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CIRCUIT SPECIAL 2024

Design Ideas, Tips & Tricks

7 Extra Circuits & Projects

- Simple Microcontroller Project Board
- A Tiny Music Box
- PIR Switch
- Inertial Switch for Hazard Lights
- Simple Analog Thermostat
- Attenuator with Auto-Range Adjustment
- Owon XDM1141 Multimeter
- Infographics: Circuit Design
- Q&A: SnapMagic's Natasha Baker
- ESP32-C2-Based Coin Cell Switch
- Arduino Plug and Make Kit

Circuit Special 2024 Bonus Edition

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EDITORIAL

BONUS: CIRCUITS AND MORE!

I am thrilled to present this bonus edition of the *Elektor Circuit Special 2024*. This magazine is packed with extra projects and tutorials tailored for all levels of electronics enthusiasts. Whether you are a professional engineer, a weekend DIY electronics maker, or a curious EE/ECE student, this issue is designed to inspire and challenge you for weeks and months to come.

In this edition, you'll find various exciting projects: a handy PIR switch circuit, a creative analog thermostat project, an ATtiny85-based music box, an attenuator with automatic range adjustment and more. Ready to dive in?

But that's not all! We also feature an in-depth interview with SnapMagic's Natasha Baker, smart tech tips, and helpful product insights.

Our goal is to equip you with practical knowledge and creative ideas to fuel your passion for DIY electronics. So, grab your tools, clear out a space on your electronics workbench, and jump into the Bonus Edition. Once you start new projects of your own, make sure you share your progress on the Elektor Labs platform!

C. J. Abate (Content Director, Elektor)

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An Inertial Switch **for Hazard Lights**

Activate Your Car's Blinkers in Case of Hard Braking

By Stefano Purchiaroni (Italy)

When driving, you may have to brake suddenly: in that circumstance, driving attentiveness is of utmost importance and there is no time to search for buttons to press in the cockpit! The microcontroller-based inertial switch, described in this article, elegantly solves this problem.

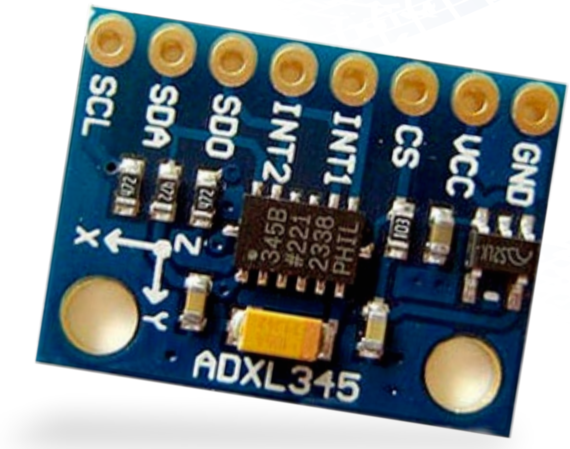

Figure 1: The author's small GY-291 module embedding the ADXL345 accelerometer by Analog Devices.

With an accelerometer and a microcontroller, this device activates both the left and right turning lights when a car suddenly brakes hard. It also features a learning function where the user may adjust the intensity of the deceleration in braking, above which this device is triggered. It requires a connection with the 12-V power supply and with the two supply lines heading to the turn indicators.

In the 1980s and 1990s, there were similar circuits for activating the L&R turn lights in the event of a sudden braking of the car; they were based on a mercury drop switch, suitably oriented "uphill." The MEMS integrated circuits, commonly used on smartphones as accelerometers and gyroscopes, are now widely used and cheap. The ADXL345 3-axis accelerometer sensor by Analog Devices [1] is available not only as a chip, but also in the form of a breakout board like the one shown in **Figure 1** (GY-291), produced and distributed by Chinese companies for just a few euros.

The strip connections provide a power supply input with a voltage between 3 V and 5.5 V, two SCL/SDA data lines for the I^2C interface, and two lines dedicated to vibration management, programmable for Tap or double-Tap, not used for our purposes. In the application diagram, only the I^2C interface is used to obtain the current acceleration measurement on the X-axis, which is taken as the direction of motion of the car.

The circuit proposed in these pages forces both L&R indicators to blink when the programmed braking intensity is exceeded. Everything is managed by a PIC12F1822 from Microchip. To program the threshold, you must enter

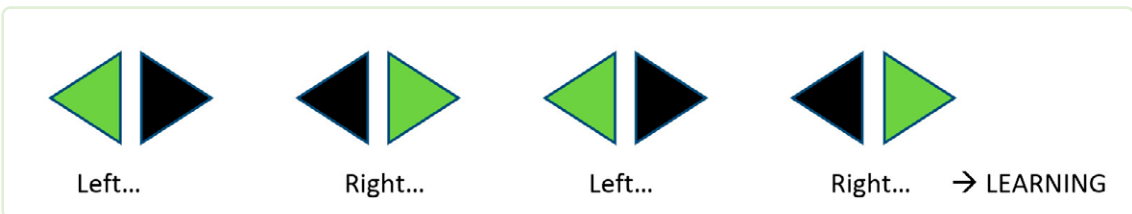

Figure 2: The L-R indicators sequence needed to enter the learning mode.

the learning mode by twice executing a quick sequence of turning the left and right indicators on and off, as shown in **Figure 2**.

If the sequence is recognized and executed within a specified time (`FLASHMAX`, the residual acceleration `StdAcc` read in a quiet state is memorized, then subtracted from the subsequent measurements as an offset, and the turning lights are turned on steadily until a breaking of the intensity that you want to define as the `MaxAcc` limit threshold occurs. If the deceleration does not take place within a time limit (`MAXLEARNTIM`), you will exit the learning mode by switching the turning lights off, and the pre-existing threshold will be kept. Otherwise, the new measured value is memorized in flash and used to decide, at each braking, whether to activate the L&R turn lights. In **Table 1** are indicated the operating

Table 1: Code Working Parameters

Parameter	Initial Value	Use
`TIC`	50 [ms]	Milliseconds between two consequent program cycles
`FLASHMAX`	2,000 [ms]	Max time to enter Learning mode
`MAXLEARNTIM`	10,000 [ms]	Max duration of Learning mode
`AMIN`	4	Minimum brake deceleration to achieve during Learning phase
`NMAX`	1	Max number of limit overcoming confirmations
`TALM`	5,000 [ms]	Alarm extra duration after overcoming ceased
`TALMCYC`	200 [ms]	Light flash on and off phases duration during blinking

parameters set in the code, which entail a recompilation in case of modification.

The flowchart of the management cycle, executed every `TIC` milliseconds, is shown in **Figure 3**.

Schematic Diagram

The GY-291 module, housing the integrated ADXL345 accelerometer, is managed by a PIC12F1822 microcontroller from Microchip that connects to it via the two I2C connec-

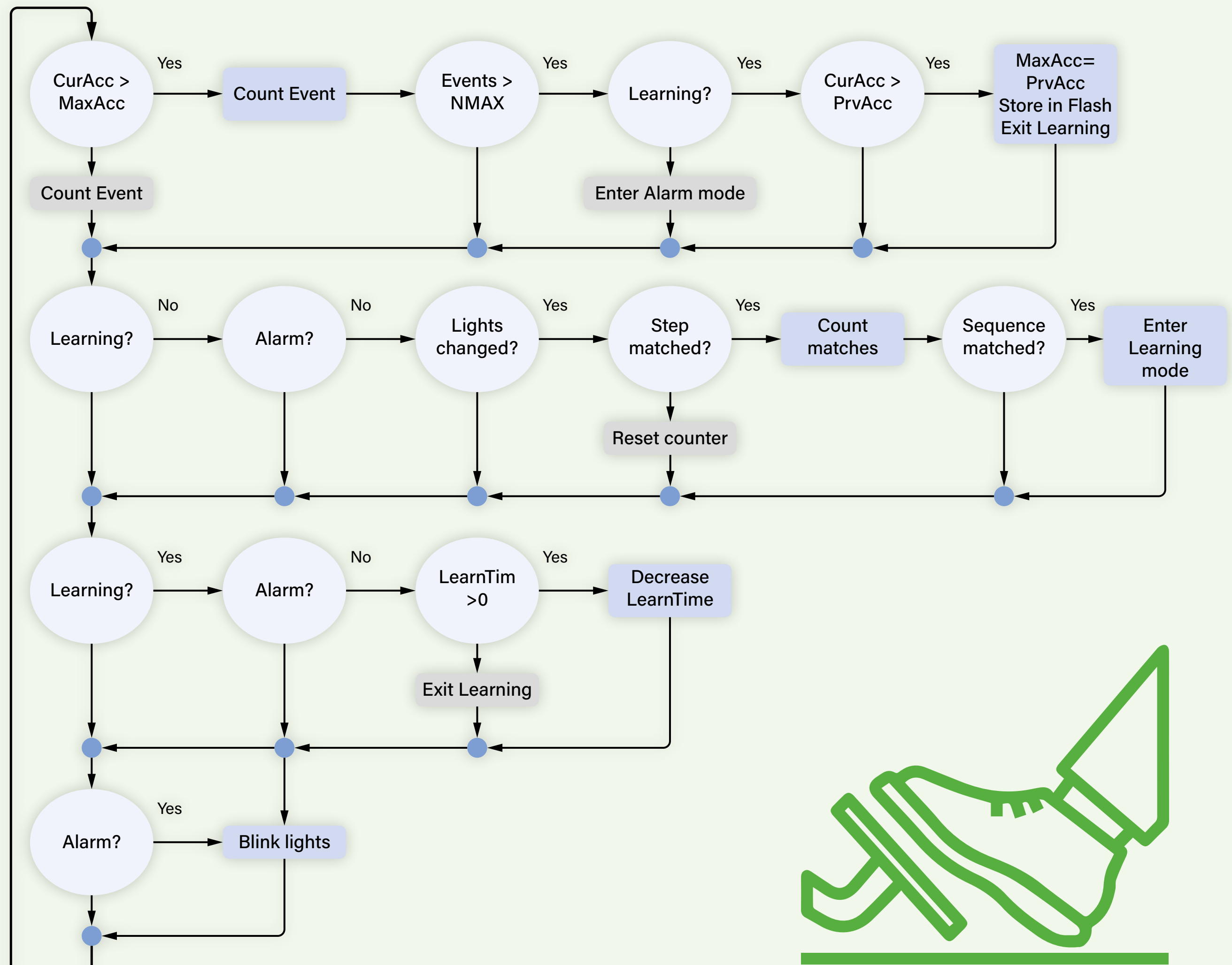

Figure 3: The microcontroller's management cycle.

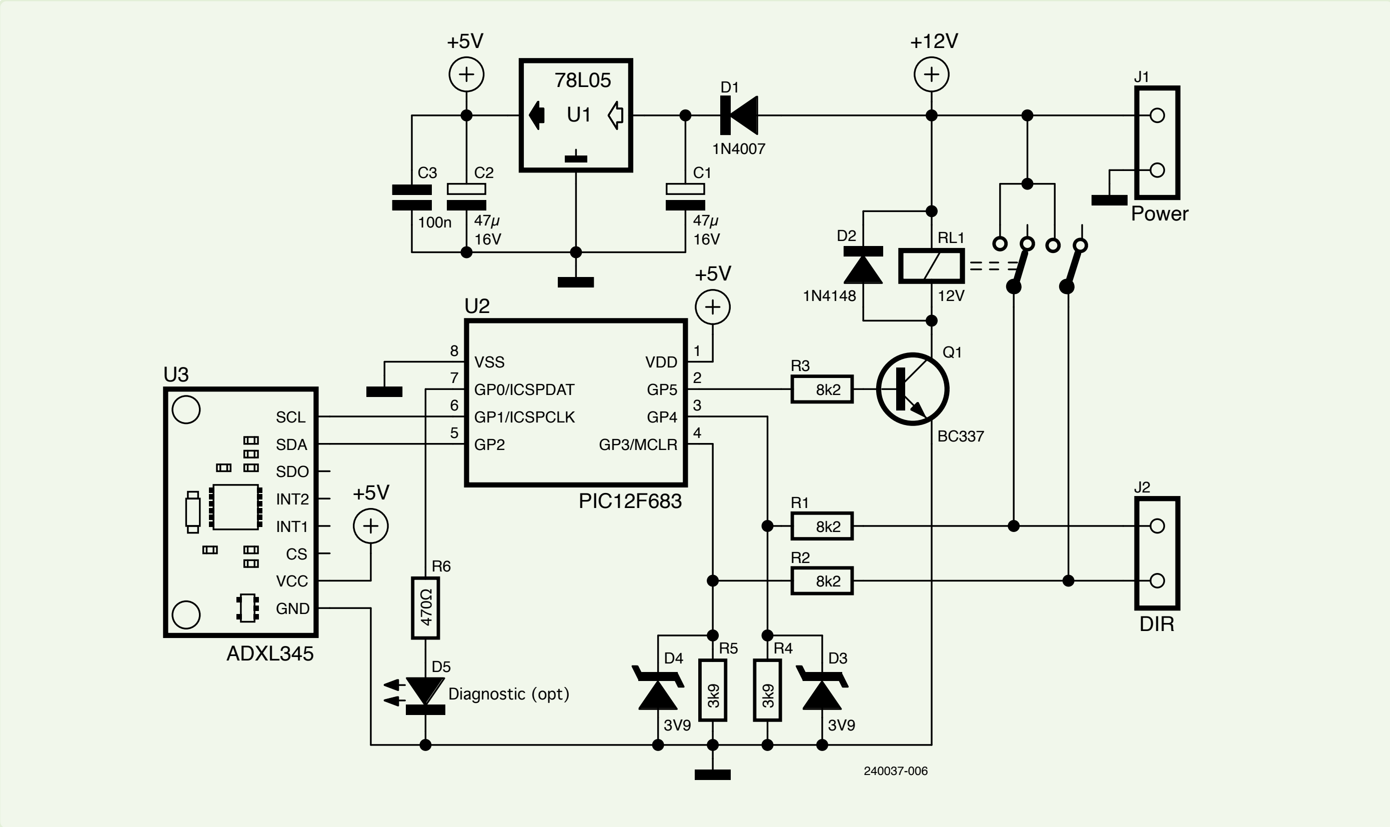

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Figure 4: Schematic diagram of the inertial switch.

tions (SDA and SCL). Furthermore, the microcontroller detects the switching on of the indicators, whose voltage is attenuated via dividing networks and further limited by the addition of protective Zener diodes. The output drives an automotive-certified relay via an NPN transistor. The protection diode on the relay coil absorbs its self-induction surges, generated when the coil is turned off. D1 prevents damage derived from incorrect connection with battery voltage.

The Zener diodes are low-power. Elements R6 and D5 are not essential to the operation of the circuit: this is a diagnostic LED that I used during the calibration stages. They are absent from the printed circuit board, shown in **Figure 4**.

The circuit board drawing shown in **Figure 5 (left)** must be rescaled to the lengths shown in the silkscreen layout of **Figure 5 (right)**. No jumpers are fitted, and the copper layer is limited to a single face.

Figure 6 and **Figure 7** show, respectively, a 3D rendering of the prototype and the circuit on a breadboard during the development stage. Note the buttons and LEDs mounted on the breadboard to simulate the turn signals and the associated control lever. The first realization did not satisfy me because the GY-291 module was a bit wobbly. I had to redo the layout to make room for a mounting post that is to be mounted in the hole between D3 and R4, making the circuit very stable. After assembling, this mechanically improved version, shown in **Figure 8**, was enclosed in a small plastic box and its operating parameters calibrated through several road test sessions.

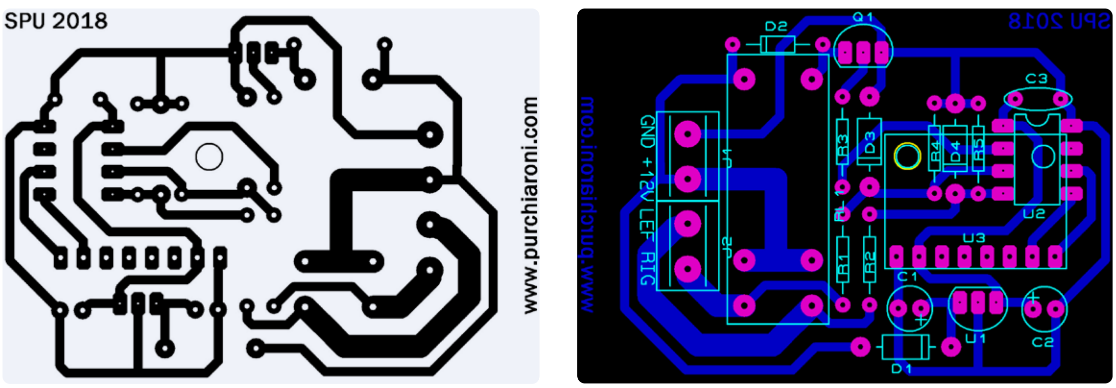

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Figure 5: The single-faced PCB layout (left) and the component side silkscreen (right).

Installation

To install the device in the vehicle, you need to locate four wires from the car's electrical system: +12 V, GND, turning lights-L, and turning lights-R. These should be connected to the terminals provided on the PCB. Do a test first, manually connecting +12V and indicators, to see if they light up. Normally, the other leads (negative) of the lights are connected to ground, but this is not granted and a verification it's always worth. It is best to secure the device by inserting a layer of shock-absorbing polyurethane foam, to avoid false readings. The device should be mounted with the connector side in the driving direction, so that the acceleration value can be read correctly.

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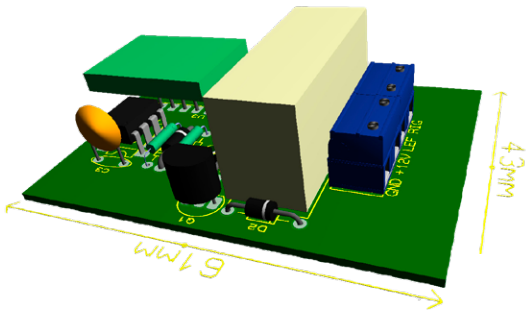

Figure 6: 3-D rendering of the project.

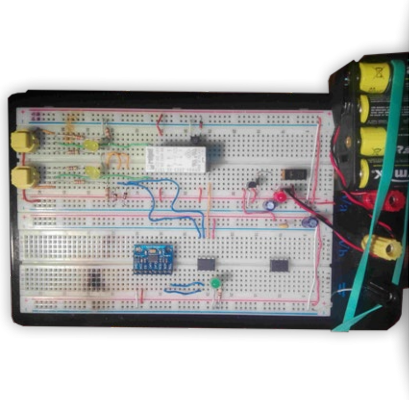

Figure 7: The early version of the project, wired on a breadboard.

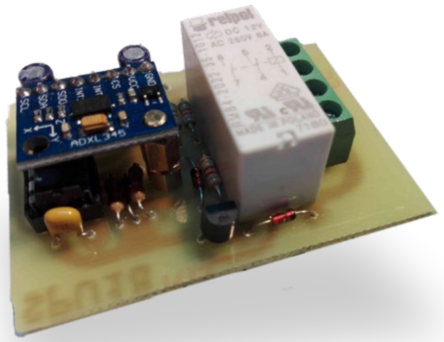

Figure 8: The finished prototype, ready for boxing and installation.

Warning!
Any alteration of the car's electric systems may cause a loss of warranty and have legal implications that may apply and vary depending on your country. Therefore, this project is provided for purely didactic purposes only.

