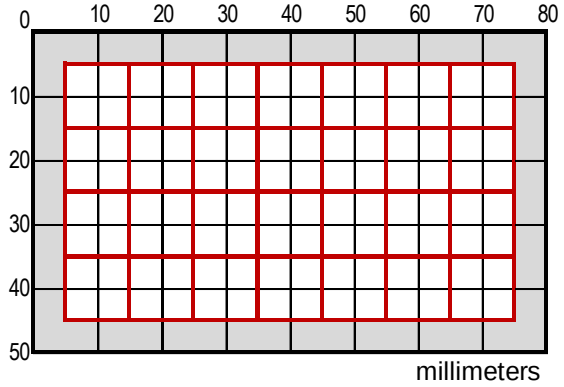

Figure 3 – Basic drill grid with 4x7 positions

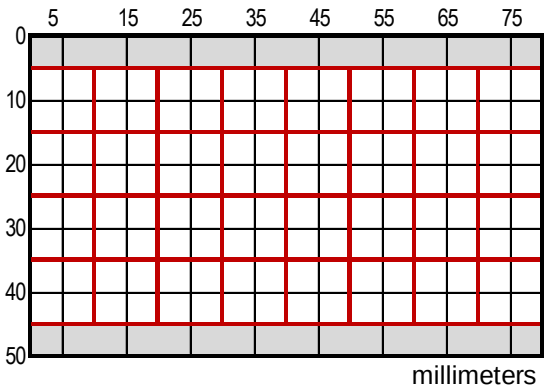

Figure 4 – High density drill grid with 4x8 positions

Large enclosure (100*98*25mm)

When a standard box is not large enough, there is a larger size available. This an almost square enclosure from approximately 10x10x2.5cm.

Figure 5 – Standard enclosure 80*50*20mm

Figure 6 – Large enclosure 100*98*25mm

Large I/O enclosure (80*25*25) and small I/O enclosure (50*25*25)
For switches and lights, the standard ULU enclosure is much to spacious. Then smaller – more suited – enclosures are used.

Figure 7 – Large I/O enclosure 25*25*80mm

Figure 8 – Small I/O enclosure 25*25*80mm

LEDs

Signal LED's (3mm opaque)
Three-millimeter opaque led in five colors are used as signal indicators. A serial resistor to allow the LED's work on 5V as well prevent blinding the eyes. It is very important to determine the preferred resistors for each and every batch of LEDs, since their performance will differ. The following resistor values may work: White – 20KΩ, Green – 0.3KΩ, Yellow – 2K2Ω, Blue – 8K2Ω and Red – 3K3Ω. These resistors are soldered on the short (-) pin, protected with heath shrink tube and provided with an earth wire (Figure 10).The + or PLus (Positive Long) pin can be soldered directly to the corresponding output connector. The LEDs are mounted in the enclosure using a 3mm metal LED holder as shown in Figure 12.

Figure 9 – Used 3mm LEDs

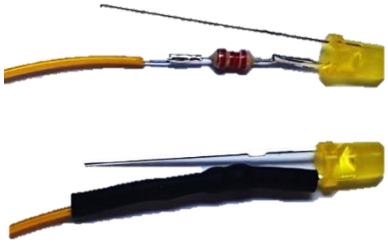

Figure 10 – Soldering LED resistor

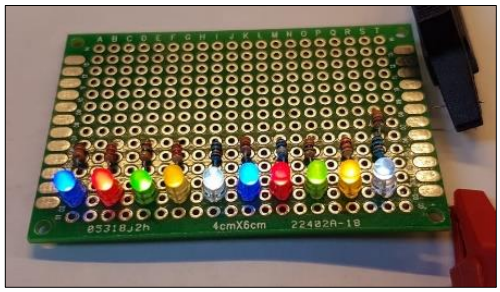

Figure 11 – The testing of LED resistors

LED graph bars (5, 8 and 10 LEDs)

Led graph bars are used to display the data bus or multiplexed outputs.

