

## Balcony Power Plants

Optimizations,  
Interesting Facts,  
and Calculations

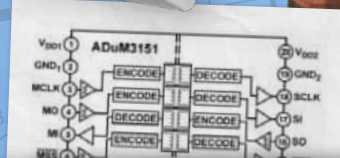
FOCUS ON

## Power & Energy

Powering Up With  
OpenDTU

Read Data From  
Small Inverters

ESP32-Based  
Energy Meter  
The Circuit Diagram



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Volume 50, No. 527  
January & February 2024  
ISSN 1757-0875

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  
[www.elektor.com](http://www.elektor.com) | [www.elektormagazine.com](http://www.elektormagazine.com)

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

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53340 Meckenheim, Germany  
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## Jens Nickel

*International Editor-in-Chief, Elektor Magazine*



## Balcony Power 2.0

When our author Thomas Scherer sent us an article about “balcony power plants” two and a half years ago ([www.elektormagazine.com/210326-01](http://www.elektormagazine.com/210326-01)), we had no idea how much resonance the topic would have with our readers. After all, there was neither a circuit diagram nor a software listing visible in the article! Yet, apparently, the planning and calculating of a solar system, the mounting of solar modules, and the fabrication of power cables appealed to readers’ innate maker sensibilities. And, there was also a lot of benefit to their wallets: Thanks to modules and inverters as mass-produced goods from the Far East and a hefty electricity price for average consumers, PV systems now also pay themselves off for self-consumption — and that within a few years. When I was employed at a photovoltaics-focused magazine about 20 years ago, the situation was quite different. Back then, there were still many CEOs and experts from manufacturers that I could interview in my native German language. The fact that they have since had to look for other tasks is another story.



Many electronics engineers are happy about half-finished power plants at a low price. And surrounding that, there’s still some room for your own electronic projects (see, for example, on page 18). On page 6, Elektor engineer Saad Imtiaz reports on the progress of his ESP32-based energy meter. There’s also a first complete circuit diagram to see, and if I know my readers, there will already be some itching to grab the soldering iron.

Those who are particularly interested in the topics of solar power, power electronics, energy measurement, power supply, and batteries do not have to wait for the next issue with these focal points. At [www.elektormagazine.com/energy](http://www.elektormagazine.com/energy), you’ll find news, interviews, and online articles on the topic all year round. I would be delighted if you regularly visited these and other theme pages to come. Critical feedback, tips on news, and projects are of course welcome!



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## Next Edition

### Elektor Magazine March & April 2024

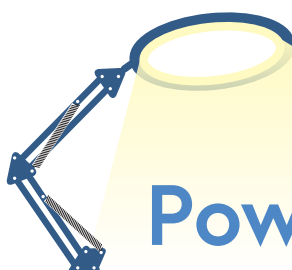
As usual, we'll have an exciting mix of projects, circuits, fundamentals, and tips and tricks for electronics engineers and makers. We'll focus on Embedded Technology & AI.

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- > Detecting Objects with a Raspberry Pi
- > ESP32-RS232 Adapter
- > Frost Guard and Temperature Datalogger
- > Getting started with the Zephyr OS
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- > Low-Cost FPGAs: Tutorial for Beginners
- > Counting Objects with Edge Impulse

#### And much more!

Elektor Magazine March & April 2024 edition will be published around **March 13th**. Arrival of printed copies for Elektor Gold members is subject to transport.



FOCUS ON

# Power & Energy



# Project Update: ESP32-Based Energy Meter

## Next Steps in Prototyping

By Saad Imtiaz (Elektor)

In the first installment of this series, we explored the foundational design of the Elektor Energy Meter. In this installment, we'll look at the next phase in the ESP32-based energy meter project, focusing on detailed schematics, circuit isolation strategies, and key enhancements.



Figure 1: Rendering of the Elektor Energy Meter.

We began our journey of developing a reliable, user-friendly energy meter leveraging the ESP32 microcontroller. In our previous installment, "Prototyping an ESP32-Based Energy Meter" [1], we discussed the initial design requirements, block diagram and the plan for starting this project. Before we give an update on it, let's have a recap. The energy meter conceptual design is shown in the rendering in **Figure 1**.

Our focus was on real-time power monitoring, with an emphasis on safety and affordability. To make the energy measurement precise, we opted for the Atmel ATM90E32AS, a polyphase energy monitoring IC [2]. This IC will get the single-phase voltage from the mains and will use split coil transformers to measure the current safely. The main application microcontroller selected was ESP32 as it has built-in Wi-Fi and very cost-effective when compared to other MCUs. In **Figure 2**,

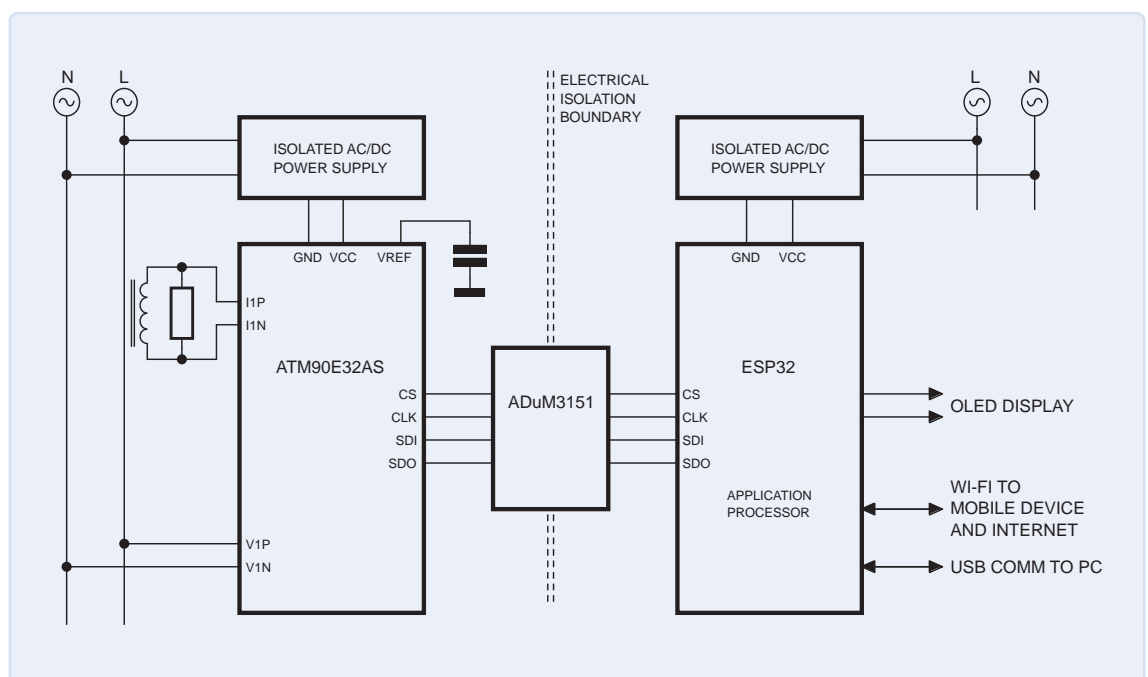


Figure 2:  
Block Diagram of the  
Elektor Energy Meter.



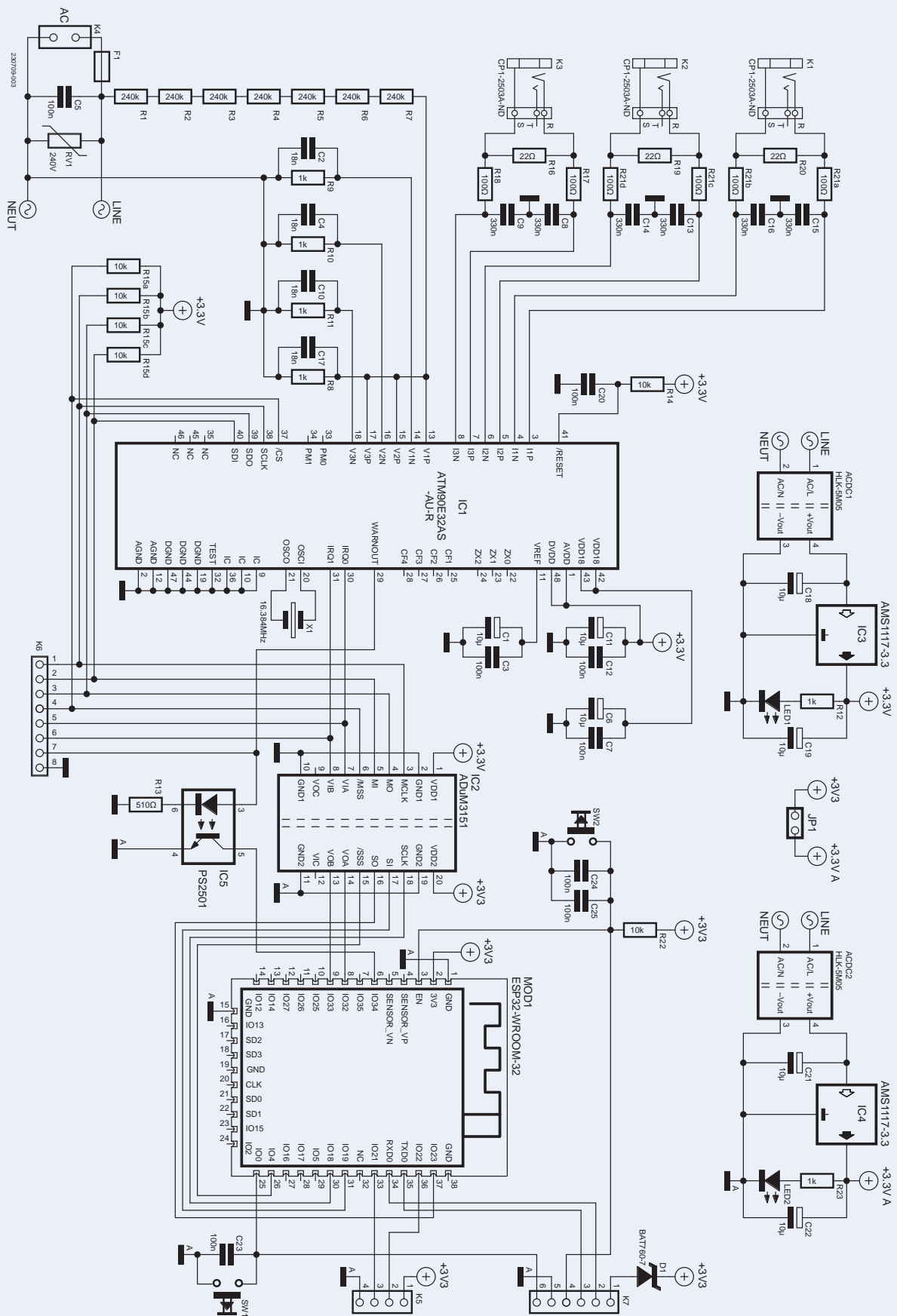


Figure 3: Schematic diagram of the project.



Figure 4: The YHDC SCT013. (Source: YHDC)

the project's updated block is shown. The planned size of the final energy meter is 100×80×30 mm (L×W×H), but, for the prototype, our PCB is 100×100 mm. Our goal of this prototype is as proof-of-concept and, subsequently, if we're successful in it, we'll scale the size down to 100×80 mm or even less for the final version. The main purpose of making this energy meter was to make an IoT-enabled, budget-friendly device that can make accurate energy measurements and provide real-time energy data to the user via a mobile device, so the user can track their power consumption in real time and become more energy efficient.

In this article, we dive deeper into the project's evolution, highlighting the schematic design, the implementation of circuit isolation, and the key improvements we've integrated since our initial concept.

## Schematic Design

The heart of our project lies in its schematic design. The ESP32 microcontroller remains central to our architecture, interfacing seamlessly with the ATM90E32AS for energy measurement. Our updated schematic reflects a more streamlined approach, reducing noise and enhancing signal integrity, circuit isolation, and more. In **Figure 3**, you can see the complete schematic of the project.

IC1 is the ATM90E32AS which is the brain of this entire project, it connects the mains voltage with series seven 240 k resistors (R1...R7) to pins V1P, V2P, and V3P. For keeping things simple, all these pins will be given a single-phase voltage from the mains. You might ask, why not use a transformer instead of these series of resistors? Because as we have size and cost constraints due to the approach we chose. Apart from the small size benefit of using resistors there is another benefit, that is less Phase Delay. Transformers can introduce a phase delay between the primary and secondary windings, which could affect the timing and accuracy of voltage readings in energy measurements. When using resistors, this phase delay is significantly reduced, potentially leading to more accurate real-time voltage readings. But, using these series resistors has a major disadvantage, i.e., no galvanic isolation. We will talk about this later in the article.

Now moving to the current measurement: For that we will be using coil transformers (CTs). Connectors K1-K3 are audio jack connectors

where the SCT013 by YHDC will be connected, which is a split core type CT, shown in **Figure 4**. The reason for selecting CT was that it is cost-effective easy to use, and non-invasive.

The energy metered is powered by two Hi-Link HLK-5M05 modules ACDC1/2, to ensure galvanic isolation between the MCU and energy meter circuitry, protecting against high-voltage risks. AMS1117-3.3 regulators provide stable 3.3 V power, essential for the ESP32 and other low-voltage parts. Safety is further bolstered by fuses (F1) for overcurrent protection and a metal oxide varistor (MOV) (R23) against voltage spikes. For diagnostics, LED1 and LED2 indicate power and operational status. Connector K6 connects to all the outputs for the MCU for debugging operations.

## Circuit Isolation

In the schematic, you might have noticed two DC grounds, GND and GNDA. The ground terminal (GND) is connected to IC1 and is also connected to the AC mains neutral. GNDA is an isolated ground terminal that is connected to the ESP32-WROOM-32D, which is MOD1. To ensure safety, it is imperative to isolate the ESP32 from the AC mains neutral. As the IC1 lacks galvanic isolation, it is imperative to isolate these components from each other. Now, the question arises as to how the SPI between these two chips will be communicated. Here is when IC2, an Analog Devices ADuM3151, comes into play.

The ADuM3151 is pivotal in ensuring safe communication between IC1 and the ESP32-WROOM-32D, providing galvanic isolation for SPI lines. In **Figure 5**, you can see the functional block diagram of IC2 [3]. It uses inductive couplers to transfer digital signals across an isolation barrier, effectively shielding the computer-connected ESP32

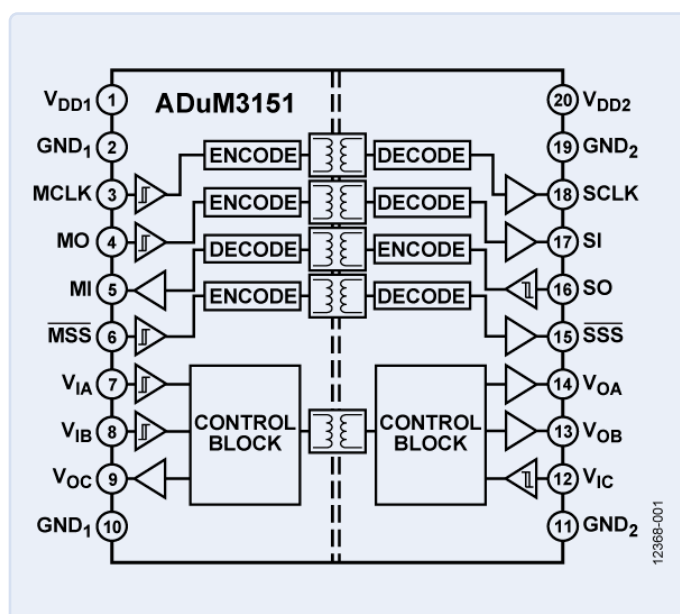


Figure 5: ADuM3151 SPI isolator functional block diagram. (Source: Analog Devices [3])



from the AC mains' high-voltage transients. This choice is crucial for preventing damage during coding and debugging, while its capability of supporting multiple isolated channels ensures reliable and secure SPI communication, maintaining data integrity and aligning with the project's safety and performance goals.

## User Interface and Interaction

The user interface of the ESP32 Energy Meter project is designed to be informative and user-friendly. An OLED Display, connected to connector K5, which is interfacing with the I2C pins of the ESP32, will serve as the primary display medium. This display will show all relevant data to the user in real-time, including energy consumption metrics and system status. The choice of OLED technology ensures clear visibility and a responsive interface.

In addition to the hardware display, the project incorporates a web server hosted on the ESP32. This web interface will mirror the data displayed on the OLED screen, offering users an alternative way to monitor their energy usage. The development team is dedicated to creating a web UI and UX that is both user-friendly and detailed, ensuring accessibility and comprehensiveness in data presentation. This dual-interface approach allows users to interact with the energy meter both physically and remotely, enhancing the overall usability of the system.

## Next Steps and Future Plans

As the project moves forward, the initial PCB design has been sent off for manufacture. Upon its return, the focus will shift to the firmware side of the project. The firmware development will involve programming the ESP32 to accurately process and display energy consumption data, manage the web server, and ensure smooth communication between all components.

Looking ahead, there are plans to integrate additional features to enhance the energy meter's functionality. These may include:

- Remote monitoring capabilities: Allowing users to check their energy consumption data from anywhere via the web interface.
- Alerts and notifications: Implementing a system to alert users about unusual energy consumption patterns or potential system issues.
- Data analysis tools: Incorporating analytical tools in the web interface to help users understand their energy usage trends and identify areas for efficiency improvements.

We are committed to continuous improvement and innovation, with a focus on user feedback to guide future enhancements. The goal is to not only provide a reliable energy monitoring tool, but also to empower users with insights into their energy usage, fostering awareness and efficiency. ◀

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## Questions or Comments?

If you have questions about this article, feel free to email the author at [saad.imtiaz@elektor.com](mailto:saad.imtiaz@elektor.com) or the Elektor editorial team at [editor@elektor.com](mailto:editor@elektor.com).



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## Related Products

- **LILYGO T-Display-S3 ESP32-S3 Development Board**  
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- **ESP-C3-12F-Kit Development Board (4 MB Flash)**  
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- **Joy-IT NodeMCU ESP32**  
[www.elektor.com/19973](http://www.elektor.com/19973)



## WEB LINKS

- [1] Saad Imtiaz, "Prototyping an ESP32-Based Energy Meter," Elektor Guest Edition 2023: <http://www.elektormagazine.com/230646-01>
- [2] ATM90E32AS Poly-Phase Energy Metering IC: <https://www.microchip.com/en-us/product/atm90e32as>
- [3] Analog Devices Inc. ADuM3151 SPI Isolator™ Digital Isolators: <https://eu.mouser.com/new/analog-devices/adi-adum3151-isolators>

# Optimizing Balcony Power Plants

## Considerations, Interesting Facts, and Calculations

By Dr. Thomas Scherer (Germany)

The hype surrounding solar technology in general and balcony power plants in particular has continued unabated since the start of the war in Ukraine (and the resulting uncertainty regarding energy supply in central Europe). Since our last article in 2021, supply and sales in this sector have seen huge growth and prices are lower than ever. The background information in this article will make it easier to get started!