About the Author

Passionate about electronics and programming, Stefano Purchiaroni shares his works by publishing projects, and also offers free robotics lessons for teens at a popular school. He is currently employed in Telespazio and works in a satellite center near the capital.

Questions and Comments?

Do you have technical questions or comments about this article? Please write to the author at info@purchiaroni.com or to the editorial team at Elektor at editor@elektor.com.

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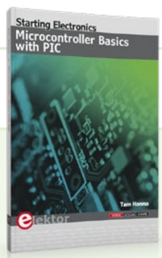


- T. Hanna, *Microcontroller Basics with PIC* (Elektor 2020)
  www.elektor.com/19188

WEB LINKS

[1] ADXL345 Datasheet: http://www.analog.com/media/en/technical-documentation/data-sheets/ADXL345.pdf
[2] Elektor Labs webpage for this article: http://www.elektormagazine.com/labs/hazard-lights-inertial-switch

PIR Switch

An Infrared-Sensitive Proximity Switch

By Giuseppe La Rosa (Italy)

Looking for a DIY proximity switch project? This PIR switch design can be useful for turning on lights or any electric appliances in basements, garages or public places where it is generally impossible or inconvenient to install a switch in an easy-to-reach location.

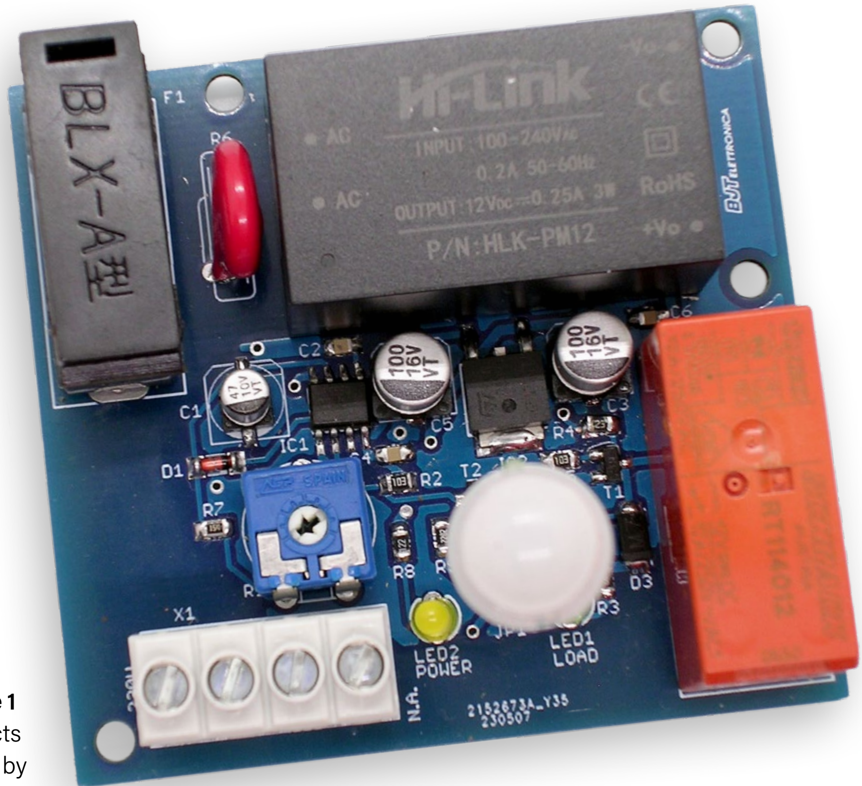


Figure 1: The finished prototype.

This passive infrared (PIR) switch project, shown in **Figure 1** as a finished prototype, uses a PIR sensor, which detects the non-visible infrared (IR) portion of the heat emitted by the human body. The sensor is mounted on a miniaturized HC-SR505 module, which includes the control electronics with a quiescent current of less than 50 µA. The sensing angle is 100°, and the maximum range is 5 m. The module has a digital output line with active (High) level of 3.3 V and Low level at 0 V.

In fact, it will be sufficient to install the device in the passing places. The circuit will activate the load for a time that's trimmer-adjustable, and then deactivate it at the end of the set cycle.

For placement in open spaces, such as gardens or courtyards, it will be sufficient to connect a twilight switch in series with the device to prevent it from activating even in daylight, saving electricity. When installed near a store's entrance, for instance, the circuit may also work as a doorbell, or as a nightly alarm, setting the siren activation time to about 30 s.

The Circuit

As visible in **Figure 2**, at the center of the circuit is IC1, an NE555 timer from Texas Instruments, wired in a monostable configuration. Its purpose is to extend the 10-s non-adjustable delay of the PIR module. When the output of this module, connected to JP1, goes to High state, it saturates transistor T2, connected to pin 2 of IC1, bringing it to Low level and keeping C1 discharged through D1. The output on pin 3, which is normally at logic Low, will immediately switch to logic High, bringing T1 ON and consequently activating relay K1.

As long as the PIR sensor signal on JP1 stays High, the output pin 3 of IC1 remains at the High level; when the PIR sensor deactivates, its output on JP1 goes Low. Then, T2 goes to Off, pin 2 of IC1 returns to High level, and C1 starts charging until its voltage reaches the threshold voltage on pin 6 of the IC. Once reached — in a time that depends on the setting of trimmer R1 — the output 3 of IC1 drops to Low level, and K1 is deactivated at the end of the delay cycle.

The time required for C1 to charge can be derived from the following two formulas:

$$T_{min}\,[s] = 0.0011 * R7\,[k\Omega] * C1\,[\mu F] = 0.0011*180*47 = 9.3\ s$$

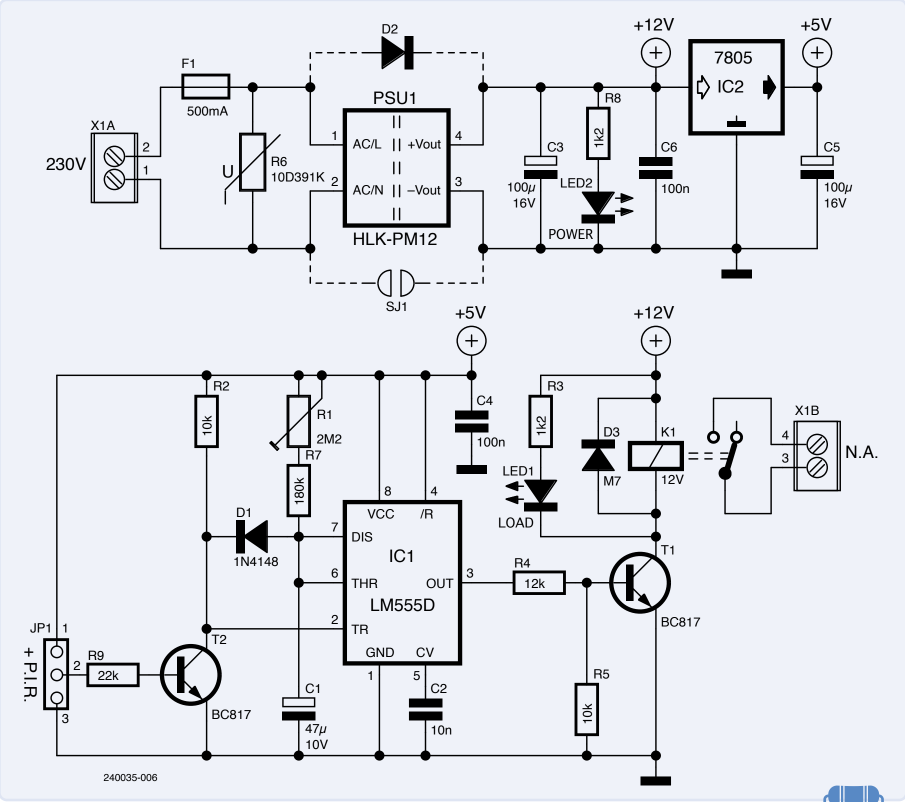


Figure 2: Schematic diagram of the PIR switch.

*Tmax [s] = 0.0011 * (R7+R1) * C1 = 0.0011*2380*47 = 123.046 s*

The first formula allows calculation of the minimum time when the trimmer is set to 0 Ω, while the second allows calculation of the maximum time, when the trimmer is set to its maximum value of 2.2 MΩ.

As can be seen from the calculations, a delay ranging from 9.3 s to about 2 min is achieved. If different timings are needed, it is possible to calculate the value of R1 — while keeping the values of R7 and C1 used in this project — with the following formula:

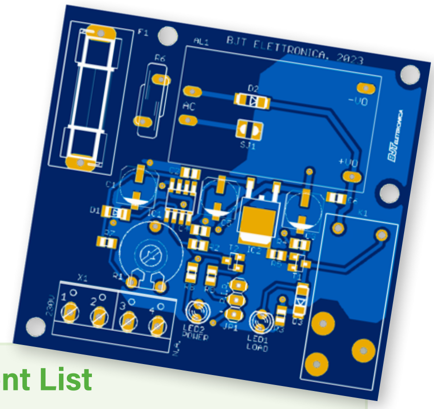
*R1 [kΩ] = (T [s] / (0.0011 * C1 [µF])) - R7 [kΩ]*

Power for the circuit is provided by the PSU1 PCB power supply module, but it is also possible to use an external 12-V source instead. In this case, PSU1 and varistor R6 may be omitted, soldering a protection diode (D2, M7 type) on the PCB as shown on the schematic diagram and bridging the jumper SJ1 with a bit of tin.

Regulator IC2 supplies the stabilized 5 V to both PIR sensor JP1 and IC2. Diode D3, applied with reversed polarity to Relay K1, is used to protect switch T1 from the negative voltage spikes generated by the inductive load of the solenoid of Relay K1 when its current is turned off. LED1, with R3 in series, indicates the operating status of the circuit.

Practical Realization and Testing

Let us now turn to the construction of the board, which is simple. The PCB is of the double-sided type with metallized holes; its layouts are available as PDF files in the downloadable materials.[1] As you can see from the completed prototype shown in Figure 1, most of the circuit components are SMD type, with some through-hole mounted elements. To this extent, take a look at the **Component List** frame, where the PCB is shown by its silkscreen side.



Component List

Resistors

R1 = 2.2 MΩ Trimmer (PT10)
R2, R5 = 10 kΩ (All 0805 SMD)
R3, R8 = 1.2 kΩ
R4 = 12 kΩ
R6 = 10D39 1 kΩ Varistor
R7 = 180 kΩ
R9 = 22 kΩ

Capacitors

C1 = 47 µF, electrolytic, 16 V (5X5)
C2 = 10 nF (0805)
C3, C5 = 100 µF, electrolytic, 16 V (6X5)
C4, C6 = 100 nF (0805)

Semiconductors

D1 = 1N4148 (MINIMELF)
D2, D3 = M7 Diode
T1, T2 = BC817
LED1 = 3 mm LED, Yellow
LED2 = 3 mm LED, Green
IC1 = LM555D
IC2 = 7805DT

Miscellaneous

PSU1 = HLK-PM12 power supply unit, PCB type
PIR sensor module = HC-SR505
K1 = 12-V Relay, 12 A, RT114012
F1 = 500 mA Fuse
X1 = Screw terminal block, 4 poles
SJ1 = Solderable jumper
1 × 5×20 mm Fuse holder, PCB type
1 × 500 mA Fuse, normal blow

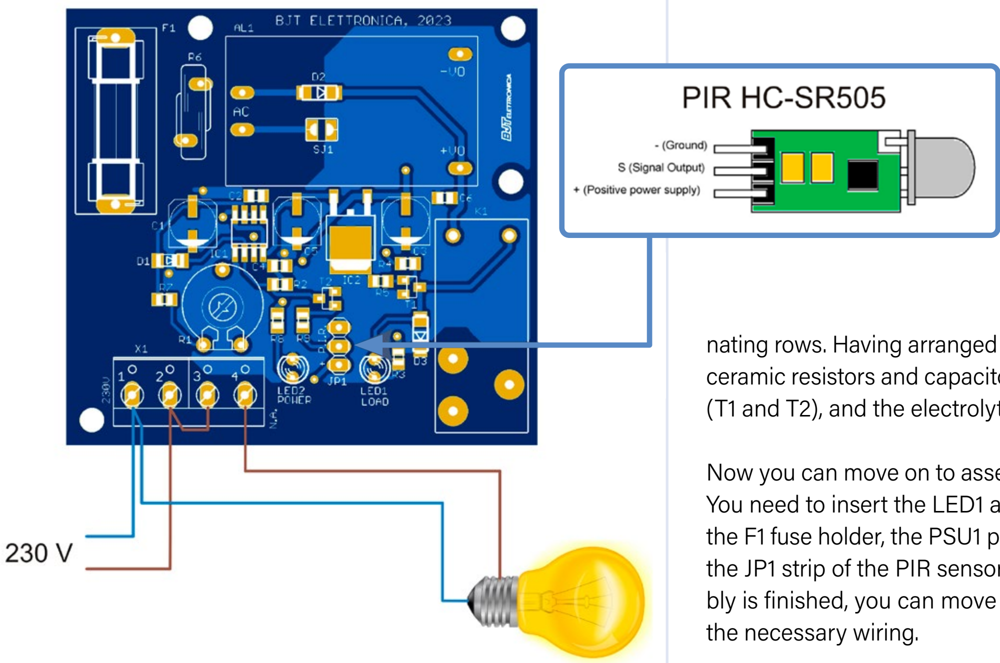


Figure 3: Wiring of the PIR sensor board.

Component assembly requires some specific tools, as well as some manual dexterity. The soldering iron must be an ultra-thin tip type for SMD and its power no more than 12 W (or better, a soldering station for SMD). The solder wire should be 0.5-mm thick, and the manual pick-and-place procedure of components should be carried out with the proper tools, possibly with the help of a magnifying glass.

On the component side of the PCB, you can assemble IC1 and IC2 first, verifying correct orientation and soldering one pin at a time, in alternating rows. Having arranged the active elements, you can solder the ceramic resistors and capacitors, then the diodes, the two transistors (T1 and T2), and the electrolytic capacitors (C1, C3 and C5).

Now you can move on to assembling the through-hole components. You need to insert the LED1 and LED2 diodes, the X1 terminal block, the F1 fuse holder, the PSU1 power supply, and finally the R1 trimmer, the JP1 strip of the PIR sensor, and the R6 varistor. Once the assembly is finished, you can move on to testing. In **Figure 3** you may see the necessary wiring.

Adjust trimmer R1 to its minimum value, and then power-on the board: the yellow LED2 should turn on. Waving your hand in front of the sensor, you will hear the click of the relay and LED1 will light up.

Willing to install the board in a junction box for electrical wiring, as shown in **Figure 4**, a 3D-printable holder visible in Figure 1 has been provided. On the Elektor webpage for this article [1], the relevant STL file can be downloaded. Two 2.9 × 9.5 mm self-tapping screws should be used to secure the holder with the board to the junction box. The box cover should be drilled at the position of the PIR sensor with a 10-mm drill bit (see Figure 4). When closing the box, the Fresnel lens of the PIR sensor is passed through the hole. If the terminals of the PIR sensor are short, they can be extended with stiff wire.

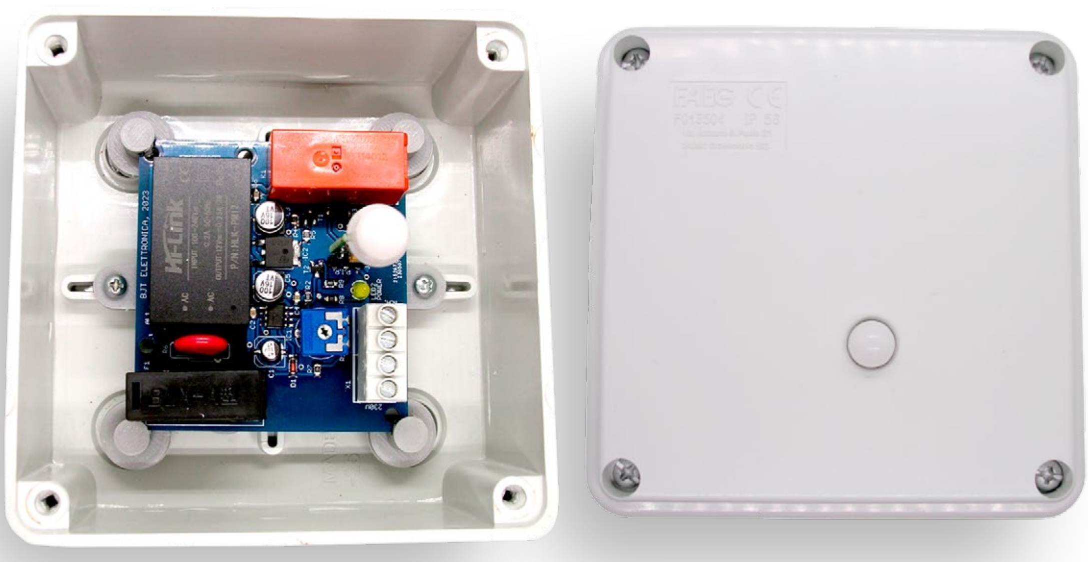


Figure 4: The ready to use PIR switch, in its final enclosure.

Alternative Supports

This project can also be realized on a solder-able breadboard by replacing the SMD components with through-hole equivalents and following the circuit diagram on Figure 2. A short video of the functional design is available on YouTube at [2]. Upon request, the bare printed circuit board for this project can be provided by the author.

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Questions or Comments?

Do you have technical questions or comments about his article? Email the author at lrgeletronic@hotmail.com or contact Elektor at editor@elektor.com.

About the Author

Passionate about electricity from an early age, Giuseppe La Rosa graduated with a degree in Electronics and Telecommunications in 2002 at I.T.I.S. "G. Ferraris" of Acireale, Sicily. Later, he began studying microcontroller systems, particularly PIC microcontrollers and the Arduino UNO open-source platform. Over the years, he has created various prototypes, many of which have been published in electronics magazines. Currently, he deals with security systems (video surveillance and anti-burglary alarms) and software for the management of points of sale.

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WEB LINKS

[1] Downloads for this article: https://elektormagazine.com/240035-01
[2] Short demo video on YouTube: https://youtu.be/aF8rz2BJr3U

Board for Simple Microcontroller Projects

By Rob Van Hest (The Netherlands)

Over the course of about five years, I posted projects using PIC12F microcontrollers and leftover PCBs. Using spare parts facilitates quick prototyping, but the results are not as professional as they could be. Because the basic circuitry around a microcontroller is always similar, why not create a board for it, usable for many of the applications? Here, I present a 37×55 mm PCB for a broad variety of simple microcontroller projects, with common components and jumpers.

Figure 1: The assembled test PCB.

In the past, I've posted a couple of projects on Elektor Labs that have two things in common:

- They use a member of the PIC12F microcontroller family.
- There is no dedicated PCB, as I repurposed a leftover PCB from another project, with numerous patches.

It's Time for a Change!

I've designed a small (37×55 mm) PCB (**Figure 1**) that can be used for a number of my projects (currently eight, but more to come). Common components for (almost) all projects include:

- A relay with a driver transistor.
- An LED to indicate an activated relay.
- An 8-pin socket for a PIC12Fxxx microcontroller.
- A basic power supply with a 78L05 (optional).
- Two jumpers, for functions like reset and setup.
- A 5-pin connector to program the PIC or connect peripheral devices.

The schematic (**Figure 2**) includes all possible components, but not all will (or can) be placed on the PCB at the same time.

