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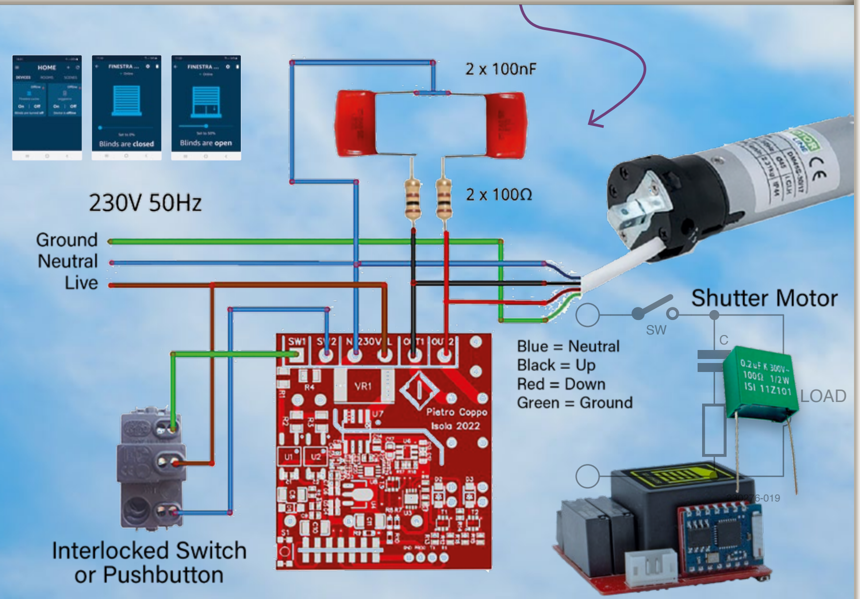
SMART ROLLER SHUTTER

Shutter Control at Your Fingertips



FOCUS ON

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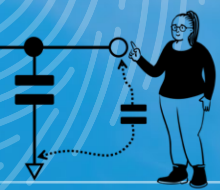
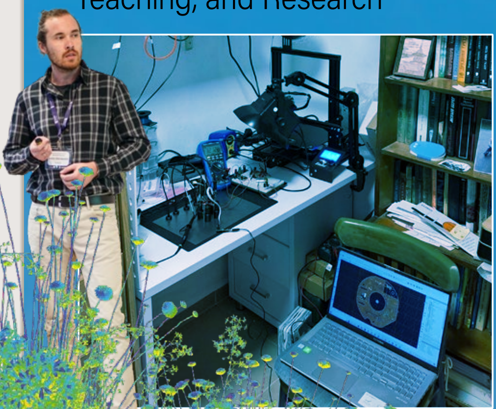
How Do Capacitive Touch Sensors Work?



HT-03 Thermal Imaging Camera

An Electronics Workspace

for Sensor-Based Solutions, Teaching, and Research



Sensor+Test 2024 and PCIM 2024

EDITORIAL

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The **July/August 2024 edition** of *ElektorMag* is available at newsstands and in the Elektor Store.

C. J. Abate

Content Director, Elektor

Bonus: IoT and Sensors Content for You!

Each year, Elektor creates, reviews, and publishes more IoT- and sensors-related content than could fit in a single magazine. This year is no different. In this bonus edition, we offer additional content that you'll find stimulating. After you read through this edition, be sure to share your own projects on the Elektor Labs platform (*www.elektormagazine.com/labs*).

Elektor's editor-in-chief, Jens Nickel, kicks things off with details about his recent trip to Sensor+Test 2024 and PCIM 20204, which took place from June 11-13, 2024, in Nuremberg, Germany. In the article, Jens describes some of the technologies and demos that caught his attention from companies such as S4sensors, MindCet, and CAE Software und Systems. The rest of the Bonus Edition includes an interesting project, an insightful background article, a helpful review, and an inspiring electronics workspace!

Visit Elektor's IoT & Sensors page (*www.elektormagazine.com/iot-sensors*) for even more projects, reviews, and background articles. We currently manage hub pages in the English language on elektormagazine.com for the following topics: Arduino, Raspberry Pi, Espressif, Power & Energy, Embedded & AI, Test & Measurement, Circuits & Circuit Design, Wireless & Communication, and Prototyping & Production. In the coming weeks, we'll have hub pages for these topics on our German, Dutch, and French magazine sites as well. Enjoy!

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COLOPHON

Elektor July/August 2024 Bonus Edition

Elektor Magazine is published 8 times a year by
Elektor International Media b.v.
PO Box 11, 6114 ZG Susteren, The Netherlands

Phone: +31 46 4389444

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Senefelder Misset, Mercuriusstraat 35,
7006 RK Doetinchem, The Netherlands

Distribution
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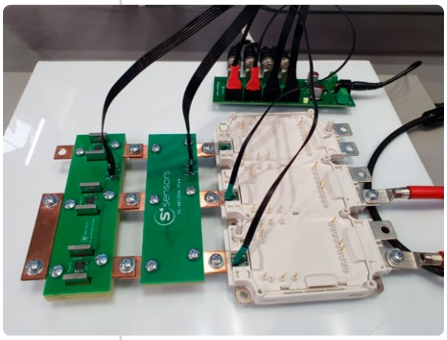
Sensor+Test 2024 and PCIM 2024

By Jens Nickel (Elektor)

From June 11 to 13, 2024, three fairs took place in Nuremberg, Germany: Sensor+Test [1], PCIM Europe [2], dealing with power electronics, and SMTconnect (Surface Mount Technology). Elektor editor-in-chief Jens Nickel was on hand to look for interesting new products. As always, his personal selection is only a small sampling of all the innovations seen at these trade shows.

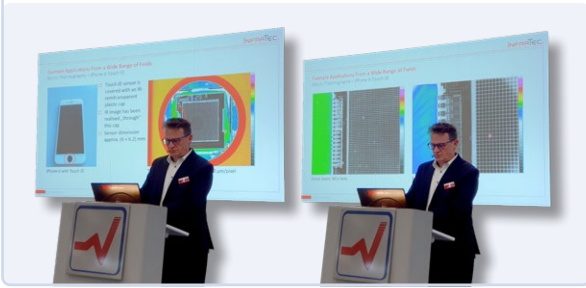
S4sensors



At the Sensor+Test, I discovered this demo from S4sensors, a semiconductor company specialized in 3D position and current measuring devices. On the left, three Hall sensor ICs can be seen. The trick is their high lateral sensitivity, which is achieved by the special manufacturing technique of the Hall sensor area inside the IC. In fact, there are even two Hall sensor areas inside each chip, making differential measurements possible, for higher immunity against stray fields.
https://s4sensors.com

InfraTec

The public sessions were also worth a visit. German IR-sensing specialist InfraTec showed an interesting lesson about what thermal imaging is capable of. One of the examples was an insight in the iPhone 6, where the cover of Touch ID sensor is transparent for IR waves (left). Thermal imaging could unveil microscopic details (right).
www.infratec.de/thermografie/waermebildkameras



CAE Software und Systems

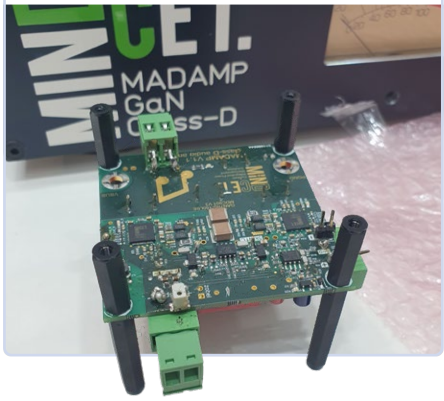
One of my favorites: The acoustic cameras of the German company CAE Software und Systems, which generate an image of sound sources, with colors symbolizing the sound level (big picture). In fact, I would have some applications in the field of audio. But the main purpose of this visualization technology is maintenance of machines and facilities, to detect, for example, leaks in gas pipes. The black "camera" on the left integrates an array of (standard market) microphones; an FPGA is doing the magic of visualization of the sound "image," which is here superimposed to a video image. The brand-new SoundCam Ultra 3 of that company (small photo) is a handheld device and even integrates a thermographic image as a third layer.
www.cae-systems.de

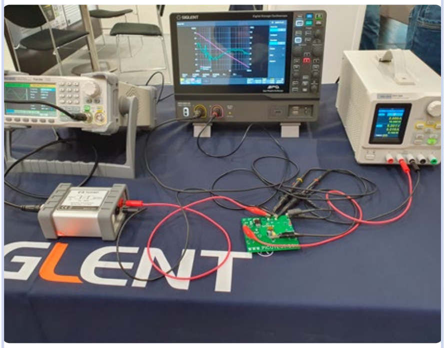
ROHM Semiconductor

At the PCIM, GaN was of course a big topic. ROHM exhibited its EcoGaN family of 150 V and 650 V class GaN high-electron-mobility transistors (HEMTs), with several evaluation kits. These FETs are dedicated for power switching and high-frequency applications. The EcoGaN devices find their way also in consumer products, like this 45-W USB-C charger by Innergie, a brand of Delta Electronics.
www.rohm.com/pcim

MindCet

Of course I also visited the guys from MindCet, who are currently developing an audio amplifier, in cooperation with Elektor. The Madamp mono amplifier board will showcase advantages of GaN power transistors, driven by the MDC901 Gate Driver ICs of the Belgian company. With better efficiency, a more compact design is possible. More on the Madamp soon in Elektor!
www.mindcet.com/asic-products



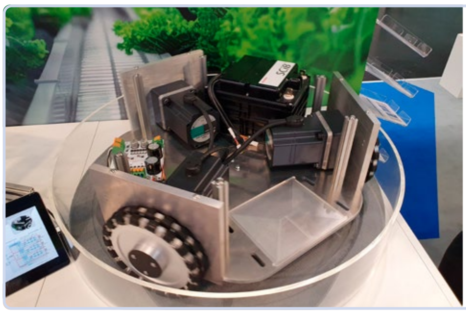


Siglent

Measuring device manufacturer Siglent demonstrated the high-resolution dual-channel oscilloscope SDS1202X HD recording a Bode diagram. The heart of the new SDS1000X HD oscilloscope series are the 12-bit ADCs with 2 GSamples/s. The devices are available in bandwidths of 100 MHz and 200 MHz and 2 and 4 analog channels.
https://tinyurl.com/siglent-oscilloscopes

Qorvo

The trend in fuse boxes is also moving towards solid-state components. Semiconductor manufacturer Qorvo presented a SiC JFET with a minimum resistance of just 4 mΩ that can replace conventional fuses. The Americans dedicated part of their stand to their simulation program QSPICE. Creator Mike Engelhardt himself showed this free-to-use and powerful SPICE-based simulator in practice.
www.qorvo.com/newsroom/trade-shows/pcim
https://p.qorvo.com/qspice-simulator.html



Toshiba

A space-saving and attractive demo: The rotating "Omniwheel Automated Guided Vehicle" has an in-house 24 V SCiB battery with 556 Wh capacity, which can be fast-charged in 20 minutes (3 C). A Cortex-M4F CPU with 160 MHz, B6 bridge gate drivers with automatic dead time optimization and UMOS-X power MOSFETs (all from Toshiba) control the three motors.
https://tinyurl.com/toshiba-pcim

240333-01

WEB LINKS

[1] Sensor+Test - The Measurement Fair: http://www.sensor-test.de
[2] PCIM Europe Expo: https://pcim.mesago.com/nuernberg/en.html

Smart Roller Shutter

Curtain Control at Your Fingertips

By Maurizio Škerlič (Italy)

Elettronica In
WWW.ELETTRONICAIN.IT

Nowadays, home automation applications are increasingly controlled by powerful voice-operated web platforms such as Google and Alexa. This project allows you to operate the motorized roller shutters in your house, either using one of these voice assistants or via an app. Connected via Wi-Fi, it is programmed with firmware that relies on the Sinric Pro [1] server.

In this new home automation project, which we have called the Smart Roller Shutter, we present a smart device dedicated to controlling electric roller shutters via Amazon Alexa, Google Assistant, or a smartphone app. The installation involves absolutely no changes to the electrical system, let alone replacing the roller shutter motor or replacing pre-existing self-locking buttons or switches.

Simply wire this device appropriately, and, within minutes, you'll have transformed your rolling shutter into a smart device. Its small size allows it to be installed in any junction box for electrical systems or mounted on a holding plate in rectangular 503 boxes using the appropriate adapters, 3D-printable, which can be downloaded from the Elektor Labs webpage for this project [2].

Wiring Diagram

To analyze the design, we take a look at the circuit diagram in **Figure 1**. We start with the ESP03 module (U5), based on the Espressif ESP8266 microprocessor with a 32-bit RISC architecture. It has an operating frequency of 80 MHz and is equipped with 1-MB flash memory. The circuit is powered by an integrated on-board switching power supply (TR1), which delivers 5 V at 1 A. The output voltage of this device is lowered to 3.3 V by U4, an NPC1117 voltage regulator. The 5 V is filtered by the multilayer ceramic capacitors C4, C5, and C8, while the 3.3-V line is filtered by capacitors C6, C7, C9, C11, and C12, which are essential to avoid random system resets or crashes. Be aware that the Espressif processor is very sensitive to voltage dips, electromagnetic interference (EMI), and the excessive ripple typical of switching power supplies, especially the low-cost ones. These are the main causes of malfunction in projects made by novices trying their hand at ESP family processors for the first time, mainly when prototypes are mounted on breadboards and connections are made with jumper wires in a chaotic and sloppy manner, or where, out of haste or laziness, the power supply is not decoupled or filtered with capacitors.