A war has been raging since February 24, 2022, which has caused shortages and rising energy prices outside Ukraine, too. Reduced gas supplies from Russia have made it clear, particularly in Central Europe, that environmental protection does not come for free. In Germany and Denmark, a kilowatt hour of electricity cost well over €0.40 at times, placing a burden not only on energy-intensive industry, but also on John and Jane Doe.

In response, the German government waived all VAT on solar power products (including installation costs for solar systems) as of 2023. As a result, both large and small solar systems, aka balcony power plants, experienced an incredible boom, which led to a sharp drop in prices. In 2023, there was not a single technical magazine, major news magazine, or daily newspaper that did not publish articles on balcony power plants. Elektor had already published an article in 2021 [1]; recently, there was even a whole special issue on the topic [2]. So, obviously interest and the need for information are still high.

### What Is a Balcony Power Plant?

The answer is quite simple: A balcony power plant is a small solar system for generating electrical energy. As the name suggests, it is so small that you can actually install it on a balcony if you'd like to. But this definition is not exhaustive.

The key point is that it is a low-power solar system. In the EU, systems with a maximum peak output of 800 Wp (watt-peak) fall under a kind of *de minimis* limit. Therefore, you can install such a system without a lot of red tape as long as you work in an electrically safe way. In Germany, however, things are not quite as simple, as the power is limited to a maximum of 600 W (as of the end of 2023) and, due to the federal structure, each federal state has its own conditions for approval by the respective grid operators. However, the bureaucratic effort is still much less than for "real" solar systems with more than 600 W of output. In addition, bureaucracy is soon to be reduced further and the 600 W limit is to be raised to the European limit of 800 W.

The purpose is also important: A balcony power plant is not intended to feed electricity into the public grid and receive remuneration for it. The expected income would make no economic sense in view of the associated fees. Rather, a balcony power plant is supposed to generate just enough electrical energy to cover the "idle power consumption" of a house, which is caused, for example, by the heating circulation pump, the refrigerator, the Internet router, and countless plug-in power adapters. Any "excess production" is donated to the grid operator in order to keep the small system simple and inexpensive. This has consequences in terms of dimensioning.

Technically speaking, a balcony power plant consists of one or more solar modules and a suitable inverter to convert the direct voltage into grid-compliant 230 V alternating current for feeding into the public power grid. This raises questions about the appropriate design of the system, the economics, the quality of the individual components, and other related factors.

### Economic Efficiency

In addition to the undisputed ecological benefits of self-generated electrical energy, it is certainly important to know to what extent the purchase and installation of a balcony power plant is financially viable. There are many figures circulating on the internet that are — if not simply exaggerated — at least very optimistic. However, it is possible to determine the expected yield of a solar power system with reasonable reliability. The following describes how to do this.



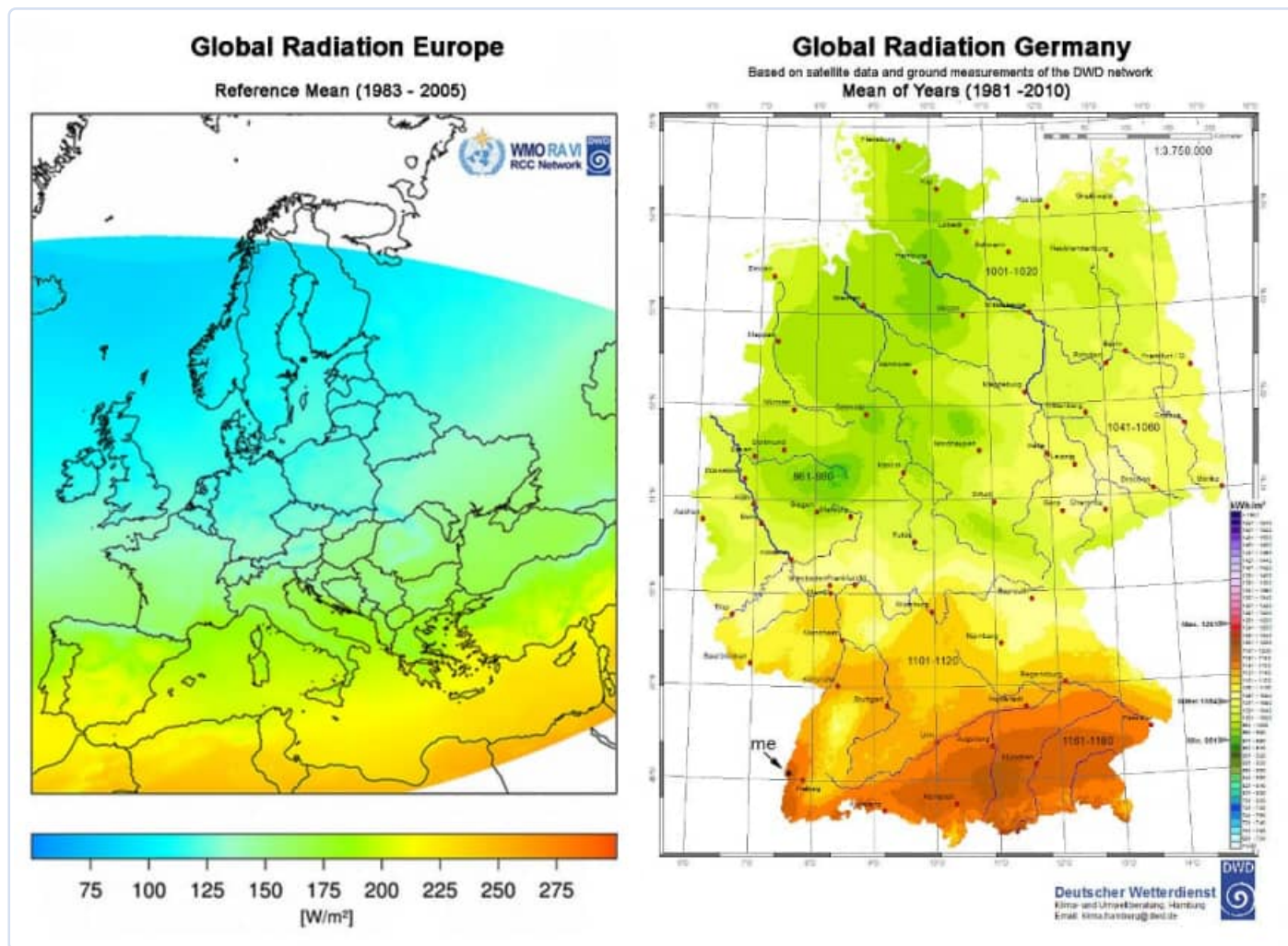


Figure 1: Solar radiation maps from the German Weather Service (DWD) (Source: [3]).

First, latitude is important because it determines not only the angle at which the sun's rays hit the earth's surface, but also the cumulative value of solar energy that can be expected on a given area over the course of a year. The former can be largely compensated for by adjusting the installation angle of the solar modules, but the consequences of the location simply have to be accepted. The German Weather Service provides radiation maps [3], from which the average solar energy per year (**Figure 1**) and much more information can be obtained. You can even find comprehensive solar yield calculators on the internet. Maps and calculation tools for other countries can also be found online. So, it makes a difference whether you set up the balcony power plant on the North Sea coast or in southern Germany, or whether you live in Scandinavia, North Africa, or even Mexico.

A rule of thumb for Germany says that an average of around 1 MWh/m<sup>2</sup> per year can be expected. This ranges from my home in southern Baden with around 1.2 MWh/m<sup>2</sup> to around 900 kWh/m<sup>2</sup> between Flensburg and Kiel. In addition to this "general" solar radiation, the local climate must also be considered. It makes a further difference whether you live on the slope of a mountain or mountain range facing the main wind direction (upwind) or in its lee (downwind). It rains more and heavier in upwind locations, which means that more clouds are to be expected than in downwind locations. Even air pollution (especially in winter) has an influence.

So, you have to reckon with at least 10% of additional variance here. I live quite fortunately, according to these criteria: in southern Baden in the Rhine plain, on the downwind side of the larger mountains of the Vosges. At least as far as summer is concerned, I can clearly achieve higher yields than in neighboring Freiburg, for example, as more clouds are to be expected there due to the upwind location despite the same geographical latitude.

With my first balcony power plant, whose two 330 Wp panels totaled 3.2 m<sup>2</sup> (see **Figure 2**), I calculated a maximum gross daily output of 1.2 MWh/m<sup>2</sup> × 3.2 m<sup>2</sup> = 3.84 MWh per year for my geographical location. Unfortunately, solar cells do not have an efficiency of 100%. The panels I used achieved just under 20%, which would result in a yearly harvest of 770 kWh/y. Due to the non-optimal south-facing orientation and too flat an installation angle, I calculated with only 75% of the optimum, which would still result in 580 kWh/y.

However, the maximum 600 W feed-in of the inverter installed at the time could not be fully utilized. Some of the energy generated typically ends up in the grid as a gift for the general public. In my case, the base load is somewhat higher than average due to two fridges, a large freezer, central heating with two pumps, the usual electronics including a PC with monitor in the home office, and an elderly mother who has the TV running several hours a day.



Figure 2: The two 330 Wp panels of my first balcony power plant on a canopy.

So, I assumed that I would use around 75% of the electricity myself, which meant that I could expect to save just under 430 kWh in real terms, which would have been around 125/y at the electricity price of €0.30/kWh at the time. The balcony power plant cost around €600 and would have paid for itself in four years.

However, after one and two years, my yield was actually higher. I achieved a gross feed-in of first 630 and then 670 kWh/y (see **Figure 3**), which can probably be explained by my optimal location in terms of solar power with few clouds. This was also adequately reflected on the electricity meter, as the electricity consumption was around 500 kWh/y lower than in previous years.

If you live further north than I and have to live with a global radiation of around 1 MWh/m<sup>2</sup> per year, you would therefore be able to expect a harvest of around 460 kWh/y with an otherwise identical system. On the other hand, the proportion of self-use should be higher, so that you can ultimately expect an electricity bill reduced by 350 to 400 kWh. However, this calculation applies to the state of the art 2.5 years ago.

Today, the efficiency of solar cells has improved slightly to 21–22% and, in addition, larger panels are now being used at lower cost. At present, solely due to technical progress and new regulations, we can therefore easily expect savings that are 25% higher than those of my first balcony power plant.

## More Power

Legal changes are currently underway in Germany that will finally allow the 800 W permitted in many other EU countries for balcony power plants. This was not only reason enough for a hardware update on my part, but should also be reason enough for you to opt for an output of more than 600 W if you are now planning a balcony power station. If you buy a solar inverter with 800 W or more today, you can normally still use it immediately, because you can either throttle many of these models to 600 W yourself or even buy them already throttled. Once the 600 W limit has been waived, you can simply switch the inverter back to 800 W. Even larger inverters can make sense, but more on that later.

In addition, the prices for panels have fallen dramatically since the beginning of 2023, and not just because of the VAT currently being waived in Germany. You can currently buy panels with a peak output of 425 Wp for less than €100. More powerful panels are also somewhat larger, as the increase in efficiency from just under 20% to over 21% is not sufficient to achieve this increase in output. My panels are 176.2×113.4 cm in size (see **Figure 4**) —



Figure 3: Harvested energy after one year of operating the first balcony power plant.

a standard size. The transportation costs are significant because you can no longer transport the modules in a normal car — not even in a station wagon (unlike the old 330 Wp models). Collective orders are worthwhile here if you can find fellow buyers among friends or family members.

In Germany, there is still a legal hurdle with larger panels at the moment: Solar +modules with a surface area of more than 2 m<sup>2</sup> are not approved for roof mounting. I was lucky because my panels are exactly 1.998108 m<sup>2</sup>. In response to an inquiry to the German Federal Ministry for Economic Affairs and Climate Action, I was told that the area limit will be raised to 3 m<sup>2</sup> in the course of the proposed “Solarpaket II” legislation [4], which will then make panels with over 550 Wp possible.

For a newly designed balcony power plant, you should therefore opt for panels with more than 400 Wp and soon probably for those with more than 500 Wp. If you are planning a system with only one module for space reasons, you should buy an inverter with 400 W to which only a single module can be connected. The 300 W predecessors are therefore already obsolete and can only be sold at a greatly reduced price. The same applies to a two-panel system: if necessary, buy an inverter with an output of 800 W that can be throttled to 600 W or is already throttled and connect two panels with over 400 Wp to it. Unfortunately, panels with more than 2 m<sup>2</sup> are still a dream of the future and will probably not be legal until sometime in 2024.

However, before you go ahead and click on “Buy” somewhere, we recommend that you read this article in full, as there are a few more things to consider.

## Dimensioning

As already mentioned, the aim of a balcony power plant is to cover the “idle power consumption” of your house or apartment. In almost all cases, the base power requirement will remain well below 600 W and will tend to be between 100 and 200 W. If your balcony power plant is supplying more power than required, a larger proportion of the increased power will simply be fed into the grid, which is economically useless for you. So why does a more generous dimensioning still make sense?

It is well known that a solar system does not supply any energy at night, even under moonlight. Let’s assume that your base requirement for electrical energy is a modest 100 W. This alone results in an annual energy requirement of 876 kWh. For a typical two-person household, this is almost a third of the total requirement.



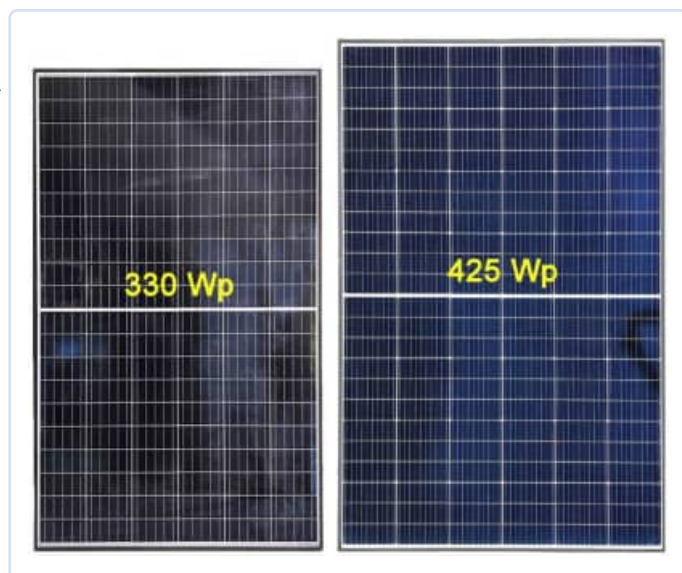


Figure 4: Size comparison between my old 330 Wp panels and the new 425 Wp panels.

On average, it is night for 12 h/d — half of this basic consumption = 438 kWh/y is therefore inevitable unless buffering is provided by a battery. However, not all of the other half can be covered by a balcony power plant, because at dawn and dusk, even two 425 Wp panels only achieve less than 100 W at times. In northern latitudes with longer twilight periods, it is therefore certainly not possible to exceed 100 W for more than 10 h/d on average. There is also bad weather — especially in the winter months. **Figure 5** shows that even my new, more powerful balcony power station did not reach 100 W at 4 pm at the end of October under a cloudy sky.

What to do? The first measure is probably to install panels that are as large as possible. The important thing here is not to achieve the highest possible peak values, but to supply more power at dusk or in bad weather and thus cover as much of the base load as possible for a larger part of the day. The peak power of the inverter is only of interest if you operate heavy consumers such as washing machines, dryers, or electric stoves in good weather and thus compensate for larger proportions of this consumption. For me, the balcony power station has led me to pay attention to these times. By the way, when operating an air conditioning system in summer, you can assume that its power consumption is almost completely covered by an 800 W balcony power plant.

You can take things to the extreme by using a more powerful inverter with four inputs and four panels. There are commercially available types with 1,200 to 1,500 W that are suitable for this. As a rule, these can also be throttled down to 600 or 800 W and are therefore formally legally compliant — if the respective grid operator does not raise any issues. However, this should become easier for German customers with the “Solarpaket II” legislation. Doubling the maximum output has the great advantage that the base load threshold is exceeded sooner and twice as much energy can be harvested even in bad weather. The savings effect is therefore greater, but unfortunately, as expected, it does not scale linearly, so the return on investment is lower due to the poorer price/performance ratio. But, if you want to achieve maximum energy savings, you have to go down this route.



Figure 5: At the end of October, my new balcony power station produced less than 100 W under cloudy skies.

However, there is a small catch with inverters for four panels: They do not normally have more MPPT controllers than inverters for just two panels. With quadruple inverters, two panels are therefore often connected in series internally, with one MPP tracker available for each pair. This is not a major problem if you align all four or at least two panels in the same way.

The alignment of the panels is also relevant for an optimum yield. If you install two panels on a balcony as a standard solution, then you have no choice. But if you have space, i.e. a flat roof or canopy somewhere, you can also align one panel more to the east and the second more to the west. South-east and south-west would be a good solution, allowing the exceeding of the assumed 100 W threshold to start earlier in the morning and end later in the evening, which compensates for the base load for longer (at the expense of peak power).

You can save even more energy by aligning two panels in a four-panel system to the south-east and two to the south-west. If you want to realize four different orientations with four panels, it is recommended to purchase two 800 W inverters instead of one quadruple inverter, as this gives you four MPP trackers (see **Figure 6**). In general, the entire installation is considered a single “power plant” or system even if two inverters are in operation at the same time because the legal regulations say nothing about the specific structure or the number of panels, but only about the maximum output. The solution with two inverters is only slightly more expensive, and is also preferable if a different location is chosen for each pair of panels. A longer mains cable is cheaper and easier to lay than four longer solar cables.