IC2, D1, and C1...3 form a simple power supply. This way, the board can be powered with 8 to 12 V DC. D1 protects against reversed connection of the power supply. If a supply of 3 to 5 V must be used, for instance from batteries, C1 is not placed, and IC2 (between input and output) and D1 are replaced by jumpers.

X1 and X3 are ground, and X5 is +5 V. At X2 and X4, I/O pins are accessible. X2 can be connected to GP2 (R1 placed and jumper SJ3 bridged) or GP4 (R2 placed), X4 to GP0 (R4 placed and jumper SJ2 connected) or GP1 (R3 placed and jumper SJ1 connected). Jumper SJ4 is connected and RN1B is placed if GP1 needs a pull-up.

C4 and/or C5 are used for noise suppression if X2 and/or X4 are used as inputs. C6 has the same function for the Reset/GP3 input.

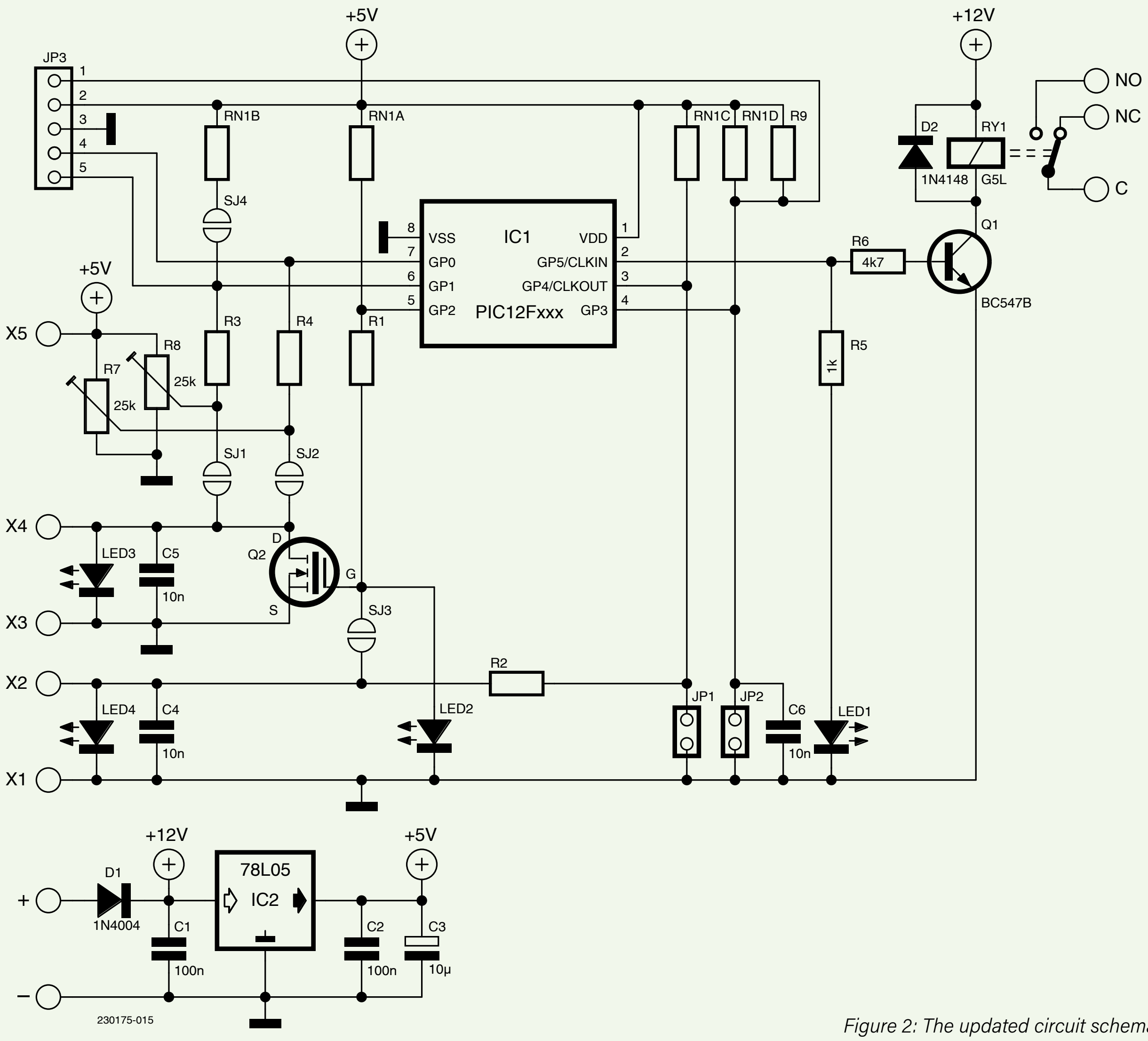

Figure 2: The updated circuit schematic.

Instead of C4, LED LD4 can be placed; in that case, GP2 must be set as an output, SJ3 bridged, and R1 is the serial resistor. Alternatively GP4 is set as output and R2 is the serial resistor.

Similarly, instead of C5, LED LD3 can be placed. In that case, GP0 must be set as an output, SJ2 bridged and R4 is the serial resistor. Alternatively, GP1 is set as an output, SJ1 bridged, and R3 is the serial resistor.

Q2 is used to provide an additional output with more current or a higher voltage (on X4, switch to ground) than the microcontroller can provide. If Q2 has to be used, GP2 is set as an output, R1 is 1 k for a BS170 MOSFET, 4k7 for a BC547 transistor or 10 k for a BC517 darlington. SJ1 and SJ2 must be open and LED2, LED3, and C5 not mounted. Instead of Q2, an additional LED, LED2, can be mounted with R1 as serial resistor. In that case, X4 is available for other purposes.

R7 and R8 are used in some projects to provide a setting to the microcontroller, e.g., a timing value. If R7 is mounted, R4 is also needed and SJ2 must be open. If R8 is mounted, R3 is also needed and SJ1 and SJ4 must be open (unbridged).

JP3 is the connector for a Microchip PICkit programmer. In some projects, a USB-to-serial adapter is connected to JP3. It can be skipped if on-board programming and the serial interface are not needed.

RN1A...RN1D are the four resistors contained in resistor array RN1. If RN1A...RN1C are not needed because GP1, GP2, and GP4 are not used as inputs, or if an internal pull-up is used, RN1D ican be replaced with a discrete resistor, R9.

For most of the projects a relay is needed. For this purpose, a driver stage with Q1 is present. The relay must be adapted to the power suppy voltage in use. If no relay is needed, R6, Q1, D2, and RY1 are not mounted.

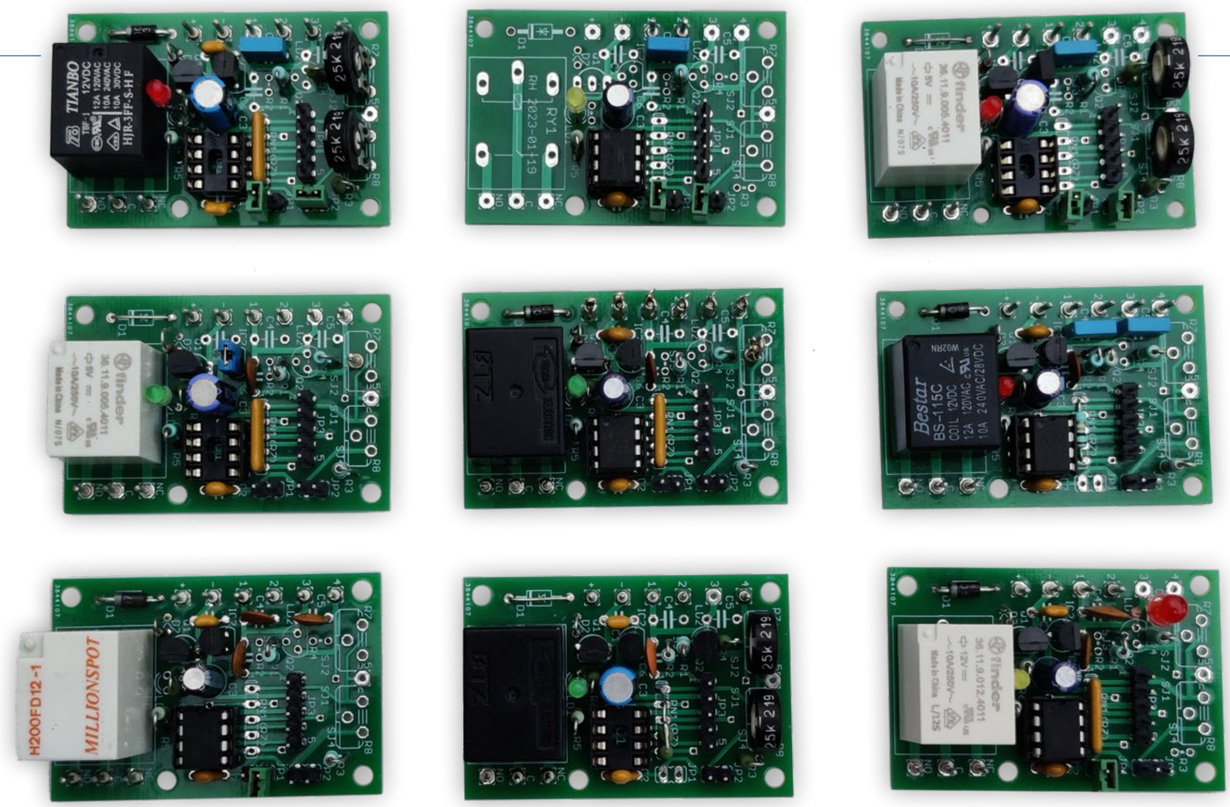

Figure 3: Some assembled boards (almost) ready for programming and testing.

For a comparison of board component configuration options, see the text box.

I am currently adapting the projects I already posted on the Elektor Labs platform to the new board. Here and there, the software requires slight modifications due to swapped microcontroller pins. Once a project is adapted and runs on the new board, I'll add the results to the relevant project page (including the parts list for the board).

Simple Test Program

To check some of the board's functions, I created a simple test program called *switch_uni.c*, which you'll find in zip file under "Software" on the Elektor Labs page for this project [4]. I wrote it for one of the simplest microcontrollers in the PIC12 family, the PIC12F509. Even this small chip can be programmed in C.

The program has two functions: If jumper JP1 is open, the relay is activated by connecting X3 to X4, and deactivated by connecting X1 to X2. If JP1 is connected, only X1–X2 is used to activate and deactivate the relay.

In **Figure 3**, you see some boards heading toward the testing stage.

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Questions or Comments?

If you have any technical questions regarding this article, contact the author at trainer99@ziggo.nl or the Elektor editorial team at editor@elektor.com.

Elektor Labs Projects Adapted to This Circuit

- **Burglar alarm**
  www.elektormagazine.com/labs/simple-burglar-alarm
- **Electronic lock (Original in Elektor [1])**
  www.elektormagazine.com/labs/simple-electronic-lock
- **Digital timer**
  www.elektormagazine.com/labs/simple-digital-timer
- **Morse code generator (Original in Elektor [2])**
  www.elektormagazine.com/labs/morse-code-generator
- **Exposure timer (Original in Elektor [3])**
  www.elektormagazine.com/labs/
  quasi-analog-exposure-timer-for-the-dark-room
- **Game assistant**
  www.elektormagazine.com/labs/little-game-assistant
- **Bathroom ventilation timer**
  www.elektormagazine.com/labs/
  timer-for-bathroom-ventilation
- **Universal IR remote switch**
  www.elektormagazine.com/labs/universal-ir-remote-switch

Board Component Configuration Options

Function	Noise suppressor	Connected	Open	Mounted	Pull-up resistor
X4 to GP0 in	C5	SJ2	SJ1	R4 = (1*)	not placed
X4 to GP1 in	C5	SJ1	SJ2	R3 = (1*)	RN1B + SJ4
X2 to GP2 in	C4	SJ3	R2	R1 = (1*)	RN1A
X2 to GP4 in	C4		SJ3	R2 = (1*)	RN1C
GP0 to X4 out		SJ2	SJ1	R4 = 0	
GP1 to X4 out		SJ1	SJ2	R3 = 0	
GP2 to X2 out		SJ3	R2	R1 = 0	
GP4 to X2 out			SJ3	R2 = 0	
GP2 to X4 out		Q2 (7*)	SJ3	R1 = 0	
GP0 to LED3 out		SJ2	SJ1	R4 = 1 kΩ	
GP1 to LED3 out		SJ1	SJ2	R3 = 1 kΩ	
GP2 to LED4 out		SJ3	R2	R1 = 1 kΩ	
GP4 to LED4 out			SJ3	R2 = 1 kΩ	
R7 to GP0 in			SJ2	R4 = 10 kΩ	
R8 to GP1 in			SJ1	R3 = 10 kΩ	
GP2 to LED2 out			SJ3	R1 = 1 kΩ	
GP2 to Q2 out			SJ3	R1 = (2*)	
JP3, P4 serout			R4		
JP3, P5 serin		SJ4	R3		RN1B
GP5 to relay				R6, Q1, D2, Ry1 (3*)	
GP5 to LD1				R5, LD1 (4*)	
Power = 8...12 V				C1, IC2, D1	
Power = 3...5V		D1 (6*)		(5*)	
Powered by JP3, P2				(5*)	

(1*): In principle 0, but higher values give some protection to the input.
(2*): Depending on Q2. BS170 (MOSFET): 1 k, BC547 (transistor): 4k7, BC517 (darlington): 10 k.
(3*): Relay coil voltage must be adapted to power supply.
(4*): Relay and LED output can be used together.
(5*): Replace IC2 with a jumper between input and output pins.
(6*): Replace D1 with a jumper.
(7*): Replace Q2 with a jumper between the drain and gate pins.

If no external pull-up for the inputs is required, RN1 is not mounted.
If only and external pull-up is needed for GP3/Reset, R9 is mounted.
Serial resistors for LEDs are specified as 1 kΩ, but lower values may be needed for higher brightness.

WEB LINKS

[1] R. van Hest, "Simple Elektronic Lock," Elektor Circuit Special 2023: https://elektormagazine.com/magazine/elektor-305/62010
[2] R. van Hest, "Morse Code Generator," Elektor Circuit Special 2023: https://elektormagazine.com/magazine/elektor-305/62011
[3] R. van Hest, "Quasi-Analog Exposure Timer for the Dark Room," Elektor Circuit Special 2022: https://elektormagazine.com/magazine/elektor-261/60669
[4] Elektor Labs page for this project: https://elektormagazine.com/labs/board-for-simple-microcontroller-project

A Tiny Music Box

A Modern Music Box with a Vintage Feel

By Bruno Clerc (France)

Hand-cranked music boxes are great, timeless objects. Let's make one, but with a twist, using an ATtiny85 microcontroller! This article details the necessary components, assembly process, and optional enhancements such as dual-speed mode or playful LEDs.

Figure 1: The completed Music Box.

Young children are full of surprises. This time, my grand-daughter Paolina has fallen in love with an empty salt box made of cardboard. But what to do with it? I suggest you turn it into a hand-cranked music box, but not a mechanical one; this one will be based on an ATtiny85. After last year's little piano with touch keys [1], this will be a second ATtiny-based toy. You can see the result in **Figure 1**.

List of Ingredients

For this recipe, you'll need:

- A salt box, or other cardboard tube
- An ATtiny85
- A BC550 transistor
- A 1-kΩ resistor
- A piezo buzzer
- A rotary encoder
- A 3.7-V lithium battery, in this case an 18650 cell that was recycled from another device
- Two 10 nF ceramic capacitors
- An electrolytic capacitor of approximately 22 µF to 100 µF, at least 10 V

Music Box Principle

The assembly is very simple. The diagram can be seen in **Figure 2**. The rotary encoder is connected to pin 2 of the ATtiny (`PB3`). A single pin is sufficient, as we don't need to worry about the direction of rotation, only about detecting it. The buzzer is driven by transistor Q1 via pin 6 (`PB1`) of the microcontroller. The encoder's built-in push-button is connected to pin 3 of the ATtiny (`PB4`).

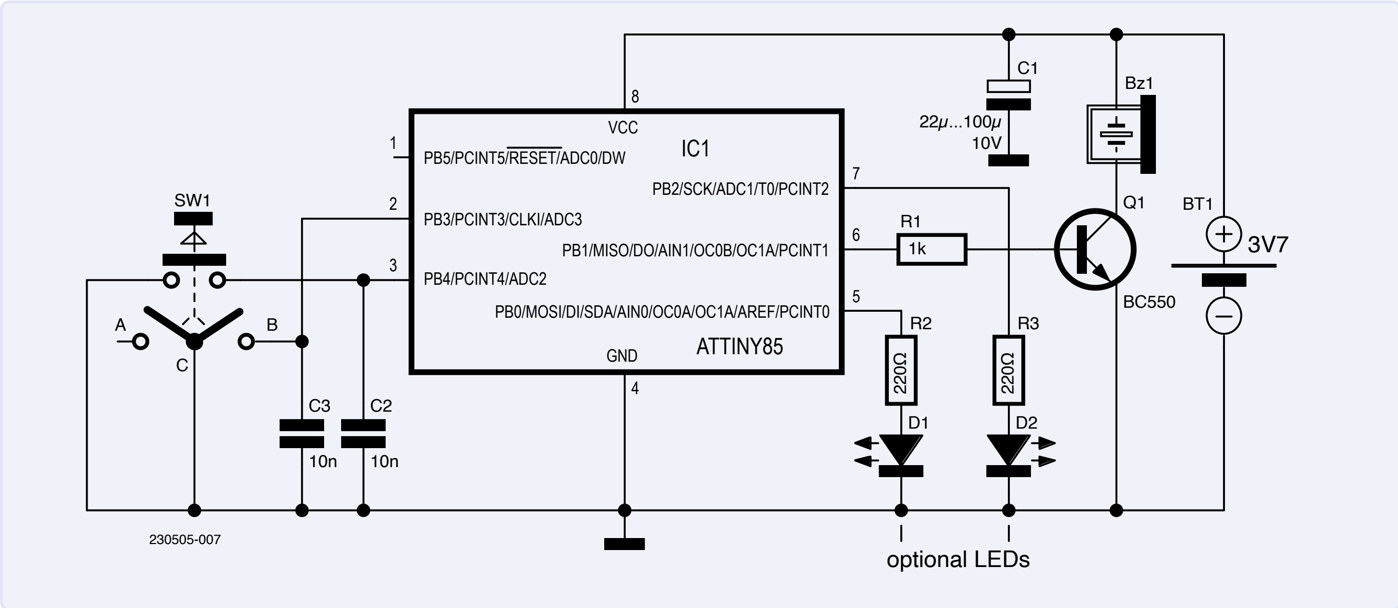


Figure 2: Circuit diagram.

Everything happens in the microcontroller code. When the crank is turned, the ATtiny detects this and plays the melody notes. In the current version, four melodies are available — it's up to you to add more! The push-button is used to change melody. The result can be seen in the video [2].

Enhancements

As an option, two LEDs can be connected to pins 5 and 7 of the ATtiny (`PB0` and `PB2`) to provide some blinking lights when the crank is turned. Notes can also be added. The current code uses only one octave. Use the `#define` directive to adjust the number of melodies and the behavior of optional LEDs. For more information on note generation, see the Elektor article [1] or the page on Elektor Labs [3] about the Tiny Piano.