The ESP03's pins 10 (GPIO 12) and 11 (GPIO 13) — SDA and SCL, respectively — are used for I²C communication with the Texas Instruments PCA9536 IC (U3), a 4-bit input-output port expander, and with the 18-bit Microchip MCP3421 analog-to-digital converter (ADC) IC (U6). We point out that as many as seven versions of this chip are marketed, differing only in their I²C addresses. The one used in our project responds to I²C address 0x69 and is labeled MCP3421A1. If you can't find one, you can safely use one with a different I²C address, but you'll have to modify the sketch accordingly. For example, if you buy the MCP3421A2 chip, as described in the datasheet, at the binary

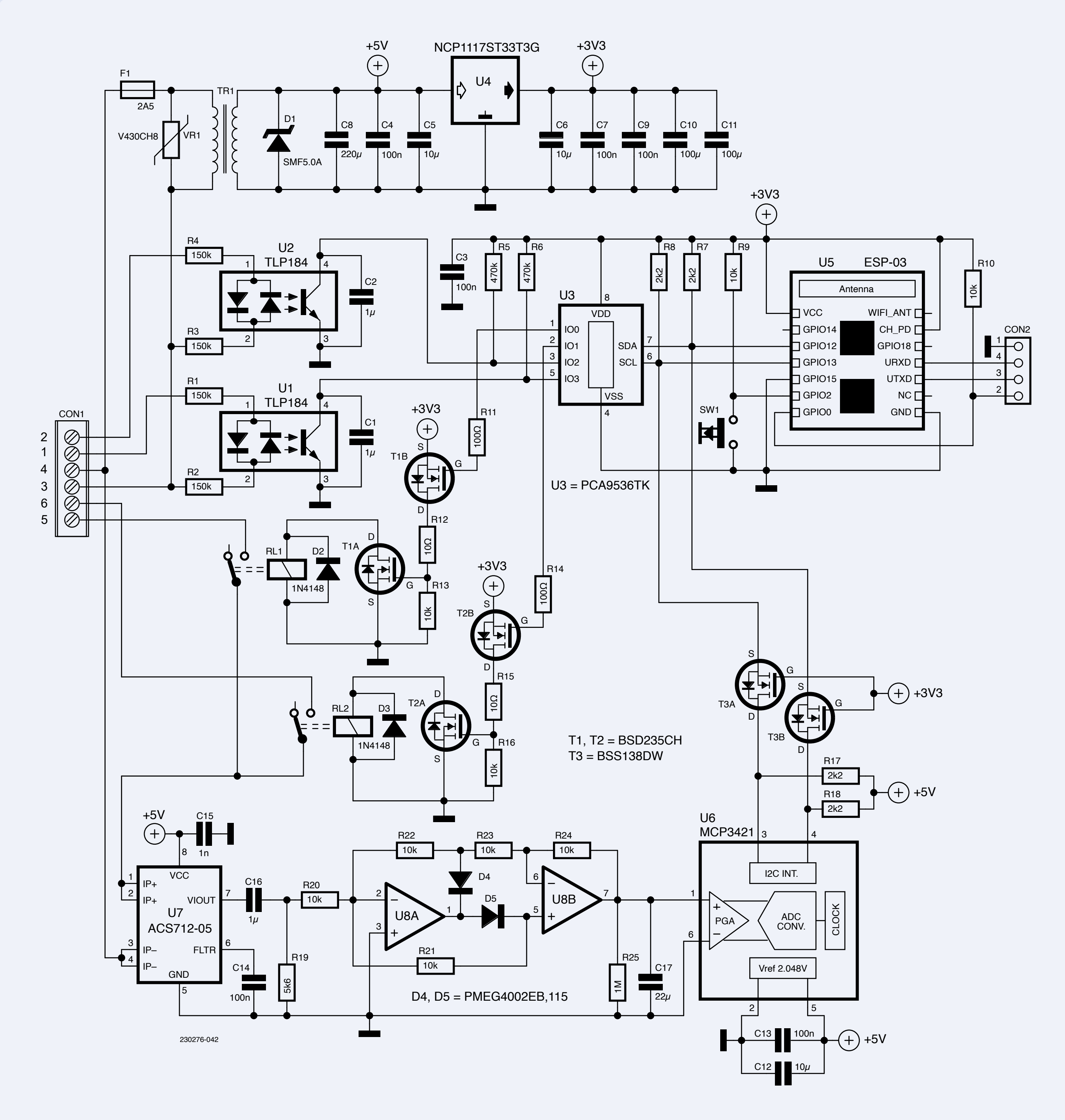


Figure 1: Schematic diagram of the project.

number 1101xxx replace xxx with the chip's address bits, which are defined by the last two values in the chip's abbreviation. In our case, it is A2, which is equivalent to address 2, expressed in binary as 010. After the appropriate substitution, the I²C address becomes 1101010, which is 0x6A in hexadecimal (**Figure 2**).

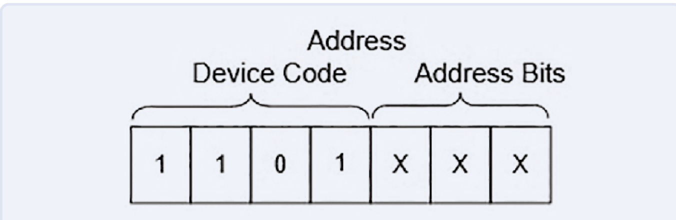


Figure 2: Procedure to derive the I²C address of MCP3421 A/D converter.

We now analyze the most important part of our device — the part that allows the shutter position to be set without the aid of a position sensor. This is done thanks to an Allegro Microsystems ACS712 Hall-effect current sensor (U7), which detects the motor's switching off once the limit switch is triggered. This is indispensable, especially during calibration, to be able to time how long it takes the shutter to close and open. This chip is marketed in three versions depending on the maximum detectable current: 30 A with a sensitivity of 66 mV/A, 20 A with a sensitivity of 100 mV/A, and 5 A with a sensitivity of 185 mV/A.

The ACS712 Integrated Circuit

Source: Allegro Microsystem ACS712 Datasheet

The Allegro™ ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, switch-mode power supplies, and overcurrent fault protection. The device is not intended for automotive applications.

The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging.

The output of the device has a positive slope (>VIOUT(Q)) when an increasing current flows through the primary copper conduction path (from pins 1 and 2, to pins 3 and 4), which is the path used for current sampling. The internal resistance of this conductive path is 1.2 mΩ typical, providing low power loss. The thickness of the copper conductor allows survival of the device at up to 5× overcurrent conditions. The terminals of the conductive path are electrically isolated from the signal leads (pins 5 through 8). This allows the ACS712 to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques. The ACS712 is provided in a small, surface mount SOIC8 package. The following table describes the function of the 8 Pins.

Pin number	Name	Description
1 and 2	IP+	Current Sense Input (+)
3 and 4	IP-	Current Sense Input (-)
5	GND	Ground reference Pin
6	Filter	External Capacitor for Bandwidth Setting
7	Vout	Analog Output
8	Vcc	Supply Input

Features and Benefits

- *Low-noise analog signal path*
- *Device bandwidth is set via the new FILTER pin*
- *5-µs output rise time in response to step input current*
- *80 kHz bandwidth*
- *Total output error 1.5% at T_A = 25°C*
- *Small footprint, low-profile SOIC-8 package*
- *1.2-mΩ internal conductor resistance*
- *2.1 kV_{RMS} minimum isolation voltage from pins 1-4 to pins 5-8*
- *5.0 V, single supply operation*
- *66 to 185 mV/A output sensitivity*

For our prototype, we chose the 5 A version of the ACS712 sensor due to its highest sensitivity of 185 mV/A, which offers more precise detection of current intensity. While there are many sensors available with varying sensitivities and features, the ACS712 was selected for its easy accessibility. This sensor measures the alternating current passing through its pins 1, 2, and 3, 4, and converts it to a voltage proportional to 185 mV/A, which can be accessed via pin 7. The output from the sensor is then processed by the MCP6402 operational amplifier (U8), configured as a dual half-wave rectifier, to obtain the RMS value of the alternating current.

The rectified signal from pin 7 of the MCP6402 op-amp (U8) is sent to the analog-to-digital converter (U6). Since the ACS712 sensor operates at 5 V, the rectified signal from pin 7 also needs to be processed by components operating at the same voltage. In this setup, both op-amp U8, configured in a dual half-wave rectifier mode, and A/D converter U6 run on a 5 V power supply. However, the ESP03 module, which communicates with the A/D converter via the I²C bus, operates at a logic level of 3.3 V instead of 5 V. To bridge this voltage gap between the 5 V signals of the sensor and the 3.3 V logic of the ESP03, we used a level-shifter. This level-shifter is built with a dual N-channel MOSFET (T3) and four resistors (R7, R8, R17, and R18), which also serve as pull-up resistors for the I²C bus, ensuring stable communication between the components.

Pins 1 (IO0) and 2 (IO1) of the port expander (U3) are designated as output ports to control the motor's operations. Meanwhile, pins 3 (IO3) and 5 (IO4) serve as input ports to detect the roller shutter button presses. To maintain these inputs at a high level, resistors R5 and R6 are used. Signals from the button presses are generated by the transistors in the photocouplers (U1 and U2) and are filtered through capacitors C1 and C2 for stability.

The 230 V AC, which comes from the roller shutter buttons connected to pins 1 and 2 of connector CON1 (for the "Up" and "Down" commands, respectively), is safely isolated using dual LEDs within the photocouplers (U1 and U2). Current-limiting resistors (R1, R2 for U1 and R3, R4 for U2) protect these components from excessive current. Resistors R5 and R6 also serve as bias resistors for the photocouplers, ensuring that they function correctly by maintaining the necessary voltage levels across their terminals.

Push button SW1 is connected to pin 9 (GPIO2) of the ESP03 module and is held at a high level by resistor R9. This button serves a critical function: If you forget the memorized system password, pressing the SW1 button will reset the password to the default value of "123456789."

Pins 1 and 2 of the PCA9536 port expander (U3) are used to control a pair of electromechanical relays through two dual N-channel and P-channel MOSFETs, which are encapsulated in a single package and labeled T1 and T2 in the schematic. These relays manage the power switching for the motor. To protect these MOSFETs from voltage spikes generated by the relay coils when they are de-energized, flyback diodes D2 and D3 are placed in parallel with the relay coils. These diodes absorb and dissipate the potentially harmful overvoltages caused by the inductive kickback, ensuring that the MOSFETs are safeguarded against damage from these high-voltage transients.

The load, which in our case is the shutter gear motor, is connected to pin 5/OUT1 (Up), pin 6/OUT2 (Down), and pin 3 (neutral/common). Line voltage leads neutral and live are connected to pins 3 and 4 of CON1, respectively.

To safeguard the circuit, several protective components are used: A varistor (VR1) and a fuse (F1) provide protection against overvoltage and overcurrent conditions, respectively. Additionally, a unidirectional transil diode (D1) is included to shield the circuit from any excessive voltage output that might occur from the power supply during a fault condition. This combination of protective elements ensures that the circuit remains robust and reliable, even in adverse electrical situations.

Practical Assembly

Before we dive into the practical assembly, it's important to note that the compact size of our printed circuit board (PCB) was necessary to ensure compatibility with commonly used modules. To accommodate all the components, we had to use some surface-mount devices (SMD) in the tiny 0201 package. Despite this, assembling the circuit doesn't demand exceptional skills or extreme precision.

Here are our recommendations for assembly:

- **Soldering Tools**: Use a fine-tipped soldering iron with a power range of 20 to 25 watts and thin solder wire, preferably no thicker than 0.7 mm in diameter.
- **Flux**: Opt for a high-quality flux that leaves minimal residue. A low to medium density flux is ideal for this project.
- **Tweezers**: Employ fine-pointed tweezers, preferably made of non-magnetic stainless steel, plastic, or ceramic, to handle the small components. Magnetic tweezers can attract components, making placement difficult.

For those who prefer to make the PCB themselves, visit the Elektor Labs webpage for this project [1], where you can find the Gerber files for the double-sided PCB, suitable for photoengraving, along with the firmware.

When assembling the PCB:

- Start with the semiconductors, ensuring correct orientation as shown in the assembly plan.
- Proceed with the smallest passive components first, then move to the larger ones.
- To save space, tin the ESP03 module (U5) on its adapter PCB before mounting it vertically, as demonstrated in **Figure 3**.
- Following these steps will help ensure a smooth and successful assembly of the Smart Roller Shutter project.

The final step involves mounting the through-hole components, such as the terminal blocks, relays, and the switching power supply.

If you encounter difficulty finding Schottky diodes PMEG4002EB,115 (D4 and D5), the PCB design provides an alternative option: the BAT54 double Schottky diode in a SOT-323 package. When selecting this alternative, it's important to choose the correct version. Pay attention to the suffix in the diode's abbreviation, which indicates the internal arrangement of the diodes. For our project, the BAT54SW type is recommended. For more detailed information on the different versions of the BAT54 diode, please refer to the text frame about the BAT54.

After assembling all components, it's essential to clean any residual flux from the PCB using isopropyl alcohol. This cleaning process helps prevent short circuits and ensures a clean and reliable build. Use a magnifying glass to thoroughly inspect for any accidental solder bridges between the pins of the components, especially between the pins of U1 and other small-pitch components, such as those with a 0201 package.

Careful cleaning and detailed inspection will significantly enhance the performance and longevity of your Smart Roller Shutter device.

At this stage, you can power up the prototype by following the wiring diagram provided. It's crucial to remember that these circuits are connected to the 230 V mains supply. Never touch any part of the circuit with your bare hands — doing so puts you at severe risk of electric shock or electrocution.