Figure 12 – 3mm LED holder

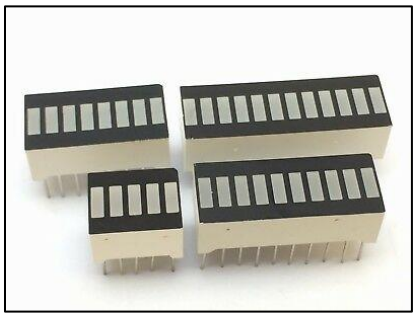

Figure 13 – LED graph bars

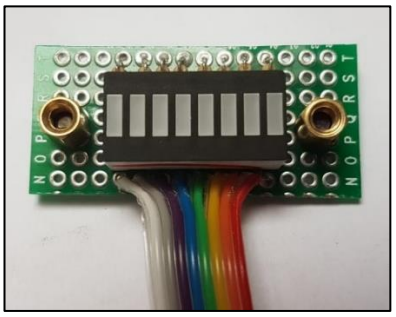

Figure 14 – 8 bit LED graph bar

Rectangular LEDs

In a number of cases, there is not enough space to use a graph bar. Then rectangular LEDs are used.

Figure 15 – Rectangular LEDs

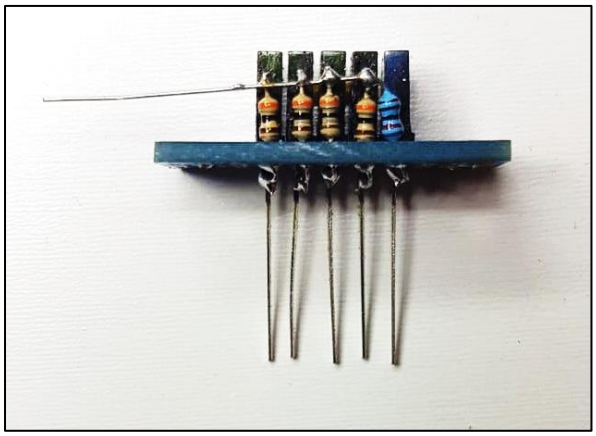

Figure 16 – Soldering of the resistors

The base of the rectangular LEDs will need some filing, to make them fit properly. All the sides of those LEDs need to be colored black (use a black marker) to avoid light shining from one to another LED. The resistors can be compact soldered as shown in Figure 16.

7-segment displays

In several ULU's 7-segment displays are used. Mostly 0.56" (14,22mm) but also 0.27" (6.86mm) displays are used. Since the signals use positive logic, common cathode (common ground) displays are used. A resistor in the signal line lowers the signal voltage to the appropriate voltage for the display.

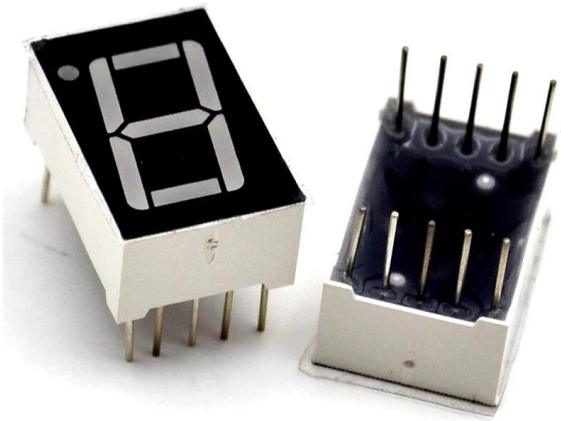

Figure 17 – 0.56 inch 7-segment display's

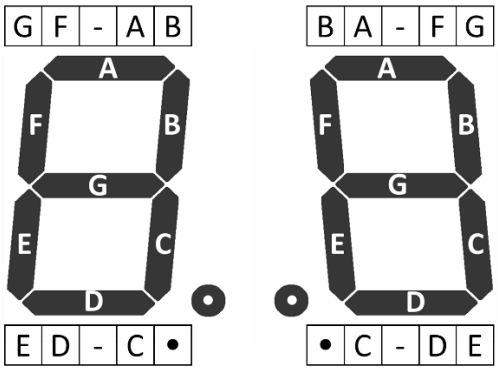

Figure 18 – Pinout 0.56" 7-segment display

Connectors (plugs & sockets)

Digital signal (2mm banana)

The digital signals are connected through a standard 2mm banana plug & socket. Since the boxes are made of metal, it is essential that a insulated connector is used. The used female socket is shown in Figure 19. Since this socket is a bit longer than the standard ULU box allows, black O-rings (9*5*2mm) are used to increase the mounting height, as shown in Figure 20.

Figure 19 – The used 2mm banana sockets

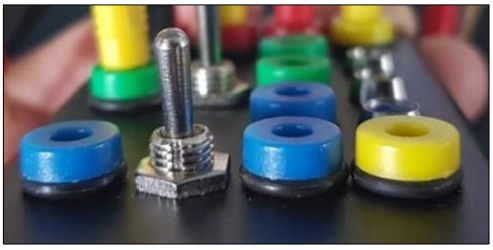

Figure 20 – The O-rings to heighten the sockets

Figure 21 – 30cm signal cables

Standard 10cm and 30cm banana plug cables are used to make the connections. It is strongly advised to use the connector type of the green connector (Figure 23), because the red type will damage the sockets. A pair of reversed tweezers is used to tighten the socket nuts, as shown in Figure 22.