In the second version of the program [4], I've added a dual speed mode. Depending on the speed at which the crank is turned, the music is played more or less quickly. In my current version, only two speeds are available: slow and fast. It's up to you if you want to add a mode where the speed is proportional to the crank speed! And you'll need to practice turning the crank regularly if you want to generate a halfway decent melody.

From a programming point of view, the speed of music reproduction is adjusted by acting on the duration of each note. To do this, when the interrupt routine (ISR, for Interrupt Service Routine) is entered, the current time is stored using the `millis()` function if the `cpt` counter variable is equal to zero. This variable is then incremented. When the counter reaches a pre-selected value, in this case 20, the `millis()` function is used again, and the elapsed time is calculated by subtracting the two stored values. If the result obtained is less than some empirically determined value (here, 500), this means that the crank is turning rapidly. We then divide the note duration by two. Otherwise, the note duration is not divided, and the melody is played at normal speed:

```
if (cpt >= 20) {
 fin = millis();
 cpt = 0;
 temps = fin - debut;
 if (temps <= 500) tempo = 2;
 else tempo = 1;
 temps = 0;
 _delay_ms(2);
}
```

Construction Notes

The cardboard salt box has been cut, leaving a 6 cm-long section. The diameter of the tube, around 7 cm, is perfect for housing an 18650 lithium cell. An old large-diameter potentiometer knob is used as the basis for the crank; another possibility would be to 3D print a crank. The buzzer is glued to the underside of a piece of metal grid, which in turn is fixed to the opening previously used for pouring salt, as can be seen in **Figure 3**. The small original mechanism of the salt box, with its pivoting plastic part, enables a kind of analog volume control, by more or less obstructing the hole.

Figure 3: Analog volume control.

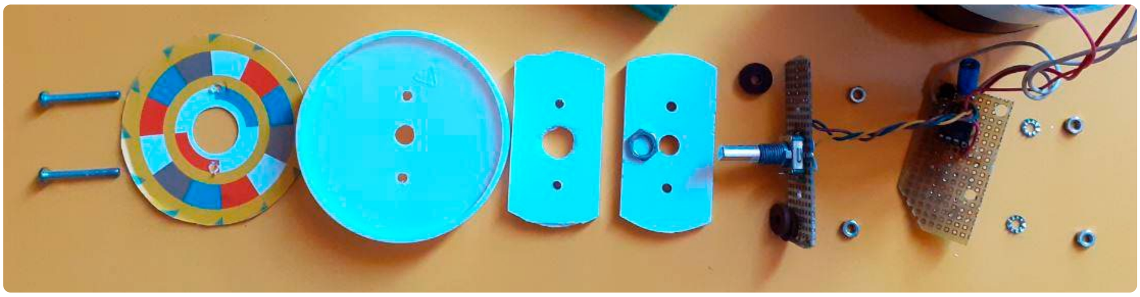


Figure 4: All the parts needed for the top of the Music Box.

An exploded view of the assembly at the top of the music box can be seen in **Figure 4**. The top of the music box is made up of the plastic part that was previously the bottom of the salt box, and vice versa.

When fitting the crank on the shaft of the encoder, be careful of the height between the lid and the crank arm, as there's a risk of trapping your fingers. Also, don't mount the potentiometer knob flush with the cover, but leave a few millimeters of clearance to allow the encoder's built-in push-button to be pressed.

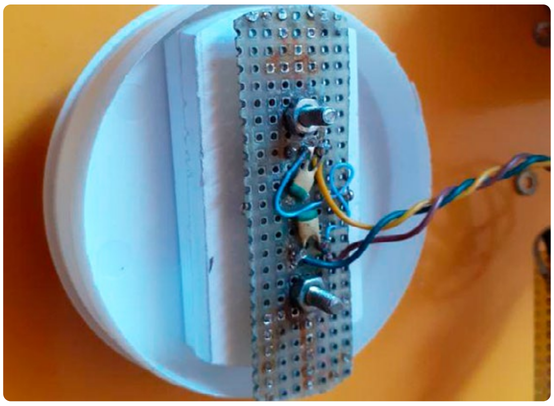


Figure 5: Assembly of the top part, without the crank.

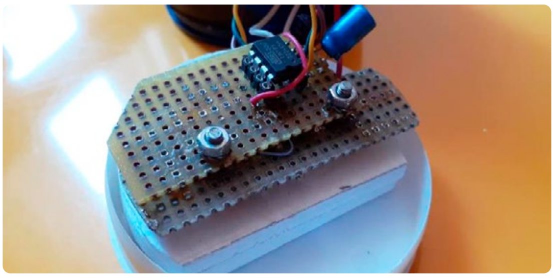


Figure 6: The microcontroller board is added.

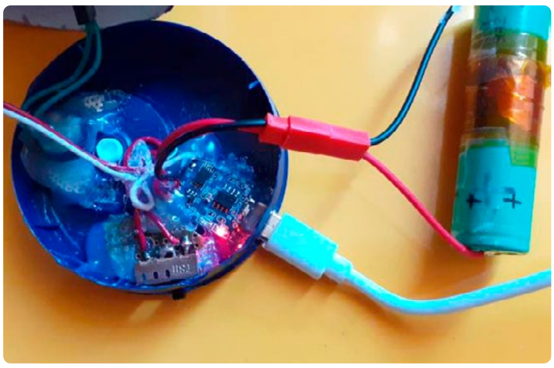


Figure 7: Battery, USB charger and on-off switch sit at the bottom.

I've used 5 mm-thick pieces of white plastic as spacers to add rigidity. Their thickness isn't critical, and they could be replaced by a single 10 mm thick plate or similar.

The crank base is wide enough to conceal the heads of the two machine screws used to fasten together the spacers, the top of the box lid and the two layers of perfboard. One of these serves as a mechanical support and houses the two 1 nF capacitors used to debounce the encoder contacts, while the second houses the ATtiny in a DIP8 package on its socket. See this assembly in **Figure 5** and **Figure 6**.

At the bottom of the music box, the buzzer is glued in front of the aperture and sheet metal grid mentioned above. A small battery charging module based on a TP4056 or equivalent and featuring a USB-C port is glued to the bottom, with the USB port accessible from the outside through an opening in the plastic. A slide switch completes the assembly (**Figure 7**). As for the battery, it sits on top of this stack, held in place with adhesive tape and pieces of foam.

More photos, the ATtiny program, and many other projects of my own can be found on Elektor Labs [4].

230505-01

About the Author

Bruno Clerc discovered electronics at the age of 12, thanks to his older brother. Curious about everything and thirsting for knowledge, he decided to study electronics in Bordeaux. He has explored a variety of fields, working in low-voltage tertiary systems, aeronautics and other sectors. Initially, Bruno focused on the maintenance of old hi-fi equipment, which he still does. But everything changed a few years ago, when his brother gave him an Arduino UNO. This small gesture marked the start of an incredible adventure for Bruno, who quickly became "Arduino47." Since then, Bruno has explored some of the infinite possibilities offered by microcontroller programming. Today, under the pseudonym "Arduino47," he creates playful assemblies, expressing his creativity mainly using recycled materials.

Questions or Comments?

Do you have technical questions or comments about this article? Feel free to contact the author at b.clerc31@laposte.net or Elektor at editor@elektor.com.

Related Products

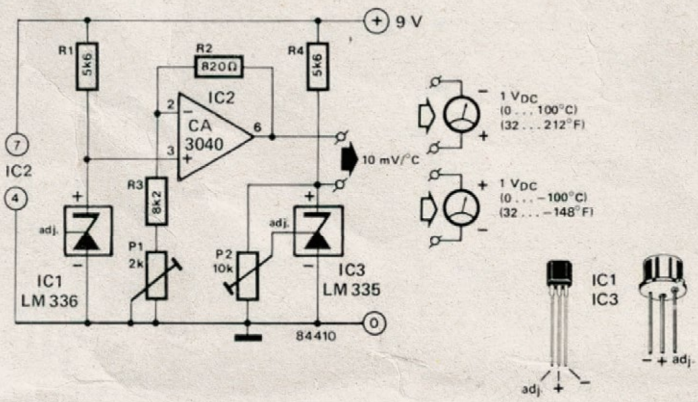
- **W. A. Smith, *Explore ATtiny Microcontrollers using C and Assembly Language* (Elektor 2021)**
  www.elektor.com/20007

WEB LINKS

[1] B. Clerc, "A T(eeny) Tiny Piano", Elektor Circuit Special 2023: https://www.elektormagazine.com/220683-01
[2] Video of the Music Box on YouTube: https://youtu.be/Xl19Wz2VOZs
[3] Project page of the Tiny Piano on Elektor Labs: https://www.elektormagazine.com/labs/piano-one-octave-with-attiny85
[4] Project page of the Music Box on Elektor Labs: https://www.elektormagazine.com/labs/attiny85-music-box

ELEKTOR SUMMER CIRCUITS 40 YEARS AGO

Temperature Measurement Using a Multimeter



The versatility of an "el-cheapo" multimeter can easily be improved by adding the circuit shown here. The temperature sensor used is an LM335, which has a linear temperature characteristic of 10 mV/K. During manufacture, this device is calibrated so that it gives an output of 2.73 V at 0°C (273°K). The LM336 in the diagram is a very stable 2.5 V Zener diode whose output is fed to IC2. The CA3040'S amplification can be varied between 1.08× and 1.1× by means of P1, so this potentiometer must be adjusted to give 2.73 V at the output of IC2 when IC1 is at 0°C. The circuit is now calibrated at freezing point.

Calibration at 100°C is carried out by comparison with an accurate thermometer. When the LM335 is at this temperature, P2 must be adjusted to give a reading of 1 V between the circuit's output terminals. The temperature reading's accuracy depends to a certain extent on the multimeter used. The greater the resolution, the better the accuracy.

The connections to the meter must, of course, be reversed to read temperatures below 0°C. This circuit can also be used to enable temperatures to be measured in degrees Fahrenheit. In this case, the freezing point adjustment is made at 32°F (2.73 V at the output of IC2). At 212°F, P2 is adjusted to give 0.9 V between the output terminals. One degree Fahrenheit is then represented by 5 mV, so a meter with 1 V full-scale deflection will read from 32 to 232°F. Current consumption is about 10 mA.

From: Elektor July & August 1984

240358-01

05 Plug and Make Kit

A New Way of Doing Arduino

By Clemens Valens (Elektor)

The Arduino Plug and Make Kit introduces daisy-chaining extension modules on an I^2C bus as a new way for rapid prototyping with Arduino. Targeted at beginners and makers alike, the new concept lets the user quickly create smart cloud-based connected IoT applications.

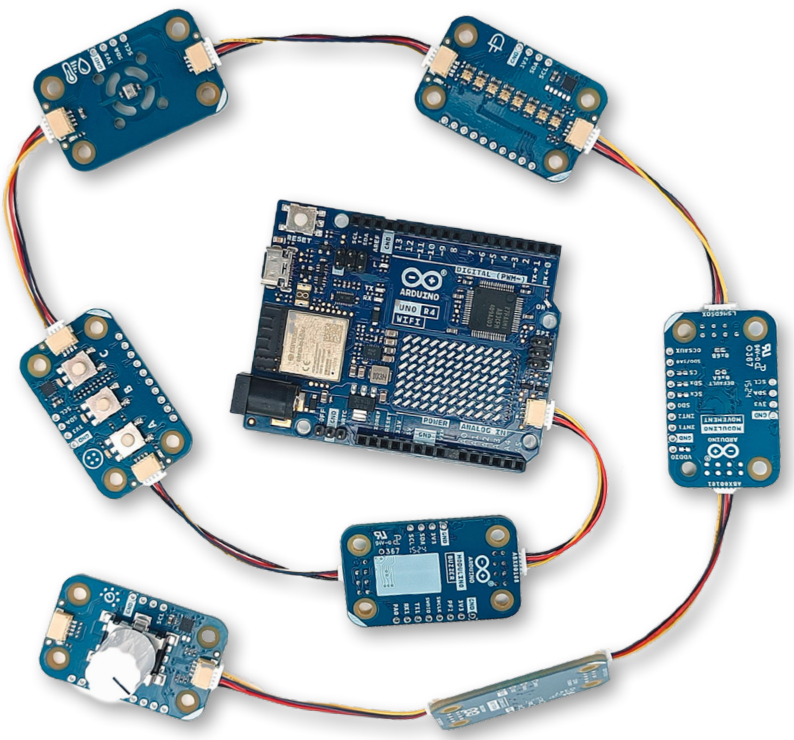


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Figure 1: Modulino are daisy-chained and communicate over I^2C.

The original Arduino concept emerged about fifteen years ago. It was based on a microcontroller board with extension boards ("Shields") that plugged in on top of the main board. A shield adds functionality in the shape of a sensor, a motor driver, a relay, or something else entirely, such as a display. Shields can be stacked on top of each other to create a compact, stacked micro-controller system. This made and still makes Arduino practical for rapidly prototyping applications. Over the years, hundreds — if not thousands — of shields have been created by Arduino users.

The Rise of I^2C

However, technology continues to evolve, and the I^2C bus, a somewhat dusty and forgotten communication bus when Arduino was born, has since become a de facto standard for connecting all sorts of components to microcontrollers. Today, a plethora of I^2C-based extension modules is available, allowing you to build applications quickly by connecting them to the microcontroller's I^2C port.

Only Fools Never Change Their Minds

The Arduino UNO has always had an I^2C port. Initially, it was a bit like a peripheral that happened to be available before getting its own pins on the extension header. In the latest iteration, the UNO R4 WiFi, the I^2C port also got its own connector (compatible with SparkFun's Qwiic specification). Now, with their new Plug and Make Kit, Arduino has fully embraced the I^2C method of rapid prototyping. Stacking shields is, of course, still possible as well.

Plug and Make Kit

The Plug and Make Kit is based on the Arduino UNO R4 WiFi and a family of extension modules called Modulino (note that plural doesn't take an "s"). A Modulino provides a function such as a sensor, a button, one or more LEDs, etc. At the time of writing, there are seven of them: Buttons, Buzzer, Distance, Knob, Movement, Pixels, and Thermo. Modulino do not plug into the shield extension connectors, but instead connect to the UNO R4 WiFi's Qwiic I^2C port. Modulino can be daisy-chained to create more complex applications (**Figure 1**).

Cloud Support and IoT

While similar systems have been around for several years, Arduino's Plug and Make Kit takes the concept a bit further. Firstly, given Arduino's educational origins, the Plug and Make Kit is supported by a cloud-based teaching environment. Not only is this intended to help the user get started quickly, but it's also the base camp for the user's IoT applications. Clearly, a lot of effort has gone into making the cloud as easy to use as possible.

Figure 2: Modulino can be stacked too.

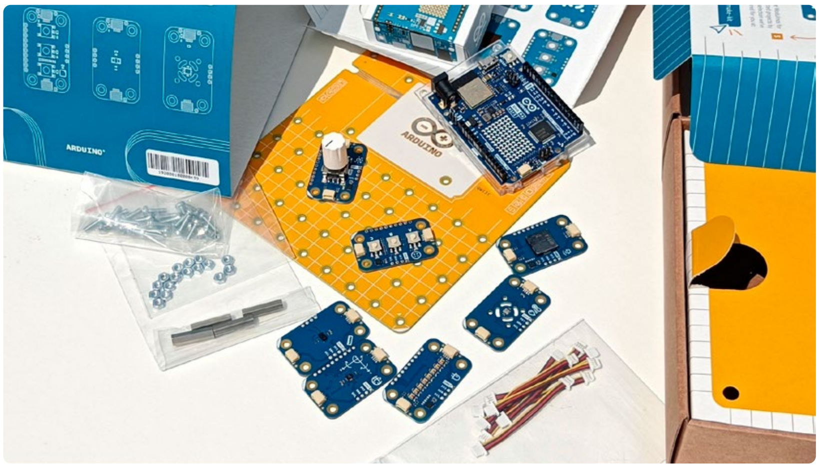

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Figure 3: The Plug and Make Kit unpacked. The USB-C cable is not visible.

Modulino Features

The second difference from other I²C-based prototyping systems is that Modulino nodes can also be used with other Arduino boards and third-party systems, since the tiny Qwiic connector can be bypassed, thanks to a footprint for a four-way 0.1" pitch connector. Therefore, if needed, you can simply connect a Modulino to another system by soldering wires (keeping in mind that Modulino require 3.3 V).

Wait a Minute, There Is Another MCU...

A third interesting difference is that Modulino featuring a device that does not have an I²C port, such as a pushbutton or a buzzer, are equipped with an STM32C011F4 Arm Cortex-M0 microcontroller to provide the I²C port. Some of this MCU's pins are accessible through a row of contacts on the side of the Modulino. Therefore, these Modulino can be used independently and even as the main controller in a Modulino chain.

Stack Anyway

Finally, Arduino did not drop the stacking concept altogether, because Modulino can be stacked too. This is possible as they all have the same footprint (or form factor, if you prefer) with the aforementioned solderable I²C port in the same position. This way, you can create a small, stacked device comprising, for example, Buttons, Buzzer, Movement, and Thermo Modulino (**Figure 2**). The application program can execute on the MCU of either Buttons or Buzzer (or on both).

Get Started

To get started with this new concept, Arduino put together a kit combining an Arduino UNO R4 WiFi, the seven Modulino mentioned above, and a Modulino Base. The base is a square 14 cm by 14 cm board on which you mount the UNO R4 WiFi and the Modulino needed for your application. Bolts, nuts, and four spacers are included. The kit also contains Qwiic interconnection cables and a USB-C cable (with a USB-C-to-A adapter, not shown in **Figure 3**).

Quality Shows in Details

Arduino tends to spend a lot of time and effort on design quality, looks, and details, and the Plug and Make Kit is no exception. You'll notice it as soon as you open the box. Everything looks great, fits perfectly, and nothing seems cheaply made. For example, the knob on the Knob Modulino is well-designed. The print on the boards is clean and readable. All the boards have orientation marks (a white corner). The cardboard support for the Modulino Base has holes and cutting marks, allowing you to use it for storing your assembled project inside the box it came in (**Figure 4**).

Figure 4: The kit's packaging allows the assembled system to be stored.