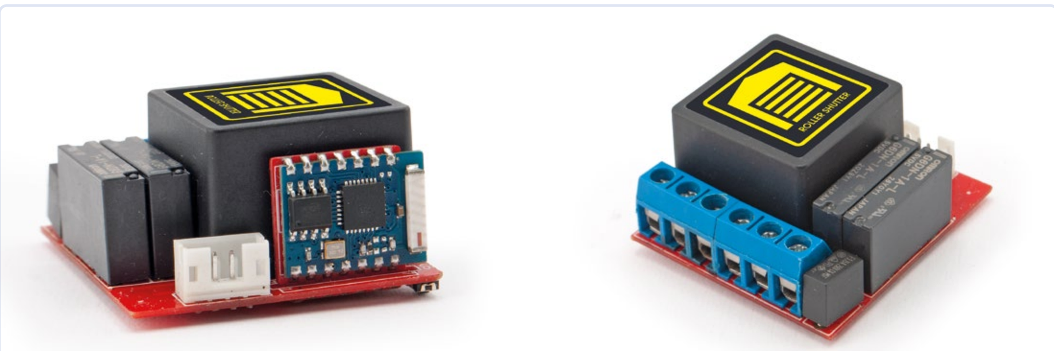
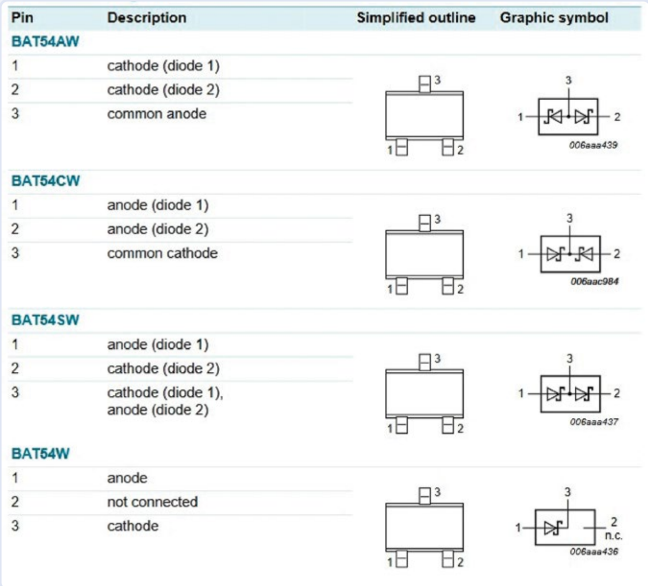


Figure 3: Mounting the ESP03 module upright on the PCB. The other side shows the screw terminal blocks for the connections.

The BAT54 Double Schottky Diode

The double Schottky diode type BAT54 with which you can replace the D5 and D6 diode pairs exists in various versions, all encapsulated in SOT-323 format packages; what distinguishes them is the pinout, which differs to offer the designer various solutions. Each pin-out is distinguished by a suffix, i.e., a pair of letters following the code. In our case we have chosen SW and therefore the printed circuit board is designed to accommodate this and not others. The possible versions, associated with the respective pin-outs, are detailed in the image in this frame.



Pin	Description	Simplified outline	Graphic symbol
BAT54AW			
1	cathode (diode 1)		006aaa439
2	cathode (diode 2)		
3	common anode		
BAT54CW			
1	anode (diode 1)		006aac984
2	anode (diode 2)		
3	common cathode		
BAT54SW			
1	anode (diode 1)		006aaa437
2	cathode (diode 2)		
3	cathode (diode 1), anode (diode 2)		
BAT54W			
1	anode		006aaa436
2	not connected		
3	cathode		

Many people believe that the residual current circuit breaker (RCCB), often incorrectly referred to as a "life preserver," will always protect them from electrocution. However, it's important to understand that the RCCB is designed to trip only when it detects current leakage to the ground. This means that if you accidentally touch both the live and neutral wires simultaneously, the RCCB might not trip, resulting in a potentially fatal shock.

Therefore, exercise extreme caution when working with or around the circuit while it's connected to the mains. Use insulated tools and ensure the power is off before making any adjustments or touching the components. Safety cannot be overstated in these situations.

Programming and Testing

To program the ESP03 module, use a USB adapter compatible with the ESP8266 or any USB TTL converter that supports 3.3 V logic, similar to those used for programming Arduino mini modules. Refer to **Figure 4** for the connection details: Connect the TX output of the converter to the RX pin 4 of the CON2 connector and the RX input of the converter to the TX pin 3 of CON2. To enter programming mode, press and hold the "Prog" button connected to pin 2 of CON2 for one second before powering the device. Release the button after one second. This will set the Smart Roller Shutter into programming mode, ready for firmware upload. Figure 4 figure provides additional references for the correct wiring of the "Prog" button.

For informational purposes, please note that the sketch for the Smart Roller Shutter was compiled using the ESP8266 package core version 2.7.4, along with these libraries: *Iotwebconf* version 3.2.1, *SinricPro* version 2.10.0, *SparkFun_PCA9536_Arduino_Library* version 1.2.2, and *ArduinoJson* version 6.19.4. Ensure that your ESP8266 package in the Arduino IDE is updated to at least version 2.7.4 to avoid issues with the *Iotwebconf* library. At the time of writing, the ESP8266 core package is available up to version 3.0.2; however, we have encountered problems with the Wi-Fi network in this version, which might be fixed in future updates.

At the beginning of the sketch, there are commented lines that are used to set the source compilation. For example, if the flash memory mounted on the ESP03 module is marked *Puya*, and you want to enable support for that memory at compile time, you need to remove the `//` comment in front of `#define PUYA_SUPPORT 1`, and if you

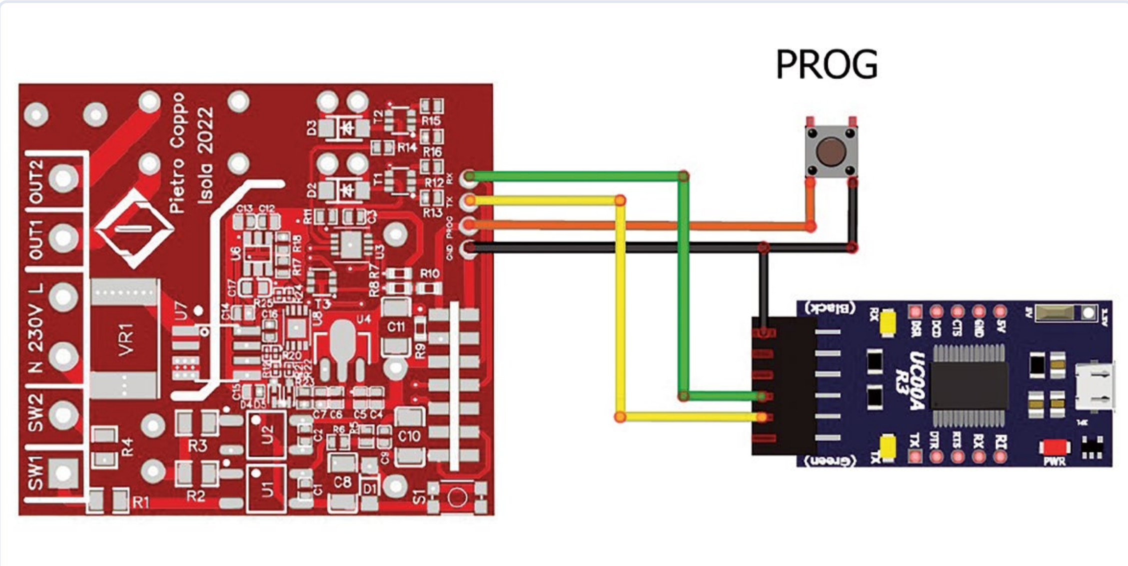


Figure 4: Connection of the serial programmer to the Smart Roller Shutter.

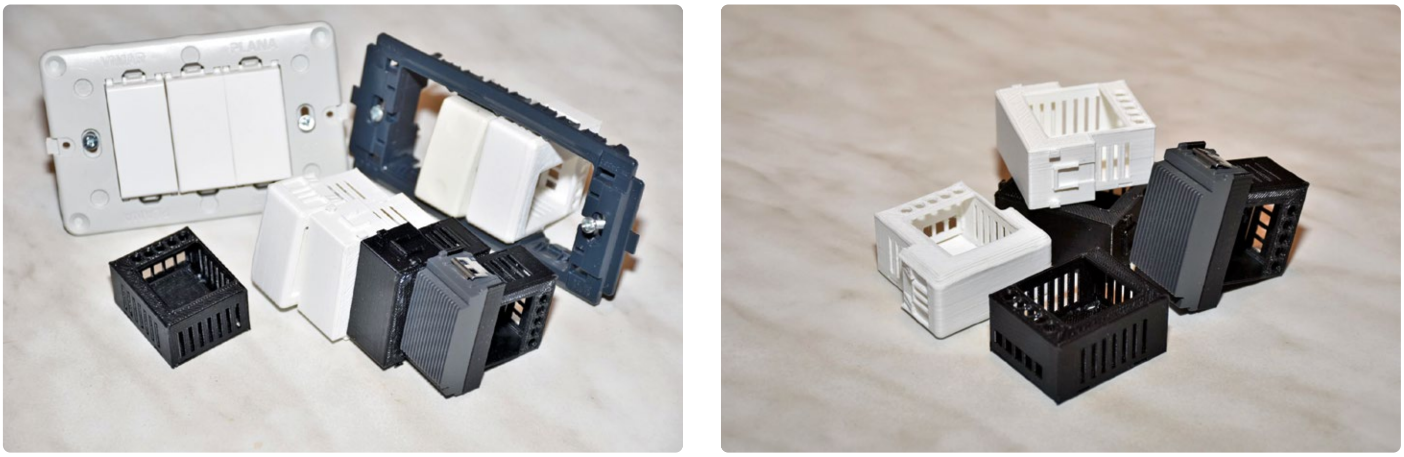


Figure 5: 3D printed enclosures, adapters and inserts for Vimar Plana, Vimar Idea, Gewiss Basic and Gewiss Playbus plates.

want to enable debugging remove the comment in front of `#define ENABLE_DEBUG`. The *Iotwebconf* library, by default, makes your IoT account's plaintext keys display on the serial. For security reasons, we recommend that you disable this option by adding the following line of text `#define IOTWEBCONF_DEBUG_DISABLED` to the beginning of the *IotWebConfSetitings.h* file, located in the *src* folder.

Among the files that can be downloaded from the Elektor website, in the *stl* folder, you will find files for 3D printing the adapters and inserts for the Vimar Plana, Gewiss System, Gewiss Playbus, and BTicino living series, visible in **Figure 5**, which will facilitate the installation of the Smart roller shutter in your home electrical system. Pay attention to the correct orientation of the enclosure cover, so that the side hole is positioned above the SW1 button, to allow you to press it in case you want to reset the device if you forget the password. For those who want to make the container themselves with the 3D printer, we recommend setting the layer height to a value no higher than 0.2 mm and, depending on the version of the slicing software, enable the use of line fill in the high-density grid fill, otherwise the container wall, which is only 1.5 mm thick, will not be filled properly and have a hollow space. Although excellent results are obtained with PLA filament, we still recommend using ABS filament that can withstand higher melting temperatures, or the self-extinguishing ABS V0 filament certified by the UL94 V0 standard.

Using the Smart Roller Shutter

Once the Smart roller shutter is turned on, you can access the initial web page, as visible in **Figure 6**, where you will see the IP number of the device, the MAC (Media Access Control) number, the current drawn by the load expressed in A, the consumption expressed in W, and the position of the shutter expressed in %. To access the configuration page, you will be prompted for a user name and password. As username enter *admin* and as password *123456789*. Once you've entered the *Settings* section, you can set the parameters, as visible in **Figure 7**.

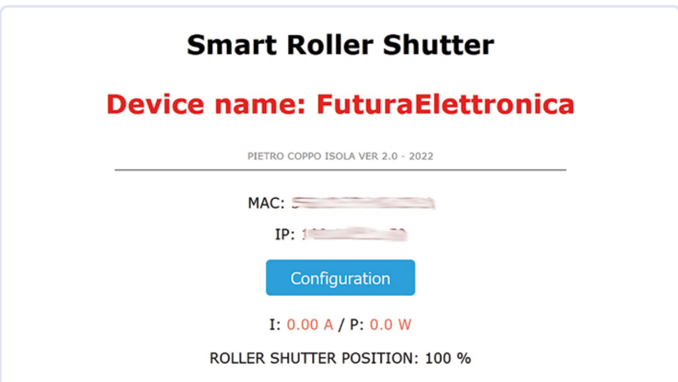


Figure 6: Home page of the Smart Roller Shutter.

In the *Shutter calibration* section you will find the calibration button, a function that you necessarily have to start when you first turn it on, for the device to acquire the time it takes for the motor to fully wind the shutter. In a nutshell, it must learn how much time elapses from the opening limit switch to the closing limit switch. For shutter positioning, our device relies on elapsed time and not on position sensors to be mounted on the motor axis making installation complicated. Certainly, using time as the measurement method, the calculated positioning will not be accurate; nevertheless it does not affect the proper functioning of the device. We are still talking about a shutter, not a CNC machine.

Even if we used sensors, we would still have a positioning error caused by the progressive increase in the rolling diameter given by the thickness of the shutter being wound on the roller. Obviously, the error increases proportionally to the length of the roller shutter and the thickness of its slats. As the roller shutter is wound on the roller, its diameter increases, consequently increasing the forward speed of the roller shutter, which will never be linear but logarithmic. In fact, once you have installed our device, you will find that at the command to position of the roller shutter at 50% it will not position halfway through the window opening. This will be more noticeable on a patio door than on a window, where the light height is almost double. To overcome this, you would have to modify the source by implementing an algorithm that calculates the opening percentage considering the roller diameter, slat thickness, and length of the shutter.