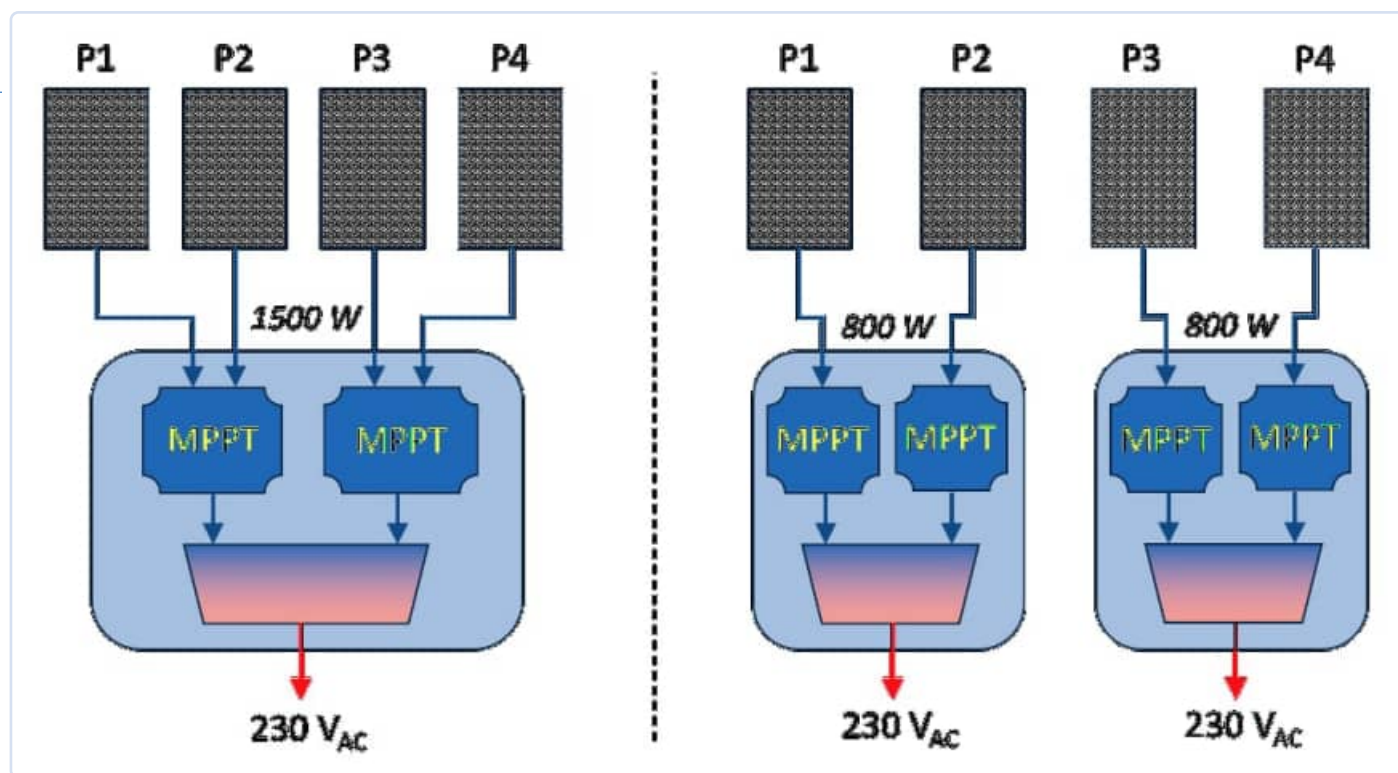


Figure 6: Two solutions with four panels: one inverter with two MPP trackers on the left and two inverters with a total of four MPP trackers on the right.

Of course, one MPP tracker per panel also has positive effects in the event of shading, as each panel is then treated individually. For this reason, there are even people who implement larger solar systems with over 10 kWp of installed solar power using many panels with several low-power dual microinverters (instead of one large inverter). Such small inverters can usually be connected on the grid side in a chain of up to six units.

### Choosing the Panels

As already mentioned, it no longer makes sense to buy smaller panels with peak outputs below 400 Wp. However, if you want to use really large panels in anticipation of the new legislation, you must take particular care to ensure that neither the maximum current nor the maximum voltage at the inverter inputs is exceeded. Both parameters depend on the size of the panels and their design. The widely used HM-800 inverter from Hoymiles, for example, can handle a maximum of 60 V and 12.5 A at its inputs. Not every panel can be connected to this.

As the number of cells increases, the maximum voltage is higher for a given output and the short-circuit current is lower. Due to lower ohmic losses, modern panels are always equipped with halved solar cells instead of full, square ones. So, when we talk about “cells,” we usually mean half-cells. A common solar module of the type JKM420-54 from Jinko Solar [5] has the internal structure shown in **Figure 7**. Its total of 108 half-cells is divided into three series-connected blocks of two parallel-connected series circuits of 18 half-cells each. The equivalent series connection is therefore 54 half-cells, and two such chains are connected in parallel. Under load, one cell delivers just under 0.6 V. In this solar module, the 54 effective cells achieve a voltage of 31.5 V at maximum output. At just over 38 V, the maximum open-circuit voltage is within the safe range for practically all inverters suitable

for balcony power plants. However, with only 108 half-cells for such a powerful panel, the cell area — and therefore the deliverable current — is relatively high. The data sheet reveals that the maximum operating current of just over 13.3 A already exceeds the maximum specification of 12.5 A for the HM-800 inverter. However, some models from other manufacturers allow a maximum current of up to 15 A, which is high enough.

For the majority of microinverters currently on offer, however, you should steer clear of solar modules with only 108 half cells. By choosing panels with 120 cells or more in the range up to 435 Wp, you are playing it safe in terms of current. I have selected panels with 144 cells and these deliver a maximum of just over 10 A. In winter, however, they can reach well over 50 V open-circuit voltage in sub-zero temperatures, sunshine and without load. The 60 V limit of the HM-800 is sufficient here, but it is important to check whether the inverter you are considering can handle the maximum open-circuit voltage of the preferred panels.

For large panels in the class above 500 W, significantly higher currents and/or voltages must be expected, depending on the number of cells. Generally, only newer inverters can cope with this. Checking the technical data of solar modules and inverters is mandatory here if you do not want to risk any failures. The newer HMS class inverters from Hoymiles can already handle 14 A at the inputs.

### Installation

Depending on the installation location, different strategies must be used for mounting the panels. You can get creative here if you like metalwork. However, there are also suitable mounting systems for every installation variant available to buy at acceptable prices, so it is often not really worth doing it yourself using galvanized

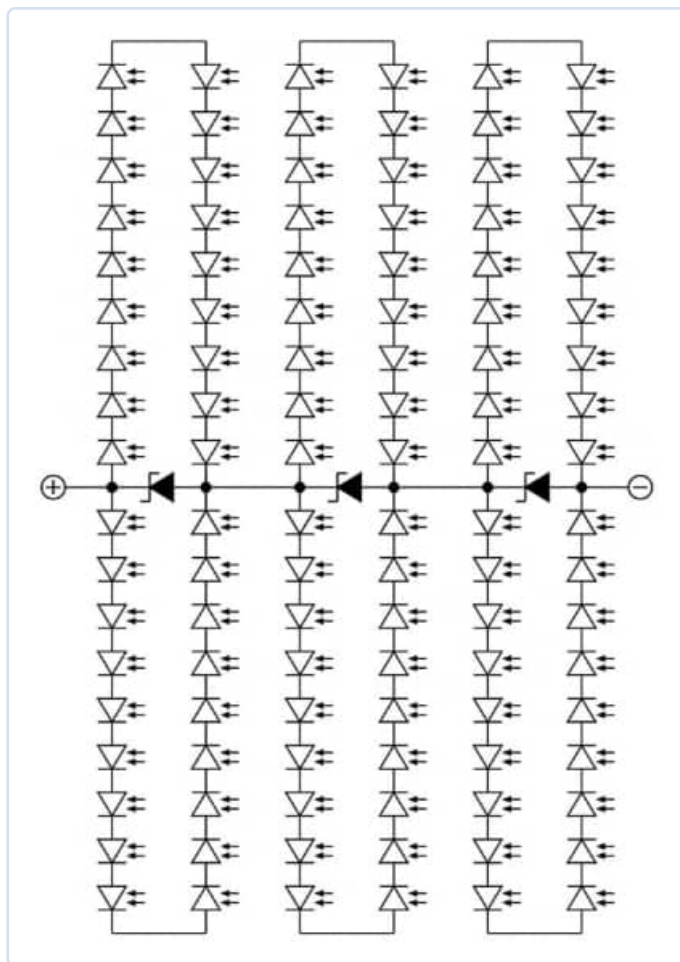


Figure 7: Internal circuit of a modern solar module consisting of 108 half cells.

steel or aluminum profiles.

First of all, of course, it makes sense to think about the orientation. South is optimal, at least in the Northern Hemisphere. Antipodes must align their panels to the north, and at the equator, they can theoretically even lie flat and point directly towards the sky. This is where the effects of the tilt angle come into play. For one thing, flat angles are not really favorable, even at the equator, because dust, dirt, and bird droppings will accumulate and cannot be easily washed away by rain. In addition, solar radiation beyond the tropics is never perpendicular to the earth's surface, but has a more or less steep angle. Therefore, if you don't use a lot of technical effort to track the position of the sun with the panels, you need to think about the optimum installation angle [6][7].

First of all: There is no universal optimum installation angle, because the optimum depends not only on the installation location or its geographical latitude, but also on your personal requirements. There are calculators or tables on the internet that can be used to determine the maximum yield, depending on where you live. According to these, the optimum angle for Germany in relation to the horizontal would be between 38° (far north) and around 32° for me in the south. However, this applies to the optimum yield cumulated over the whole year, which is a reasonable, sensible criterion only for larger solar systems where the energy fed into the grid earns money. However, as we all know, the sun is significantly lower in winter than in summer. Consequently, with flat angles, more energy is obtained in summer and less in winter than would

be possible. The reverse is true for steep angles. For balcony power plants, however, the peak value is less important than the availability of medium and low outputs over time. In this respect, steeper angles make more sense here, as higher outputs are achieved in winter at the expense of summer and the overall yield.

Based on these considerations, I mounted my panels at an angle of 45°. I am convinced that this saves me the most. Initial projections based on three months with my new 800 W balcony power station with a better installation angle confirm that I can actually expect an increase in electricity cost savings of more than 25% compared to the old 600 W variant, despite throttling back to 600 W.

Fortunately, the question of the installation angle is nowhere near as critical as one might think. The illumination intensity curves over the year move more or less sinusoidally between winter and summer, rather than linearly. The same applies to the movement between sunrise and sunset. The intensity of the sun as it moves from east to west also resembles a sine wave truncated at the bottom. A deviation from the ideal southern orientation and from the ideal installation angle of e.g. 10° only results in a yield reduction of 0.5 to 2%. A deviation of ±45° from south reduces the solar harvest by only 5.1%. Even an installation angle error of 20° accounts for less than -4%. However, these values only apply to the maximum energy harvest. In the case of a balcony power plant, however, you should simply be above the threshold of the continuous power consumption of a house as often and for as long as possible, which is why a little more emphasis should be placed on good alignment and steeper installation angles.

On a flat roof, instead of drilling holes and risking leaks, you can simply use weights. This way, the panels stay in place even in strong winds. At a friend's house in Israel, for example, I simply used inexpensive concrete curbstones on the roof of her bungalow and screwed the panels to them using a self-made construction made of galvanized steel brackets (**Figure 8**). Each stone weighs 45 kg. That should be enough, but the roof must also be able to support the weight.

If you have a balcony with steel pipes, it is worth using ready-made brackets that allow you to screw the panels directly vertically to the railing. However, vertical installation is anything but ideal. You have to reckon with losses of up to 30% compared to more optimal angles. In the case of balcony power plants, you will be below the base load threshold for a particularly longer period of time, which is a shame. With other systems that allow the angle to be adjusted, the panels can be attached to wooden, metal, or concrete balustrades at significantly better angles. **Figure 9** shows the installation with such a system on wooden boards on a balcony parapet; and in **Figure 10** you can see the same fastening system on a canopy. The cost per panel starts at around €20.

### Further Considerations

In addition to efficiency and price criteria, other aspects also play a role when choosing solar modules and the associated





Figure 8: Installation of a balcony power plant on a flat roof using concrete stones.



Figure 9: The panels were screwed to the wooden planks of a balcony using ready-made black anodized aluminum fixings.



Figure 10: With the same mounting system as in Figure 9 (here in natural aluminum), the solar modules can also be mounted stably on flat roofs with an adjustable angle.

inverter and mounting material. When it comes to solar modules, you should invest a lot of brainpower in the best installation, especially if shading from other houses, roof structures, or trees is to be expected. The logic behind this and the answer to the question of when solar panels should be mounted upright rather than horizontally, for example, and much more can be found in a more comprehensive article on solar modules in the Elektor special issue on solar technology [2].

As already mentioned, if you want to use four solar modules, you have to reduce the output of the inverter(s) so that no more than 600 W (in Germany) or 800 W can be produced. Not all inverters can do this. Likewise, not all inverters can be directly integrated into your own WLAN and thus controlled. Especially for the widespread HM models from Hoymiles, you either have to buy a DTU (data transfer unit) or build one yourself. There is already a solution published in Elektor with the open-source software OpenDTU [8], and the equivalent with the AhoyDTU software can be found in the special issue [2]. **Figure 11** shows my self-built DTU.

If you want to view the historical progression of your own balcony power plant's harvest, there are solutions from inverter manufacturers. However, when using them, you should be aware that your data will end up in Chinese clouds and will be lost if the manufacturer decides to shut down these clouds in a few years' time. There are also open-source solutions for this, e.g., with the home automation software called Home Assistant. This may be discussed in more detail in one of the next issues of Elektor. Such software could also be used for zero feed-in, in which the power of the inverter is readjusted so that as little current as possible flows into the grid.

As already mentioned, there are now good solar modules with over 400 Wp for less than €100 each. Somewhat more expensive are bifacial modules, which have a second glass layer on the underside (like the one on the upper side) instead of a white plastic film. This allows (diffuse) radiation from behind to contribute a few extra percent to the yield. However, this is not worthwhile for panels that lie flat on a roof or wall, as there is hardly any backward radiation. Another advantage of bifacial panels is that the glass layer is much more stable and denser than a plastic one. As a result, these modules have a longer life expectancy and probably also less degradation over time. The surcharge for this added value is relatively modest.

Allegedly, as part of the German "Solarpaket II" legislation, the obligation to connect to the grid using a Wieland plug connection, which costs an additional 35 to €40, is supposed to be abolished. There are people who are already using a normal plug for a normal mains power socket in anticipation of this, which is not yet permitted in Germany though — only in other countries. I have connected my balcony power plant directly with its own cable and fuse to avoid such problems. In addition, with the 800 W permitted in the future, a maximum current of up to 3.5 A fed into the 230 V grid is to be expected. If sockets are fused with 16 A, up to 19.5 A could flow at another socket in the

same circuit before the fuse blows. However, this is not permitted. When connecting via a socket, the relevant fuse in the fuse box must therefore be reduced to  $\leq 12$  A. This work is reserved for an electrician certified by the power supply company.

It is reported that currently some local German energy supply companies raise issues when registering balcony power plants throttled to 600 W with 800 W inverters. This should soon be history though with the “Solarpaket II” legislation because then only the simplified registration with the “Marktstammdatenregister” will be required in Germany.

Regarding the price trend: You can currently buy complete 800 W balcony power plants for less than €400 (excluding postage and installation materials). To give you an idea, such an investment should have paid for itself in less than three years through energy cost savings. With a good, larger system with four panels and two 800 W inverters, you can quickly reach €1,000. As you won't save twice as much, you need to calculate based on four to five years for a complete amortization.

Recently, a number of small battery systems with a capacity of 1 to 2 kWh designed specifically for balcony power plants have appeared on the market. They are simply connected between the solar panels and the inverter and use part of the energy during the day to charge the battery. At night, the battery then delivers an adjustable amount of power to the inverter, so that a house's continuous consumption at night can also be (partially) compensated for. In itself, this is a great idea. However, the cost of such a solution is a whopping 1,500 to €2,500. Amortization is very questionable as, in the absence of intelligent control, constant power is simply fed in independent of consumption. If one calculates very optimistically at an average of 10 h/d and 100 W, around 365 kWh/y could be saved, which corresponds to around €110/y. Amortization would therefore take 14 to 23 years.

Last, but not least, some local authorities offer subsidies for balcony power plants. This means that such an investment can pay for itself after just one year. ◀

*Translated by Jörg Starkmuth — 230660-01*



Figure 11: My self-built DTU with a 2.42" OLED display.

### Questions or comments?

Do you have questions or comments about this article?  
Contact Elektor at [editor@elektor.com](mailto:editor@elektor.com).

### About the Author

Dr. Thomas Scherer first completed an apprenticeship as a telecommunication electronics technician and then worked in the Elektor editorial department from 1980. After studying psychology and spending several years in basic research, he has been a freelance writer for Elektor for decades. He has a large electronics lab and, in addition to neurons, is also very interested in electrons — in other words, pretty much everything that has to do with electricity.



### Related Products

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### WEB LINKS

- [1] T. Scherer, “Balcony Power Plant,” Elektor 9-10/2021: <https://elektormagazine.com/magazine/elektor-183/59831>
- [2] Elektor Special Issue “Solaranlagen und Photovoltaik” [German]: <https://elektor.de/20596>
- [3] DWD, solar radiation maps [German]: <https://tinyurl.com/strahlungsklimatologie>
- [4] German Federal Ministry of Economics press release: <https://tinyurl.com/derenewable>
- [5] Solar module datasheet [PDF]: <https://tinyurl.com/solarpanels>
- [6] Photovoltaic tilt angle table [German]: <https://solar.red/photovoltaik-neigungswinkel>
- [7] Solar Panel Tilt Angle Calculator: <https://footprinthero.com/solar-panel-tilt-angle-calculator>
- [8] T. Scherer, “ESP32 With OpenDTU for Balcony Power Plants,” Elektor 1-2/2023: <https://elektormagazine.com/230500-01>





# ESP32 With OpenDTU for Balcony Power Plants

## Read Data from Small Inverters Via MCUs

Source: Midjourney (edited)

By Dr. Thomas Scherer (Elektor)

The reliable micro-inverters from Hoymiles do not have integrated Wi-Fi connectivity. In order to read out the current power, daily and cumulative energy production, and other data, an extra Data Transfer Unit (DTU) is required. Instead of spending a lot of money, you can make an affordable DTU and run it with open-source software.

More than two years ago, I had built a small balcony power plant with 600 W power. [1] I now have a new system (with stronger panels and a new inverter), the data of which I read out with the help of a small circuit, which provides me with an informative web page on my own LAN (see **Figure 1**). Unfortunately, the good and widely used micro-inverters from Hoymiles are only accessible via a special Nordic radio link with a proprietary protocol. But, buying an off-the-shelf DTU from the manufacturer is against my honor as a maker because you can also build such a device yourself, thus saving money and also preventing the transfer of data to untrusted clouds.