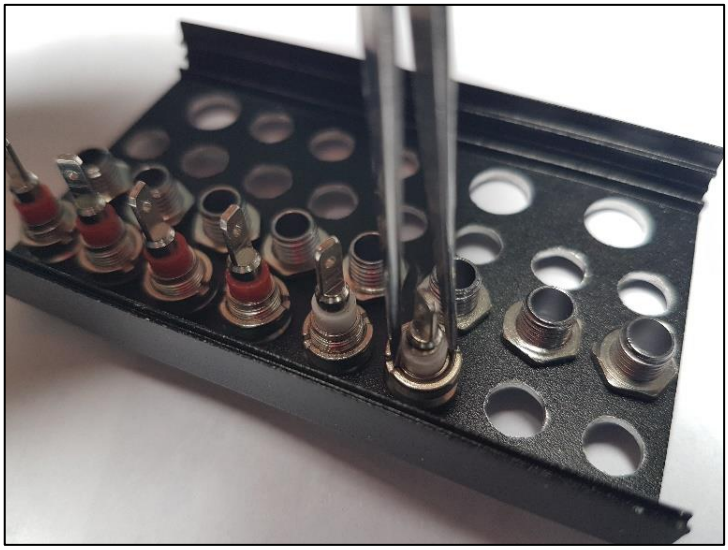

Figure 22 – Tightening the connector nuts

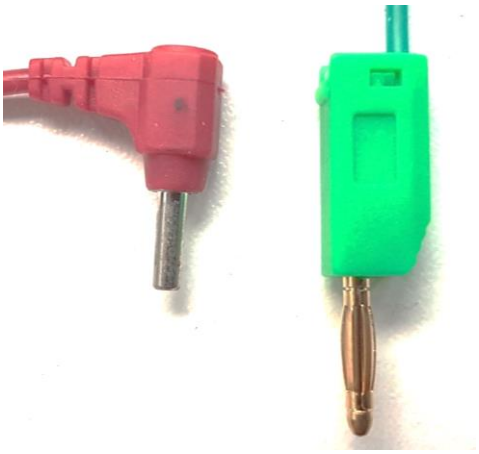

Figure 23 – Proper (green) connectors

Power (5.5*2.1mm power)

Standard 5.5*2.1mm power sockets are used to provide power to the ULUs. Several cables are used to distribute the power among the ULUs as shown in Figure 25 – Figure 27.

Figure 24 – Power sockets

Figure 25 – USB to power plug cable

Figure 26 – Power switch cable

Figure 27 – Power extension cable

4-bit data bus (4-pole 3.5mm jack)

In order to reduce the number of sockets and cables used, a standard 4-bit data bus has been created. This appears to be a very useful feature. For this data bus 3.5mm 4-pole (audio) jackets are used since they are widely available. Colored O-rings are used to indicate whether the bus is input or output. The rings are key-caps dampening O-rings: 1.5 x 8mm in several colors (see Figure 30).

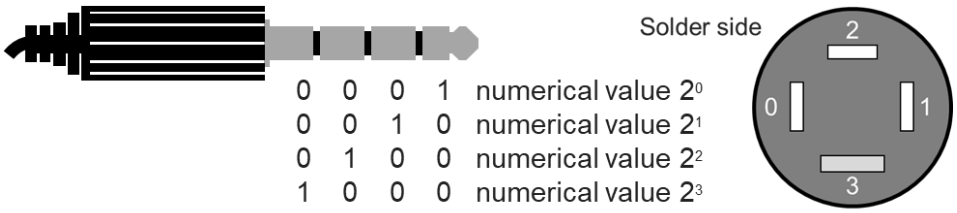

Figure 28 – Plug and socket specifications of the 4-bit data bus

Figure 29 – Data bus socket

Figure 30 – Colored O-rings

Figure 31 – 30 cm data cable

Figure 32 – Data-splitter cable

Active components

Relays

Relays are used for basic ULU functionality. The modern relay is small, switches in about 10ms and can easily switch 1A. Therefore, no output buffering is needed. Relay circuits are easy to understand and easy to create. So, they are ideal for the use within ULUs, especially because high switching speeds are not necessary. Two types of relays are used, as shown in the figures below.