In the *Roller shutter start position* section, the *Start at last position* checkbox allows you to enable the function of restoring the last stored position. After a restart, for example due to a power failure, the device, to resynchronize with the end stops, will first close the shutter and then reposition it to the last set position. The *Start at custom position* checkbox allows you to enable the positioning of the shutter to a percentage value that can be set from the *Set custom position* drop-down menu. Also in this case, after a reboot, the device will resynchronize by closing the shutter and then will move to the set position. If you do not select any of these functions at startup, the shutter will remain

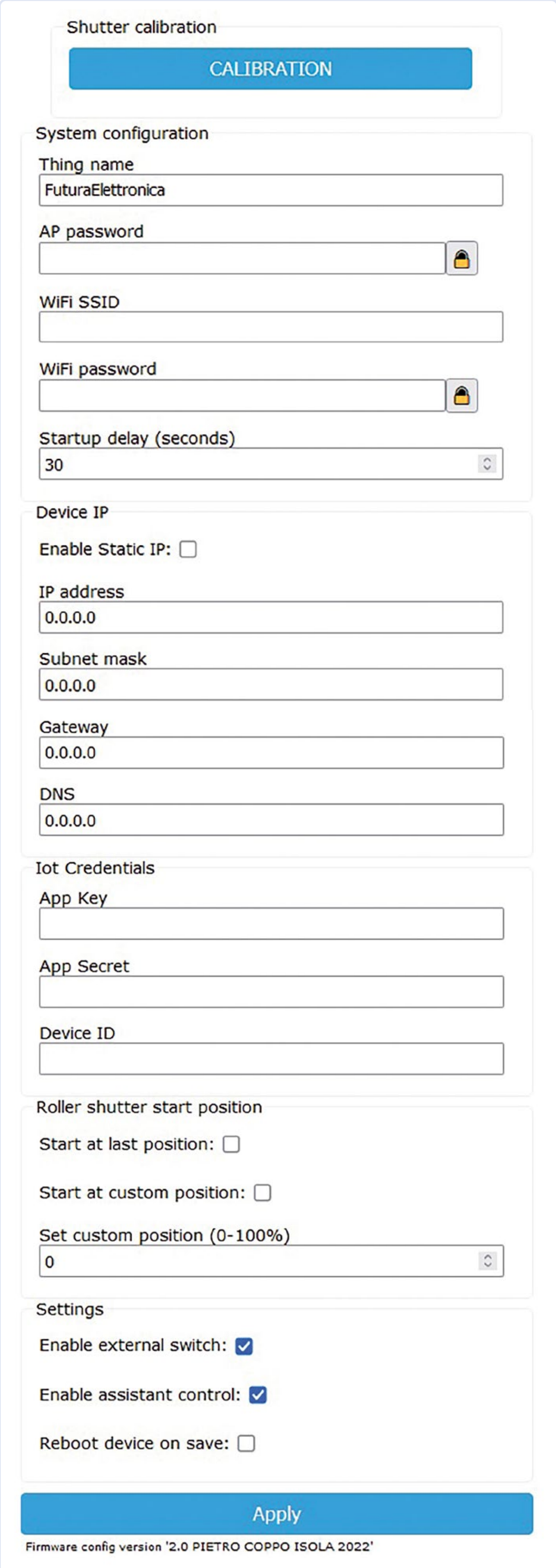


Figure 7: Screenshots of the Smart Roller Shutter configuration web page.

stationary. In this case, synchronization will have to be carried out by bringing it, with a voice command or with the button, to one of the two positions of limit switch open or closed.

We point out that the device, to minimize errors, resynchronizes each time it reaches one of the limit switches. The checkbox *Enable external pushbutton* allows you to enable or disable adjustment by external pushbuttons or switches. The checkbox *Enable assistant control* checkbox allows you to enable or disable control by assistant voice Amazon Alexa or Google assistance. The *Reboot device on save* checkbox, enables the device to reboot after saving the settings by pressing the *Apply* button.

Once you have configured the device, we recommend that you set the *Startup delay* found in the *System configuration* section to 1 s, so if the Smart roller shutter reboots, for example due to a momentary power line voltage drop, instead of waiting for the preset 30-s delay, it will connect to the Wi-Fi network immediately and be active faster. The 30-s delay is only for the first startup during configuration, when the device becomes an access point (access point) to allow you to locate it and select its SSID. In **Figure 8** you will find the connection diagram of the Smart Roller Shutter.

If you install the Google Home application on your smartphone, the Smart roller shutter can also be controlled with the voice assistant Google Assistant. Below are some commands recognized by Amazon Alexa voice assistant. Suppose that in *https://sinric.pro* our device you have assigned the name *Kitchen Window*. To raise the whole shutter, you say, "Alexa, open kitchen window," or "Hey Google, open kitchen window." To lower the whole shutter, say, "Alexa, close kitchen window" or "Hey Google, close kitchen window." To set the shutter halfway up: "Alexa, set kitchen window to 50%" or "Hey Google, set kitchen window to 50%." To increase the opening by 10%: "Alexa, increase kitchen window by 10%" or "Hey Google, increase kitchen window by 10%." To decrease the opening by 10%: "Alexa, decrease by 10% kitchen window" or "Hey Google, decrease by 10% kitchen window." In **Figure 9** you can observe the interface images of the Sinric Pro app, while in **Figure 10** you can observe the images of the Google Home app.

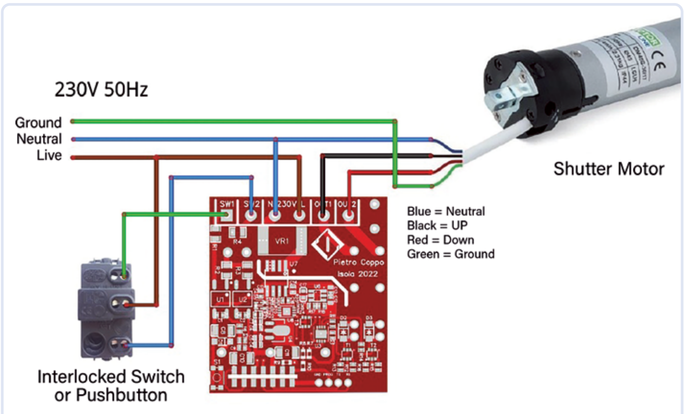


Figure 8: Wiring diagram of the Smart Roller Shutter with the interlocked button and shutter motor.

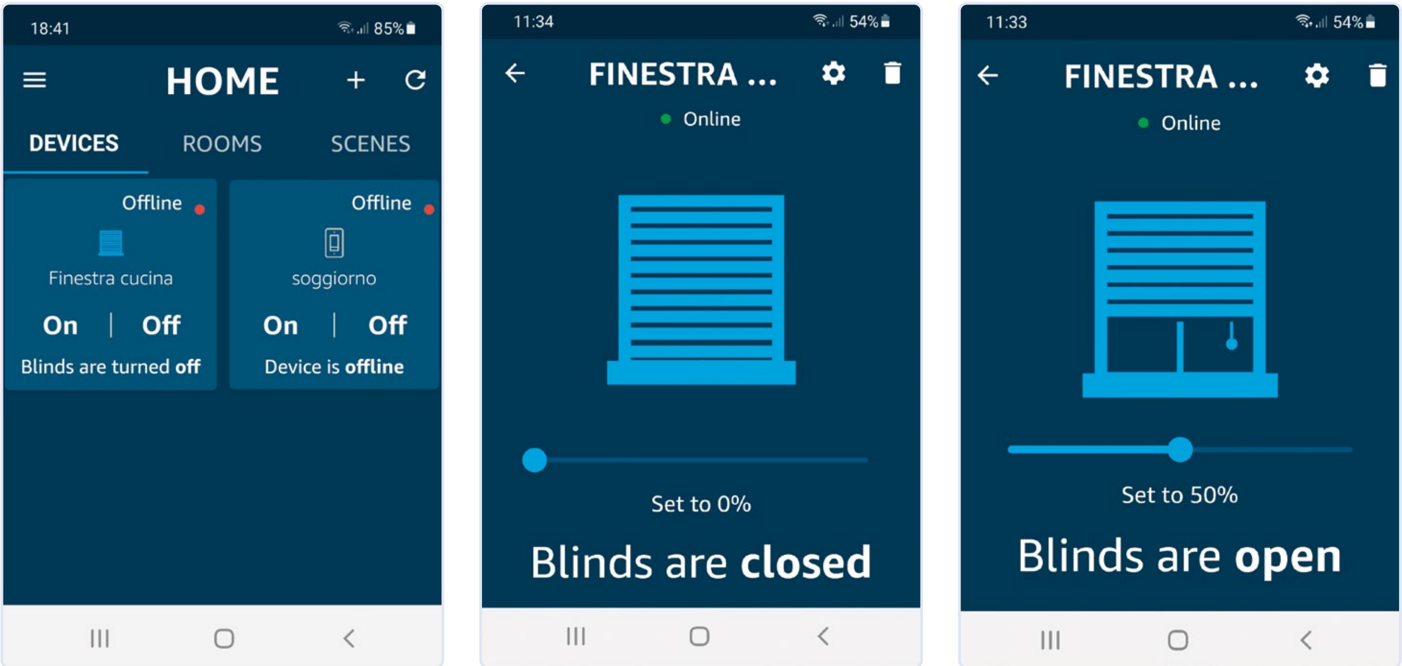


Figure 9: User interface of the Sinric Pro app.

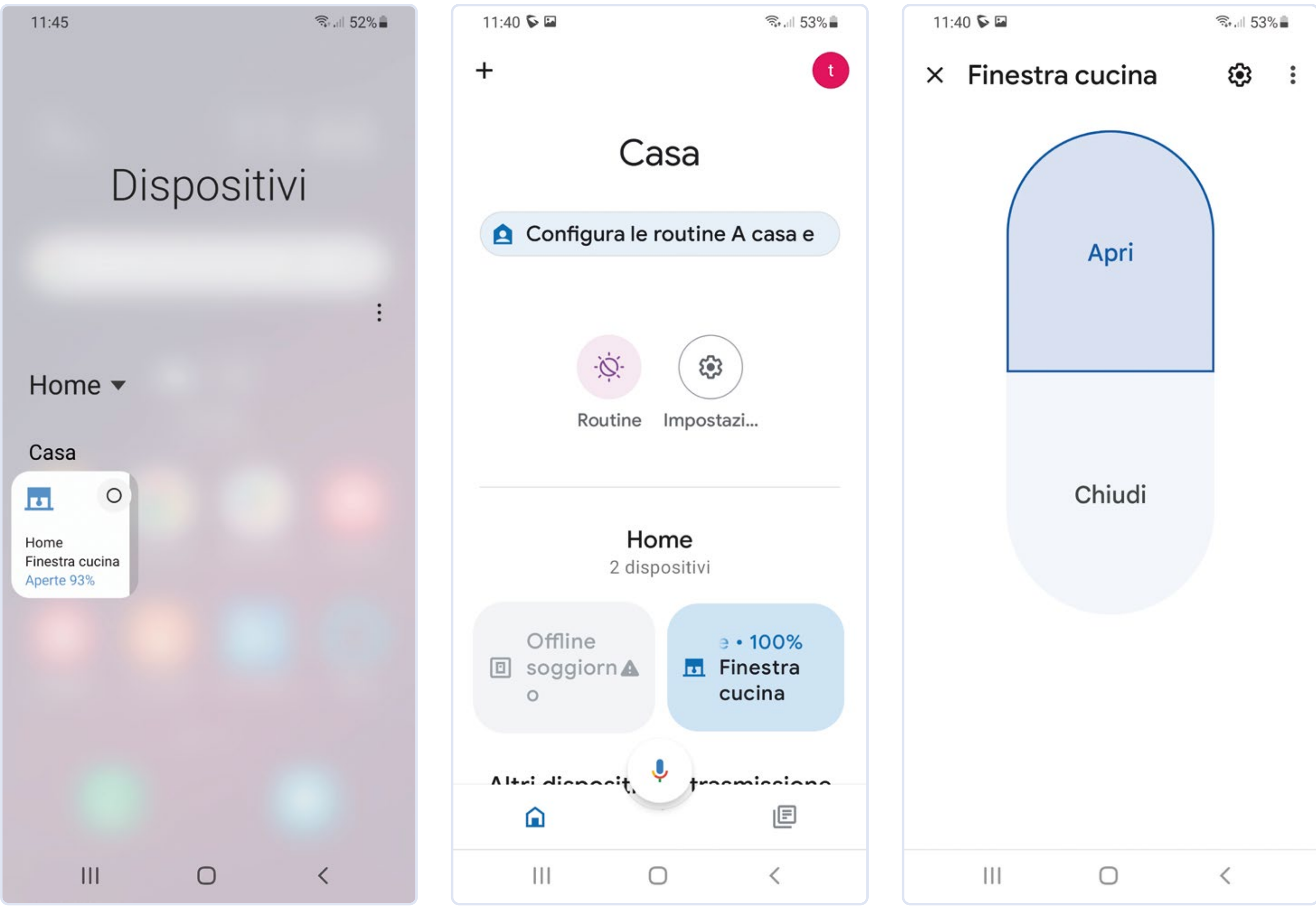


Figure 10: Interface of the Google Home app.

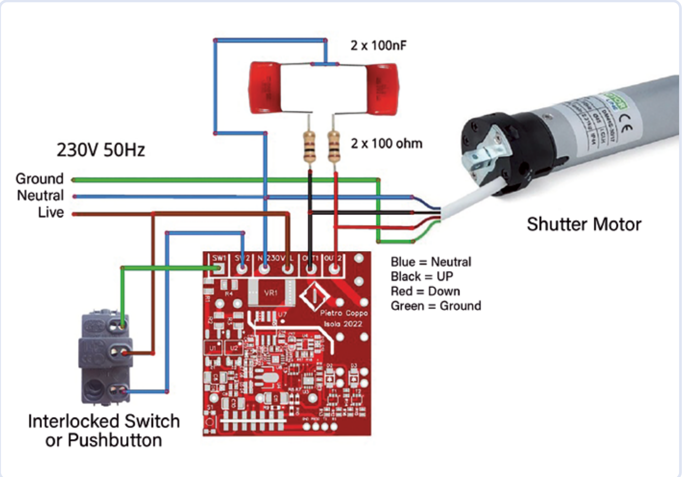


Figure 11: Wiring of snubbers to limit EMI noise.