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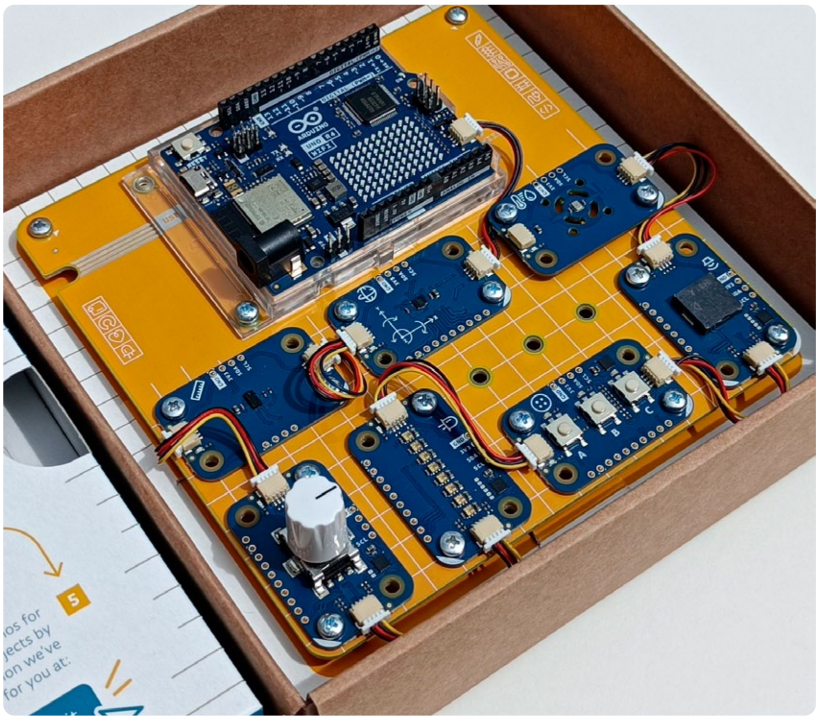


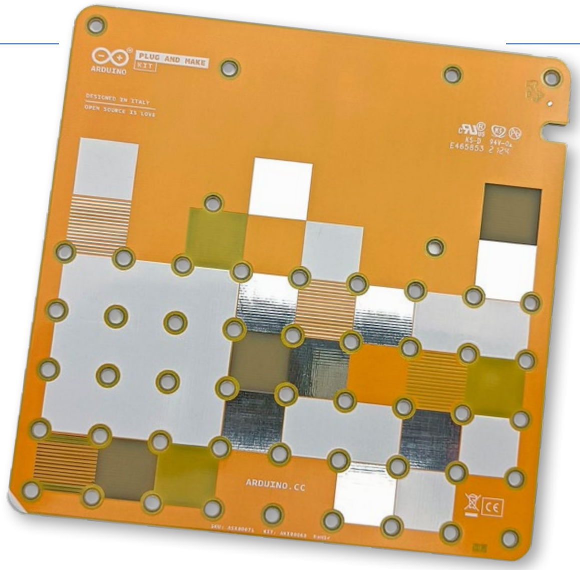


Figure 5: The backside of the Modulino Base is a true work of art.

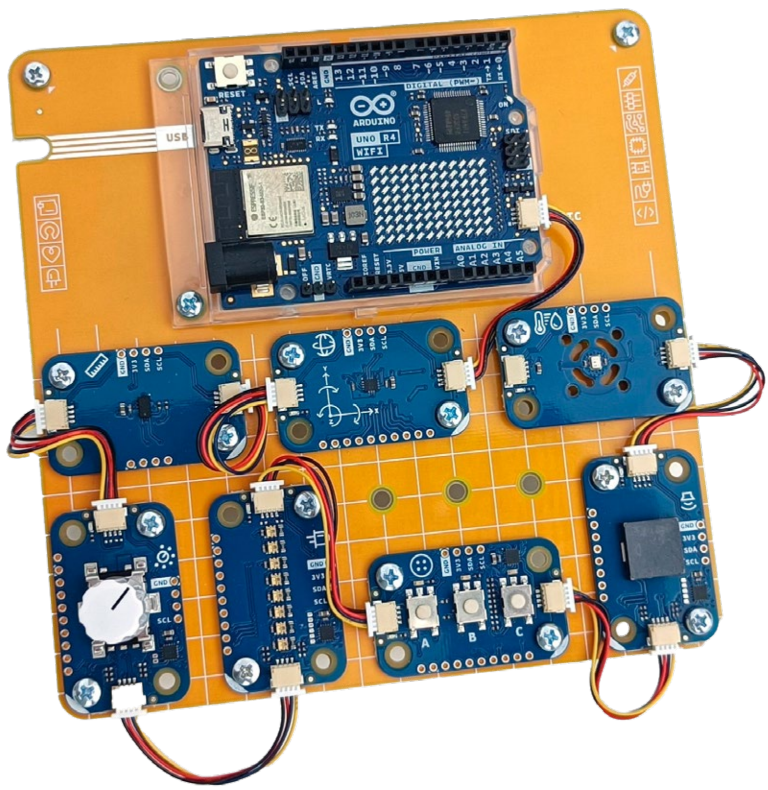
Kudos for PCB Artwork

Being an engineer with a strong interest in PCB design, I couldn't help but notice the artwork on the backside of the Modulino Base (**Figure 5**). It features a colorful geometric pattern built from squares. The color of a square is determined by the PCB (plated) copper layer, the solder mask, and two silkscreen layers instead of applying full-color silkscreen (which some pooling services have started to propose). Some colors are obtained by "mixing" layers. I like it a lot.

Modulino Base Space Is a Bit Tight

All Modulino nodes can be connected together, but none of the initial projects suggested requires using all of them at once. That's why the baseboard might seem a bit tight, if trying to mount all seven Modulino and connect them simultaneously (**Figure 6**). For the same reason, there aren't enough bolts (24) and nuts (20) to secure all 36 mounting holes (counting the four standoffs). This is not a problem, however, as two bolts per Modulino and UNO R4 WiFi are enough. Keep in mind that if you develop your own idea including all seven Modulino, you have to fix two of them to standoffs in a corner. Once you have bolted them to the base, connecting them together will become a bit of a challenge as space is tight. As mentioned before, it can be done, but you can also re-bolt only the Modulino you need when you change configuration.

Figure 6: Mounting all seven Modulino on the base is a tight fit.



Into the Cloud

I connected my all-singing, all-dancing Plug and Make Kit to my computer and then pointed my browser to the Arduino Plug and Make content platform. To access it requires logging in to your Arduino Cloud account. If you don't have one, you can create an account for free.

In the cloud, I simply clicked *Welcome* (**Figure 7**). This guided me through the process of setting up my kit, or, to be more precise, the UNO R4 WiFi board. I did not encounter any difficulties worth mentioning and went on to importing my first template. This too went smoothly, and I found myself with a Pixels Modulino showing a colorful rainbow. Turning the knob moved the rainbow up and down and also moved the striped pattern shown on the UNO R4 WiFi's LED matrix to the left or right. The only thing I had to type to get this far was the credentials for my Wi-Fi network.

Incidentally, it is interesting to note that I ended up with this demo, and not another, as there are six to choose from (**Figure 8**). You choose a demo by connecting two Modulino from a list of possible combinations. As I had all seven connected, I had selected every possible combination. The demo I got is (coincidentally?) the last one in the list.

Trying Out a Project

Now it was time to try out a demo project. There are seven of them, and I opted for Sonic Synth. For each demo, an estimate is given of the time it will take to complete a project. Sonic Synth takes about 35 minutes.

Sonic Synth uses only four Modulino (Buttons, Buzzer, Knob, and Pixels) but I tried with all seven strung together. To load the demo, you must import the corresponding template, detach from the current project, and associate the UNO R4 WiFi to the new template. This means re-entering your network credentials. After going through all the steps, nothing happened. No sound. After removing the superfluous Modulino and rebooting the kit, there was still no sound.

Fixed It

Trying to reload the template again was not possible as I had reached my free cloud plan limits. Deleting the first demo template solved this problem. A beginner user would not face the same issue, as they would not have used up their free Arduino Cloud allowance, like I had from tinkering with other projects. After going through the project steps once more, I finally got sound when pressing the pushbuttons. The tone's frequency and duration are controlled by sliders in the cloud dashboard. Even though listed at the start of the project, Knob and Pixels come into play only in the second step of the project.

User Experience

Fiddling around with this demo showed me two things:

1. With Plug and Make Kit, the objective is to build a clever connected gadget in a few minutes without having previous knowledge about IoT and programming. As much as Arduino has simplified the experience, if something goes wrong you still need to be comfortable diving into the cloud environment to find clues and ways to fix the problem.

2. Personally, I feel the Modulino Base is more in the way than it is helpful, when experimenting and playing around. In a classroom, it may help to protect the hardware, but reconfiguring the system is a bit tedious. Shorter bolts would help, but ideal would be some sort of clipping system. Also, the UNO R4 WiFi is positioned too far to the right for the short Qwiic cables. Therefore, I preferred working without the baseplate.

Classic Arduino

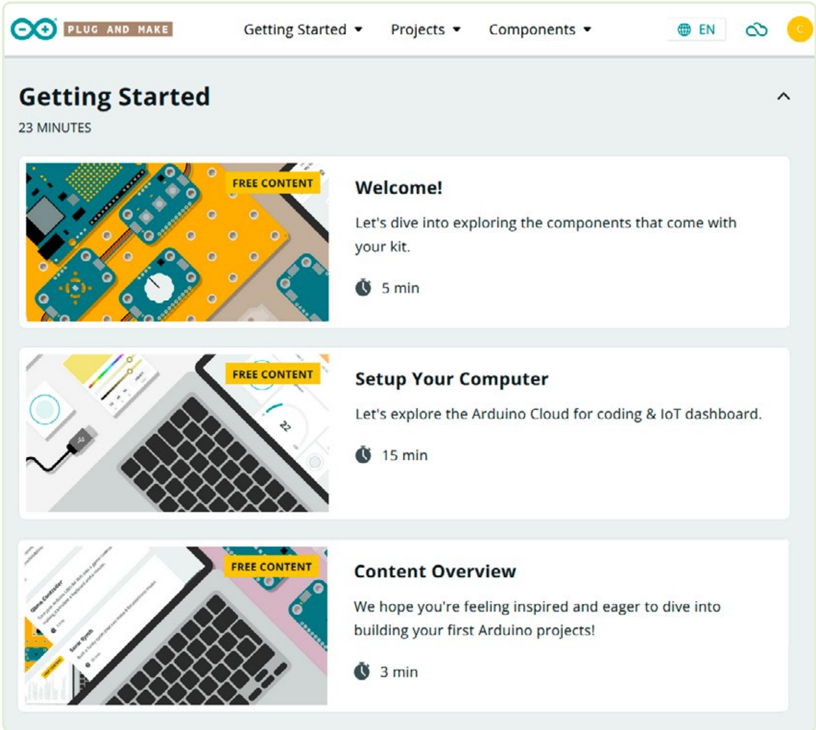
The Arduino Plug and Make Kit is targeted at cloud-connected IoT applications. Behind Arduino Cloud shines the Arduino programming environment. You can inspect and modify the source code of your applications by opening the *Sketch* tab. Doing this for the Sonic Synth project reveals a rather simple Arduino sketch that imports a Modulino library (**Figure 9**). This library is also available in the library manager of the classic offline Arduino IDE. Therefore, nothing obliges you to develop cloud-based IoT applications with the Plug and Make Kit. You are free to do with it whatever you want.

Competition

As said at the beginning of this article, the concept of Arduino's Plug and Make Kit is not new, but it adds a few interesting things. Probably the first I²C-based prototyping system is Grove from Seeed Studio (it is a bit more, actually). The main problem of the Grove system is the proprietary connector it uses with a 2 mm pitch. Grove has been copied by other manufacturers, who all replaced the Grove connector with their own non-standard or difficult-to-solder/cable/find connector. Examples are Adafruit's Stemma and Sparkfun's Qwiic, but there are more. Arduino has done the community a favor by equipping the Modulino nodes also with a normal (read: maker accessible) I²C connector besides a Qwiic connector.

BBC micro:bit

While playing around with the Plug and Make Kit, I couldn't help but think of the BBC micro:bit. This is a small microcontroller board designed to introduce children to programming and electronics. It targets an even younger audience (10+) than the Plug and Make Kit (14+). Both boards/systems have similar features: an Arm Cortex-M4 microcontroller, wireless capabilities, an LED matrix, several sensors connected to an I²C bus, a buzzer,



▲ *Figure 7: The Plug and Make Kit start page in Arduino Cloud.*

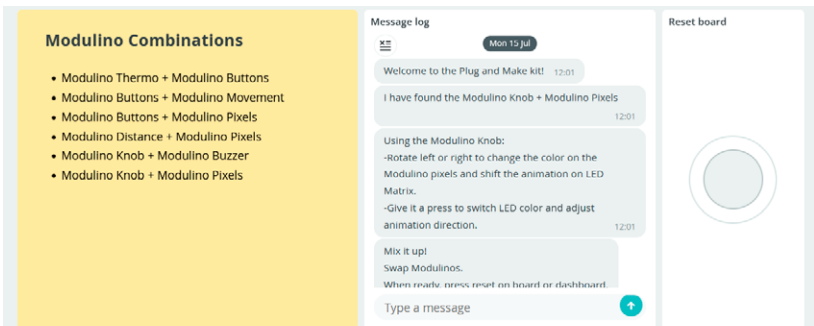
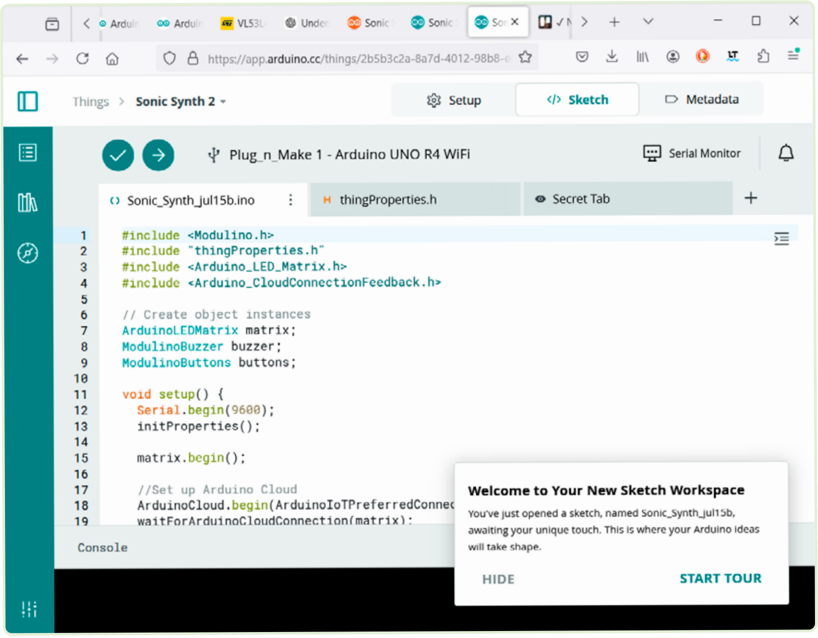


Figure 8: The Getting Started demo depends on which Modulino combination you chose. ▼



▲

Figure 9: A Modulino library is included at the beginning of the Sonic Synth sketch.

pushbuttons, and cloud-based programming and IoT applications. The main difference is that the BBC micro:bit integrates all this onto a single board, whereas the Plug and Make Kit consists of eight boards (the baseplate does not count as it has no electrical functionality, and only serves as a structure to organize projects). So, if you want something smaller, take a look at BBC micro:bit.

New Way of Using Arduino

The Arduino Plug and Make Kit introduces a new way of using Arduino. Instead of stacking shields on a baseboard, the extension modules (Modulino) are daisy-chained on an I²C bus. This bus is provided by the kit's Arduino UNO R4 WiFi. A Modulino Base is included for securing the various Modulino and the UNO R4 WiFi, creating a transportable system.

The Plug and Make Kit embodies everything we have come to expect from Arduino: aesthetics and high-quality hardware and software (even though it wasn't yet 100% up to speed at the time of writing because I'd received an advanced sample of the product before launch). Targeted at electronics newbies, hobbyists, and makers, the kit is supported by a good amount of online documentation, example projects, and tools in Arduino Cloud.

The new Modulino product line may have some potential, I believe, especially if support for the STM32 microcontroller used on some of them is provided (schematics, libraries, and bootloader). Arduino is planning to release more Modulino nodes in the future, but cannot confirm any further details at the moment. Competition is fierce in the I²C arena.

240384-01

Questions or Comments?

Do you have technical questions or comments about his article? Email the author at clemens.valens@elektor.com or contact Elektor at editor@elektor.com.

Related Products

- **Arduino Plug and Make Kit**
  www.elektor.com/20920
- **Clemens Valens, *Mastering Microcontrollers Helped by Arduino* (Elektor)**
  www.elektor.com/17967

WEB LINKS

[1] Arduino Plug and Make Kit: https://store.arduino.cc/products/plug-and-make-kit
[2] Arduino Plug and Make in the cloud (requires login to Arduino service): https://courses.arduino.cc/plugandmake

06 Owon XDM1141 Bench Multimeter

Excellent Value for the Money

By Harry Baggen (The Netherlands)

Every electronics engineer with a home lab has probably looked now and then for a bench multimeter to expand their instrumentation. But such a device must offer many functions and good specs, and it must also be affordable. In that case, the Owon XDM1141 could be a good choice!

Figure 1: The Owon XDM1141 comes with a power cable, a USB cable and test probes with alligator clips.

The XDM1141 (**Figure 1**) is the latest addition to a series of budget table multimeters from the Chinese manufacturer Owon. In recent years, this company has specialised in measuring equipment that offers good quality for a very affordable price.

A benchtop multimeter is often a better choice than a handheld multimeter in a home lab because the device can be placed stationary between the other devices, and it is also equipped with a mains power supply, so you can easily leave it on all day. The Owon XDM1141 is the successor to the well-known XDM1041, which is very popular among electronics enthusiasts. It has adopted many features from its predecessor, but is now equipped with a (in my opinion) better enclosure.

Hardware

The plastic case is neatly finished, and with dimensions of 20 × 8.8 × 15 cm, it is somewhat deeper than its predecessor, the XDM1041. This has the advantage that the meter stands more stable on the table, although you still have to hold the case before pressing a key to prevent it from slipping. The front plate and all keys are identical to those of the XDM1041, the options and settings have also remained the same. There is a support at the bottom with which the front of the meter can be raised slightly.

The back of the device contains a mains entrance (including a support for the mains fuse) and a USB connector for connection to a PC (**Figure 2**).

Figure 2: There is room for a fan on the side, but this is not necessary with this meter.

Figure 3: The display is bright and easy to read, even at an angle.

Using the Windows software that can be downloaded from Owon, you can operate and read the meter on your computer. In addition to the usual measuring functions, the meter also contains a data record function that makes it possible to save measured values manually or automatically. In auto mode, the user can set the interval time and the number of readings to be recorded (max. 1000).

Possibilities of the Owon XDM1141

The large and clear display with a resolution of 480 × 320 pixels shows the measured value and the functions of the soft keys located to the right of the display (**Figure 3**). The brightness is adjustable in four steps. The maximum measured value is 55,000 (4.5 digits). The measuring speed can be set to low, mid and high. At low, this is slightly more than 1 measurement/s and at high approximately 2.5 measurements/s. The autoranging function works well, but requires quite some time for the correct setting. It sometimes takes a few seconds before the correct range is found and the measured value appears. You also have to be patient with capacitance measurements, with larger electrolytic capacitors (100 µF and more) the measuring time quickly increases to more than 10 s.

The *Utility* button provides access to various settings, such as display brightness, type of temperature sensor, the maximum resistance for the continuity tester at which it must respond and the maximum forward voltage for the diode tester. There are also settings for a serial port, which refers to the USB connection. The buzzer produces a fairly loud beep, but can be turned off in the menu. It is a pity that all settings made are not saved when switching off, as far as I have noticed, only the display brightness is saved. Finally, there is also a time setting for the built-in clock with backup battery.

With the *Dual* button, you can display the frequency in addition to the AC voltage. Pressing this button again switches the voltage and frequency reading on the display. The *Math* button offers the option to show the maximum, minimum and average value on the display below the measured value. And there is a dB function where the load resistance can be set, and a relative measurement can be performed.