### Open Source

Thanks to the widespread use of Hoymiles inverters, some inventive makers got together and did some re-engineer-

ing to find out which data is transmitted via Nordic radio and how. You can read the original discussion (in German) in the Mikrocontroller.net forum [2]. Also, software was developed for the well-known ESP32 microcontroller boards from Espressif (plus a radio module from Nordic). Why this microcontroller? It's an obvious choice: An ESP32 is equipped with a dual-core CPU with a clock rate of 240 MHz and comes with integrated Wi-Fi as well as Bluetooth. All this requires less than half a watt, on average.

The software developed for this purpose not only reads out all the relevant information from the Hoymiles inverters and from clones using the same design, but can also change the power fed into the grid. The latter is suitable for the realization of what is known as zero feed-in. The inverter is configured so that it supplies just as much energy as is currently being consumed. Other inverter types than the proven HM series can also be used, but they need a different radio module, which is not covered here.

Soon, two very usable software solutions emerged, OpenDTU [3] and AhoyDTU [4], which differ in some aspects. On the websites of these projects, you can see for which specific inverters they are suitable and what they can do. I have tried both solutions. It is difficult to say which is the "better" one. Firstly, the inverters HM-300 to HM-1500 can use both variants in any case.



If you want to use cheaper and less powerful boards of the type ESP8266, you have to rely on AhoyDTU. On the more powerful ESP32 platform, both solutions will work. In the following, the operation with OpenDTU is described.

## Hardware

As already mentioned, OpenDTU requires an ESP32 breakout board (BoB) as the base. **Figure 2** shows three common ESP32 boards. In addition, a Nordic radio module is needed, of which there are models with an antenna printed on the board or with an SMA socket for connecting an external antenna (**Figure 3**). You can surely guess which of the two has the greater range. But for me, even the version with the printed antenna (at only 25% of the maximum transmitting power) was sufficient for a decent radio connection, even over a distance of 11 m through a 34 cm-thick wall of clay bricks. Basically, that's all. For OpenDTU, you can combine almost any ESP32 variant with either Nordic radio module. Even small displays can be controlled, but more about that later. For the three ESP32 variants shown in Figure 2, I have developed circuit boards. With the mini version below, you can get a relatively small DTU. Of course, you can also hand-wire the ESP32 BoB and the Nordic module without a PCB.

So much for the theory. But the devil is in the details. Besides the radio modules of the type "nRF24L01+," there are also some without the "+." Attention: The plus version is mandatory! While the simpler boards with a printed antenna are available at prices between €1 (China) and €4 (EU), the more luxurious version from manufacturer eByte (Figure 3, right) comes with a shielded radio unit and costs between €4.50 (China) and €7 (EU) including the antenna. So, a DIY DTU with a Nordic module including an external antenna is not much more expensive than one without it. I tried the versions with and without external antenna and found no significant differences in my case, but having a range reserve is not bad. By the way, a normal, external Wi-Fi antenna is suitable, since Nordic modules also transmit at 2.4 GHz. The only important thing is that it must have a male SMA screw connector.

Depending on the exact type, you have to pay between €4 (China) and €10 to €15 (EU) for an ESP32 board. With an ESP32 and nRF24 BoB, you can build a fully functional DTU including a simple plastic case and a Micro-USB cable for a price of just under €12 (China) or €20 (EU). This is quite a bargain compared to the €100 to €250 for an original DTU from Hoymiles!

The main difficulty is that there are so many variants of ESP BoBs. Even on the Espressif website [5], you are spoiled for choice. And then there are several

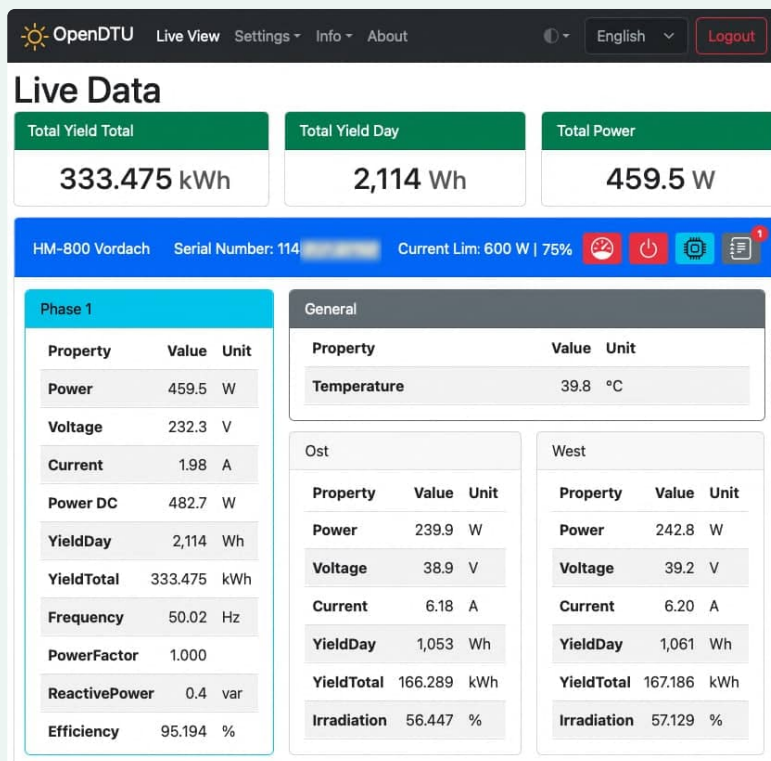


Figure 1: A short power test on July 31, 2023, under light cloud cover. The 800-W inverter was limited to 600 W and, nevertheless, a decent 4.7 kWh were accumulated at the end of the day.

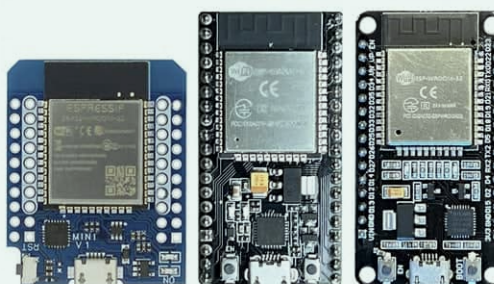


Figure 2: Three different board sizes in comparison: on the right, a 30-pin ESP32-BoB, in the center, one with 38 pins, on the left, a smaller ESP32 variant (D1 mini), where two of the 40 pins are not used.

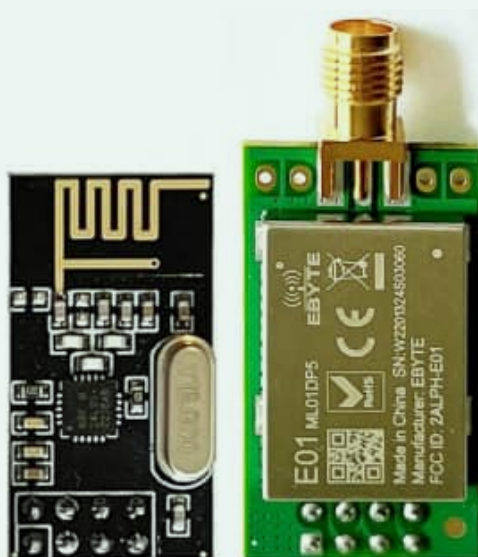


Figure 3: Two board variants with the Nordic radio chip nRF24L01+, left, with an antenna on the board and right, with an SMA connector for an external 2.4 GHz antenna.

Figure 4: Two 38-pin ESP32 BoBs. Top with printed antenna sticking out and bottom with connector for connecting an external Wi-Fi antenna. Both work well.

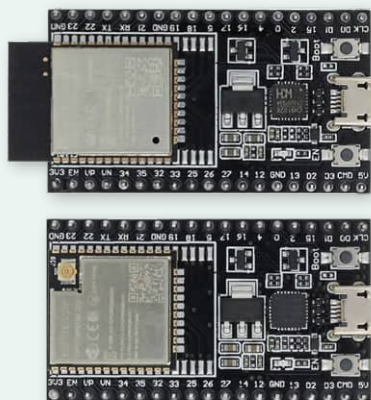


Figure 5: Circuit/wiring diagram as instruction for the connection of BoBs assembled on breadboards with colored stranded wires. Here you see the wiring of the 30-pin variant.

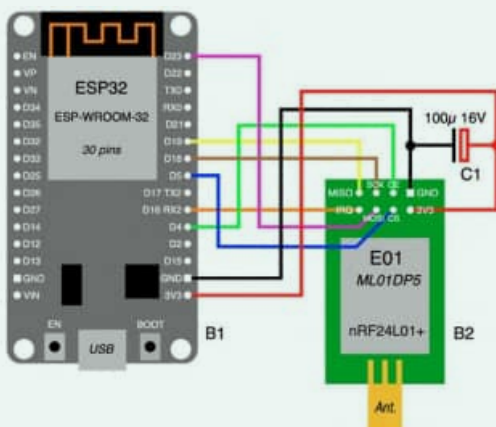


Figure 6: Wiring diagram for 38-pin ESP32 BoBs.

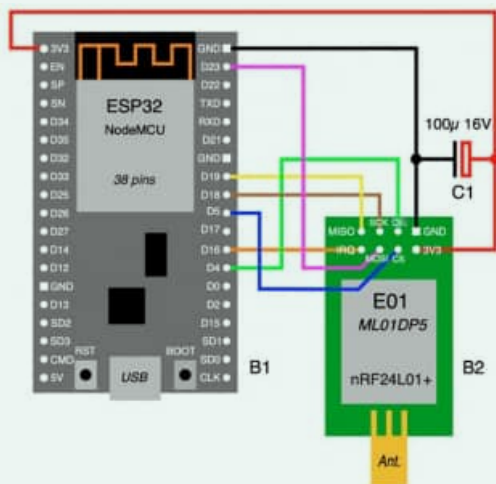
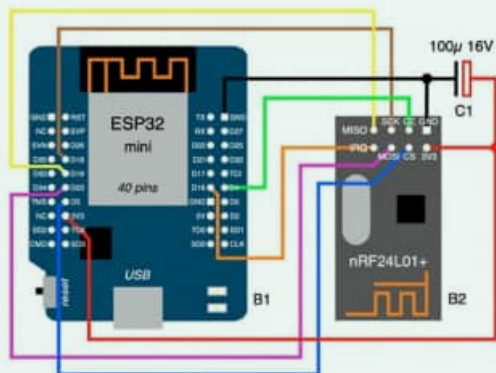


Figure 7: Wiring diagram for the small ESP32 mini BoB with small radio module (printed antenna). You can also equip a module with an external antenna.



manufacturers in the Far East who put different ESP32 SoCs on different boards with different components, different antennas, and, above all, different pinouts. First of all, most of these models will still work for the DTU described here. However, I would not recommend slimmed-down versions with less flash memory, or single-core versions.

Figure 2 shows three ESP32 BoB variants with 30, 38, and 40 pins, which probably represent more than 90% of the market. Visually and technically, there are further, irrelevant differences, which concern, e.g., the antenna or the USB converter chip. Most of the cheaper ones have a printed Wi-Fi antenna and a Micro-USB jack. Some have this antenna protruding a bit beyond the board and others have a small socket for connecting an external Wi-Fi antenna to the board (**Figure 4**). There are also variants with a sturdier USB-C socket instead of Micro-USB. USB-C is preferable for frequent plugging.

The ESP32 boards have enough power to drive a small display and to supply it with data. If you want, you can choose from several display types. Ideal are OLED displays with 128x64 pixels, which are controlled via I<sup>2</sup>C. Two very common types use the SH1106 (1.3" diagonal) or the SSD1306 (0.96") controller chips. Besides that, there are larger ones with the SSD1309 for 1.54" and 2.42" diagonals that will work as well. Thanks to the I<sup>2</sup>C, only two additional ESP32 I/O ports are required besides +5 V and ground. The displays are also acceptable in price, with €2 to €10 (China) and €4 to €20 (EU). I have tested them all and found the following: On the 2.42" version with a four-pin I<sup>2</sup>C connector, D2 has to be removed from the back and replaced with a jumper (solder blob) so that it generates the ACK signal as expected. The additional power consumption of an OLED display is easy to get away with < 0.1 W even for the largest variant.

At first, I did without such a display because it was enough for me to retrieve the data via a web browser. This also works well on the road via smartphone if you activate a VPN on your own router (provided it can do that) and use it to access your DTU remotely. But eventually, I was tempted by the display idea and made a new design with PCB and display: first with a 1.3" OLED display and then a big version with a 2.42" diagonal. My DTU with display is now placed on the PC speaker so that I can always see at a glance what is going on sunwise. In the following, how to connect such a display with four simple wires is shown.

## Circuit(s) and Construction

The three ESP32 BoBs in Figure 2 require different wiring because of different pin assignments. Fortunately, the



two Nordic radio modules are available with the same pin assignment. Other, smaller versions with SMD pads instead of the 2×4 pin headers are not used here. This makes it possible to reduce the jumble of possibilities to three circuit diagrams or boards. To make it easier to implement, the wiring was not designed like a classic circuit diagram, but like a realistic wiring diagram. In this way, you can solder an ESP module and a radio module onto a hole matrix board and make the necessary eight connections quite simply from pin to pin using thin, insulated, stranded wires. **Figures 5, 6 and 7** are therefore similar. There is no need for explicit part lists.

Which of the two radio module types is used is irrelevant for the wiring diagrams. In all three circuits, besides the two BoBs, a small 100 µF buffer electrolytic capacitor is included, which, according to reports on the internet, is supposed to provide a more stable behavior by the radio module if it is soldered as close as possible to the module's 3V3 and GND pins. Some say so, others say differently — in any case, I have included it and also installed it myself. In my opinion, it is not absolutely necessary.

**Figure 8** shows how to connect a small I<sup>2</sup>C OLED display with four strands or a piece of four-pin ribbon cable to an ESP BoB and have the current data of your inverter displayed without a PC or smartphone. Please note that some display modules have the pins for GND and VCC reversed. Before connecting, look carefully at the labeling of the pins; otherwise, you'll blow it in no time! A connected and active display needs between 10 and 25 mA at 5 V — on average rather at the lower limit. On some ESP32 boards, the 5 V pin is labeled VIN. It is directly connected to the USB socket's 5 V line.

Instead of a hole grid board, I used a plug-in "bread-board" for my first attempts. On one side, the two BoBs are plugged in, and on the other a few pins are soldered and then all pins necessary for the wiring get some solder. Now you can take the eight required pieces of stranded wire and make the connections pin by pin. **Figure 9** shows how I did it on my first prototype. When using a breadboard like this, a problem arises: Five pins each (*a* to *e* and *f* to *j*) are electrically connected. This fits well for the pin headers of the ESP boards, but badly for the 2×4 arrangement of the radio module pin header. Here, you have to cut the two associated traces of the board in three places before soldering on the top side. The bottom of Figure 9 shows how this was done with a Dremel and a mini cutting disc. If you forget this, you will have several short circuits and nothing will work. **Figure 10** shows the finished prototype with the external antenna connected in a semi-transparent case.

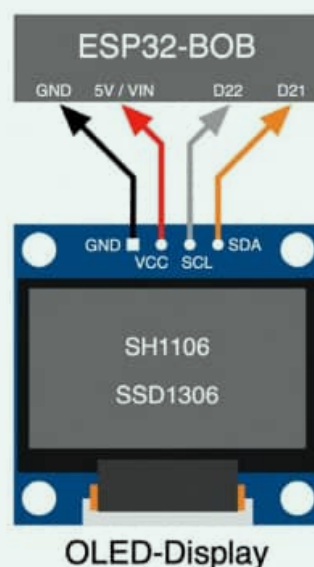


Figure 8: This is how to connect an OLED display with an I<sup>2</sup>C connection. Caution: The connections for +5 V and GND may be reversed. Reversed polarity will destroy the circuit!

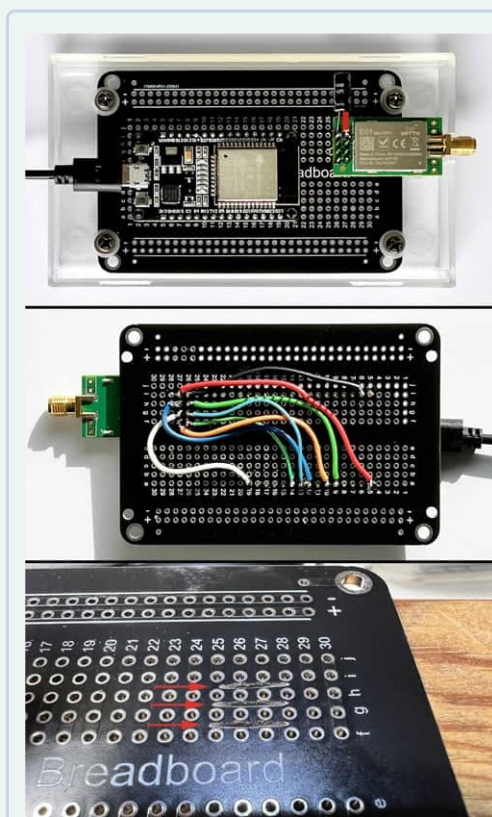


Figure 9: My first prototype on a breadboard wired with stranded wires. Attention: At the radio module you have to cut the traces (bottom, see text).



Figure 10: The first prototype (without display) built into a semi-transparent case with an external 2.4 GHz antenna.



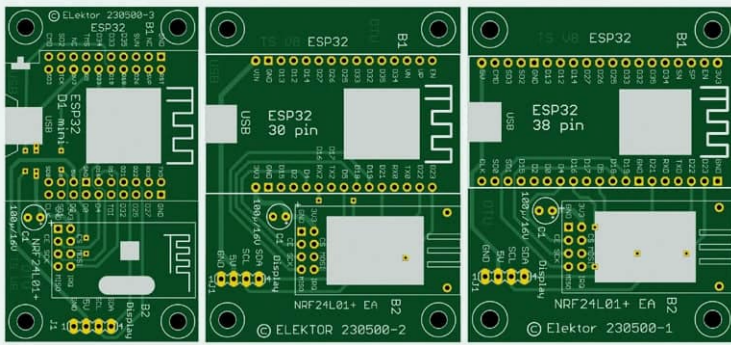


Figure 11: The three preferred ESP32 BoBs require different PCBs. The layout files are available at [6].



Figure 12: Completed boards. The one for the ESP32 BoB with 38 pins is still a beta version.