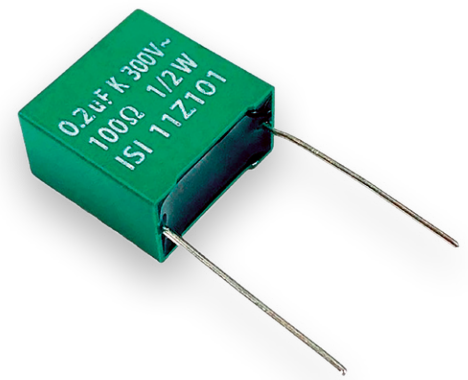


Figure 12: Commercially available integrated snubber. (Source: Elettronica In)

Due to the small space, we were not able to implement the anti-noise snubbers on the printout. If the operation of the shutter motor disturbs other household devices or appliances, or you want to protect the relay contacts from deterioration caused by induced currents, we recommend that you insert in parallel to the motor windings a snubber consisting of a capacitor and a 1 to 2 W resistor, as visible in **Figure 11**. It should be specified that the capacitor should be of class X2, possibly MKP, while the resistor preferably metal layer and absolutely not wire. Alternatively, on the market you can find ready-made and integrated snubbers, with components of different values and specific characteristics (an example can be seen in **Figure 12**) whose case resembles a common rectangular polypropylene or polyester film capacitor. You can connect it near the gearmotor in the shutter box or, if you have space, in the junction box that makes connections.

Transient Voltage Suppression

When the switch opens, the charge stored in the load inductance causes an over-voltage due to the fact that the inertial nature of the inductors with respect to current tends to make the regime of the previous instant persist; you can calculate the generated over-voltage using the following formula:

$$V = \frac{L \times I}{t}$$

Where *V* is the voltage to be calculated, *L* is the value of the coil inductance, *I* is the rated current of the coil, and corresponds to the release time of the power supply. This voltage occurs between the contacts of the switch, which at the time of opening presents a minimum distance between the contacts. Therefore, the formation of an arc between the contacts can occur almost immediately, i.e. at the instant in which these are separating and are not touching each other more.

The phenomenon can also occur with loads that are resistive, but it is accentuated in inductive ones, which result in an intense electric arc that reduces the life of the switch. Even if the contacts are coated or made of Tungsten (also called Wolfram) i.e., a metal that melts at very high temperatures (3,410°C), over time, however, they can erode. In DC circuits, to eliminate the induced high-voltage current, a diode known as a flyback diode is normally used. Unfortunately, the application of this diode in AC circuits is not feasible. When dealing with alternating current, there are three possible solutions: use a metal-oxide-varistor (MOV), a suppressing diode for bidirectional transient voltage (transient voltage suppression - TVS) or an RC suppression network, also known as "snubber."

In addition to these solutions there is also that of not use any suppressor, however, in this case the life of the contacts will be affected. MOV and TVS diodes conduct current only when the threshold voltage is exceeded. Normally, these diodes are connected in parallel to the switch contact and are able to operate efficiently at both low and high voltages. The RC snubber, on the other hand, has the advantage of limiting the voltage exactly during the open of the switch, that is, when the distance between the contacts is small. It is realized by a capacitor and a resistor connected to each other in series and can be mounted in parallel to the switch contact or in parallel to the load, as visible in **Figure 13**.

Although mounting the snubber in parallel with the contact is the ideal configuration, there is a huge disadvantage when these are open, as it causes current to flow to the load. Conversely, if the snubber is

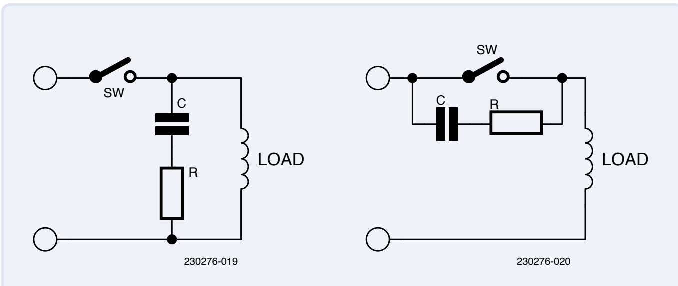


Figure 13: Snubber wiring parallel to the switch (top) and parallel to the load (bottom).

installed in parallel with the load, the impedance of the load can affect the efficiency of the RC circuit. So when the snubber is in parallel with the switch contacts, the resistor must have a high enough value to limit the capacitor discharge current when the switch contacts close. At the same time, it must have a value small enough to limit the induced voltage when the switch contacts open.

If we choose a capacitor with a high value, it will certainly better reduce the extra voltages when the switch contacts open; but at the same time, such a capacitor may be more expensive, bulkier, and may cause more damage during its discharge on the contacts when they close. On the other hand, when the snubber is in parallel with the load, to decrease the degradation of the contacts due to arcing, we need to make sure that the value of the resistance is minimal.

At the same time, however, to reduce arcing on the contact, due to the inrush current of the capacitor, the value of the latter must be greater. As you have seen, many factors are that determine the choice of the value of R and C. Since the snubber, in our case, must protect the contacts of a switch, and not a MOSFET in a high-frequency switch, the choice of the RC value will not be critical. In principle, we could choose resistor R values between 10 Ω to 220 Ω and for the capacitor C between 100 nF to 330 nF. For reasons of availability, we usually choose for R a value of 100 Ω and for C a value of 100 nF. In addition to this empirical and unscientific method, let us see together how one should choose the values of these components.

Snubber Design

Usually to find the RC values one connects in parallel to the load an oscilloscope and measure the shape waveform of the induced voltage generated when a turned off an inductive load, called the frequency resonance frequency, which we denote by F_{RING1}. In parallel to the load, we connect a capacitor of value low that must be gradually increased until it succeeds in halving the amplitude of the initial resonant frequency. We call this halved frequency F_{RING2}. The value of this capacitor will be the capacitor C_s of our snubber. We estimate the parasitic inductance L_p, using the initial resonant frequency F_{RING1}, without capacitor, and that with the addition of the capacitor F_{RING2}, using the equation:

$$L_p = \frac{1}{(2\pi(F_{RING1} - F_{RING2}))^2 \times C_s} = \frac{1}{4\pi^2(F_{RING1} - F_{RING2})^2 \times C_s}$$

We estimate the parasitic capacity C_p using the equation:

$$C_p = \frac{1}{(2\pi F_{RING1})^2 \times L_p} = \frac{1}{4\pi^2(F_{RING1})^2 \times L_p}$$

Having calculated the parasitic inductance L_p and the parasitic capacitance parasitic *Cp*, we calculate the value of the resistance of the R_s snubber using the equation:

$$R_s \geq Z = \sqrt{\frac{L_p}{C_p}}$$

Technical Specifications

- Installation in flush-mounting box or on Vimar, Gewiss or BTicino mounts.
- Maximum load 550 W.
- Thermal overcurrent and overvoltage protection.
- Compatible with voice assistants like Amazon Alexa and Google Assistant.
- Configuration via web interface.
- Connection to home Wi-Fi.
- Operation with interlocked pushbuttons or switches.
- Password protection.
- Password reset via pushbutton.
- Current and power consumption detection.

To attenuate the resonant frequency, it is necessary to choose for the snubber a resistance R_s equal to or greater than the impedance *Z*, and for C_s to choose a value 1 to 4 times greater than that of the parasitic capacitance C_p. This procedure also requires non-negligible precautions when making oscilloscope measurements on the 230-VAC power line. One must use a special oscilloscope with galvanically isolated or battery-powered inputs, use special differential type probes or galvanically isolated probes, alternatively use an isolation transformer with 1:1 transformation ratio, with adequate power, capable of powering the circuit on which we want to make the measurements.

There is an additional method, which we should not even mention since it is dangerous, and that is to remove the ground connection of the oscilloscope and make the measurements by always connecting the alligator clip of the probe on the neutral of the power line (not the phase, because you would end up with the phase on the oscilloscope casing and if you touch it ...). We recommend using the transformer, which by the way is the safest and costs the least. An alternative method is to use the equation developed by C.C. Bates and published in the article "Contact protection of electromagnetic relays" in the journal *Electro-mechanical design* back in August 1966 [2].

$$C = \frac{I^2}{10}$$

$$R_s = \frac{V_p}{10 \times I \times \left(1 + \left(\frac{50}{V_p}\right)\right)}$$

- V_p = Peak voltage
- I = Load current (before the opening of the contact)
- R_s = Resistance of the RC snubber expressed in µF
- C = RC snubber capacitance
- R_L = Load resistance

$$V_p = V_{rms} \times \sqrt{2}$$

$$V_p = 230\ V \times 1.414213562373 = \mathbf{325.27\ V}$$

To understand how to use the equation, let us give an example calculation for the design of an RC snubber for an electric motor with a power rating of 300 W, operating with an AC voltage of 230 V. The design parameters on which we base are P = 300 W, V_{RMS} = 230 V, Vp = 325.27 V.

We begin with the calculation of the peak voltage:

$$V_{pp} = V_{rms} \times 2 \times \sqrt{2}$$

We then determine the peak-to-peak voltage:

$$V_{pp} = 230\ V \times 1.414213562373 = \mathbf{650.54\ V}$$

We continue with the calculation of the RMS voltage:

$$V_{rms} = \frac{V_p}{\sqrt{2}} = \frac{325.27\ \text{V}}{1.414213562373} = \mathbf{230\ V}$$

We turn to the equation to calculate the current drawn by the load:

$$P = I \times V_p \quad \Rightarrow \quad I = \frac{P}{V_p}$$

$$I = \frac{300\ \text{W}}{325.27\ \text{V}} = \mathbf{0.922\ A}$$

Now let's look at the equation to calculate the value of the snubber network capacitor:

$$C = \frac{I^2}{10} = \frac{(0.922\ \text{A})^2}{10}$$
$$C = \mathbf{85\ nF}$$

Instead, to determine the value of the snubber network resistor, we apply the following equation by performing the calculations:

$$R_s = \frac{V_p}{10 \times I \times \left(1 + \left(\frac{50}{V_p}\right)\right)}$$
$$R_s = \frac{325.27}{10 \times 0.922 \times \left(1 + \left(\frac{50}{325.27}\right)\right)}$$
$$R_s = \frac{325.27}{10 \times 0.922 \times (1 + 0.1537)}$$
$$R_s = \frac{325.27}{9.22 \times 1.1537}$$
$$R_s = \frac{325.27}{10.637}$$
$$R_s = 30.579\ \Omega \cong \mathbf{30.58\ \Omega}$$

Let us now see how to calculate the current flowing through the RC snubber: First, we need to calculate the capacitive reactance (X_c) of the capacitor belonging to the grid (the mains frequency is 50 Hz) remembering that the pi term is worth 3.1415926:

$$X_C = \frac{1}{2\pi \times f \times C}$$
$$f = 50\ \text{Hz}$$
$$C = 0.085\ \mu\text{F} = 0.000000085\ \text{F}$$
$$X_C = \frac{1}{2\pi \times 50\ \text{Hz} \times 0.000000085\ \text{F}}$$
$$X_C = \frac{1}{2 \times 3.14159 \times 50\ \text{Hz} \times 0.000000085\ \text{F}}$$
$$X_C = \frac{1}{0.0000267\ \text{F}} = 37313.432\ \Omega$$
$$X_C = \mathbf{37313.43\ \Omega}$$

At this point, we write the equation to calculate the current flowing through the snubber network:

$$I = \frac{V}{R} = \frac{V_p}{(X_C + R_s)}$$
$$I = \frac{325.27\ \text{V}}{(37313.43\ \Omega + 30.58\ \Omega)}$$
$$I = \frac{325.27\ \text{V}}{37344\ \Omega}$$
$$I = 0.00871\ \text{A} = \mathbf{8.71\ mA}$$

Finally, we use the equation needed to calculate the power dissipated by the RC snubber resistor, which, being a dissipative component, must be sized appropriately to prevent it from overheating and burning:

$$P = V \times I$$
$$V = R \times I$$
$$P = V \times I = (R \times I) \times I = R \times I^2$$
$$I = 0.00871\ \text{A}$$
$$P_R = I^2 \times R_s$$
$$P_R = (0.00871\ \text{A})^2 \times 30.58\ \Omega$$
$$P_R = 0.002319\ \text{W} = \mathbf{2.319\ mW}$$

Designed by Students

With this device, we hope to have satisfied our readers who wanted to make a smart shutter switch that can be easily managed and remotely controlled by smartphone or voice assistant, as well as being of a size small to facilitate installation in system's home. As a reminder, the Smart roller shutter is part of a series of modules and home automation actuators designed and implemented by the students of the Technical Institute Pietro Coppo Isola, Slovenia. They all fall under the concept of IoT and devices connected, specifically aimed at the automation of home environments through the connection Wi-Fi and integration with apps and voice assistants, which are very much fashionable today.

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About the Author

Maurizio Škerlič graduated in Natural Science from the University of Trieste, Italy. After that, he continued studying and obtained a Master's degree in Computer Science at the University of Primorska, Slovenia. Finally, he obtained a second level Master's degree in Robotics at the University of Trieste, Italy. In 2017, he won the blue ribbon award at the Rome Maker Faire, European edition. He currently teaches computer science at the High school Pietro Coppo in Isola, Slovenia.

Questions or Comments?

Do you have technical questions or comments related to this article? Please contact the Elektor editorial team at editor@elektor.com.