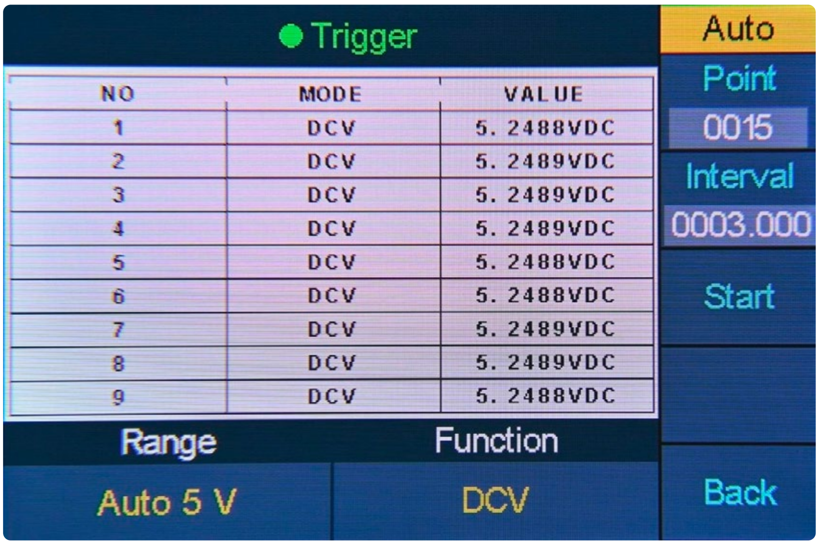


Figure 4: Up to 1000 readings can be stored in the internal memory.

XDM1141 Accuracy

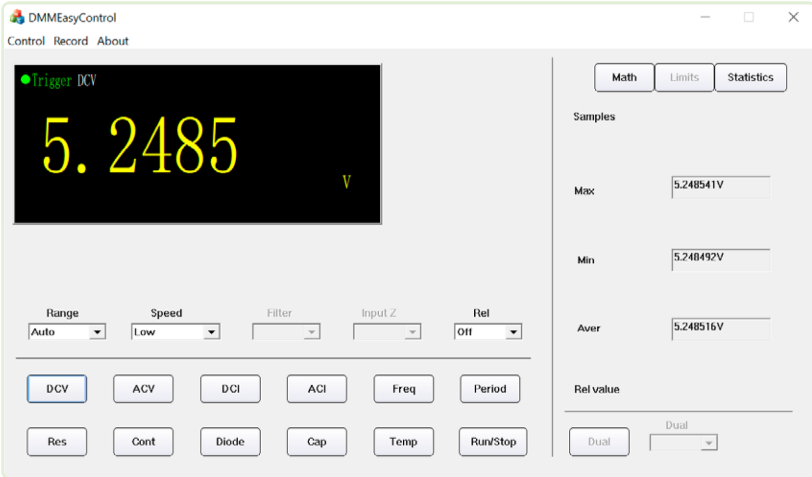
To test the accuracy of the Owon XDM1141, I compared it with two professional meters with a basic accuracy of respectively 0.02% and 0.03%. In all ranges, the accuracy is excellent, well within specifications. The measurement of V_{DC} in particular is excellent (better than the specified basic accuracy of 0.05%). During AC voltage measurements, I noticed that the meter did not show a value below 50 mV in the AC voltage range in the auto mode (**Figure 4**). If you manually switch to the mV_{AC} range, values below 50 mV will be displayed correctly above approximately 5 mV. When using the dual function (V_{AC} + Freq.) the frequency display starts to work above about 190 mV. The displayed value remains accurate up to approximately 4 kHz and then slowly decreases. That is much better than the value Owon specifies (up to 1 kHz).

For the frequency/period time measurement, a minimum input voltage of approximately 380 mV_{RMS} is required for a stable frequency value. At higher frequencies, the input sensitivity decreases, but with about 1 V_{RMS} the specified range of 60 MHz can still be achieved (measuring such frequencies is not easy with two banana jacks as inputs). DC- and AC-current measurements remain neatly within the specs of Owon (0.15% and 0.5%, respectively). Very nice is the high resolution of current measurements (0.01 µA). Resistance measurements are also accurate, usually within 0.1%. Capacitance measurements show somewhat larger deviations that are close to the manufacturer's specifications (2.5% and 5% for larger values), but many multimeters have difficulty with this (the only solution for this is a good LCR meter). The meter cannot measure values below approximately 600...700 pF; it simply remains at zero (for some reason it does work if you activate the *Rel* function). Temperature measurements are also possible. You can choose between a K-type thermocouple and a PT100 sensor. I have only briefly tried this function with a thermocouple, but in the absence of a suitable reference the accuracy has not been checked; at room temperature, the display showed at least a few degrees too little.

Software

The Windows program DMMEasyControl is available on the Owon website [1], with which the meter can be operated and read from a PC. To install the program, you must first download and install NI-VISA software from National Instruments, a package that is used by several measurement equipment manufacturers as the basis for their software.

DMMEasyControl is a fairly basic program that allows you to control all functions of the meter (**Figure 5**). There is a data record function to save a number of measured values in an Excel sheet via the PC, and the measurement series stored in the XDM1141 can also be transferred to an Excel sheet via *Device data export*. The XDM1141 can be further controlled using SCPI commands. Owon offers an extensive manual with an explanation of all commands for this purpose.



▲ *Figure 5: DMMEasyControl allows the meter to be controlled via the computer.*

Excellent Performance for the Price

The Owon XDM1141 has a lot to offer for the money you pay for it. In this price range, there are few multimeters that combine so many options and such good accuracy. Unfortunately, there are also some minor imperfections, such as not remembering settings made and the fact that small AC input voltages and capacities are not displayed. These are issues that can probably be resolved with a firmware update. Apart from these comments, the Owon XDM1141 is a great bench multimeter with an excellent price/performance ratio.

240268-01

WEB LINKS

[1] Product Webpage with Software-Download: https://tinyurl.com/4p37mr54

07 Attenuator with Automatic Range Adjustment

An Attenuator Design for Beginners

By Tam Hanna (Hungary)

Metrology is one of the most challenging tasks in the field of electronics — at least if you are not an audiophile. The following steps show a basic attenuator for a voltmeter, also intended to encourage further experiments.

In general, attenuators are creatures with two hearts. Heart number one is the generation of a signal that makes optimum use of the range of the analog-to-digital converter (but not exceeding this range in order to avoid damage to the hardware).

Heart number two is the protection of the evaluation circuit. Multimeter testers today expect the multimeters to have almost Herculean resistance (see [1] for example). In general, this can be achieved by tightly limiting the currents flowing into the component. We recommend taking a look at the circuit topology shown in **Figure 1**.

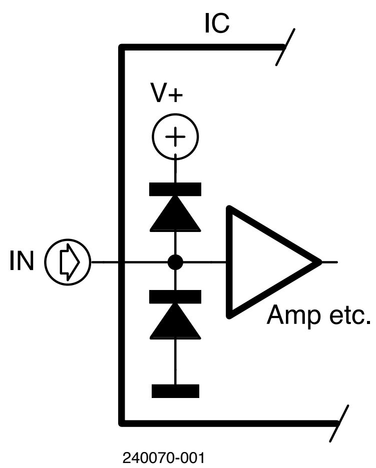


Figure 1: The two (parasitic) protection diodes are part of the current limitation.

In this case, the task of the attenuator would be to limit the current flowing into the protective diodes. For practical purposes, it should be noted at this point that the current flowing into any protective circuit naturally has a negative effect on the accuracy of the measuring system [2]. Some circuits based on FETs excel in this area. Service manuals for older multimeters are a good source of inspiration.

The Clacking of the Reed Relays

Renesas specifies two topologies in application note AN028. The author's practical experience shows that topology A, shown schematically in **Figure 2**, is widely used. For the dimensioning of attenuators of this type, please refer to [3].

The most important advantage of this topology is the constant resistance to the load. In his reference work, "Troubleshooting Analog Circuits," analog guru Robert Allen Pease described problems caused by mechanical range selector switches and the resulting current changes. The resistance of the reed relays, on the other hand, is less troublesome in practice than one might at first glance assume. The main reason for this is the very low current flowing through them, especially when a buffer is used between the attenuator and the ADC. Finally, unlike in Pease's days, it is now possible to compensate for these errors in the software easily.

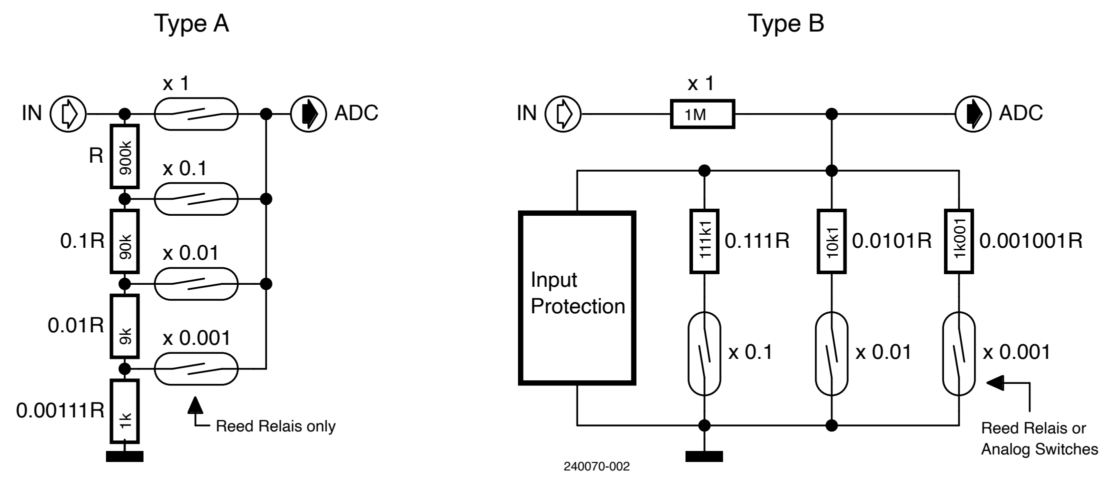


Figure 2: Common topology A requires the use of high-quality analog switches. (Source: Renesas)

A Real-Life Example

A practical example implementation for the ESP32 is shown in **Figure 3**. Due to the comparatively low requirements, the author used two relatively inexpensive relays from Songle Relay. Above all, it is important to observe the principle of break-before-make. However, the opening and closing of the connections in the relays takes some time. It is important to wait for one contact to open completely before activating the other.

Another advantage would be the use of a buffer capacitor before the input of the ADC. Ideally, an amplifier would then be used to separate the impedances more cleanly. This is because some ADCs cause considerable input current peaks.

Although the attenuator shown here offers plenty of scope for improvement, it demonstrates the basic procedures for circuit design. The author hopes you will enjoy your own experiments.

Translated by Jörg Starkmuth — 240070-01

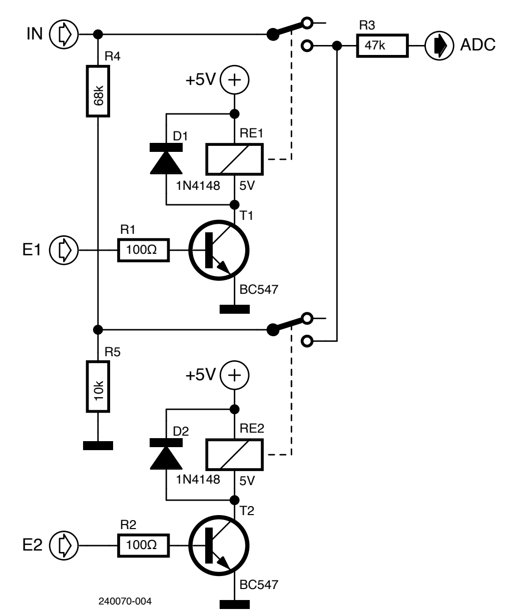


Figure 3: A primitive but functioning attenuator.

Questions or Comments?

Do you have questions or comments about this article? Email the author at tamhan@tamoggemon.com, or contact Elektor at editor@elektor.com.

A Jerky, but Steady Ride!

In the field of metrology technology, a constant, relatively high error is preferable to a variable, but lower error. The reason for this is the ability to calibrate the system using software.

WEB LINKS

[1] DMM Information and Reviews: https://lygte-info.dk/info/indexDMMReviews%20UK.html
[2] The Secret Life of Diodes: https://holzleitner.com/el/picoampere/index-en.html
[3] The Design of Meter (and Oscilloscope) Attenuators: https://sound-au.com/articles/meter-atten.htm

ESP32-C2-Based Coin Cell Switch

Hardware Design and Optimization

By Zhang Wei (Espressif)

With the rapid development of the smart home market, there is an increasing demand for low-power yet high-efficiency wireless switches. This article presents a cutting-edge solution, an ESP32-C2-based Coin Cell Switch, aiming to tackle challenges like delayed response and the need for additional gateways, which are commonly faced by other wireless switch solutions based on technologies like Bluetooth LE and Zigbee.

Figure 1: The ESP32-C2-based Coin Cell Switch in its enclosure.

The ESP32-C2 is a low-cost, Wi-Fi 4 and Bluetooth 5 (LE) chip equipped with a single-core 32-bit RISC-V processor, 272 KB of SRAM and 576 KB of ROM. It has been designed to target simple, high-volume, and low-data-rate IoT applications.

The ESP32-C2-based coin cell switch (**Figure 1**) adopts innovative hardware design, aiming for simplicity and long-lasting battery life. It is suitable for control applications employing fast wireless communications (e.g., ESP-NOW). The switch boasts several advantages over other wireless switch alternatives:

- Powered by coin cell batteries, the device's size is minimized, supporting versatile product form factors like adhesive switches, multi-key switches, touch switches, and rotary switches.
- The ESP32-C2 remains in a complete power-off state when not in use, enabling a single CR2032 coin cell battery to last up to five years (assuming 10 presses per day).

Throughout this article, we delve into the comprehensive implementation details of the ESP coin cell switch, showcasing its prowess in addressing the demands of modern smart home technology.

Coin cell batteries, such as the commonly used CR2032, serve as a prevalent power source for IoT devices. Known for their compact design and lightweight, coin cell batteries are well-suited for small electronic devices, without adding bulk or weight. Their relatively high-energy density allows them to store more energy in a smaller volume, resulting in an extended usage lifespan. Additionally, coin cell batteries exhibit a lower self-discharge rate — meaning, they retain their charge even during prolonged periods of non-use. Providing a relatively stable voltage output during discharge, coin cell batteries play a vital role in ensuring the normal operation of devices. However, due to their design, they typically offer lower current output, making them unsuitable for high-power devices.

For example, the power consumption characteristics of Wi-Fi devices pose two main challenges when applied in low-power domains. On one hand, the significant reception current makes it difficult for the chip to sustain continuous operation in the receiving state. On the other hand, the instantaneous high current during packet transmission can impact the voltage stability of the chip's power supply, potentially leading to chip resets. In this article, we present a design of a coin cell switch based on the ESP32-C2 that tackles these challenges by employing a well-balanced combination of software and hardware, resulting in impressive battery life.

The article is divided into two main sections. Firstly, we study the hardware design, offering guidance on device selection. Secondly, we evaluate various technics to reduce power consumption and boot time, and we will compare the performance with measurement results.

Circuit Design

The overall goal of the circuit design is to achieve a robust and cost-effective solution that meets the power requirements of the ESP32-C2, while also optimizing the device's performance and battery life. Collaborating with experienced hardware engineers and utilizing appropriate components and techniques can lead to a successful circuit design that meets the specific needs of the coin cell battery-powered Wi-Fi switch. It is essential to consider both production costs and the required performance when designing the circuit. **Figure 2** shows a simplified view of the circuit design of the coin cell switch.

From Figure 2, it can be seen that the buttons are not connected to GPIOs in the usual way. Instead, they are switches that control the power supply of the coin cell switch (i.e., when the button is pressed, the device is powered on, and tasks are executed according to the software). When the button is released, the power is totally cut off. In this hardware design, up to five buttons can be supported. By reading the voltage level on the IO port, software can identify which button is being pressed.

Boost Converter

The ESP32-C2 requires a working voltage of 3.3 V, which is higher than the voltage provided by the coin cell battery. Therefore, a boost circuit needs to be designed to step up the voltage. The stability of the power supply directly impacts the packet transmission performance and overall stability of the device. A well-designed voltage regulator circuit can enhance the RF performance and battery life of the device.

The voltage boost circuit should be carefully designed to ensure efficient power conversion with minimal power loss. Additionally, it should provide a stable and reliable power supply to the ESP32-C2, enabling it to perform optimally during both active and sleep modes. Moreover, the circuit design should take into account factors such as current consumption, heat dissipation, and efficiency to strike the right balance between performance and power consumption.

The coin cell battery can be considered as a voltage source with rapidly increasing internal resistance as it discharges. Initially, its internal resistance is approximately 10 Ω, but it can increase to as high as hundreds of ohms as it nears the end of its discharge cycle. The ESP32-C2, as the output device, requires a power source capable of providing a current output of 500 mA or higher. The power supply ripple can significantly impact the RF (radio frequency) TX performance.

When measuring power supply ripple, it is crucial to test it under normal packet transmission conditions. The power supply ripple can vary depending on the power mode changes. Higher packet transmission power can lead to larger ripple effects. To mitigate the impact of the high internal resistance of the coin cell battery, the boost converter's minimum input voltage requirement should be as low as possible, while maintaining high efficiency.

For this design, the SGM6603 was selected as the boost chip, as shown in **Figure 3**. It offers a minimum input voltage as low as 0.9 V and a maximum switch current of 1.1 A, making it suitable for efficiently boosting the voltage from the coin cell battery to meet the ESP32-C2's power requirements.

Capacitor Selection

There are two sets of capacitors related to the power supply: the capacitors before and after the boost converter. The capacitors after the boost converter are typically connected in parallel with the Wi-Fi module's power input, providing the function of stabilizing the output voltage and reducing the voltage drop during packet transmission. Larger capacitors result in a smoother voltage change for the chip's power supply. On the other hand, the voltage across these capacitors follows the chip's power supply voltage. When the Wi-Fi chip is powered, the capacitors are charged, and when the chip is powered off, this set of capacitors is completely discharged. Therefore, using excessively large capacitors can lead to reduced system efficiency. It is essential to strike a balance between capacitor size and system efficiency.

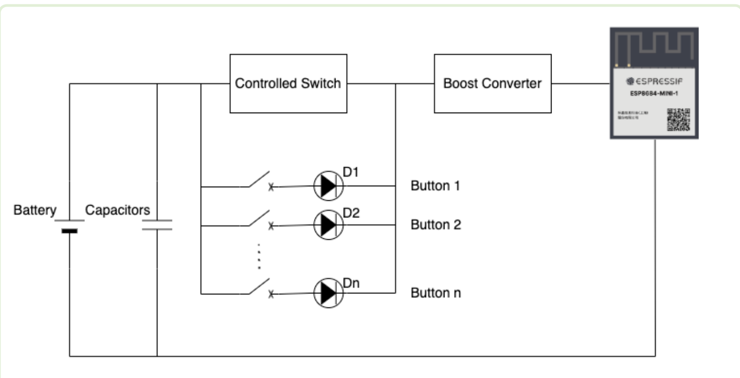


Figure 2: Simplified view of the circuit design of the coin cell switch.

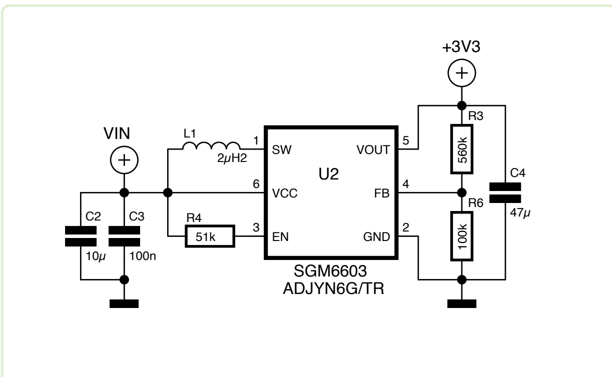


Figure 3: The boost chip SGM6603 offers a minimum input voltage of 0.9 V and a maximum switch current of 1.1 A.