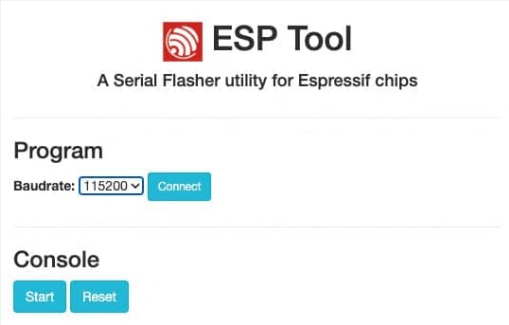


Figure 13: Start screen of the ESP Tool online flasher from Espressif with correctly set baud rate.

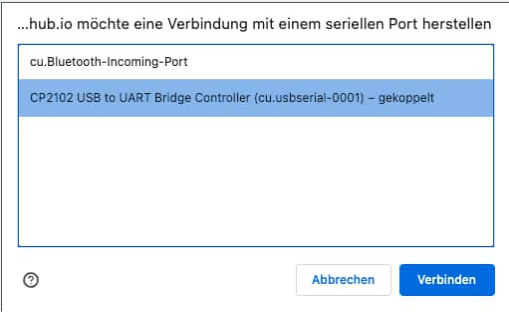


Figure 14: This pop-up window should show the virtual serial port of the connected ESP32 if the correct driver is installed.

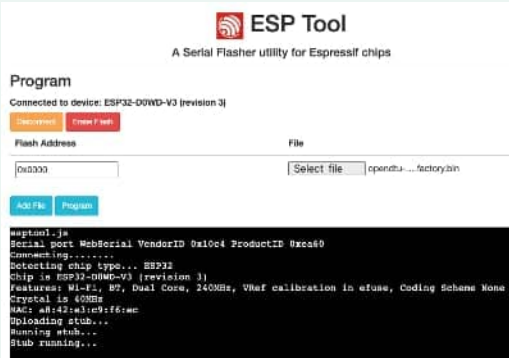


Figure 15: The first flashing should be done with the firmware file opendtu-generic.factory.bin at address 0x0000. Buttons must be pressed to connect (see text).

A more comfortable, easier solution, avoiding the many little error sources of a freely wired setup, is using one of the PCBs I developed (Figure 11). Their layout files are available for download in Eagle format, free of charge, on the Elektor website for this article [6]. The free version of Eagle CAD software is sufficient because it can handle two-sided boards of up to half Euro card size. When populating the ESP32 BoBs, you only have to solder in the pins with square and round pads — this is enough for stability and the necessary electrical connections.

As soon as I got the (first versions of the) boards back from the manufacturer after sending in the Gerber files, I assembled all three variants. All three boards have pads for stranded wires to connect a display. It is also possible to mount four-pole connectors at this point to connect the display in a removable way. Top of Figure 12 shows the top view of populated, but not yet final boards.

### Firmware

The first installation of the OpenDTU firmware on the still-bare ESP32 is not trivial. First, you have to visit the corresponding website [3] and read up a bit. There are several methods described. I prefer the online tool from Espressif [7], which does not run on Safari on the Mac — but there are other browsers. After connecting the DTU to the PC or Mac via USB, first set a baud rate of 115,200 under *Program* and then click on the blue *Connect* button (Figure 13). In the popup window that appears (Figure 14), select the appropriate serial interface (light blue). You can already see the type of the USB/serial converter chip — here a CP2102 — but there are others as well. Of course, this only works if the appropriate driver is installed, which should be a piece of cake in Windows 11 thanks to automatic installation. If not, suitable links can be found on the Espressif website. Flashing with the Mac using Chrome is also problem-free after installing the CP2102 or CH340 drivers.

Now, it could happen that you wait a long time for something to happen. On the ESP32 BoB, there can be one or two small button(s). With two buttons, you first press Boot and then briefly EN at the same time, whereas with the mini-BoB with one button, you have only one choice. Only then the tool connects to the ESP32 and the screen in Figure 15 appears. To be on the safe side, first erase the memory using *Erase Flash* and then select the firmware file *opendtu-generic.factory.bin* [8] under *File*. This file is the right one for the **first** flashing, because it also contains a bootloader. Later, you can update directly via Wi-Fi or OTA (over the air). Before clicking on *Program*, the address *0x0000* must be set as the *Flash Address* as shown. What happens (hopefully) after clicking *Program* is shown in Figure 16: After 1.5 minutes, the programming of the ESP32 is finished.

After rebooting the ESP32, the list of available WLANs should show one with the SSID "OpenDTU-\*". The asterisk stands for a sequence of numbers. The connection to this network works with the default password, "openDTU42." If you now enter <http://192.168.4.1> in the browser's address bar, the DTU website appears (Figure 17). This will also work with Safari.

You can now log in as *admin* with the password *openDTU42*. It goes without saying that you should change this in the settings as soon as possible. Once you are logged in, you can make the necessary adjustments in the *Settings* menu. By the way, in addition to English, the website's language can be changed to German or French. First, we go to *Network Settings* (Figure 18). Here, you enter the SSID and the password of your own Wi-Fi network, so that the DTU logs into your own network at the next boot, and you can reach it conveniently. To do this, you must check your own Wi-Fi router to see what IP address the DTU has been assigned. Most routers then allow the DTU to be assigned the same IP address always. This is useful because it allows you to bookmark the DTU. Further below, the time in minutes is specified during which the DTU acts as an access point after booting, and provides the WLAN with the SSID "OpenDTU-\*."

Under *NTP Settings*, you can specify a time server and enter the latitude and longitude of the position of the balcony power plant [9] so that no pointless queries of the inverter take place during the night. In the inverter's settings, you must enter its serial number and assign a name (Figure 19). An inverter can only be addressed and identified with this number. Since the serial number is attached to the inverter, it should be noted or photographed before installation. You can also specify multiple inverters. Clicking on the pencil next to the inverter you've created leads to a configuration page where you can activate things such as the DTU's night shutdown and enter designations and the connected solar modules' power.

Finally, there is *Device Manager*. Figure 20 shows the configuration of the pins and devices. However, they cannot be set here, but can only be selected as a profile at the top if a suitable profile has been read in beforehand. A click on *Display* leads to the window with the self-explanatory settings in Figure 21. But, how do you obtain the necessary profiles if you want to activate a display, for example? Profiles can be found on the GitHub page [10], among others, where you can download one. These are easily editable *.json* files. An *OpenDTU\_ESP32\_NRF24\_OLED.json* profile, tailored to the nRF24L01+ radio module and OLED displays — with the options visible in Figure 20 — can be downloaded together with the PCB files

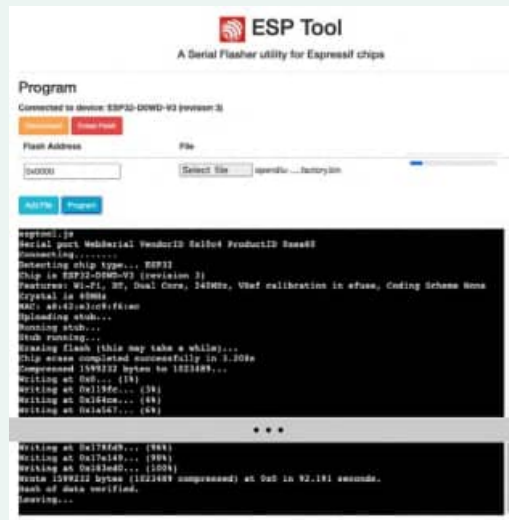


Figure 16: After 1.5 minutes, the firmware is loaded into the microcontroller and the DTU reboots.

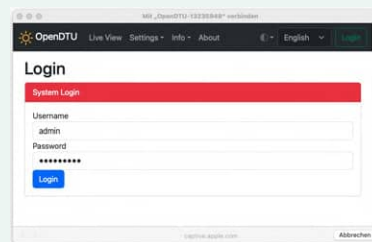


Figure 17: After connecting to the DTUs Wi-Fi network, you can reach this DTU configuration page at <http://192.168.4.1>, where you have to log in.

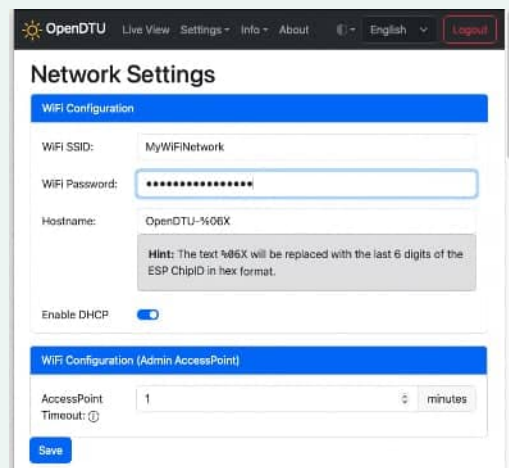


Figure 18: Now it's time to start with the settings. First, enter the SSID and password of your own Wi-Fi network.

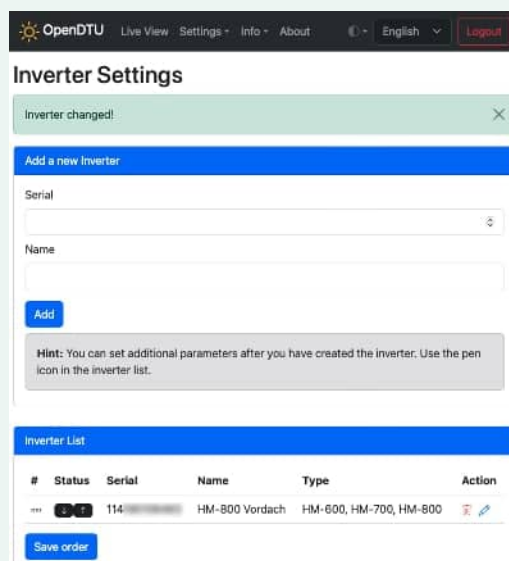


Figure 19: Here you enter the serial number of your inverter as well as the duration of the access point function and add the data of the connected solar panels via the pencil icon at the respective inverter.

Figure 20: By means of a file with profiles, the assignment of the I/O ports to connected devices can be specified. Here the radio module and the display are of interest.



from the Elektor website for this article [6]. You import the profile file via **Config Management (Figure 22)** by switching to **Pin Mapping** mode in the center left, selecting the **.json** file with the desired profile and clicking **Restore** next to it on the right. Then, the DTU reboots and you can make the described selection of the display etc. shown in Figure 20.

In **Figure 23**, you can admire a prototype in its transparent plastic case. This DTU is located directly on the left speaker on my desk, close to the monitor. Thanks to the large 2.42" display, I am always informed about the current solar harvest.

### Furthermore

In the OpenDTU settings, you can configure many nice little things, as you will surely find out quickly. The system retrieves date and time automatically via an NTP server. If this does not work with the preset server, you can enter your own router's IP address. Another nice thing is that you can save the configuration (see Figure 20) so that you keep a working version in case you mess up your configuration.

If you click on the red button with the measuring instrument in **Live View**, a window pops up where you can set a power limitation temporarily (until the inverter is restarted) or permanently (e.g., if you have a stronger inverter than the law currently allows). **Figure 24** shows my 800 W inverter limited to 75% = 600 W. Once the legal situation in Germany changes (hopefully this year), I will set the value to 100%.

In addition, with the help of external software (home automation system or similar) and appropriate current sensors, it is possible to achieve automatic tracking of the generated power, so that a zero feed-in (i.e., pure self-consumption) is achieved.

OpenDTU is able to send the data via MQTT to what is known as an MQTT broker. Such solutions are available in the cloud and locally (i.e., on small computers such as a Raspberry Pi). With the appropriate tools, the incoming data can be viewed graphically from anywhere, via the internet. You are then not dependent on proprietary clouds and have full control over your data. The DTU itself requires about 70 to 110 mA without display at 5 V and only a little more with display. That is quite little!

I have also tried the other open-source solution – AhoyDTU – and can't quite decide which one I like better. OpenDTU offers more information, but is not quite as easy to install and configure as AhoyDTU.

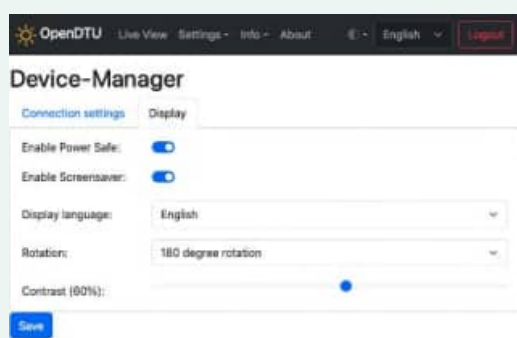
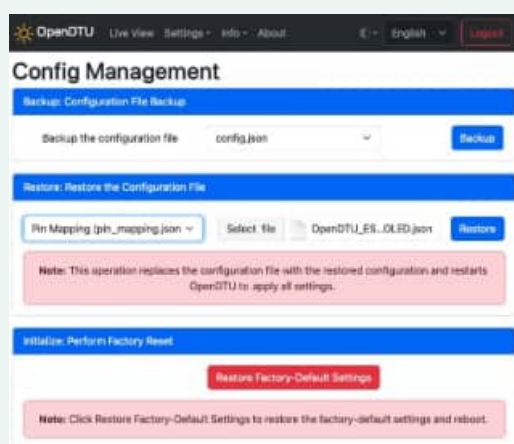



Figure 21: A few settings for the connected display.

Figure 22: Here you can save the configuration to a json file and specify the pin assignment of Figure 20 with an imported profile file. In addition, all settings can be reset to the "delivery state" here.





How to install the latter software is described in a German Elektor special issue on solar technology. [11] 

Translated by Jörg Starkmuth — 230500-01

### Questions or Comments?

Do you have questions or comments about this article?  
Contact Elektor at [editor@elektor.com](mailto:editor@elektor.com).



### About the Author

Dr. Thomas Scherer first completed an apprenticeship as a "Telecommunication Electronics Technician" and then worked in the Elektor editorial department from 1980. After studying psychology and spending several years in basic research, he has been a freelance writer for Elektor for decades. He has a large electronics lab and, in addition to neurons, is also very interested in electrons – in other words, pretty much everything that has to do with electricity.



### Related Products

- Joy-IT NodeMCU ESP32 Development Board (SKU 19973)  
[www.elektor.com/19973](http://www.elektor.com/19973)
- ESP32-DevKitC-32E (SKU 20518)  
[www.elektor.com/20518](http://www.elektor.com/20518)



Figure 23: A prototype with a 2.42" OLED display sits on the left speaker of my computer workstation. As you can see, it was slightly cloudy.

Figure 24: Clicking on the red icon with the meter brings up this setting of the maximum power of the inverter. You can set the power in percent or as an absolute value in watts, both temporarily or permanently.



### WEB LINKS

- [1] Thomas Scherer, "Balcony Power Plant," Elektor 9/2021: <https://elektormagazine.com/magazine/elektor-183/59831>
- [2] Mikrocontroller.net forum (German): <https://mikrocontroller.net/topic/525778>
- [3] OpenDTU on GitHub: <https://github.com/tbnobody/OpenDTU>
- [4] AhoyDTU on Github: <https://github.com/lumapu/ahoy>
- [5] ESP32 boards from Espressif: <https://espressif.com/en/products/devkits/esp32-devkitc>
- [6] Files for download: <https://elektormagazine.com/230500-01>
- [7] Online flasher for ESP32: <https://espressif.github.io/esptool-js>
- [8] OpenDTU firmware file: <https://github.com/tbnobody/OpenDTU/releases>
- [9] Coordinate finder: <https://latlong.net>
- [10] Device profiles: <https://tinyurl.com/opendtugithub>
- [11] Elektor-Sonderheft Solartechnik: <https://elektor.de/20596>



# Variable Linear Power Supply Ensemble

0...50 V / 0...2 A + Dual Symmetrical Supply

By Steve Griffin (United Kingdom)

When opening a 40-year-old, home-built power supply revealed a construction not up to the author's current build standards, he decided to do it all over again. Using modern parts and minimizing wiring, he came up with the refreshed design presented here.

In 1980, when browsing through the Elektor Summer Circuits edition, I came across just what I had been looking for: a decent power supply for my electronics workbench [1]. It was to be my first major project (i.e., one with a box around it). Along with the addition of a simple, low-current symmetrical supply for powering op-amps, all my power needs would be met in the one box. After a few weeks of PCB manufacture, adding a moving-coil meter (MCM), fabrication, and wiring, it was finished. It worked like a dream, and then continued to do so for more than 40 years.

## 40 Years Later...

Fast-forward to the present day. On my faithful power supply, all the front panel labeling had been done using rub-down transfers, which

wore away as the years went by. Therefore, I decided that the appearance of the old box needed a bit of a refresh. So, I removed the front panel to start work on a new, smart, computer-aided design for it. However, when I looked inside, I was horrified by what I saw. "Did I really wire it up like that?" Surely, it couldn't go back together like that again, and the idea of a complete rebuild emerged. If I was going to do that, I should use modern components, which meant surface-mount devices (SMDs) and modern connectors.

The block diagram of my new power supply is shown in **Figure 1**. Let us start with the PSU.

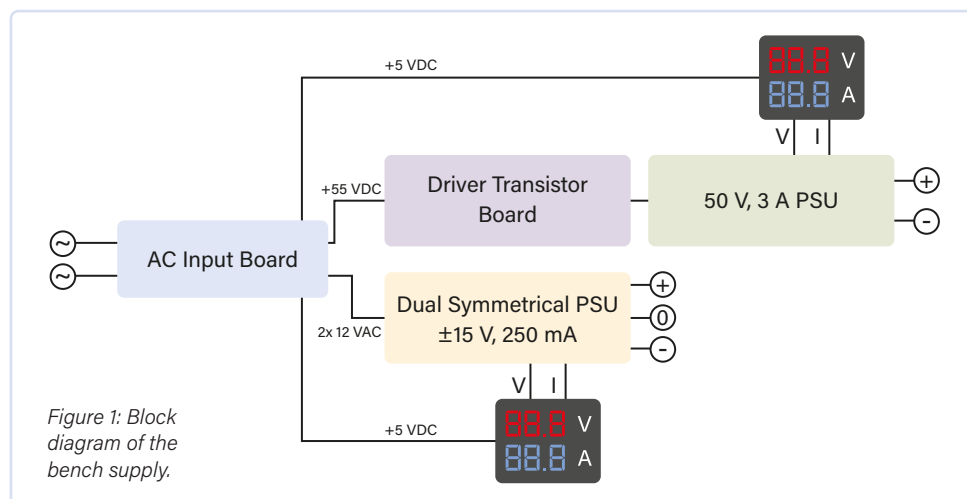


Figure 1: Block diagram of the bench supply.