Related Products

- **ESP-12F – ESP8266-Based Wi-Fi Module**
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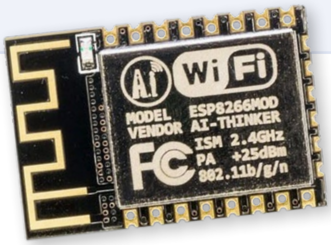

WEB LINKS

[1] Sinric Pro: https://sinric.pro
[2] Elektor Labs page for this project: https://elektormagazine.com/labs/smart-roller-shutter
[3] Arc Suppression Technologies Whitepaper: https://tinyurl.com/arcsuppress

HT-03 Thermal Imaging Camera

By Clemens Valens (Elektor)

The HTi HT-03 Thermal Imaging Camera is an affordable and easy-to-use device with some practical features capable of capturing images and recording videos. It covers a wide temperature range from –20°C to 550°C (–4°F to 1022°F) with a 0.1°C resolution and a precision of ±2%. Its emissivity parameter lets you adjust the camera to the subject for the best precision possible. Let's give it a try.

Like most of its competitors, the HT-03 Thermal Imaging Camera [1] by HTi too comes as a handheld pistol scanner kind of device. For some reason, these cameras never look like photo/video cameras. Which is strange, if you ask me because if it is so practical, then why don't photo and video cameras look like thermal cameras? Both take pictures and videos, point & shoot; it is just that they present the results in different ways. As a matter of fact, the HT-03 also integrates a normal, visible-light camera.

Figure 1: Front and read side of the HT-03 Thermal Imaging Camera. Pull the trigger for about 2 seconds to switch on or off the LED.

HT-03 Thermal Imaging Camera by HTi

The camera comes in a nice cardboard box that you can use for storing the device when you don't need it. The box also contains a manual in English (the camera itself speaks English, Chinese, Italian and German), a USB cable and a USB power adapter. The one in my box has American-style prongs, so, depending on where you live, you may need an adapter for the adapter.

Interestingly, the box includes a card written in Chinese and English with detailed instructions on how to find leaks in radiant floor or under-floor heating systems. Is this an indication of the target audience of this product?

First Power-On

After charging the HT-03's (removable!) battery (2200 mAh, good for 2 to 3 hours), I could switch it on. This is a bit long as you must press the On/Off button (**Figure 1**) for at least four seconds. Then it takes another almost 15 seconds before you can start using the camera. (Power off is long, too.)

The HT-03 Has a Large Display

The 2.1" display (240 × 320 pixels; 120 × 90 pixels infrared resolution, 160 × 120 for the HT-04D) shows a live thermal image. The temperature in the center is shown, together with the lowest and highest values in the image. These two values tend to jump around a lot, which can be disturbing, and so you can switch them off in the settings menu. Their values remain visible at the bottom of the screen.

The HT-03 features two temperature ranges: –20°C to +120°C and 120°C up to 550°C. This is what makes this camera interesting to me, as I have found that an upper limit of 120°C can be a bit tight (let alone those cameras that max out at 85°C or so). Of course, you can switch to Fahrenheit if you prefer (the image processing utility does Kelvin, too).

Visible-Light Camera

The integrated visible-light camera (640 × 480) is practical as it can be mixed with the thermal image, allowing you to see what you are pointing at (**Figure 2**). A thermal image can be a bit confusing, and this option removes that. There are five mixing levels, from visible-light-only to thermal-only in steps of 25%.

Besides mixing the two images, you can adjust the brightness of the screen in three steps, and you can select a different temperature-to-color mapping. Navigating through the menus is easy and intuitive.

Emissivity Is Important

The emissivity menu option is important. As with any measuring device, if you don't know what you are doing, then don't expect super precise results. For an infrared imaging camera like the HT-03, the emissivity of the subject under scrutiny is important for obtaining accurate temperatures. Not every surface has the same value. On the HT-03, you can set the emissivity from 0.01 to 1.00, or you can choose one of the four presets. The manual has a list of emissivity values for common materials.

Image and Video Capture

Photos are taken, or, if you prefer, images are captured, by pulling the trigger. You must confirm if you want to keep it (as JPG). To record a video (MP4), pull the trigger for a few seconds, then confirm (or not). Captured videos and photos can be played back on the device itself, or you can download them to a computer. The camera has about 3 GB eMMC memory available for your productions.

The HT-03 Has PC Utility Built-in

After connecting the HT-03 to a computer, it is detected as an external drive with images in the *IMGS* folder and videos in the *VIDEOS* folder. The drive also contains an image processing IR ImageTools. If you install it, you can visualize your screen captures (not the videos). Now you can take measurements in points or in areas that you can draw in the image. An interesting feature here is the blend slider (**Figure 3**). With it, you can adjust the mix between the thermal and normal image. This is not possible with a normal JPG image viewer.

Summarizing

The HT-03 Thermal Imaging Camera is an affordable and easy-to-use device with some practical features capable of capturing images and recording videos. It covers a wide temperature range from −20°C to 550°C (−4°F to 1022°F) with a 0.1°C resolution and a precision of ±2%. Its emissivity parameter lets you adjust the camera to the subject for the best precision possible. And, as with any precision tool, takes some time to learn how to use it best.

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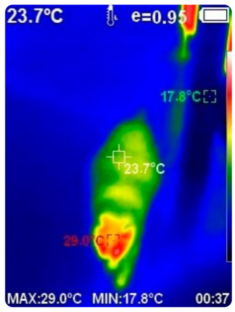
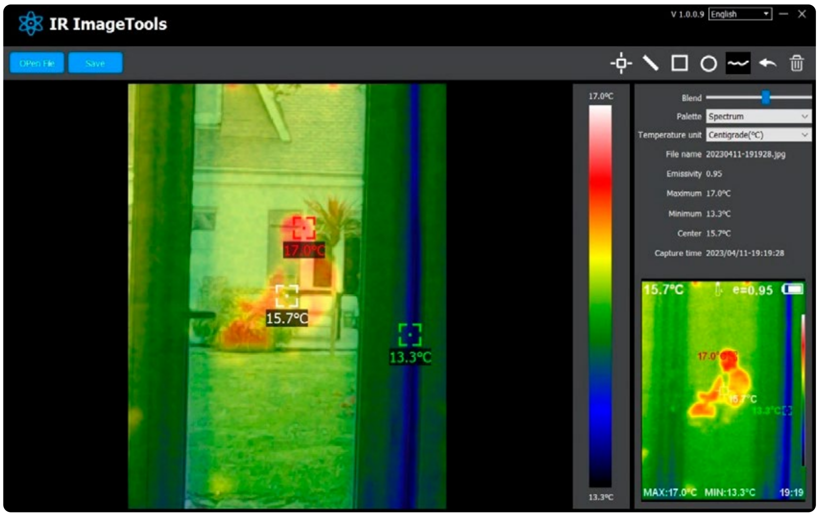


▲

Figure 2: What is the emissivity value for a cat?



▲

Figure 3: Captured a ghost? Oh no, it is just my reflection in the window. The blend slider works on captured images too.

Questions or Comments?

If you have any technical questions, you can contact the Elektor editorial team at editor@elektor.com.

Related Products

> **HT-03 Thermal Imaging Camera (120×90)**
www.elektor.com/20434

WEB LINK

[1] T. Beckers, Review: Thermal Imaging Camera HT-02, elektormagazine.com, October 2018: https://www.elektormagazine.com/review/review-thermal-imaging-camera-ht-02

How Do Capacitive Touch Sensors Work?

By Stuart Cording (Germany)

Capacitive touch interfaces really took hold after their success in the Apple iPod with its rotary wheel. Since then, touch buttons have made their way into almost every household appliance, industrial application, and even our cars. Here we explore the principles of capacitive touch and the challenges of making it robust enough for deployment in a real application.

One day, we were all quite happy with mechanical buttons. Then, in 2003, an Apple iPod [1] with an all-touch interface appeared. Seemingly overnight, the minds of product marketers worldwide were blown, and everything from washing machines and coffee makers to car door handles had to have a touch interface. Much of the success of the iPod can be attributed to its touch-controlled user interface. Behind its shiny ring and its glowing buttons were capacitive sensors [2]. Evaluated many times per second, any change in their capacitance indicated the presence of a finger to signal a press or a rotation. Of course, the phenomenon used was nothing new. The influence of human body capacitance on electronic circuits was discovered in 1919 when Leon Theremin [3] used it for controlling a heterodyne oscillator in his instrument of the same name [4].

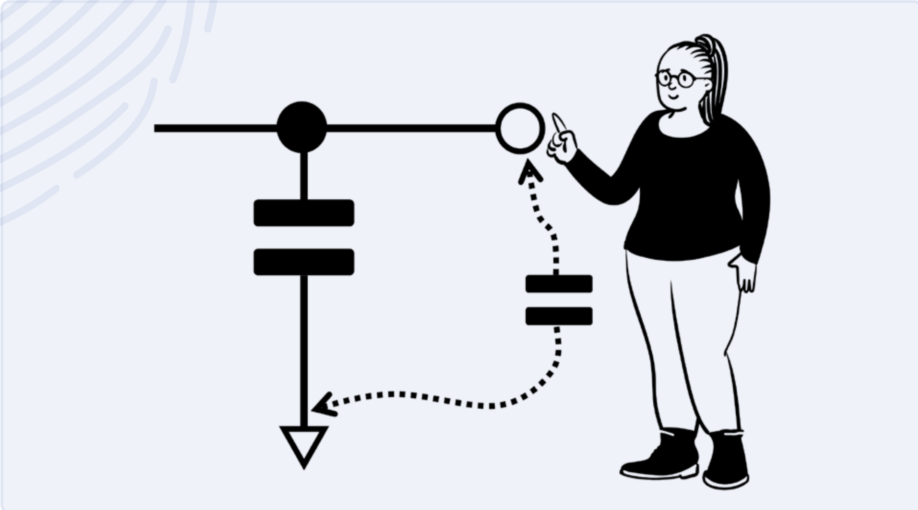


Figure 1: The human body introduces a small, parallel capacitance when touching circuitry (Source: Stuart Cording).

Impact of Capacitance on Circuits

Those with experience in electronics will probably have experienced the impact a finger has on a circuit. Audio and radio circuits often respond to the presence of a finger by changing their output pitch or tuning to a different radio station. I once heard of someone discovering their radio receiver suddenly operated as expected by placing their finger on one of the valves. Being uninclined to place the said finger in the back of the radio forever, they replaced it with a sausage which provided good service for some time and a surprise for the technician who eventually had to replace the pork product with an actual repair.

Capacitive touch circuits rely on the change in capacitance a finger or body part has on the function of a circuit. The presence of a finger forms a parallel capacitance to ground that increases the value of the capacitor in the circuit (**Figure 1**).

One approach could use the capacitors in an oscillator. In this example, we vary the value of C2 between 1 µF and 7 µF in steps of 1.5 µF to simulate the introduction of a parallel capacitance (**Figure 2**).

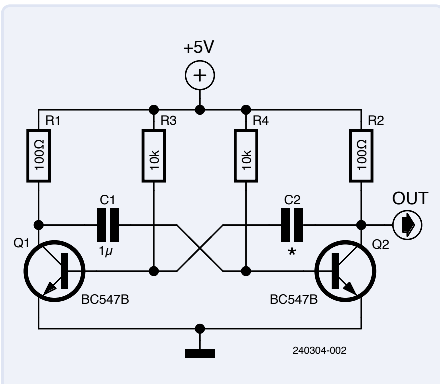


Figure 2: An astable circuit could use one of its capacitors as a touch sensor. In this simulation, C2 is varied to demonstrate the effect.

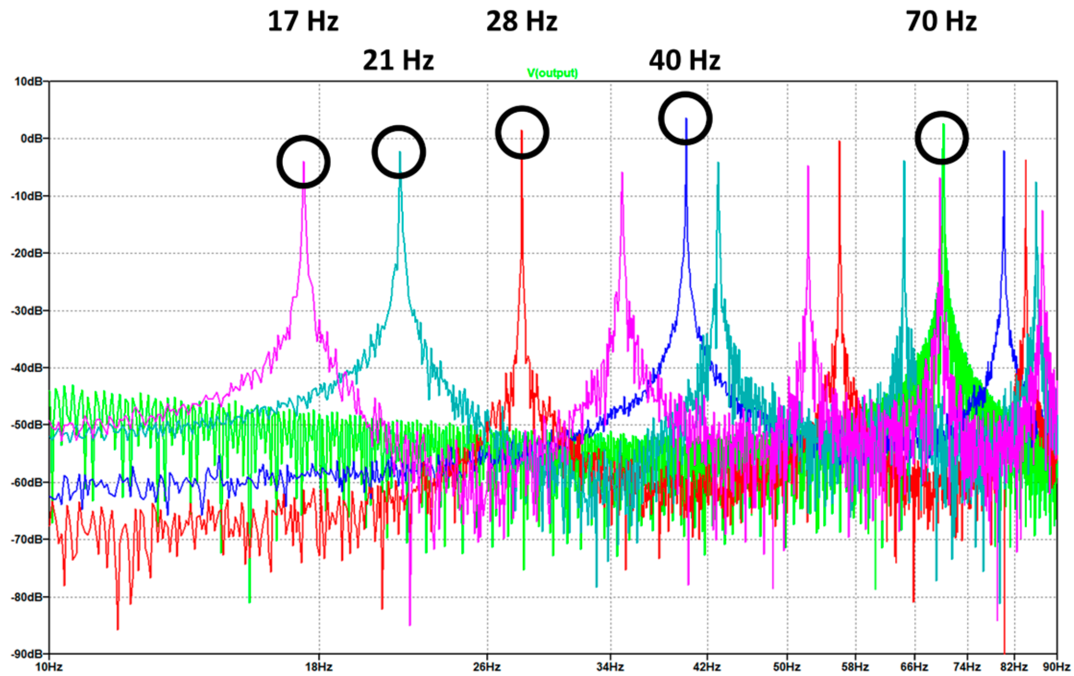


Figure 3: As the capacitance increases, the frequency drops. This could be used to detect a finger touching our capacitive sensor.

Looking at the output's fast Fourier transform (FFT) from **Figure 3**, we can see the frequency starts at 70 Hz, dropping to 40 Hz, 28 Hz, 21 Hz, and then 17 Hz in response to these changes. It should be noted that the output is a square wave, so many harmonics are obscuring the view.