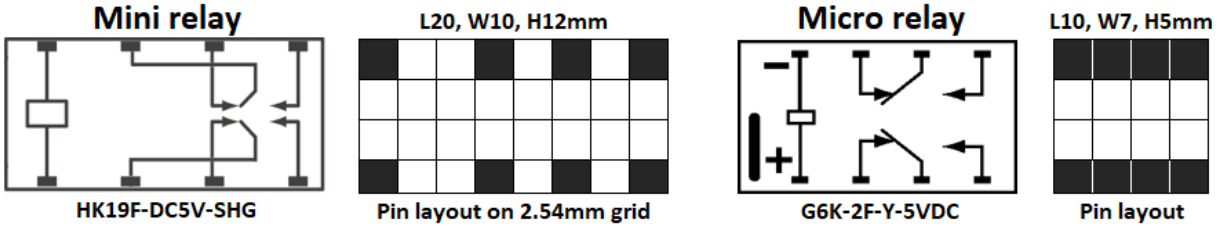

Figure 33 – Schematics and dimensions of both relays

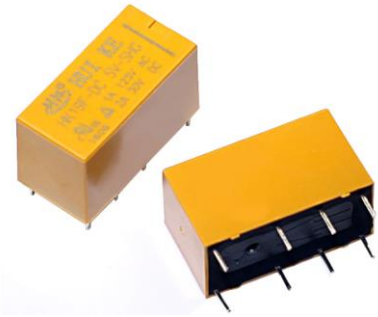

Figure 34 – The HK19F-DC5V-SHG

Figure 35 – mini and micro relay

Figure 36 – The G6K-2F-Y-5VDC

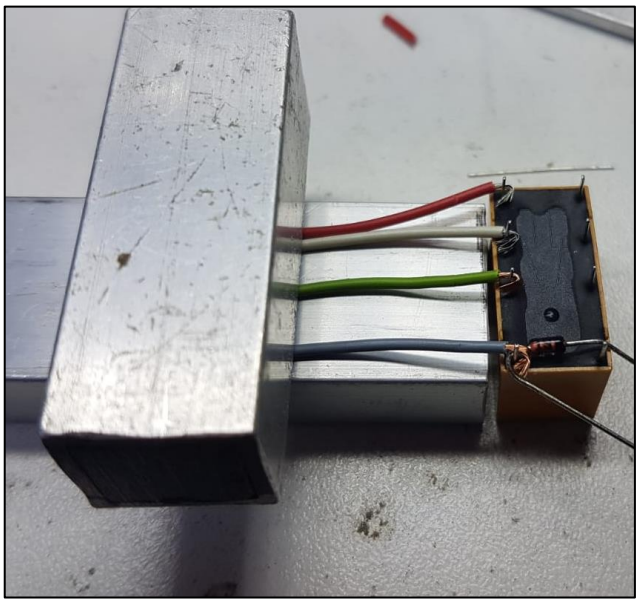

Figure 37 – Soldering fixture mini relay

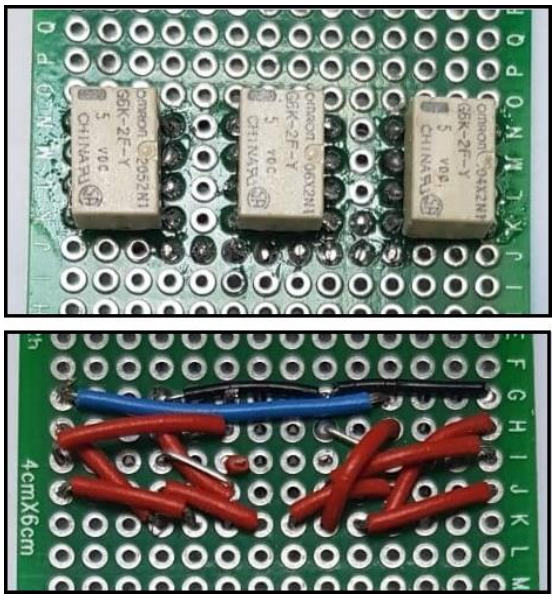

Figure 38 – Front and back side micro relay

Arduino Nano

When more complex functions are needed (for example a 4-bit adder) an Arduino Nano is used. The size of the Arduino is approximately 43mm × 19mm and therefore will easily fit into the standard ULU box. The Chinese Arduinos are cheap (± €3,-) and there is a wide variety of sensor- and display hardware available that can be “plug and play” connected to the Arduino. Nine Arduino Nano interface types are specified in Figure 40.