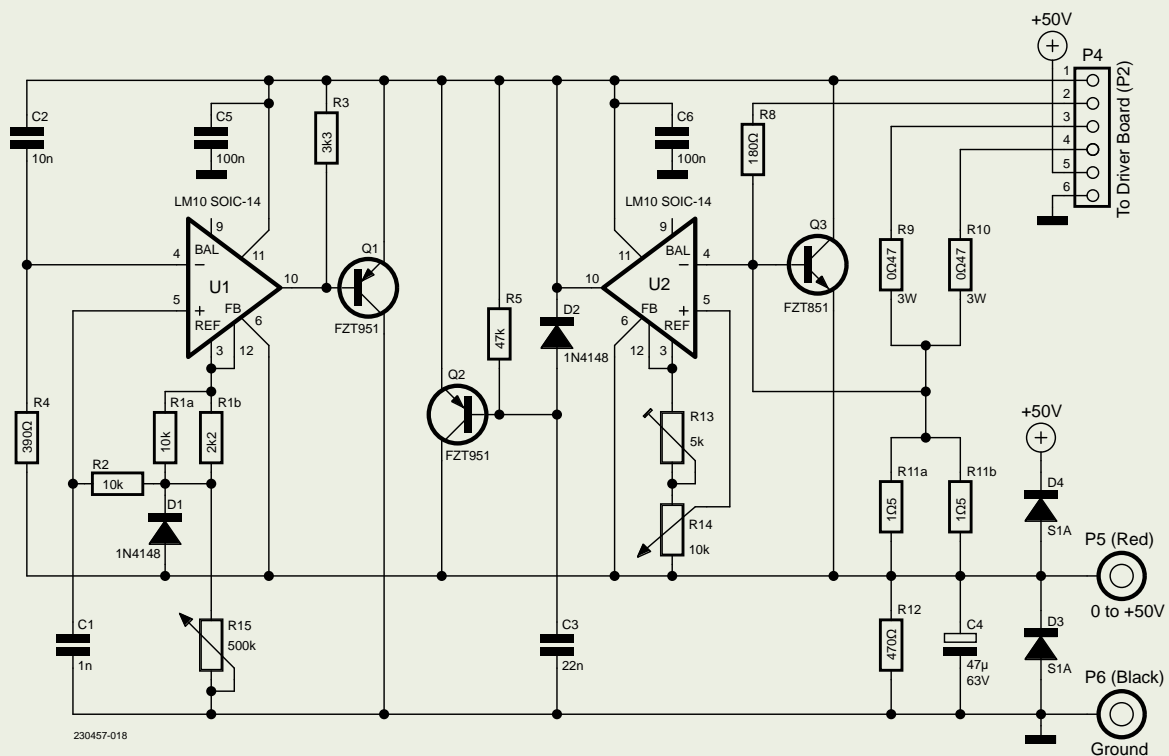


Figure 2: The 50 V regulator circuit. The values of R1A and R1B have been empirically derived using my components. This exercise will set the maximum output voltage to 50 V, nominally producing 100  $\mu$ A flow if P1 (max. position) is exactly 500 k $\Omega$ .

## Refreshing the 0...50 V PSU

One of the main considerations was to tidy up the wiring. This led to a design of three parts: the main regulator board, the driver transistor board and the power transistor heat sink. These were all connected using neat wiring and multiway connectors.

Of course, I could have purchased a new, reliable switched-mode power supply unit (SMPSU) for a reasonable sum, so why bother? The answer is easy: Electronics has been a lifelong hobby for me, and creating useful electronic devices is something I always find very rewarding.



**This design requires the use of mains-powered transformers. People inexperienced with mains voltages should not attempt this project or should ask someone with experience who can help with this part of the assembly!**

## The New Design

The new circuit (Figure 2 for the regulator board and Figure 3 for the driver board) faithfully follows the original 1980 design; this goes right down to the numbering of components. The other obvious difference was the use of SMDs. This caused a problem, as most of the semiconductors used in the original project were not reproduced in SMD form, thus requiring a search for equivalents. The only components to survive the update were the transformer, the reservoir capacitor, the trusty 2N3055 power transistors, and the enclosure.

## The Potentiometers

Regarding circuit operation, the main points to note are that potentiometer R14 controls the output current setting and potentiometer R15

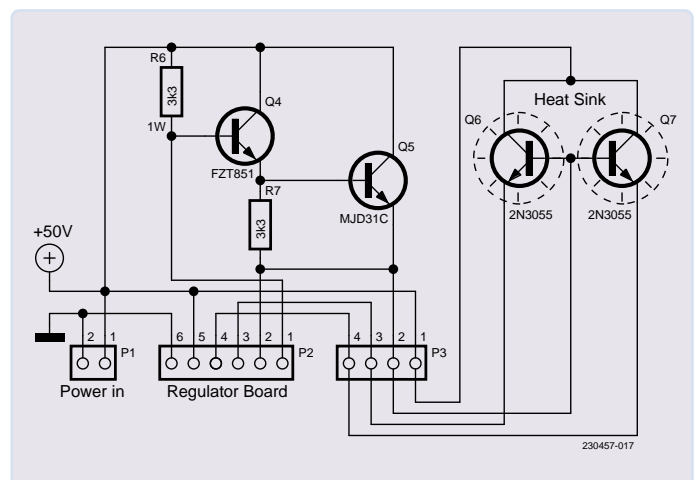


Figure 3: The driver-transistor board including heat sink components. Q6 and Q7 are displayed 'in-circuit' for readability purposes, but, in reality, connect to P3. Q5 will require a small heat sink. A 5°C/W stick-on type would be sufficient. Q6 and Q7 need to be mounted using insulation kits on a large heat sink or attached to the enclosure.

adjusts the voltage output. Both circuits must be configured before use. In the case of R14, preset R13 must be set to limit the maximum current output. In the case of R15, the original author decided to use fixed resistors to set the maximum output voltage at 50 V, obtained by setting the current flow through R15 at 100  $\mu$ A.

The original circuit has not been changed except for the use of SMD components and the inclusion of decoupling capacitors for U1 and U2. Another variation is the use of two components for R11 to dissipate



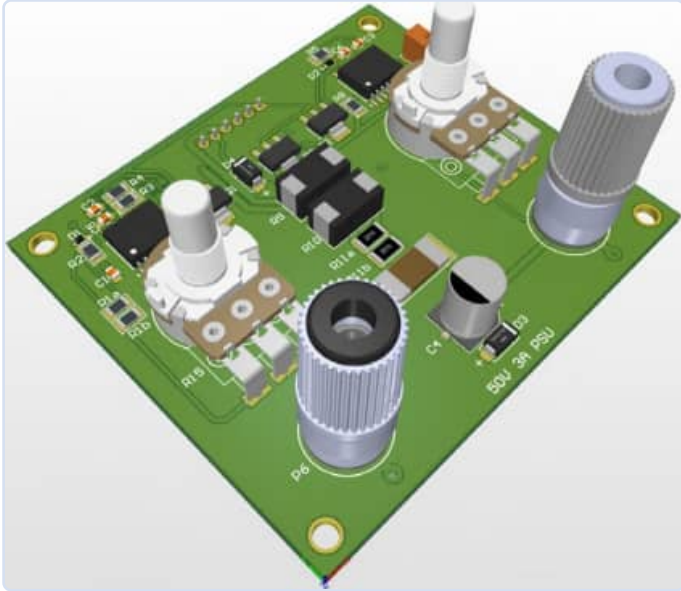


Figure 4: A 3D rendering of the 50 V regulator board.

the heat better and to offer more options when setting up the Q3 fast current-limiting feedback circuit.

Reading the original article [1] and the National Semiconductor application notes for the LM10 opamp will provide more detailed background information regarding the circuit operation if required.

## Reducing Wiring

One change from the original design is the mounting of the potentiometers directly on the regulator board — see **Figure 4**. This removes five fly leads and gives more support options for the PCB. The major difference is in locating the driver transistors on a separate board. Conversely, it reduces the number of wires in the enclosure. This is because I assembled the driver board and power transistors together on the back panel, with P4 providing the only wiring to the regulator board. Another point to mention is that this connector is mounted on the rear of the main PCB for front-panel mounting. But this can be reversed if the board is to be mounted horizontally.

## The AC Input Board

For the 50 V supply, this board only provides fuse protection and rectification, plus a convenient connection to chassis-mounted capacitor C1 (**Figure 5**). For the dual supply (see below), this board provides mains AC input feeds (**Figure 6**) to the dual 12 V supply transformer, which is a chassis-mounted type wired to the PCB. This allows for some flexibility in the selection of this component, whereas a PCB-mounted transformer has precise wiring requirements.

Fuse links F2 and F3 provide 100 mA continuous current with resettable protection for each supply. Each winding then feeds directly to the regulator board via connector P5.

I made some variations from the original design. The main input components are all chassis-mounted. The mains transformer I used has two 20 V outputs, which I wired in series to provide 40 V<sub>RMS</sub>. This will output

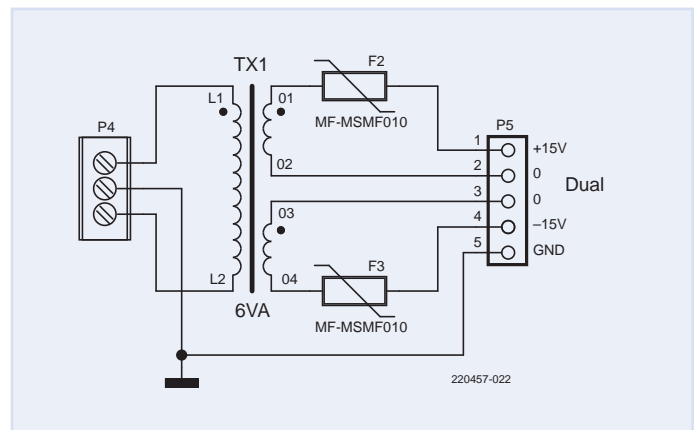


Figure 6: The fused AC supply for the dual variable supply board is also mounted on the AC input board.

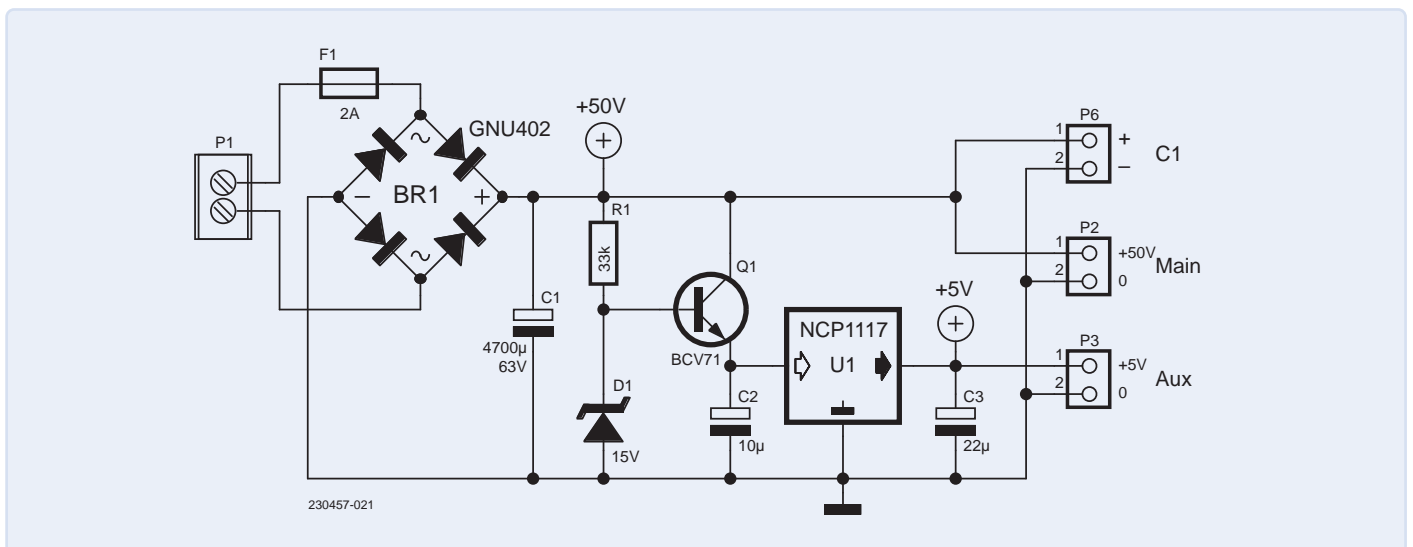


Figure 5: This circuit, mounted on the AC input board, supplies the regulating unit and provides the auxiliary 5 V supply for the panel meters. C1 is too large for the board, and is therefore mounted on the chassis, connected to P6.

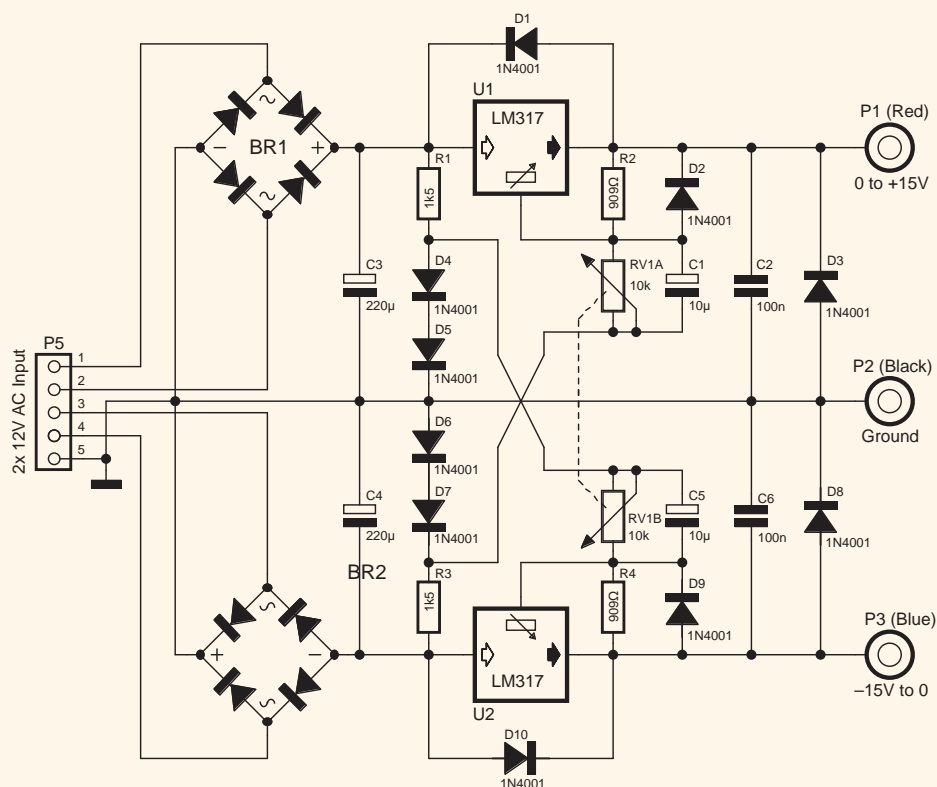


Figure 7: The dual variable PSU circuit. For higher positive currents, U1 can be replaced with an LT1085/4/3 and heat sink. For higher negative currents, U2 can be replaced by an LT1033 with a heat sink.

56 V when rectified and smoothed. The original design specified an 80 VA to 100 VA rating, but I chose a 120 VA version, which provides up to 3 A, as it is still well within the limits for the output transistors.

It's worth noting that chassis-mounted transformers are expensive items, so decide the maximum current output required before purchasing one. The transformer then feeds BR1, a 4 A bridge rectifier with a 1 V forward voltage drop, and will provide 55 V to C1, a 4,700  $\mu\text{F}$ /63 V electrolytic type. This component is costly as well and requires consideration. So, the 63 V rating will be fine, provided that the RMS output from the transformer does not exceed 40  $V_{\text{RMS}}$ .

### Simple Dual Symmetrical Supply

This circuit is easy to make and is constructed from readily available SMD components. The circuit design is mainly taken from the manufacturer's application notes, with a couple of additional embellishments. The output has been designed to work from 0 V to  $\pm 15$  V (dual tracking) with a maximum output current of 250 mA, although both features can be upgraded easily if required. But, for my purposes, a low-power flexible unit is precisely what I require for powering opamps, for example.

As you can see from the circuit diagram (Figure 7), it is simple and based upon two adjustable linear voltage regulators, an LM317 and the negative LM337 regulator, both adjusted via a dual potentiometer. The circuit includes protection diodes to guard against transients. It also has biasing circuits that minimize the effect of the 1.25 V reference voltage required by the regulator chips. Normally, with circuits of this type, the output voltages could not be adjusted down to zero, but, by using the forward voltage drop of two biasing diodes in both the positive and negative adjustment circuits, this problem is mainly

overcome. To simplify the final assembly, the potentiometer and power output sockets have been employed to mount the PCB on the front panel as well (Figure 8). Again, the connector is mounted on the back of the board.

### Dual Supply Circuit Description

This board only requires two 12  $V_{\text{RMS}}$  input voltages to work, as the bridge rectifiers and reservoir capacitors are included on the PCB. The capacitors must be rated at at least  $1.5 \times$  the peak transformer voltage, which is  $1.41 \times 12 \text{ V} \times 1.5 = 25 \text{ V}$ .

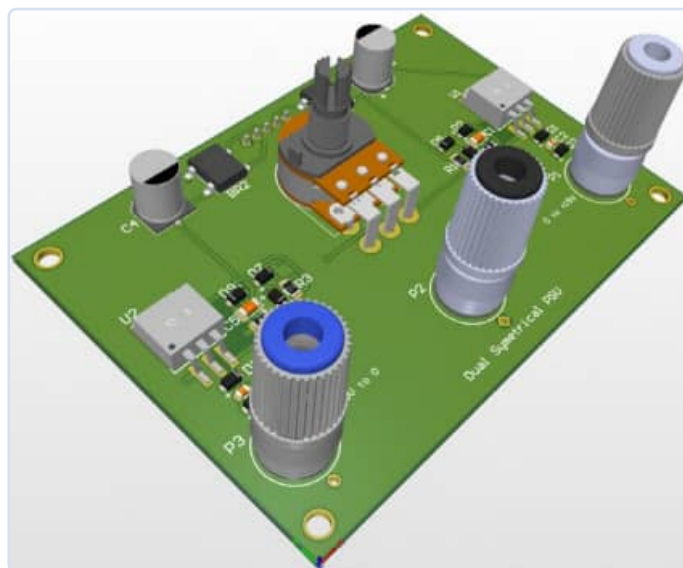
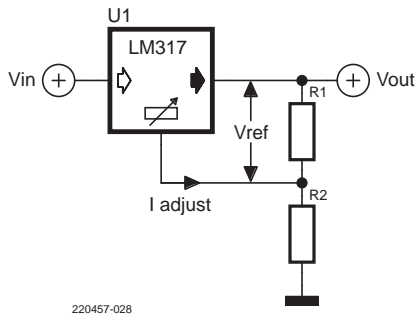


Figure 8: A 3D rendering of the dual variable PSU circuit.