Here we have the beginnings of a touch detection circuit. The output could be connected to a counter. The difference between touch and no-touch can be determined by counting the number of pulses in a specified time period, say 100 ms, and setting a count threshold. Another approach is to measure the variation in on-pulse widths.

At this point, real life comes into play as we try to implement such circuits. The human body forms a capacitance of somewhere between 100 pF and 200 pF. Replacing C1 in our circuit with a 300-pF capacitor and sweeping C2 between 100 pF and 200 pF, the output changes from 356 kHz with no human touch, dropping to 284 kHz in the presence of maximum human-body capacitance, as shown in **Figure 4**. It should be noted that this is only a simulation, and the transistors selected may not operate at this frequency in reality. However, we have the makings of a capacitive touch sensor.

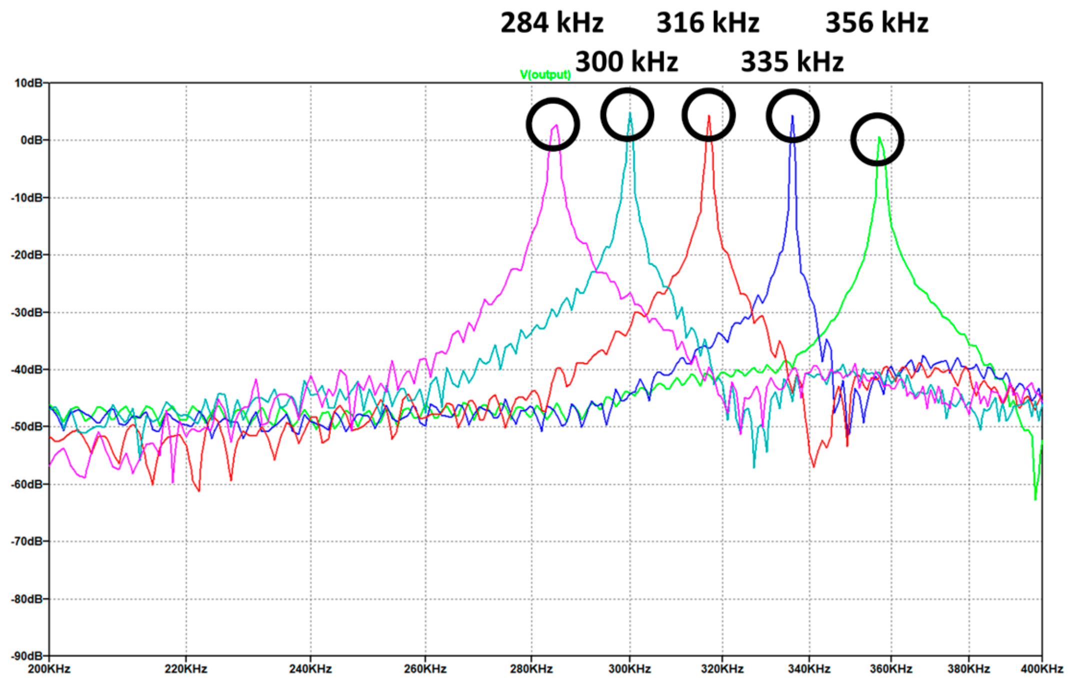


Figure 4: Using the tiny capacitances of the human body, our oscillator operates closer to 350 kHz before being touched.

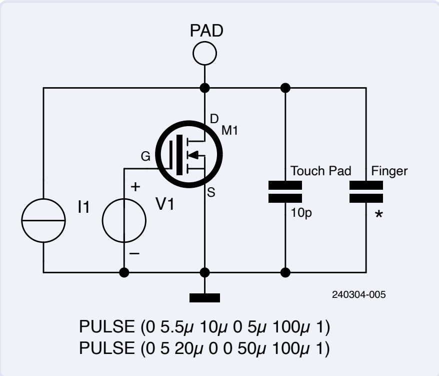


Figure 5: The Microchip CTMU consists of a current source plus a switch to discharge the sensor capacitor.

Types of Capacitive Sensor: Self-Capacitance

There are two types of capacitive sensing: self-capacitance and mutual capacitance. Self-capacitance is the approach described above, where the touch sensor forms a capacitor to ground, and the circuit measures the change in its value when a finger is placed on it. Rather than use the capacitor as part of an oscillator, touch circuits typically use approaches that can more accurately control the charge applied.

One example is the Charge Time Measurement Unit (CTMU) [5], a peripheral in some of Microchip's microcontrollers. It works by applying a constant charge (0.55 µA, 5.5 µA, or 55 µA) to the sensor for a fixed period. Once this period is over, the voltage on the sensor is measured using an analog-to-digital converter (ADC). With the ADC measurement complete, the sensor is discharged completely, allowing the process to be repeated. This is replicated approximately in **Figure 5**.

Like any analog sensing application, the measured signal will be influenced by interference, and some filtering will be necessary to detect a finger touch accurately. In the measurements from **Figure 6**, an approaching finger reduces the peak voltage attained at the sensor.

Self-capacitance touch sensors are typically used when only a limited number of buttons are required or for proximity detection. Grouping sensors together, they can form rotary interfaces or sliders. Interleaving the copper pads on the circuit board can smooth the transition between the individual sensors (**Figure 7**).

Interference is tackled by applying ground rings around the sensor or placing a hatched ground behind the sensor. However, care must be taken to avoid reducing the sensitivity too far. The size of the sensor is also important. Ideally, the sensor area should match that of a human fingerprint, somewhere between 8 and 20 mm in diameter.

Capacitive sensors are typically implemented behind a plastic cover. The thicker the material, the lower the sensor sensitivity. Finally, many surfaces, such as the user interface of a washing machine, are

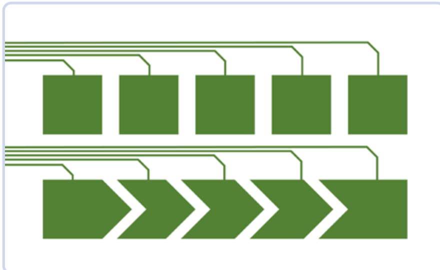


Figure 7: More complex sensors like sliders (top) can deliver "bumpy" results. Interleaving the sensors (below) can help to improve the smoothness of the output.

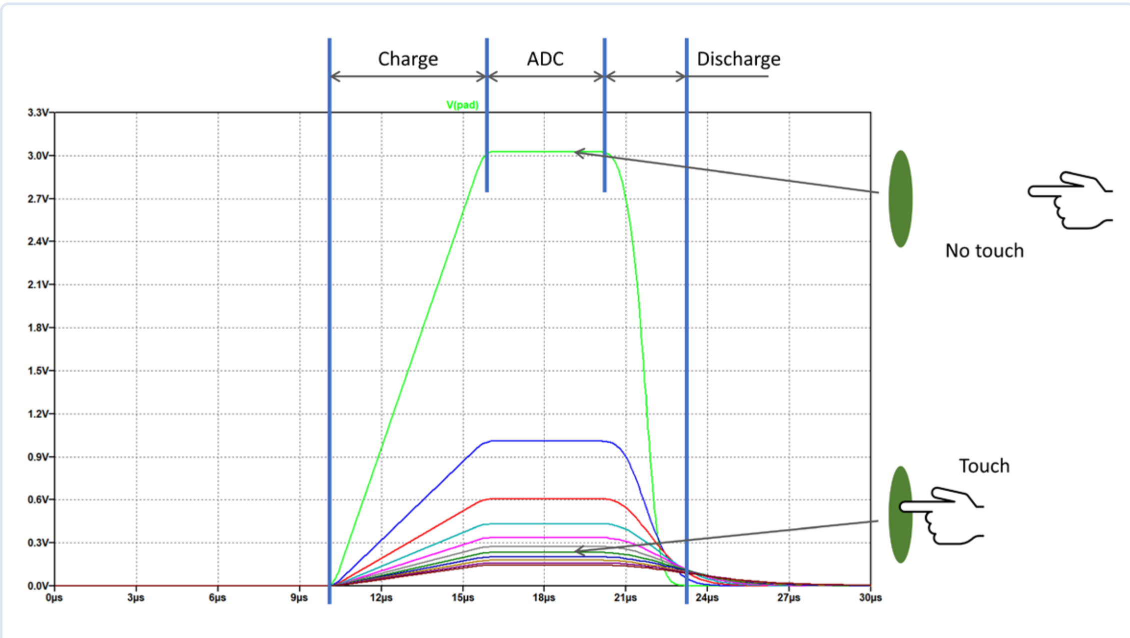


Figure 6: The CTMU delivers a lower voltage in the presence of a touch at its sensor.

curved, while a printed circuit board is typically flat. Flexible PCBs on polyimide can be used to resolve this, but flex PCBs are expensive. Alternatively, the distance between the touch surface and PCB can be bridged using springs or conductive foam. While this resolves the issue mechanically, extra testing and further tuning of the circuitry and software are needed to ensure reliability.

Types of Capacitive Sensor: Mutual Capacitance

Mutual-capacitance sensor approaches use a capacitive sensor connected between two pins of the touch chip or a microcontroller, measuring the change in charge with and without the presence of a finger. The finger essentially steals charge from the capacitor as if it were being placed between the two plates. Thus, a touch appears as a drop in capacitance. This approach allows the creation of a grid of capacitors across flat surfaces to support touch screens, which is typically termed projected capacitive touch, or PCAP. One method charges the X rows of the sensor area sequentially, evaluating the capacitances using the Y rows, with each cycle occurring tens of times per second (**Figure 8**). This is the preferred capacitive touch approach used for the screens of smartphones and touchpads on laptops.

The diamond grid pattern is a good starting point and works well in copper. Ideally, both the X and Y rows should be on the same side, requiring a lot of through-hole connections for either the X or Y rows. Other patterns may also be used depending on application demands, such as size and sensitivity. In smartphones, the pattern is applied to the glass cover above the display using Indium-Tin Oxide (ITO) [6]. This material has a relatively low resistance, and it's transparent, minimizing the impact of screen legibility and loss of brightness. Other materials, such as ultra-fine copper tracks on transparent foil, have also been used. To avoid impacting the visual effect of the display, the copper tracks are applied to lie between the rows of the display's pixels.

These applications make use of dedicated chipsets, such as MaxTouch [7]. Designers

Do It Yourself: LTspice Code

Astable circuit at 70 Hz:

```
Q1 N002 N004 0 0 BC547B
Q2 N003 N005 0 0 BC547B
R1 N001 N002 100R
R2 N001 N003 100R
R3 N001 N004 10K
R4 N001 N005 10K
C1 N005 N002 1µ
C2 N003 N004
V1 N001 0 5V
.model NPN NPN
.model PNP PNP
.lib C:\Users\<USER>\Documents\LTspiceXVII\lib\cmp\standard.bjt
.tran 15s startup
.step param X 1u 2u 0.5u
.backanno
.end
```

Astable Circuit @ 350 kHz:

```
Q1 N002 N003 0 0 BC547B
Q2 OUTPUT N004 0 0 BC547B
R1 N001 N002 100R
R2 N001 OUTPUT 100R
R3 N001 N003 10k
R4 N001 N004 10k
C1 N004 N002 300p
C2 OUTPUT N003
V1 N001 0 5V
.model NPN NPN
.model PNP PNP
.lib C:\Users\<USER>\Documents\LTspiceXVII\lib\cmp\standard.bjt
.tran 1ms startup
.step param X 100p 200p 25p
.backanno
.end
```

CTMU Model:

```
CTouch_Pad PAD 0 10pF
CFinger PAD 0
I1 0 PAD PULSE(0 5.5u 2u 0 0 5u 100u 1)
M1 PAD N001 0 0 NMOS
V1 N001 0 PULSE(0 5 12u 0 0 50u 100u 1)
.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\<USER>\Documents\LTspiceXVII\lib\cmp\standard.mos
.tran 30u
.step param X 0p 200p 20p
.backanno
.end
```

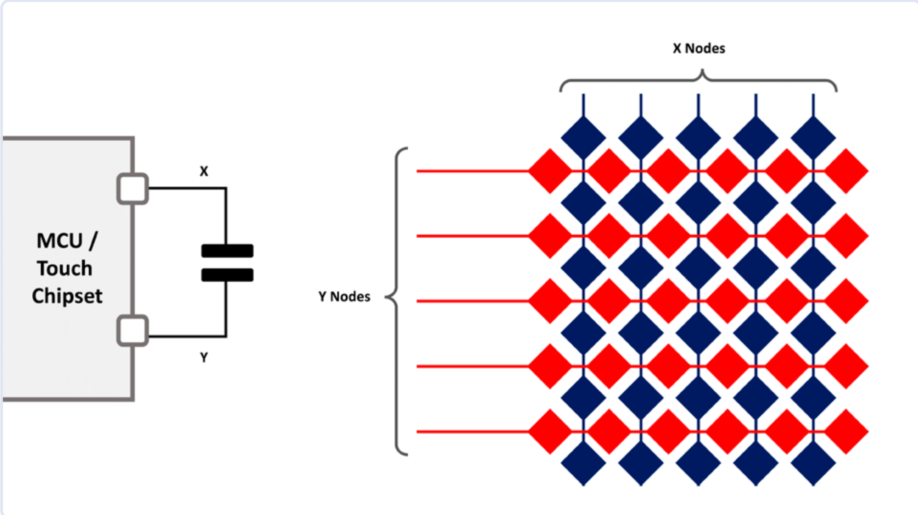


Figure 8: Mutual capacitance implements the capacitive sensors between two pins of the microcontroller or sensor IC (left). Touch screens and touchpads use a grid of diamonds or similar patterns to implement a touch surface (right).

appreciate such fully-featured solutions, as they can evaluate hundreds of capacitances per second and apply the necessary filtering. At their output, they reduce user interaction into X-Y coordinates for each finger and can even provide the gestures used (pinch, swipe, rotate). In the application software, this sensor data is treated much the same as other input devices, such as a mouse, without worrying about decoding gestures and removing noise from the signals.