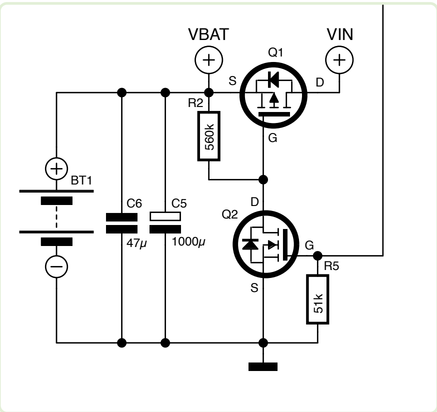


Figure 4: The design incorporates a controlled power switch consisting of two MOSFETs.

The capacitors before the boost converter are connected in parallel with the battery. Their main function is to reduce the instantaneous current from the battery. During periods of high current, the capacitors act as the primary power source, while during periods of low current, the battery becomes the main power source and charges the capacitors. When the boost converter is not operational, the only power consumption in the circuit comes from the capacitor's leakage current. Considering volume and leakage current, solid-state electrolytic capacitors and aluminum electrolytic capacitors are ideal choices. For instance, a 1000-µF solid-state electrolytic capacitor typically has a leakage current of around 1 µA at 3 V voltage.

Controlled Power Switch Design

In applications where the device's operational lifetime is measured in years, standby current (leakage current) during non-working states becomes a critical factor affecting the device's overall lifespan. To address this concern, the present design incorporates a controlled power switch consisting of two MOSFETs (**Figure 4**). This switch allows the chip to actively close or open the connection with the battery, effectively disconnecting the power supply module and RF module from the battery when the device is not in use. The two MOSFETs are electronic switches capable of handling high currents and voltages.

The complete circuit composition is shown in **Figure 5**. When the device needs to be turned on, a button is pressed, providing a conductive pathway for the chip to be powered on. At the same time, the chip utilizes ADC voltage sampling to identify which button has been pressed.

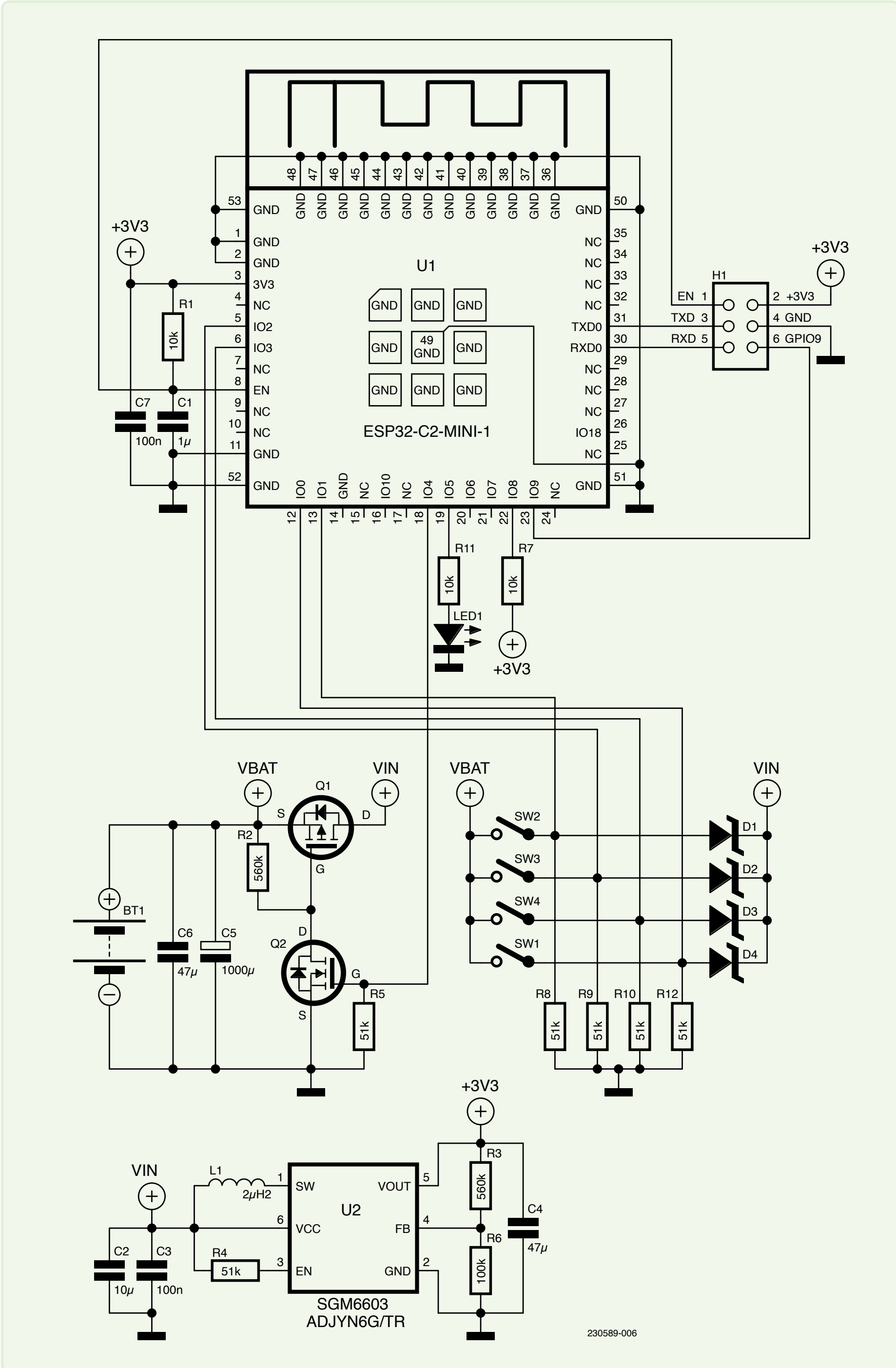


Figure 5: Schematic diagram of the coin cell switch.

The utilization of this controlled power switch ensures efficient power management, reducing unnecessary energy consumption during idle periods and extending the overall battery life of the device. By completely disconnecting the power supply and RF modules when not in use, the device's standby current is minimized, optimizing its longevity and usability in various consumer electronic applications. In addition to the above-mentioned components, the circuit also includes the ESP32-C2 minimum system and an LED indicator light.

Software Optimization

The initialization process of a Wi-Fi chip involves several stages, from power-up to the completion of signal transmission. We conducted a thorough analysis of each stage and its respective duration. By default, the chip startup includes the boot, Wi-Fi initialization, and Wi-Fi start processes. Among these, the boot initialization takes the longest time, and Wi-Fi start results in the highest short-term power consumption. To reduce the bootup time and current consumption, the following optimizations can be performed:

Table 1: Energy consumption before initialization process optimization.

Action	Duration (ms)	Average power (mW)	Energy consumption (mJ)
Boot	490.7	50.8	24.9
Wi-Fi Init	162.5	59.6	9.68
Wi-Fi Start	51.3	263.0	13.5

Table 2: Energy consumption after initialization process optimization.

Action	Duration (ms)	Average power (mW)	Energy consumption (mJ)
Boot	34.1	42.6	1.45
Wi-Fi Init	3.44	68.1	0.23
Wi-Fi Start	7.93	104.5	0.83

1. Disabling Logging: We turned off logging outputs to minimize the execution time and power consumption during the boot and normal running process. Related configurations are:

- `CONFIG_BOOT_ROM_LOG_ALWAYS_OFF=y`
- `CONFIG_BOOTLOADER_LOG_LEVEL_NONE=y`
- `CONFIG_LOG_DEFAULT_LEVEL_NONE=y`

2. Enable compilation optimization. Related configurations are:

- `CONFIG_BOOTLOADER_COMPILER_OPTIMIZATION_PERF=y`
- `CONFIG_COMPILER_OPTIMIZATION_PERF=y`

3. Flash Verification: We disabled flash verification, as it was not essential for our operation. Related configuration is:

- `CONFIG_BOOTLOADER_SKIP_VALIDATE_ALWAYS=y`

4. Wi-Fi Calibration Information: To avoid frequent Wi-Fi calibration, we stored the Wi-Fi calibration information in NVS (non-volatile storage) and set calibration to none. Related configuration is:

- `CONFIG_ESP_PHY_RF_CAL_NONE=y`

5. Since ESP32-C2 supports QIO flash mode, we can enable it. This can almost double the speed at which code is loaded or executed from flash compared to the default DIO mode. It would have more effect to boot time if the firmware size is bigger. Related configuration is:

- `CONFIG_ESPTOOLPY_FLASHMODE_QIO=y`

Take a look at **Table 1** and **Table 2**. By implementing these optimizations in the *ESP-NOW coin_cell_demo* application [1], we managed to reduce the energy consumption during the initialization process from 48.1 mJ to 2.51 mJ. Additionally, the initialization time decreased from 704.5 ms to 45.5 ms.

In the coin cell switch demo, in additional to the configuration optimizations, we also put the application into light sleep for 30 ms before each transmission. As mentioned in the capacitor selection, there are capacitors connected in parallel to the battery. During sleep, the battery becomes the main power source and charges the capacitors. A 30 ms charge can almost fully charge the capacitors so that they can provide enough power for the subsequent transmission. This technic further improves the robustness of the software operation.

Final Considerations

The ESP32-C2 coin cell switch provides a convenient and versatile way to control smart devices. Leveraging the ESP32-C2's flexible power management combined with a creative hardware design, this solution realizes a coin cell switch based on the Wi-Fi protocol, allowing easy communication with other devices equipped with Espressif chips. As part of our future plans, we aim to integrate this technology into Matter (formerly known as Project CHIP) standards, enabling flexible multi-device control and collaboration with conventional power-supplied devices.

The coin cell switch solution enhances convenience and efficiency in the realm of smart homes and the Internet of Things. With its optimized design and efficient power management, it ensures long-lasting battery life, providing users with a reliable and enduring smart device control experience.

240375-01

About the Author

Zhang Wei is currently a senior staff application engineer in Espressif Systems. A seasoned software engineer with over two decades of experience in embedded systems, wireless networking, and IoT development, he enjoys finding simple and clean solutions for solving problems. Holding a bachelor's degree in electrical and computer engineering and a master's degree in knowledge engineering from the National University of Singapore, he has enriched his expertise through roles at tech companies like STMicroelectronics, Greenwave Systems, and dormakaba digital. Outside of work, Zhang Wei likes football and travel.

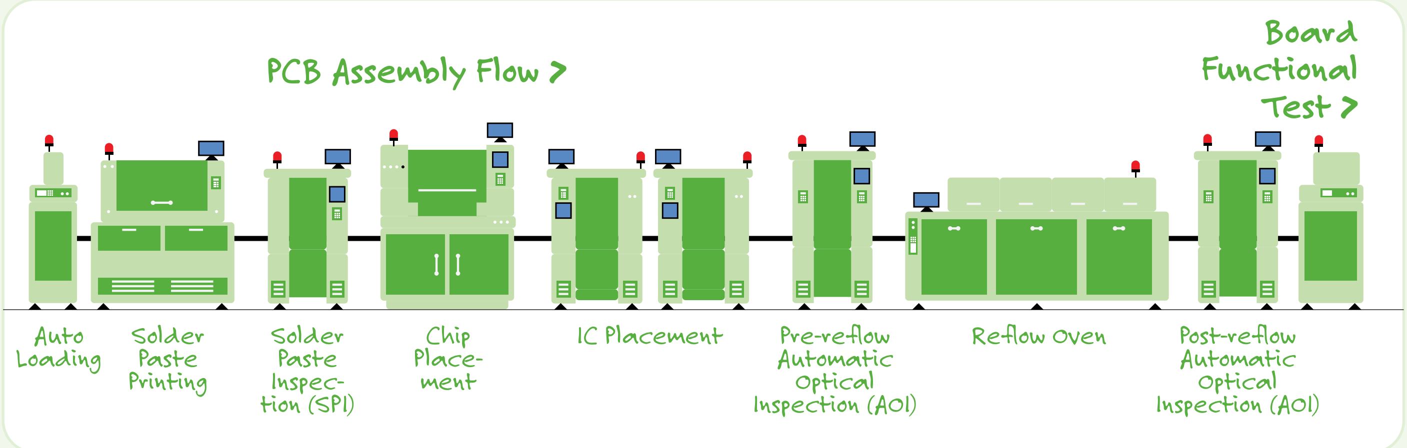
Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the author zhang.wei@espressif.com or the Elektor editorial team at editor@elektor.com.

WEB LINK

[1] ESP-Now coin_cell_demo [GitHub]: https://tinyurl.com/esp-now-coin-cell

The SMT Assembly Process



Surface mount technology (SMT) assembly is a multi-step process that requires precision, automation, and rigorous quality-control measures. The typical SMT assembly process involves the following key stages [1][2]:

- Solder Paste Printing
- Solder Paste Inspection (SPI)
- Component Placement
- Pre-Reflow Automated Optical Inspection (AOI)
- First Article Inspection (FAI)
- Reflow Soldering
- Post-Reflow Automated Optical Inspection (AOI)
- Inspection and Testing

Exciting Trends in the **SMT Industry**

The world of SMT is evolving, driven by the constant need for smaller, more powerful, and more efficient electronic devices. As we look ahead, there are several exciting trends [1] shaping the SMT industry:

- **Miniaturization and Smaller Packages:** Continued focus on smaller and more compact designs with chip-scale packages (CSPs), wafer-level packaging (WLP), and emerging panel-level packaging technologies enabling higher component densities.
- **3D Packaging and Through Silicon Via (TSV):** Exploration of innovative 3D packaging solutions like Through Silicon Via (TSV) technology for vertical stacking of multiple dies, reducing package footprint and improving signal integrity.
- **New High-Density Interconnect Technologies:** Development of advanced interconnect technologies such as embedded trace substrates and fan-out wafer-level packaging (FO-WLP) to support finer-pitch interconnects and higher I/O densities.
- **Advanced Materials and Substrates:** Research into new materials like low-loss substrates and flexible substrates to enhance signal integrity and reduce electromagnetic interference (EMI), alongside the exploration of stretchable substrates for wearable electronics.
- **Industrial 4.0 and Smart Manufacturing:** Adoption of Industry 4.0 principles and smart manufacturing technologies like IoT, big data analytics, and AI for optimized processes, quality improvement, and increased efficiency in SMT assembly lines.

The Maker Movement: **Innovators and Tinkerers Unite** (And Occasionally Blow a Fuse)

In recent years, the entrepreneurial landscape has witnessed the rise of the Maker Movement [3], marking a shift towards hands-on creation and collaboration. Entrepreneurs are using Industrial Revolution 4.0 technologies to transition from hired talent to independent innovators.

Makers often come together in community workshops, known as makerspaces, where they can access shared tools, learn from one another, and collaborate on projects [4]. Makerspaces come in various forms, including:

Originating from MIT

FabLab: small-scale workshops for digital fabrication. The concept began as an outreach project to provide access to modern tools for innovation, such as electronics equipment, laser cutters, routers, and milling machines, enabling makers to create almost anything.

Over 2,300 FabLabs worldwide [5]

Hackerspace: community spaces for computer programmers to collaborate. Over time, they evolved into makerspaces with a focus on hacking physical objects.

Initially started in 1995 in Berlin [6]

Over 2,500 hackerspaces worldwide [7]

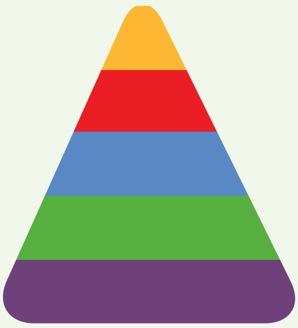
The maker mindset

Adapt to changing markets

Emphasizes learning, flexibility, and a growth mindset

Fostering this mindset and driving innovation

The Maker Mindset for Future Success



01 Stay ahead of the curve

02 Foster a culture of continuous learning

03 Embrace failure as a learning opportunity

04 Encourage collaboration and diversity of ideas

05 Be adaptable and agile

The Advantages?

This movement challenges established industries by enabling makers to create tailored products at a fraction of the cost of mass-produced alternatives. For example, in personalized healthcare, makers are developing affordable, portable medical devices that empower individuals to monitor their own health.

WEB LINKS

[1] What is SMT Assembly?: https://www.pcbelec.com/what-is-smt-assembly.html

[2] The SMT Assembly Process: https://www.surfacemountprocess.com/

[3] FasterCapital, "The Future of Maker Entrepreneurship: Trends and Opportunities," 2024: https://tinyurl.com/Maker-Trends

[4] What is a Makerspace?: https://www.makerspaces.com/what-is-a-makerspace/

[5] The Fab Foundation: https://fabfoundation.org/

[6] C-Base, Berlin: https://www.c-base.org/

[7] List of Hacker Spaces: https://wiki.hackerspaces.org/List_of_Hacker_Spaces

240283-01

Q&A With Natasha Baker

SnapMagic's Evolution and Future in AI-Powered Electronics Design


SnapMagic founder and CEO Natasha Baker.

Questions by Brian Tristam Williams (Elektor)

In 2018, we had the pleasure of interviewing Natasha Baker, where we discussed the inception of SnapEDA, its innovative parts library for circuit board design, and the challenges and triumphs of building a startup from scratch. Now, six years later, we're excited to hear about the impressive advancements and future plans for SnapMagic.

Brian Tristam Williams: It's great to catch up with you again after almost six years. The SnapMagic tagline is "Your AI Copilot for Electronics Design." AI is a big buzzword these days. Was that always your catchphrase?

Natasha: That's right. Our motto was originally about creating what we called the Google for electronics designers. My background is in electrical engineering, and in designing electronics, there's so much data you need — symbols, footprints, 3D models, data sheets, pricing, availability. Our initial goal was to create the first search engine for electronics designers, a place where engineers could find all the data they needed for any component in their design.

Brian: You started out as SnapEDA, but your new name, SnapMagic, is a lot catchier. What were your motivations behind the rebrand? Any new strategic direction it represents?

Natasha: Absolutely. The name change reflects our expanded vision of bringing to life our new AI copilot for electronics design. Our mission has always been to help engineers design electronics faster and bring new products to life. Initially, we focused on creating a search engine for electronics designers, but we've realized over the years that we can pair this data with AI to automate and assist engineers throughout more of the design process, not just part selection. Our new product, SnapMagic Copilot, embodies our core values of making things fast and seamless for engineers, creating an experience that feels almost like magic.

Brian: You've been a leader in the AI design space before AI became such a big trend. Did you feel pressure to accelerate your AI-powered offerings?

Natasha: Engineers are incredibly excited about using AI in their design process. We've conducted hundreds of feedback calls and surveys, and the scope of where they see AI helping them is massive. We definitely feel the pressure to bring this to market. We started by focusing on integrating it with some PCB tools, particularly Altium first, which makes up about 35% of our user base. Next on our roadmap are Autodesk Fusion, KiCad, and Cadence.

Brian: Speaking of KiCad, which is huge in the Elektor community, how significant is its share among your users?