Interface ❶ is used to connect a regular output port to the Arduino. Since the output current is limited, a G6K-2F-Y-5VDC relay is used for output buffering. The current needed to switch this relay is within the allowed Arduino limits, so it can be connected directly to an output port.
Interface ❷is used for setting switches, for instance if 2-complement encoding is used. This interface uses the standard pullup feature of the Arduino Nano.
Interface ❸ is used when a signal or setting can be entered through a 2mm input socked as well as a switch on the ULU. A 10KΩ resistor is used as a pull-up resistor.
Interface ❹ is used for a regular input socket and detects the 5V as input.
Interface ❺ is used for LEDs and 7-segment display segments.
Interface ❻ is used for enabled output. Enabling can be done through a 2mm socket, a switch or both.

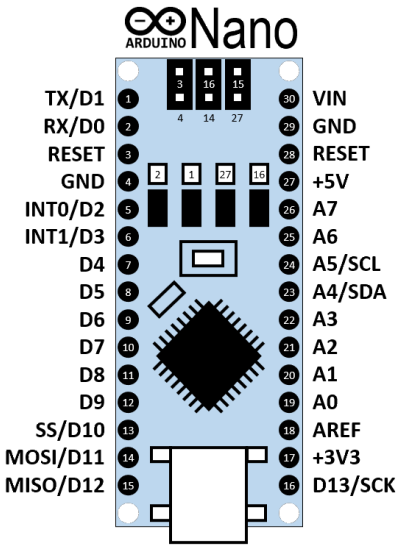

Figure 39 – Nano pinout

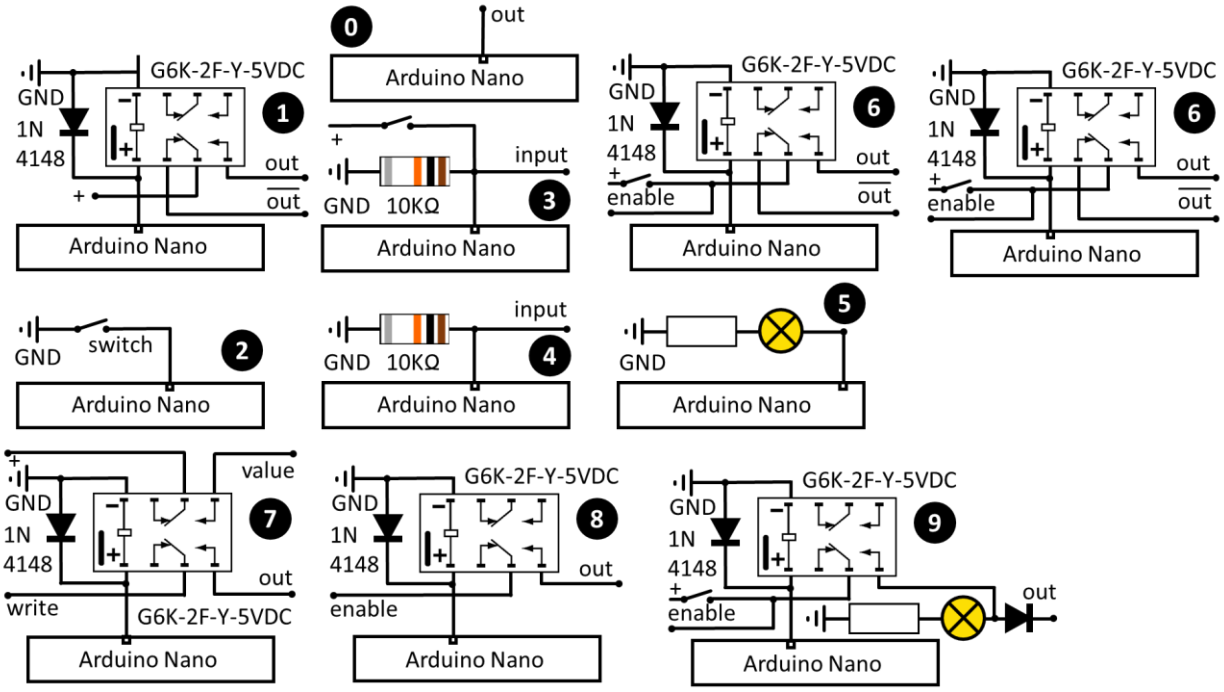

Figure 40 – Arduino Nano interface specification

Interface ❼ is used for a combination of enabled output and permanent output.
Interface ❽ is used for enabled output without the use of a switch.
Interface ❾ is used for enabled output to a bus, where the bus value will not be shown on the LED attached to the output.