Adding Capacitive Touch to Arduino and Raspberry Pi

Ready-to-use capacitive touch ICs are available from Microchip [8], Azoteq [9], and Texas Instruments [10]. These greatly simplify circuit construction, typically providing a digital output or serial interface that interfaces directly with an Arduino or Raspberry Pi. However, it should be noted that successful deployment in an actual application requires much testing with different sensor designs and configurations to ensure long-term robustness and reliability. Alternatively, libraries are available for Arduino [11] that enable the creation of capacitive sensors using just a resistor. This is more than enough to enable students and makers to create touch interfaces for exploring interface concepts and trying out ideas rapidly.

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Questions or Comments?

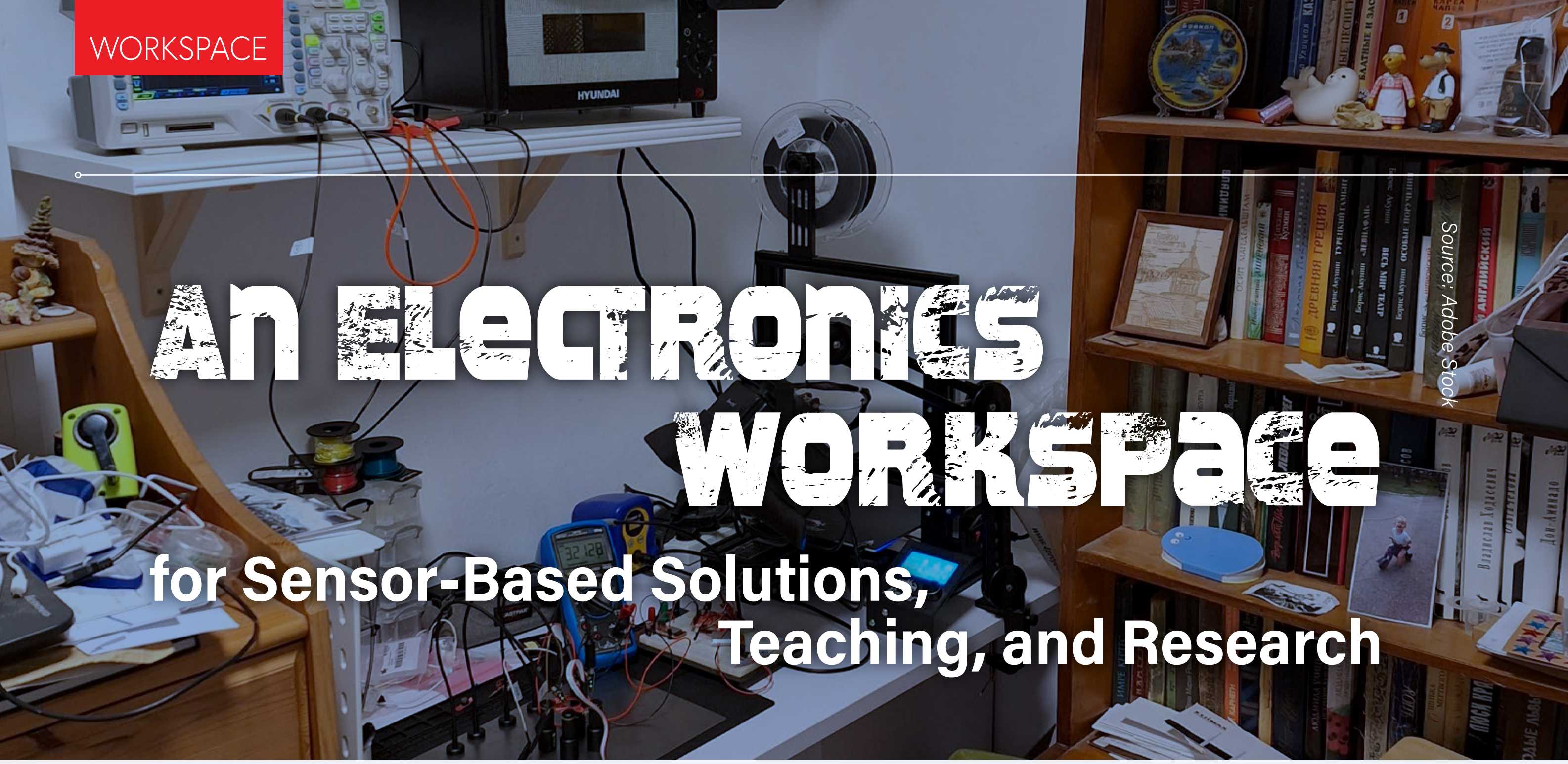
If you have questions about this article, feel free to email the Elektor editorial team at editor@elektor.com.

About the Author

Stuart Cording is an engineer and journalist with more than 25 years of experience in the electronics industry. He specializes in video content and is focused on technical deep-dives and insight. This makes him particularly interested in the technology itself, how it fits into end applications, and predictions on future advancements. You can find many of his recent Elektor articles at www.elektormagazine.com/cording.

WEB LINKS

[1] Apple iPod: https://en.wikipedia.org/wiki/List_of_iPod_models
[2] Capacitive Sensors: https://commons.wikimedia.org/wiki/File:Ipod_backlight_transparent.png
[3] Leon Theremin: https://en.wikipedia.org/wiki/Leon_Theremin
[4] Theremin instrument: https://en.wikipedia.org/wiki/Theremin
[5] Charge Time Measurement Unit : https://ww1.microchip.com/downloads/en/DeviceDoc/61167B.pdf
[6] Indium-Tin Oxide: https://diamondcoatings.co.uk/ito-coated-glass
[7] MaxTouch: https://tinyurl.com/maxtouch-touchscreen
[8] Capacitive touch ICs from Microchip: https://tinyurl.com/microchip-capacitive-touch
[9] Capacitive touch ICs from Azoteq: https://azoteq.com/products/proxsense
[10] Capacitive touch ICs from Texas Instruments: https://tinyurl.com/ti-capacitive-touch
[11] Libraries are available for Arduino: https://arduino.cc/reference/en/libraries/capacitivesensor



An Electronics Workspace for Sensor-Based Solutions, Teaching, and Research

Source: Adobe Stock

Dima Shlenkevitch is a dedicated maker and freelancer specializing in the development of sensing systems. He works from his home office in Israel, which he has been using for over a year. Dima's workspace is integral to his daily activities, reflecting his commitment to innovation and continuous learning

What is your current occupation?

Dima Shlenkevitch: I am a maker. I work as a freelancer in the development of sensing systems. As part of my job, I work on designing electronics, mechanics, software, and sometimes other disciplines defined by the project. I find it very fascinating to work on a new project with new things to learn; this is something that unites the makers over the world. During my daily work, I prototype with breadboards and then design electronics (schematic and layout). Generally, a mechanical enclosure is required. Thanks to the 3D printer I have, I can test my mechanical designs. After PCB production, I assemble everything together, program, and test it.

Dima's electronics workspace.

How would you best describe your space? And how do you use it?

Dima: I describe my space as my home laboratory. I decided to make a home laboratory last year because I wanted to create things even at home. I use my lab almost daily for electronics and prototyping for my work projects. Additionally, I use my lab for personal projects and for teaching my kids about electronics, learning, and research.

When you designed and set up your space, what were your requirements and goals?

Dima: I had very limited space for the lab, so the main constraints were physical dimensions. It started from finding the working table of the right dimensions. I had to find a place for my tools. Many of them are located on the walls, shelves, or hidden in drawers, as you can see in the photo.

Tell us about your technical interests. What sort of projects do you work on in your space? Why do you focus on such projects?

Dima: I like challenging projects with a limited budget. Generally, my projects involve electronics, programming, and mechanics. I am very interested in technology, so I like to see new things and find new solutions. I like limited-budget projects because it forces me to think about unique solutions that are not straightforward. I explore different technologies from other areas to find something helpful for my project to achieve its goal. Sometimes a simple solution may be in front of our eyes, but many times we are fixed on the way that we were taught to do things.

What sort of equipment and tools do you have in your space? Can you tell us how and where you store the equipment and tools?

Dima: I have in my lab: soldering station, power supplies, oscilloscope, multimeters, 3D printer, reflow oven, microscope, hot plate, caliper, soldering equipment, PCB holders, tweezers, electronics components, and modules. I store my equipment on shelves, wall-mounted, and some in drawers.

What do you consider to be your most important or valued piece of equipment or tool? And why?

Dima: A good laboratory power supply. You need it for every project. I am using Rigol DP832. It has good specifications, good user reviews, and a good price for the value.

Is there anything special or unique about your space? What makes this feature so special or important?

Dima: I have a small benchtop reflow oven for prototyping. I like it very much because I made it myself. It is based on the Controleo3 kit that I bought, but it required many modifications to adapt it to my needs. It took me several weeks of work in the evenings to assemble it, but finally, it was done, and I am happy with the result. This equipment made my life much easier when assembling PCBs. Before this, I was assembling PCBs with a hot plate, but the results were not satisfying, and a lot of rework was needed each time. Now, the reflows are the easiest part of every new prototype assembly. Besides the usefulness of the equipment, it was a very nice project to do.

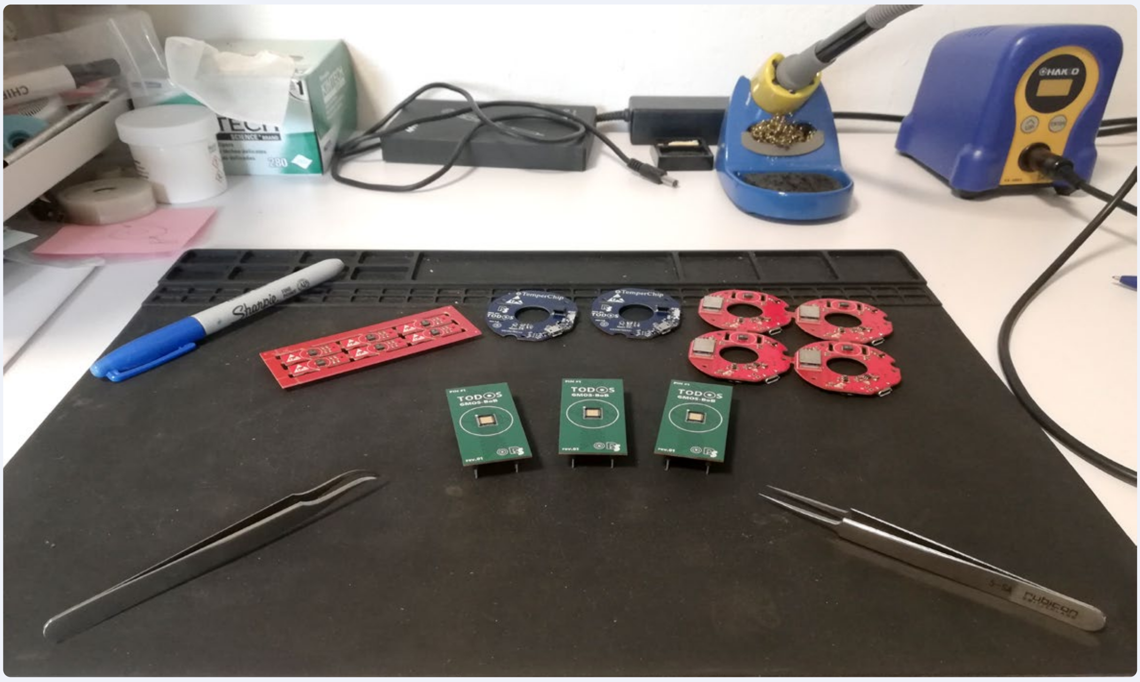
Are you planning anything new for your space?

Dima: I am thinking about upgrading the lab with a new 3D printer. A thermal camera would also be a great improvement for PCB evaluation.

Tell us about your favorite electronics-related project. Did you learn anything interesting?

Dima: I have been working for a while on a new gas sensor. This work is related to my academic work while pursuing my Master's degree in electronics. This gas

Dima Shlenkevitch gives a presentation.



A project in the works.

sensor works on a slightly different physical principle than common commercial sensors. It is based on a miniature thermal sensor and uses a combustion reaction to detect combustible gases in the ambient. This project involves PCB design for sensor evaluation, both for analog and digital parts. I have learned a lot about PCB design and layout. The other part of this project is programming and searching for algorithms for selective gas detection. I like to use Arduino IDE to program and evaluate my projects. It is easy to learn and makes prototyping accessible. I like to use the Artemis module MCU from SparkFun in my projects, as it is very powerful and supported by Arduino IDE.

Are you currently working on an electronics or programming project?

Dima: In recent years, I have been working on the development of sensing systems, and I ran into the idea of making a universal modular sensing system. Today, I am working on a prototype of such a sensing system that should be Lego-like with different blocks that may configure the whole system to my special needs, such as: display block, connectivity block, different sensors, etc. The main requirement I defined for the system is the automatic detection of each block without any intervention from the user. It is my hobby project, so hopefully, I will be able to share it soon.

Do you have a dream project or something you'd love to tackle?

Dima: A project that I have been thinking about for a while is an environmental robot. I live near the sea, and I love to spend time on the beach. The most annoying and frustrating thing is the cleanliness of the beaches. Some beaches that are under municipal responsibility are cleaned from time to time, and others are cleaned only by volunteers a few times a year. So, overall cleanliness is poor. The idea is to make an autonomous robot that can selectively clean the beaches in defined areas without a high labor force. It will be able to clean much larger beach areas and can access areas that are poorly cleaned.

Do you have any advice, tips, or encouragement for other engineers or makers who are thinking of putting together a workspace?

Dima: If you think that you need a workspace, just plan and make it. Don't over plan; start with something small and make it bigger when you need.

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