Natasha: KiCad has a significant share, around 20–25%. Many engineers start with KiCad, especially in startups or smaller companies, and often switch to Altium as they mature for more enterprise capabilities.

Brian: I once designed a board using Tango PCB. They didn't have all the components I needed, but I enjoyed making every part of the silkscreen and footprint myself. What drew you to that kind of creative design process initially?

Natasha: My motivation was bringing ideas to life. I was designing a circuit board for a trade show demo at National Instruments, connecting a Nintendo Wii to a custom circuit board as a steering wheel. The lack of available symbols and footprints was holding me back. What should have taken a few hours ended up taking several days due to the difficulty in finding accurate data. That process, for an engineer, is incredibly frustrating, and that experience highlighted the need for a comprehensive, trustworthy source for component data.

Brian: You offer a lot of free resources. How do you keep the lights on while giving so much away for free?

Natasha: We believe that helping engineers also helps component suppliers. Our platform enables more engineers to use products from our component supplier partners. We've been profitable for a long time, running off our revenues until recently, when we raised venture capital to invest in growth. Very importantly — and I had to push back hard on this — we don't sell anyone's data. Instead, we focus on making the engineer successful, which in turn makes the supplier successful.

Brian: One of your differentiators is your trusted, verified component library. How do you ensure data quality and consistency as your library grows?

Natasha: Data quality is crucial for AI-driven design. We have a component engineering team and a lot of automation technology to ensure accuracy. We follow standards guides and have received a patent from the U.S. Patent & Trade Office for our verification technology. Our verification checker on the SnapMagic website ensures that models meet high standards, such as correct silkscreen placement and proper symbol mapping. We've also introduced features for customizing models to match engineers' internal standards.

Brian: It's been six years since your last interview with Elektor. What's been the biggest innovation or product you've worked on since then?

Natasha: The biggest innovation is our new AI assistant, SnapMagic Copilot. We've built a massive proprietary database of trusted models over the last decade, and now we're pairing that data with AI to streamline the design process. It's not a pivot but an expansion of our mission to help engineers design faster and more efficiently.

Brian: Are you still based in Silicon Valley?

Natasha: Yes, we're doubling down on Silicon Valley, looking to double our team this year. We have a global team, but we're focused on growing our software engineering team in the Bay Area.

Brian: What was your initial experience like moving to Silicon Valley?

Natasha: I fell in love with Silicon Valley immediately. I came here for either DesignCon or PCB West, one of those, and the technical sophistication and culture around technology were incredible. When I first started the company in Toronto, no one fully grasped what my vision was about, or understood what EDA or CAD was. Then I came to Silicon Valley again for, I think, the Y Combinator interview, and stepping off the plane, I saw a huge ad for Cadence, and I thought, "these are my people and this is my place!"

Brian: Over the last six years, what has been the most unexpected challenge or learning experience at SnapMagic?

Natasha: The most challenging aspect was starting from nothing in two industries — building a massive library of accurate CAD models and building trust with engineers and component suppliers. We faced challenges in getting engineers to trust third-party libraries and educating component suppliers on digital technology's role in driving design wins. It was painful but rewarding to go through this process, and today, we have great relationships with both our users and supplier partners.

Brian: You've certainly taken a holistic approach to getting your product out there. I'm glad we had this chance to catch up after six years.

Natasha: Thank you so much for the opportunity. I really appreciate it.

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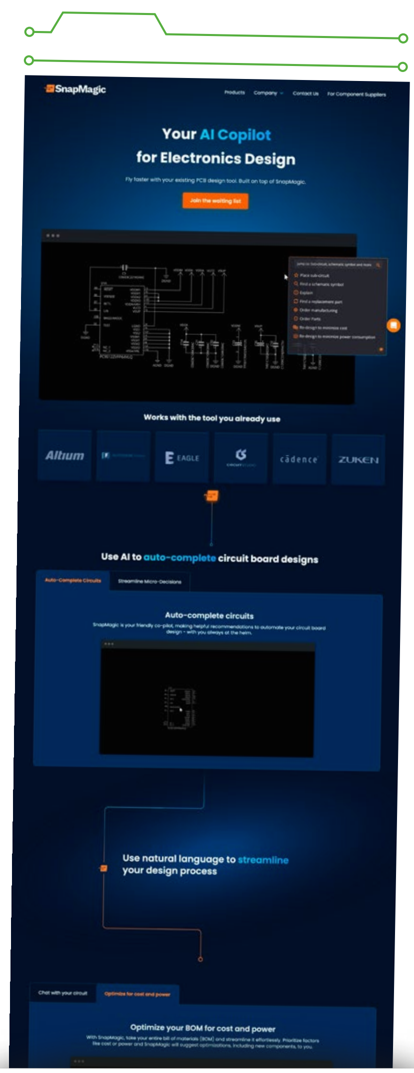
Questions or Comments?

Do you have technical questions or comments about this interview? Email the author at brian.williams@elektor.com.

Related Products

- **P. Dalmaris, *KiCad 6 Like a Pro — Projects, Tips and Recipes* (Elektor 2022)**
  www.elektor.com/20160



The SnapMagic website.

WEB LINK

[1] SnapMagic: https://snapmagic.com

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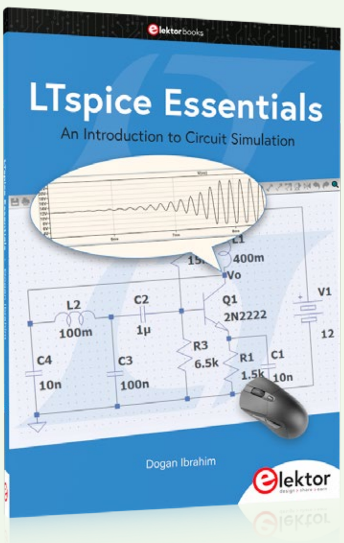

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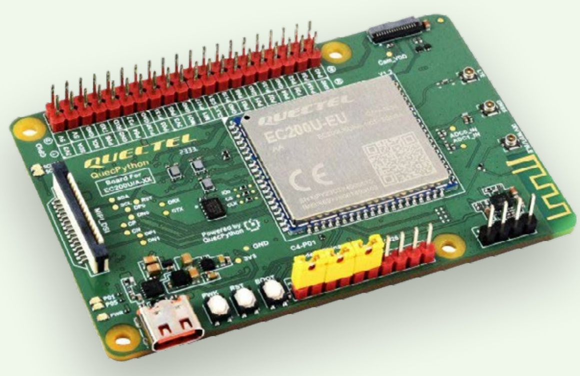

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09 Simple Analog Thermostat

A Compact and Reliable NTC-Based Design

By Giuseppe La Rosa (Italy)

Need to precisely control one of your devices by temperature? This reliable thermistor-based thermostat, with an adjustment range of about 0°C to 60°C, will allow you to regulate it perfectly in aquariums, terrariums, boilers and more.

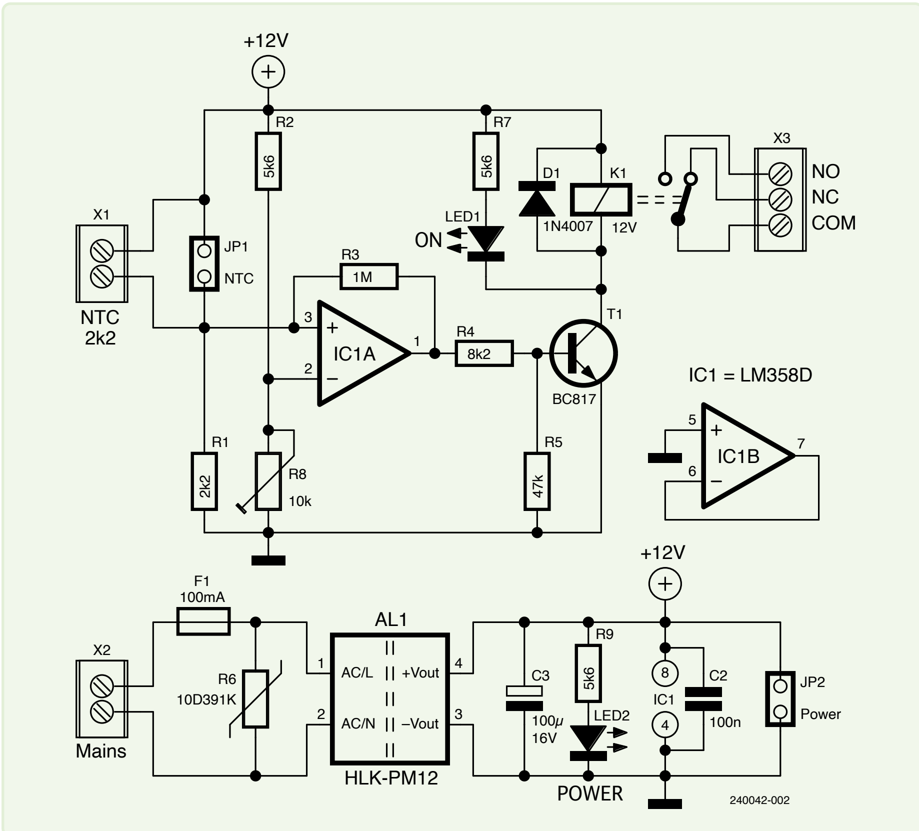

Figure 1: Schematic diagram of the project.

With this simple and small-sized analog design, it is possible to drive any kind of external loads through an insulated set of NO-NC contacts (Normally Open, Normally Closed) of a relay, thus allowing you to control heating devices through the NC connection, or — with reverse logic — to regulate cooling with fans or air conditioning systems through the NO connection.

Circuit Diagram

The thermostat circuit shown in **Figure 1** consists of the operational amplifier IC1, used as a comparator, to sense the voltage difference between pin 3 (non-inverting input) referred to the NTC sensor applied to terminal block X1, and pin 2 (inverting input) fed by a voltage divider consisting of R2 and R8. Trimmer R8 allows the reference voltage at pin 2, i.e., the thermostat trip temperature, to be varied.

Negative Temperature Coefficient (NTC) thermistors have the characteristic of decreasing their resistance as temperature increases. They are widely used, over a temperature range of -100°C to 450°C, and valued for their high sensitivity and short response time.

Their transfer curve has exponential trends that can be pseudo-linearized by connecting a bias resistor in series — as was done in this project — and eventually refined with resistor values placed in parallel to the NTC [1].

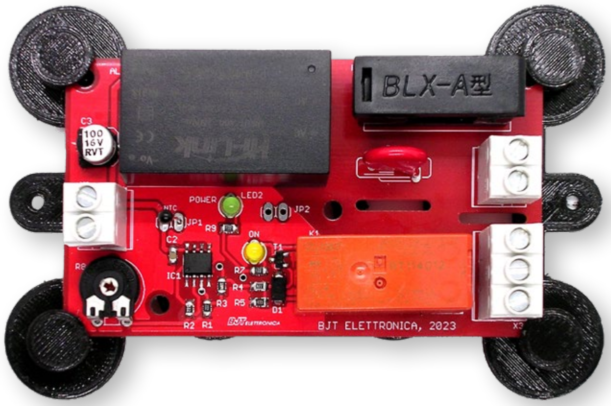

Figure 2: The finished prototype, with the NTC soldered on JP1.

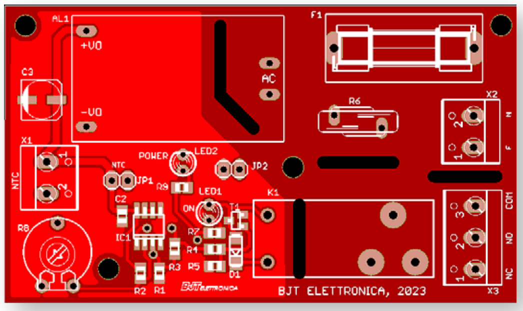

Figure 3: Silkscreen of the PCB. The four millings for increasing the insulation between the mains voltage section and the low-voltage area of the circuit are well visible.

In this design, an NTC thermistor was used that has a nominal value of 2.2 kΩ at 25°C. To obtain a pseudo-linear response, the NTC was connected in series with R1 resistor, forming a voltage divider. In practice, when the NTC sensor is subjected to a temperature above 25°C, its internal resistance drops, causing the voltage at pin 3 to rise.

When the voltage at pin 3 exceeds the voltage present at pin 2, the output at pin 1 of the op-amp switches to logic level 1, causing T1 transistor to saturate and K1 relay to energize. If it proves difficult to find an NTC of the value of 2.2 kΩ, a component of the nearest value (at 25°C) can be adopted and resistor R1 replaced with one of identical value.

Trimmer R8 allows the switching threshold of IC1 to be adjusted. Resistor R3, connected between pin 3 and pin 1 of IC1, determines the hysteresis, which is the tolerance range (Δt) around the switching point. Without hysteresis, when the sensor temperature is close to the switching temperature — but does not permanently fall above or below that value — relay K1 could switch continuously, causing contact wear and possible malfunction of the controlled device.

The presence of R3 ensures that the transition between the resting and active states occurs only when the temperature exceeds the switching threshold by a small margin, avoiding uncertainty at the time of switching.

Op-amp IC1B, which is not used, has been configured as an idling voltage follower, with non-inverting input on pin 5 connected to ground. This choice avoids noise and ensures proper operation of the circuit.

The power for the circuit is supplied by PCB power supply module AL1, but it can also be drawn from an external source without installing this component on the PCB.

PCB

As can be seen from the finished prototype shown in **Figure 2**, mounted on 3D-printed supports, the circuit was made largely from SMD components, with the remainder using through hole mounted elements. The construction of the board is simple, although SMD components require more care in placement and soldering.

The board used is double-sided with plated-through holes, and it should be populated by following the silkscreen shown in **Figure 3**. If the thermostat is used to control the AC line voltage, the millings shown in black in the same picture must also be made, to increase the isolation between the mains voltage and the low-voltage section of the circuit.

Circuit assembly requires some specific tools for placing SMD components, as well as a certain amount of manual dexterity. The soldering iron should preferably be a very fine-tipped type and with a power rating of no more than 12 W. The use of an SMD soldering station is still the best choice. Tin wire should be no more than 0.5 mm thick. The layouts for the PCB, including the .stl file for the 3D-printable supports, are available for download at [2].

Assembly and Testing

You can start by applying IC1 respecting its orientation and soldering one pin at a time, in alternating rows. Next, the resistors and

Component List

Resistors (SMD 0805)
R1 = 2.2 kΩ
R2 = 5.6 kΩ
R3 = 1 MΩ
R4 = 8.2 kΩ
R5 = 47 kΩ
R6 = 10D391K varistor
R7, R9 = 1.2 kΩ
R8 = 10 kΩ PT10 trimmer
NTC = 2.2 kΩ (25°C) thermistor

Capacitors
C1 = Not Used (see text)
C2 = 100 nF (SMD 0805)
C3 = 100 µF 16 V (SMD 6X5)

Semiconductors
D1 = M7 diode
T1 = BC817 transistor (SOT-23)
IC1 = LM385D (TSSOP)
LED1 = yellow, 3 mm, (through-hole)
LED2 = green, 3 mm, (through-hole)

Miscellaneous
K1 = 12 V relay, RT114012
F1 = 500 mA T 5×20 fuse with fuse holder
X1, X2 = 2-pole screw terminal block
X3 = 3-pole screw terminal block
AL1 = HLK-PM12 power supply module

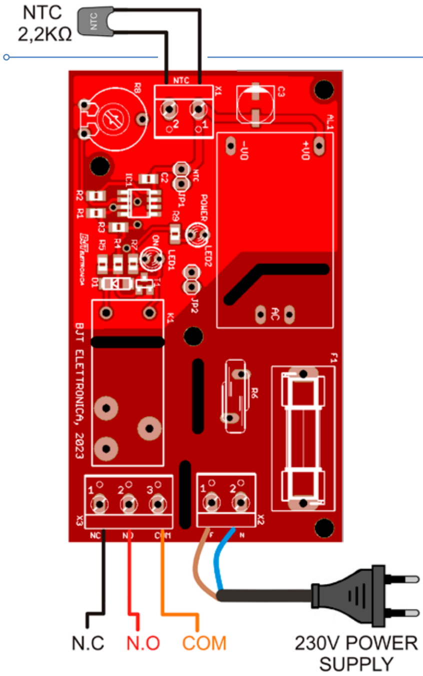

Figure 4: The basic wiring diagram of the thermostat. COM-NO contacts are used to control a heating device, while COM-NC may control a cooling system.

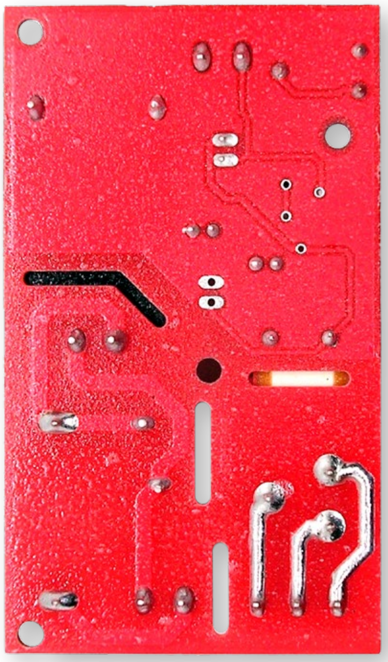

Figure 5: The solder side of the PCB, with the thickened tracks visible in the bottom-right corner. This allows to control heavier loads without heating the copper tracks.

ceramic capacitors can be treated. Finally, D1 diode, T1 transistor, C2 and C3 electrolytic capacitor can be placed.

Please note that due to a mistake in the deployment phase of the PCB, the component count for the capacitors started from 2; therefore, there's no C1 on board. Don't look for it!

At this point, one can move on to the assembly of the through-hole components. You have to insert LED1 and LED2 diodes, then X1, X2 and X3 screw terminals, F1 fuse holder, AL1 power supply, and finally R8 trimmer and R6 varistor.

Please note that the NTC leads can either be connected to JP1 pads or to X1 screw terminal block, whose contacts are connected in parallel through the PCB. Furthermore, one of the two could be utilized for connecting a compensating resistor in parallel to the NTC, in case a specific linearization curve was needed.

Once the assembly is finished, you can proceed with testing. **Figure 4** shows the necessary wiring. If you connect high-current loads to the relay PCB tracks going to terminal X3, you need to thicken them with tin, as shown in the bottom-right corner of **Figure 5**.

For testing, you should set R8 trimmer to one-fourth of the travel (CW) and supply power to the board. The green LED2 should light up. By heating the NTC thermistor, LED1 will light up and at the same time you will hear K1 relay tripping. If everything has gone as described, the circuit is operational, ready to be adjusted to the desired trip temperature and used in your application.

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Questions or Comments?

Do you have technical questions or comments about his article? Email the author at lrgeletronic@hotmail.com or contact Elektor at editor@elektor.com.

About the Author

Passionate about electricity from an early age, Giuseppe La Rosa graduated with a degree in Electronics and Telecommunications in 2002 at I.T.I.S. "G. Ferraris" of Acireale, Sicily. Later, he began studying microcontroller systems, particularly PIC microcontrollers and the Arduino UNO open-source platform. Over the years, he has created various prototypes, many of which have been published in electronics magazines. Currently, he deals with security systems (video surveillance and anti-burglary alarms) and software for the management of points of sale.

WEB LINKS

[1] Amphenol Advanced Sensors Whitepaper: https://tinyurl.com/3sxcyx42
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[3] Short video on YouTube: https://youtu.be/RuZSwumMCJY