Port	Restriction
D0	Output only
D1	Output only
D13	Output only, mostly used for heartbeat
A6	Input only, no Pullup feature, no digitalRead
A7	Input only, no Pullup feature, no digitalRead

Figure 41 – Arduino Nano digital port restrictions

There are severe restrictions on the use of digital I/O on the Arduino Nano ports. It took me some failures to find out (see Figure 41).

Various parts

Diodes
Two types of diodes are used, the 1N4148 switching diode and the 1n5817 schottky diode. The first one is mainly used as a fly-back diode for both the relays. The second diode can handle current up to 1A and is used for diode matrices as implemented in several ULUs.

Switches
ULUs use switches for I/O and parameter settings. When an ULU has different moda operandi, the required one can be selected by the switch setting. The three types of switches that are mainly used can be found in the figures below.

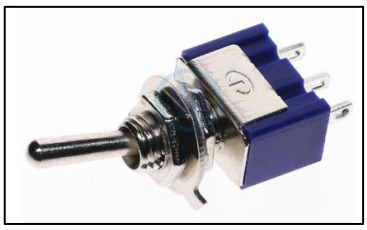
Figure 42 – SPDT rocker switch


Figure 43 – SPDT on-off-on switch


Figure 44 – SPDT push button

Figure 42 shows a one pole ON-Off rocker switch. This switch is mainly used to enable output or to code two alternatives. Figure 43 a one pole ON-OFF-ON rocker switch. This switch is used for coding three alternatives Figure 44 shows a single pole push button, mainly used for controlling an Arduino.

M3 Standoffs & bolts
LED 7-segment displays and LED graph bars are connected to the enclosures with M3 standoffs and M3 bolts, as shown in the figure below. When there is a need to fit two circuit boards, then two standoffs and an extra-long M3 bolt are used. The most commonly used standoff is a 5mm male-female standoff.


Figure 45 – Single and dual circuit boards standoffs


Figure 46 – Standoff with bolt and nut

Experiment board
The circuit designs used for the logic of the ULUs is not very complicated. It is mostly used for pull-down resistors, resistors to limit the LED current for 7-segment displays or LED graph bars and for the micro relays (G6K-2F-Y-5VDC) used. The majority of connections is between the PCB and connectors, not between points on the PCB. Therefore, standard prototype board is used to implement this logic. The connections used in logic implemented using mini relays (HK19F-DC5V-SHG) are soldered directly on the relay pins, to save space.

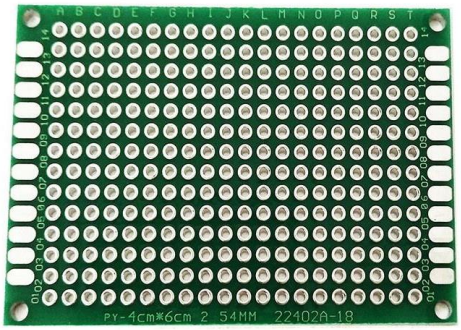

Figure 47 – Standard 2.54mm prototype board

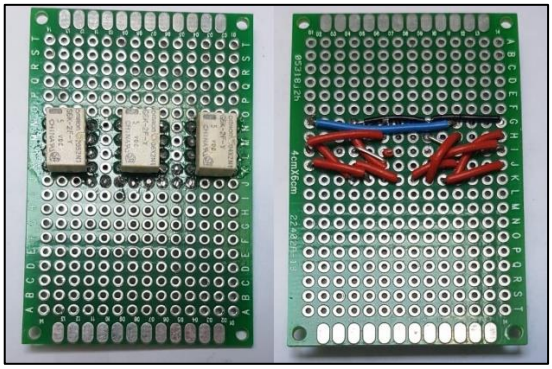

Figure 48 – Mounting the G6K-2F-Y-5VDC relays, with the cabling soldered on the back-site

Wire

For the wiring, 0.14mm^2 flexible copper wire is used. The brown wire is used for +5V DC, the grey wire for the ground. For the other connections the color of the attaches socket is used. I made a wire holder to hold the 10 wire colors as shown in Figure 58

Shrink fit tubing

Shrink fit tube, especial the diameters 1mm, 2mm and 3mm are often used. To insulate the micro relays, shink fit tube with a diameter of 10mm is used. Wire and shrink fit tubing are not separately specified in the bill of materials of each ULU.