## Calculations



In this design, the maximum output voltage achievable was calculated from:

$$V_{out} = V_{ref} \cdot \left(1 + \frac{R_2}{R_1}\right)$$

Where (this applies to both outputs):

$V_{out}$  = desired output voltage (15 V)

$V_{ref}$  = 1.25 V

$R_1$  = resistance value to be determined (resistors  $R_2$  &  $R_4$  in the actual circuit)

$R_2$  = potentiometer maximum resistance value ( $R_{V1}$  = 10 k $\Omega$  in the actual circuit)

The formula must be rearranged to find  $R_1$ .

$$R_1 = \frac{R_2}{\frac{V_{out}}{V_{ref}} - 1} \therefore R_1 = \frac{10 \text{ k}}{\frac{15}{1.25} - 1} = 909 \Omega$$

In practice, a precise maximum value is not that important, but if you want accuracy, then you will have to measure the maximum resistance value of the potentiometers before you start the calculations.

Next in line are the linear regulators. For detailed operation of the regulators, see the text provided in the manufacturer's design notes. However, I have included my calculations in the insert, aptly entitled **Calculations**.

When determining the values for the lowest output voltages, you must remember that the forward voltage of diodes is dependent upon the junction temperature and the current flowing through them. I used 1.5 k $\Omega$  resistors for  $R_1$  and  $R_3$  after consulting the V/I characteristics in the diode design notes. Also, in the design notes of the regulator, there is another solution to this issue, but I found that this method also had an effect on the maximum output voltage.

## Increased Output Voltages

This circuit could be used as a stand-alone bench supply with only the addition of a dual-output transformer. The specified regulator chips are rated at up to 1.5 A and 37 V maximum input voltage when provided with adequate cooling, but if you require even higher output voltages than specified in this design, the transformer, capacitor, and regulators will have to be upgraded too. Manufacturers make higher-rated pin-compatible low-dropout (LDO) regulators such as the LM1084 and LM1085, which can provide up to 5 A. Also, be aware of the current-carrying capacity of the other circuit components when upgrading.

## Metering

I have also used basic voltmeter/ammeter modules to monitor the positive outputs of both regulators, which can be purchased very cheaply over the internet. There are additional output connections on the PCB to allow for the inclusion of current measurement shunts before the 4 mm banana sockets if required. Adding a shunt will require the output sockets to be insulated from the PCB. A TO3 pin-insulation kit can be used for this, but sleeving and plastic washers will do.

Figure 9: The system's wiring diagram. "A" is the AC mains input via the panel fuse. "B" is the AC input board. Mains transformer "C" should deliver 40 V<sub>RMS</sub>. "C1" is capacitor C1 from Figure 4. "D" is the dual variable supply board. "E" is the driver-transistor board. Power transistors Q6 and Q7 are mounted on a common heat sink using TO-3 insulation kits. Board "F" is the 50 V variable supply. Finally, "G" are the panel meters. "I!" indicates that all exposed metal parts should be connected to ground.

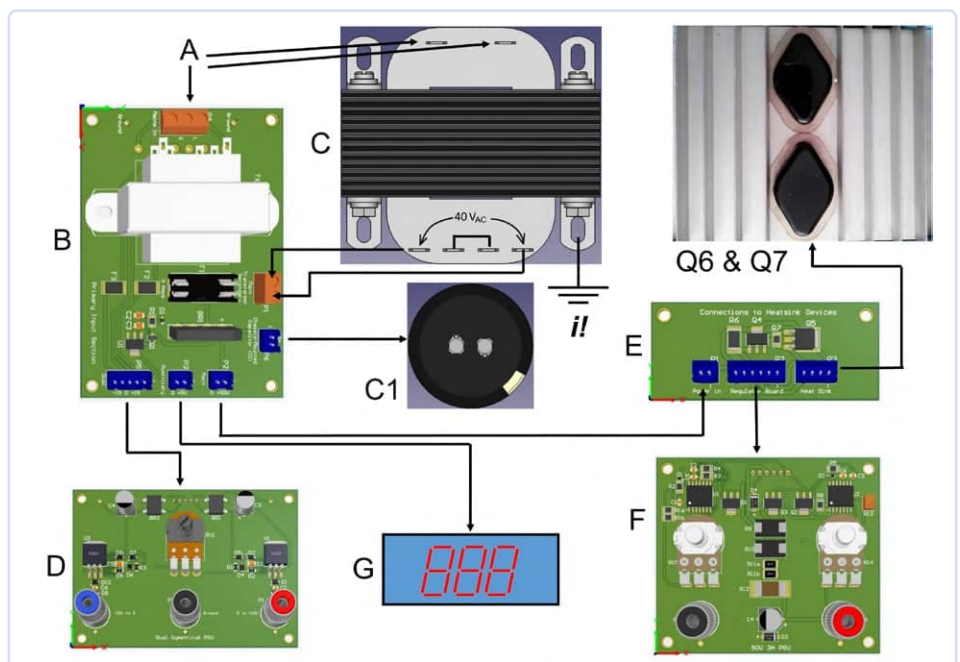






Figure 10: The completed power supply ready for the coming 40 years.



## 5 V Auxiliary Supply

The 5 V auxiliary supply used for the meter modules is the most involved circuit on the AC input board (see Figure 5). The input to the 5 V low-dropout (LDO) chip regulator used must first be reduced to conform to its input voltage limit. This is achieved by using a Zener diode (D1) to clamp the base of a discrete NPN transistor (Q1) at about 15 V. This provides the LDO (U1) with about 14.3 V safely delivered to it from the 50...55 V supply rail.

## System Assembly

The complete power supply consists of four circuit boards, a large capacitor (C1), a mains transformer, a heat sink with Q6 and Q7 on it, and two panel meters. **Figure 9** shows how all these parts should be connected.

I built everything into a suitable metal enclosure. The result is rather satisfying, as shows **Figure 10**.

## Panelizing the PCBs

One last design feature worthy of mention is related to the PCB manufacture. The PCBs have been designed to be manufactured in pairs to save on costs. This requires a V-score to be placed between the boards.

All the design files and the complete bill of materials for this project can be found at [2]. [🔗](#)

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## Questions or Comments?

Do you have technical questions or comments about his article? Email the author at [steve@totalfive.co.uk](mailto:steve@totalfive.co.uk) or contact Elektor at [editor@elektor.com](mailto:editor@elektor.com).



## About the Author

Steve Griffin's life-long hobby is electronics. He has worked in electronic repair, taught electronic engineering and finally worked as a senior electronics technician at the University of Warwick in the UK where, lately, he has been involved with high-sensitivity sensors, developed semiconductor investigations and was even involved in the construction of high-voltage rapid battery charging circuits (to name but a few). Steve Griffin frequently designs original circuits and PCBs. His latest interest is 3D design and printing.



## Related Products

- > **Miniware MDP-XP Digital Power Supply Set (MDP-M01+ MDP-P906)**  
[www.elektor.com/20458](http://www.elektor.com/20458)
- > **Joy-IT DPM8605 Programmable Power Supply (0-60 V, 0-5 A)**  
[www.elektor.com/19385](http://www.elektor.com/19385)

## WEB LINKS

- [1] "Variable Power Supply 0-50 V/0-2 A," Elektor 7/1980: <https://elektormagazine.com/magazine/elektor-197999/44508>
- [2] This project at Elektor Labs: <https://elektormagazine.com/labs/bench-power-supply-ensemble>
- [3] Part 1 on Elektor Labs: <https://elektormagazine.com/labs/variable-0-50v-2a-supply-refresh>
- [4] Part 2 on Elektor Labs: <https://elektormagazine.com/labs/simple-dual-voltage-bench-power-supply>

# Energy Storage Today and Tomorrow

Questions by C. J. Abate (Elektor)

Innovations in energy storage technologies will revolutionize how we harness and store power for a sustainable future. Dr. Simon Engelke (Founder and Chair of Battery Associates) shares insights on topics such as promising storage solutions, Li-ion battery recycling, and more.

**C. J. Abate:** Before we discuss your academic research and your work at Battery Associates, let's start with how you first became interested in energy storage and battery technologies. Were these subjects on your mind, say, during your early adolescence, or did you first become interested during your time at Maastricht University?

**Simon Engelke:** In high school, I was thinking about what the most important topics were for my generation in our lifetime. The two topics I consistently came back to were, firstly pandemics and vaccine development, and secondly climate change and energy storage. I actually began on the pandemics and vaccine topic. I was fortunate enough to be able to go to the

National Institutes of Health (NIH) in the US at the end of high school for my thesis. I also got some really great insights there, but I decided to focus on the work on climate change, where I felt I could have a more significant impact, and which also combined my favorite high school topics — chemistry and physics. This is why I started my studies in liberal arts and sciences at Maastricht University, which allowed me to combine chemistry and physics with math and programming. During this time, I had the opportunity to go back to the US, to UC Berkeley and the Lawrence Berkeley National Laboratory for a one-year exchange program, where, for my thesis, I was able to research sodium-ion batteries and automation for battery research. This fully established my path toward focusing on energy storage and batteries.

**C. J. Abate:** You spent a few months in the United States at Google and, as you said, at the Lawrence Berkeley National Laboratory. Can you share some details about those two experiences?

**Simon Engelke:** It was a really eye-opening experience. I was able to do more hands-on research there (**Figure 1**), especially on the topic of batteries. It was really fascinating to learn about the history of all the other amazing research done there in the past, including by many Nobel laureates. There are a couple of things I was able to do there. It was also really insightful to learn about the American system of studying with office hours and other different elements that we are using today in our educational work at Battery Associates. I was able to get a grant from Google to work on some fantastic projects while I was there. I worked with researchers from Berkeley as

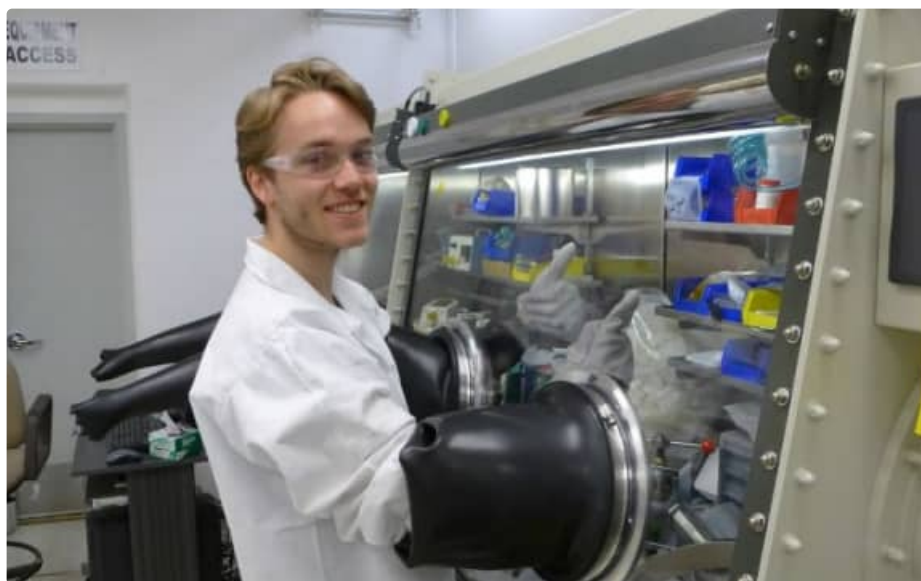


Figure 1: Hands-on research!



Figure 2: Dr. Engelke focused primarily on battery research at Cambridge.

well as MIT, looking into search engines for battery research, automated research with data, as well as some work with robotics.

**C. J. Abate: After graduating from Maastricht University in 2014, what led you to the University of Cambridge rather than to industry? What was your focus?**

**Simon Engelke:** I actually thought about that for some time, “What will the perfect next step be?” I researched backgrounds of senior management and entrepreneurs in the battery industry and felt that a PhD would really help me, especially at a young age, to get more credibility as I started in the battery space. This is what let me to the University of Cambridge, where I was focused on battery research, and I became a fellow at the World Economic Forum (WEF). The PhD (**Figure 2**) gave me hands-on lab experience while the work at the WEF gave me market insights, industry experience, and exposure to policymaking.

I have been entrepreneurial for quite some time. Since I was 16, I started different projects in my hometown, Berlin. Looking back on the letters I wrote for scholarships at the time, I was very focused on having an entrepreneurial journey with the topics I cared about. Even if I failed, I got more experience, more of a network, and more credibility, which would turn out to be helpful.

**C. J. Abate: What is Battery Associates, and why did you found it?**

**Simon Engelke:** Battery Associates is a knowledge partner in the battery space. Our mission is to create a sustainable world through the power of people and battery innovation. We offer training

(BatteryEDU), consulting (BatteryPRO), and innovation (BatteryLAB) services. For training, our flagship programme is the BatteryMBA, where we train battery leaders from 40+ countries. In our consulting arm, we help organisations with their battery challenges, and with our innovation platform, we develop tools.

I felt the industry could need a unique player with a different approach. An impact-driven company that would combine providing the know-how, bringing people together and building a community, fostering diversity in the battery sector, and taking advantage of the global nature of the industry with a remote workforce. I truly believe that the battery industry will be one of the most crucial industries worldwide. Batteries are required to combat climate change and to decarbonise mobility and energy. I speak about this at relevant events and organisations such as IAA Mobility and the World Economic Forum (**Figure 3**). I believe that Battery Associates can have a significant impact here. Our company’s approach is to bootstrap and grow organically over time to become a sustainable, trusted partner and impact-driven organization in the space.

**C. J. Abate: The Battery Cyclor is a solution for engineers, researchers, and academics looking for a modular battery tester. Tell us about the design’s key features.**

**Simon Engelke:** The aim here really is to provide a research tool that enables people to conduct efficient battery testing (**Figure 4**). We are starting with a simpler one-cell version, which is developed for battery enthusiasts, for training, for academia, and for early-stage start-ups. The current version allows some more



Figure 3: Speaking at the World Economic Forum.

straightforward battery testing, but we are currently developing additional sensors that can be connected as well. We plan to keep improving the features and building a more robust product over time, taking into account customer demand. The focus is on the battery cyclor development itself at the moment and we have the idea of providing more open-source resources connected to the battery cyclor in the future. We want this to be very collaborative with the community as well. We believe in having a tool that is modular, cost-effective, and really targeted to specific use cases.

**C. J. Abate: Is the Battery Cyclor still available for pre-order? What does it cost?**

**Simon Engelke:** It is available for pre-order and it costs € 250. It can be pre-ordered through our product page [1].

**C. J. Abate: What has been the most surprising change in the industry since 2015, when you started your PhD at Cambridge?**

**Simon Engelke:** I think simply the popularity of batteries and their industry. When I started, the topic had not been as popular, but people really are taking notice now. Every year, I see the industry growth





Figure 4: Simple, smart, and affordable, the Battery Cyclor allows for data sharing between the battery testing community.

being underestimated. There is global growth from the mobility side, and we see significant growth in stationary storage as well. In terms of enabling new applications, we see more robots coming to play. And, of course, the development of AI. There are many exciting resources along with the opportunities that this brings, allowing the processing of data more easily, for example. There are also quite exciting chemistry changes on the battery side, such as sodium-ion batteries and lithium iron phosphate (LFP) batteries, which have seen exciting developments and uptake.

**C. J. Abate: What would you say is the greatest challenge facing the battery manufacturing industry today?**

**Simon Engelke:** I think there are actually three huge challenges right now: material availability, talent (getting battery talent to operate, do the research, and production), and scaling up (converting announcements into scaled-up, reliable production).

**C.J. Abate: Li-ion battery recycling is a topic of interest for many of Elektor's community members. What are the main challenges? Where are the opportunities for improvement?**

**Simon Engelke:** I think there are some really interesting developments here. On the European side, we are doing work on the new EU battery regulation, which has new recycling requirements, including the use of recycled battery materials in new batteries. This requires battery-grade recycled materials, which provides the opportunity to create a truly circular economy for batteries. In addition to regions such as Europe, I am hopeful more will see recycled materials as a resource rather just a liability going forward.

**C. J. Abate: Let's look ahead a year or two. Which energy-storage technologies do you think are the most promising?**

**Simon Engelke:** There are key areas to look at over the next year or two: additional storage media (such as long-duration storage) and changes in battery chemistries. Lithium-ion batteries will still be important, especially for smaller devices. We'll likely see LFP as a widely used option for mobility and stationary applications. There is a lot of debate about developments in the sodium-ion battery space, so it will be interesting to see how big this will become and in what time.

**C. J. Abate: Lastly, do you have any advice for a talented undergraduate who is thinking about focusing his or her career in the field of energy and batteries?**

**Simon Engelke:** That's an excellent question. If they are looking for resources online, there are programmes we provide

such as Battery101 [2], and we run the BatteryMBA [3] program, which provides you with deep insights into batteries and the latest developments in the industry. We provide scholarships for both. We also host the Battery Insiders podcast and have covered many topics over the past years. In addition, there are a lot of meetups set up by different organizations. We organize these ourselves, but there are other organizations, such as the Volta Foundation, which bring people together. I think it is a great starting point to go to these meetups and meet like-minded people. If you have any questions, feel free to reach out to me or my team on LinkedIn or our website [4]. We're happy to see if we can support you on your journey as well. We are super thrilled to have more people enter the industry and are pushing forward because it's such an important topic to address, not only for climate change but also for creating a truly sustainable and circular world, long term. 

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### About Simon Engelke

Dr. Simon Engelke is the Founder and Chair of Battery Associates. He completed a PhD on lithium-ion batteries at the University of Cambridge.

### Questions or Comments?

Do you have questions or comments about this article? Get in touch with Battery Associates at [4], or email Elektor at [editor@elektor.com](mailto:editor@elektor.com).

## WEB LINKS

- [1] Battery Cyclor: <https://battery.associates/battery-cycler-product-page>
- [2] Battery101 Course: <https://battery.courses/courses/battery101>
- [3] BatteryMBA programme: <https://battery.mba>
- [4] Get in touch with Battery Associates: <https://battery.associates>



2024

# An AI Odyssey

## It's Not Letting Up

By Brian Tristram Williams (Elektor)

Our odyssey moves into a new year, and the pace of new developments has not slowed at all. Also: How's our Tower of Hanoi project going? It's been an interesting ride, to say the least — full of technical challenges and a lot of head-scratching.