2mm male & female cable connectors

These are used to make the cabling adapters as described in the next section.

Figure 49 – Male and female 2mm connectors

Cabling adapters

Power to signal adapter

It might be necessary to provide a logical 1 to a certain input. Therefore, this cable is used: it has a standard power plug (5.5*2.1mm) on one side and a male (2mm banana) signal connector on the other side. The cable length between the plugs is 5cm.

Figure 50 – Power to signal adapter

Signal to power adapter
Several ULUs don't have enough space for a signal socket. In that case the signal to power adapter can be used. It combines the ground from a male power cable with the 5V from a signal cable to a regular power plug.

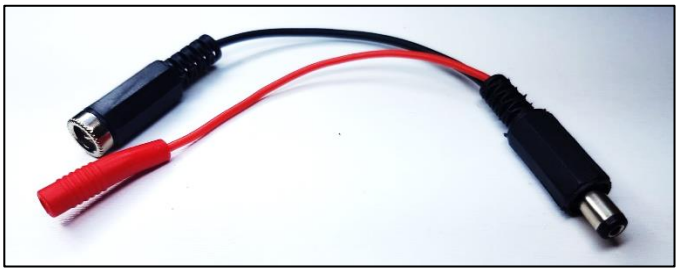

Figure 51 – Signal to power adapter

Data to quad signal adapter
It also might be necessary to split the data bus in its separate signals. Therefore, these cables are used: they have a data bus connector (4 poles 3,5mm connector) on one side and four (2mm banana) signal connectors on the other side. The cable length of the short wires is 3,5cm. The LSB (2^0) is always marked with a green connector.

Figure 52 – Several types of data to quad signal adapters

Diode cable
A simple diode cable with the 1n5817 schottky diode is made to use when necessary. The construction of this cable is shown in Figure 53.

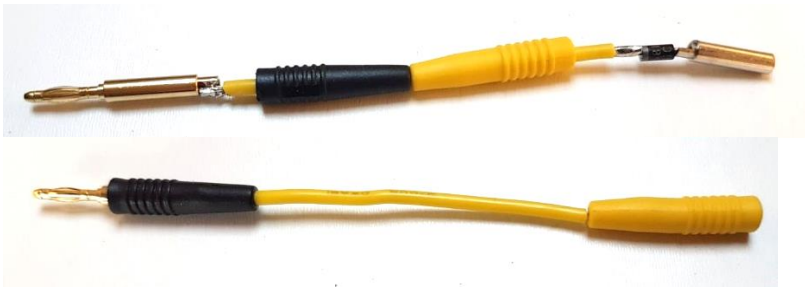

Figure 53 – Diode cable

Signal expander

A simple but effective signal expander can be made with an aluminum box profile from 10 x 20 x 1.5mm. A piece of 30mm is cut off and six 4mm (3.8mm) holes are drilled according to the drill guide (Figure 56). Then non-insulated 2mm sockets (Figure 54) are put in the holes. A piece of tape can be used to finish the signal expander (Figure 55). The single (red) signal line can be expanded according to the needs and will result in the connection of two to five output lines (green) to one input line (see Figure 57).

Figure 54 – The used uninsulated 2mm sockets

Figure 55 – 1 to 5 connections signal expander

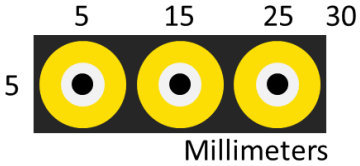

Figure 56 – Drill guide

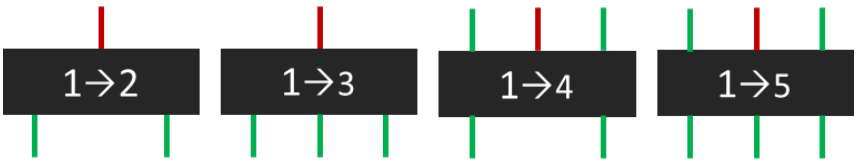

Figure 57 – Connection possibilities

Useful tools

Several tools appear to be useful for making the ULUs. They are shown in in Figure 58:

- Tweezers are used to guide the wires.
- The reverse tweezer is used to tighten the nuts of the 2mm sockets (also see Figure 22).
- The scissor plier is used to bend solid wire.
- Two lead weights (square aluminum tubing filled with lead) are used to fixate wires.
- The machine vice is used to fixate the ULU enclosures when soldering.
- The soldering hand is used to solder resistors to wires.
- The set of desoldering cleaning rods is used to clear holes that are filled with solder.
- Finally, the purpose of the wire cutter and wire stripper is obvious.

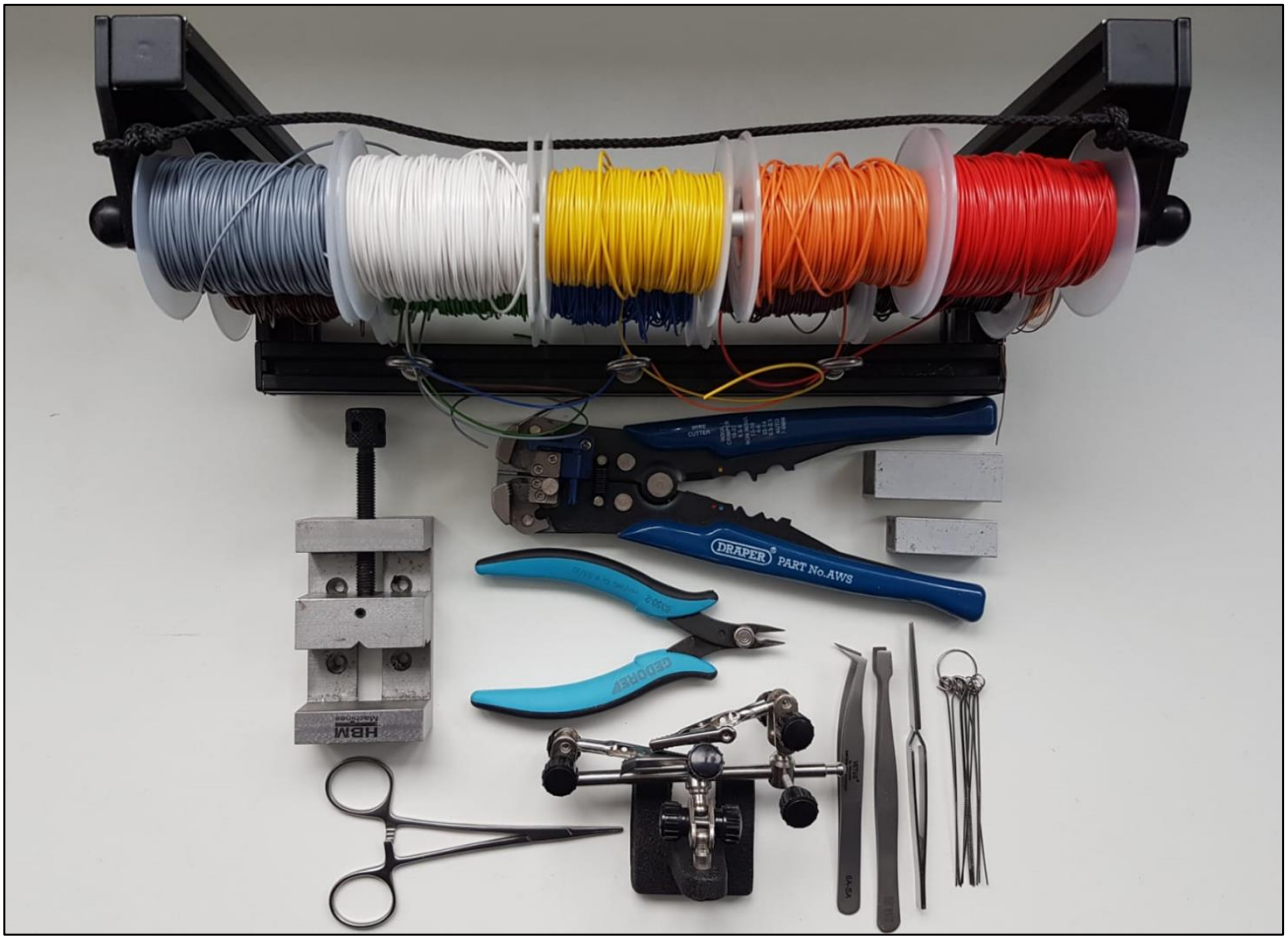

Figure 58 – Tools I found especially useful for making the ULU's

Finally…

At this moment there are over 60 different ULUs specified. The number of experiments and applications is even more. You don't need al those ULUs before experiments and applications get interesting. So my advice is: first think of an interesting experiment you would be willing to conduct and then build the necessary ULUs.

Wishing you plenty of joy and happiness building ULUs and playing with them!

Jeroen Brinkman