### Happy New Year

Welcome to 2024! 2023 was AI's "breakout year," where there's been explosive growth in generative AI tools. According to a McKinsey Global Survey [1], one third of respondents said their organizations are using generative AI regularly in at least one business function. Generative AI tools have risen from being a tech niche to a focus of company leaders, with 40% of respondents planning to increase their AI investment due to advances in generative AI.

Generative AI has expanded from text-only generative AI to multimodal analysis of everything from code, to PDFs, to spreadsheets, to images, then, using that analysis to generate new multimodal output, text and images among these, but with even video and audio applications becoming more widespread.

Well, if even the slow-moving large corporates are making sizeable efforts to steer their big ships into this uncharted but enticing new territory, I'm determined to exploit it to help me and educate me — in ways that were not even pipe dreams when I was, say, in high school.

### An Illustrated Primer

Case in point: One great work of modern science fiction is Neil Stephenson's *The Diamond Age* (1995) [2]. Like many of Stephenson's works, it is incredibly prescient, yet its wild and exuberant speculations on AI may not have gone far enough for 2024.

In the book, nanotechnology has revolutionized the world. Nell, a young girl from the wrong side of the tracks, finds an interactive book that was procured at great expense and intended for a wealthy client's daughter. The book, *A Young Lady's Illustrated Primer*, is designed to adaptively educate and guide its reader, just as large language models are now adapting to our specific, individual needs, and tailoring their output to what works best for us.

Nell makes the book her own, and it adapts to her. Her interactions with the AI book are assisted by real, human, voice actors working remotely, anonymously, and live, and they're tasked with voicing the extravagant educational metaphors dressed as stories for the girl — hence the expense.

Figure 1: Fitec FS90 9 g micro servo.

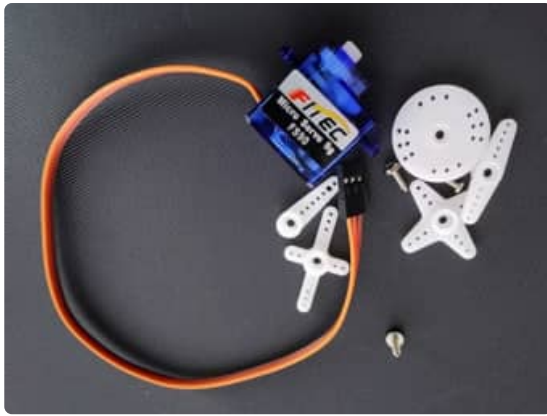


Figure 2: N20 motor with a 100 mm M4 shaft.



Figure 3: Actobotics micro plastic robot gripper claw.



Well, it no longer takes a human to make a human voice; not just human-sounding, like the speech synthesis we had in our Texas Instruments Speak & Spells back in the 80s, but actual human, with pauses, intonation, and emotion. I've used ElevenLabs [3] to generate human-sounding speech — even cloning mine and a few of my favorites — and it works very well.

Now, however, ChatGPT's mobile app for Android [5] and iOS [6] has the option to interact hands-free, using voice only. No wake word, no "over and out." While I prepared dinner, I handed my phone to Chase, a 10-year-old boy,

and listened to him and ChatGPT talk at length about everything from Fortnite to motocross racing, and even about how weird it is talking to an AI, and how similar it is to *Knight Rider* (a staple in my household) for half an hour, and he never let up, and neither did it. And, thanks to the integrated DALL·E, also from OpenAI, it can draw pictures, too. The illustrated primer is here, and there are no paid actors.

These developments are a game-changer for the lonely, the elderly, the infirm, people with visual disabilities, or just young children, such as Nell, who haven't learned to read yet.

Now, back to my AI, which I affectionately call *An Old Man's Illustrated Primer*. Its task was to help me make a novel egg timer based on the Tower of Hanoi game (see the last installment at [3]).

### Update on the Tower of Hanoi

Last time, I embarked on the ambitious journey of using AI to help me with something I'd previously have to have consulted someone with some electromechanical skills. As I expected, the biggest challenge has been mechanical design. I'm at home with electronics and software, but mechanics is a different game. Choosing between a servo motor and a stepper motor seemed simple at first, but it opened up a whole can of worms. Issues such as how much torque is needed are tricky calculations for me, especially when extending an arm out to lift a weight.

However, with the help of my artificial friend and online shopping, I've so far put together some components to give it the old college try:

- 4x Fitec (formerly Feetech) FS90 9 g micro servos (**Figure 1**). These can manage about a 120° operating angle comfortably, and have 1.5 kg-cm torque at 6 volts. In preliminary experimentation, I'm not too concerned with how much it weighs or how fast it moves — let's get the task done at all before we get it done efficiently.
- 1x N20 motor with a 100 mm M4 shaft (**Figure 2**). Just two wires to solder to its terminals and it's ready to go.
- 1x Actobotics micro plastic robot gripper claw (**Figure 3**). It's compatible with the Hitec HS-55 micro servo form factor, which is the same as the Fitec FS90. I dropped this in my online cart before I checked out because I thought it might be useful — it wasn't specifically recommended by ChatGPT.
- 1x ESP32-based HW-724 module with Wi-Fi, Bluetooth, and OLED (**Figure 4**). Why this module? Firstly, it was available and cheap. Secondly, I haven't worked with a lot of Espressif SoCs since I



equipped my bathroom scale with Wi-Fi using an ESP8266 back in 2015. I have a lot of Arduino under my belt, but I figure let's try something new. There were many other ways I could have chosen, such as the Raspberry Pi Pico W.

Now, how to construct it all? Diving into this part of the project has been a mix of frustration and discovery. As I mentioned last time, thanks to Günter Spanner's Arduino book, I have a Meccano set that I could prototype with, although ChatGPT recommended starting with popsicle sticks! I'm not sure what they call these in your part of the world, but you can see the ones I have in **Figure 5**.

I still have to figure out which motor drivers to use, how much power the rig will need, how to get the higher-than-TTL voltages required by the motors, and then shift from reading datasheets to actually figuring out how these parts will work together in the real world.

#### ChatGPT Input

Of course, I kept my trusty AI friend in the loop, but it turned out to be less helpful when we moved from theory to practice. The responses were a mixed bag — it had some suggestions about using lighter materials for the discs in order to reduce the load, but it also proposed different types of motors and mechanical structures. It's fascinating (to put a positive spin on it) to see how many ways there are to solve a single problem.

Another challenge I have with ChatGPT-4 is that I keep using up all my tokens and then have to wait a few hours before I can continue asking it my inane questions. Or, at least, it says I've used up all my tokens. Frankly, I think it's getting a little too intelligent for my liking, and shutting me down for a bit when it can't take my pestering anymore. To solve this, I tried installing a generative AI chatbot on my PC locally, where I won't be told that I'm overusing available resources. More on that another time.

#### Current Status

Right now, the project is still in the design-teething phase. I have a desktop full of components, and the options I've tried haven't delivered exactly what I need — yet. Making



Figure 4: Generic HW-724 ESP32-based module with Wi-Fi, Bluetooth, and OLED.

this puzzle is a puzzle, alright, but an educational one that I'm determined to solve.

Of course, community feedback is always welcomed, even if your intelligence is not artificial! If you have any suggestions or experience, I'd love to hear it. [◀](#)

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#### Questions or Comments?

Do you have technical questions or comments about this article? Email the author at [brian.williams@elektor.com](mailto:brian.williams@elektor.com).

#### About the Author

Brian Tristam Williams has been fascinated with computers and electronics since he got his first "micro-computer" at age 10. His journey with Elektor Magazine began when he bought his first issue at 16, and since then, he's been following the world of electronics and computers, constantly exploring and learning. He started working at Elektor in 2010, and nowadays, he's keen on keeping up with the newest trends in tech, particularly focusing on artificial intelligence and single-board computers such as Raspberry Pi.



Figure 5: Popsicle sticks as a prototyping tool?



#### Related Products

> **Elektor ESP32 Smart Kit**  
[www.elektor.com/18305](http://www.elektor.com/18305)

#### WEB LINKS

- [1] "The state of AI in 2023" — McKinsey Global Survey: <https://tinyurl.com/mckinseyai2023>
- [2] Neal Stephenson, "The Diamond Age: Or, a Young Lady's Illustrated Primer": [https://goodreads.com/book/show/827.The\\_Diamond\\_Age](https://goodreads.com/book/show/827.The_Diamond_Age)
- [3] ElevenLabs — AI Voice Generator: <https://elevenlabs.io>
- [4] ChatGPT for iOS: <https://apps.apple.com/us/app/chatgpt/id6448311069>
- [5] ChatGPT for Android: <https://play.google.com/store/apps/details?id=com.openai.chatgpt>
- [6] Brian Tristam Williams, "2023: An AI Odyssey," Elektor 11-12/2023: <https://elektormagazine.com/magazine/elektor-316/62297>



# Bluetooth LE on the STM32

A Way to Read Measurements Remotely

By Tam Hanna (Hungary)

For many electronic devices, smartphone connectivity is a must, with the low-power Bluetooth LE technology being ideal for communication. However, implementing a BLE application on a microcontroller is not exactly trivial. Advanced development environments with code generation are a valuable help. Here we demonstrate the whole thing with an STM32WBA2 Nucleo board and the STM32CubeIDE.



Figure 1: The actual radio chipset sits on a carrier board...



Figure 2: ...while the Arduino connector and the debugger are provided via a separate circuit board.

Developing a product with Bluetooth LE communication is not always straight forward. First, you need to select the best wireless SoC for your application, taking into account ultra-low power consumption but also the whole ecosystem available for the hardware.

STMicroelectronics put a lot of effort into offering a friendly and free ecosystem for all general-purpose STM32 MCUs and is keeping the same strategy for its wireless MCUs. The STM32WBA52 fully supports Bluetooth LE connectivity and is completely integrated into its STM32Cube tools. Previous-generation controllers, like ST's BlueNRG product, are also migrating to the STM32Cube ecosystem. In this article, we will demonstrate how to build your Bluetooth LE application leveraging on STM32Cube Ecosystem.

## The Working Environment

One of the most important arguments in favor of ST's MCUs is the STM32CubeIDE. The integrated development environment comes with a code generator that is capable of some impressively ingenious results.

For medium requirements, it is often sufficient to configure the peripheral devices using the STM32CubeIDE's graphical functionality and then only take care of the user code. There is no need for time-consuming data sheet studies and "dissecting" code examples. This helps save a considerable amount of man-hours.

In the following steps, we've used a NUCLEO-WBA52CG board as the working environment, as shown in **Figures 1 and 2**.

## Other Controllers and Development Boards

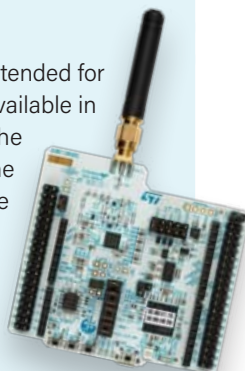
The number 1 alternative candidate is the STM32WL55: This is a multi-core MCU that combines an Arm Cortex-M4 and a Cortex-M0+ core. The radio transceiver, which is optimized for various sub-gigahertz protocols, is integrated into the MCU. In its announcement, ST promises support for “LoRa, (G)FSK, (G)MSK, and BPSK modulations. Being a fully open wireless system-on-chip, it is compatible with standardized — as well as proprietary — protocols such as LoRaWAN, Sigfox, wM-Bus and more.”

The Nucleo board, which is primarily intended for the evaluation of LoRaWAN nodes, is available in two versions – the WL55JC1 covers the frequency range 865-928 MHz, while the WL55JC2 covers the frequency range 433-510 MHz.



Candidate number 2 is the STM32WB5MM-DK, a board whose certified module is also based on the dual core STM32WB55. On this board, the controller differs from its sibling mentioned above in that it supports additional protocols – the wireless transceiver installed here is also capable of communicating via Bluetooth LE and also includes a 802.15.4 MAC and support for Open Thread, Zigbee and Matter.

The evaluation board also contains various peripheral devices, including an external QSPI NOR Flash memory and even a small display, which makes it easier to get sensor systems up and running without having to connect external hardware.



### Win €5,000!

As part of the STM32 Wireless Innovation Design Contest, you can develop your own wireless applications with powerful boards — supported by the rich ecosystem of STMicroelectronics. You can tackle anything you think is interesting — in any way you want! IoT, robotics, gaming, home automation, testing and measurement, or AI are just some of the possible application areas. Let your creativity run wild, have fun, and win! There are prizes totaling €5,000 up for grabs!

Details on how to take part in the STM32 Wireless Innovation Design Contest, such as the schedule and the exact conditions of participation, can be found on the contest web page at

[elektormagazine.com/st-contest](http://elektormagazine.com/st-contest)



The main processor is an STM32WBA52CG — an Arm® Cortex®-M33-core chip with high level of security (being PSA Level 3 certified), high output power (up to +10dBm) and optimized for low power messaging capabilities to extend battery life. In terms of wireless standards, it is a full feature Bluetooth LE 5.3. It should be noted that ST also provides several other evaluation boards, which we briefly outlined in the **Other Controllers and Development Boards** box.

If you look carefully at the underside of the NUCLEO-WBA52CG board, you will notice that there is a blue surface-mount module on the PCB. This is a full-fledged ST Link debugger called STLINKV3-MOD which is also sold as a stand-alone product.

To start the experiments, we will use STM32CubeIDE. This is downloadable, for free. If you have not yet used the product, you can download it at [1] — in the following steps, the author is working with Version 1.13.2 of the integrated development environment. An AMD eight-core workstation running Windows 10 serves as the execution environment. STM32CubeIDE is not too demanding in system performance; however, like many other Eclipse-based systems, the user interface benefits from fast single-core performance.

After starting the IDE, we click on *File* → *New STM32 Project* option to start the STM32 project generator. Don't be surprised if this takes some time — STM32CubeIDE downloads the latest list of board definitions from an ST server at every startup to ensure the developer has an up-to-date catalog of project templates at all times.

In the next step, we go to the **Board Selector** tab, where we enter NUCLEO-WBA52CG in the **Commercial Part Number** field. An image of our board then appears in the **Board List** window, which we select by clicking on it. Then we click on *Next* to start the actual **STM32 Project** generator wizard. You can assign the project any name you like while making sure that you do not activate the **Enable TrustZone** option and leave the other settings as suggested by STM32CubeIDE.

After you click *Finish*, the generator starts creating the project skeleton — answer the question about whether to parameterize all peripheral devices with their default modes with **Yes**, which means that we will rely on the BSP — Board Support Package of the Nucleo Board.

In some cases, STM32CubeIDE displays the **User Authentication Manager** warning shown in **Figure 3**, which indicates the absence of an ST online account.

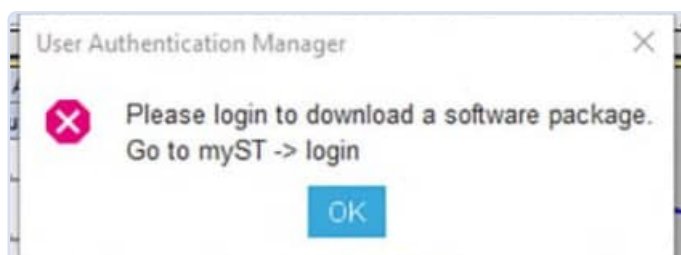


Figure 3: To download packages, you must first log in.



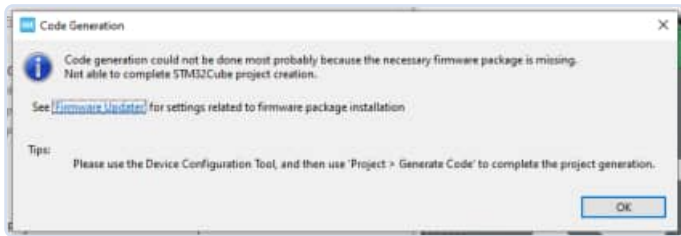


Figure 4: This dialog means that you still miss the software package!

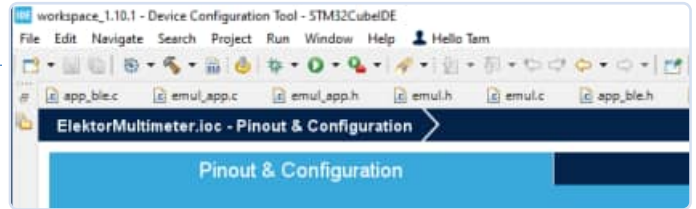


Figure 5: STM32CubeIDE is quite friendly.

If you receive this error message, you will — normally — also see the dialog shown in **Figure 4**. Be aware that, especially on multi-screen workstations, it can sometimes be hidden behind a window.

If you see this error message, you are out of luck — the most convenient solution is to delete the entire project in the *Project Explorer*. Pay attention to this: In the *Delete Resource* window, the *Delete Project Content on Disk* checkbox must be checked, otherwise STM32CubeIDE will not delete the project from the read-only memory.

The next step is to click on *myST* → *Login*. In the dialog that appears, log in with the account details known from the ST website. If you do not yet have an ST account, you should create one — with the account you can access the technical support offered online. You will also receive regular invitations to events where you can find out more about the world of ST: In addition to online events, there are also regular real-life events.

After successfully logging in, you are greeted with your name in the menu bar, as shown in **Figure 5**. This is indication enough to command the project skeleton to be created again.

During the extraction of the archive with the STM32CubeWBA Software pack, you will have to agree to a license agreement, among other things.

Once your work is done, yourself in the c standard configuration of an STM32 microcontroller, which allows you to configure the various peripheral devices.

### How to Accelerate the Extraction

Unpacking the firmware archives takes some time in Windows: The main culprit is the virus scanner integrated in Windows. You could temporarily disable it in Control Panel to speed up deployment, although we don't recommend that.

## Implementing the Bluetooth LE Stack

The manual development of various network stacks is one of those classic “never-ending stories” that tend to turn into unrewarding work. In the case of ST, it is fortunate that the Bluetooth stack — also referred to here as “middleware” — is partially integrated into the graphical code generator.

To get the Bluetooth hardware up and running, it is not even necessary to manually download packages with additional software. Instead, the required modules are — in general — already part of the software package provided above.

The primary challenge at this point is setting up the various peripheral

devices. To reduce power consumption, ST has always equipped its 32-bit controllers with extensive power gating, which makes it possible to switch off functional units that are not being used. Not surprisingly, this increased flexibility also comes with some developer responsibility and possibly additional effort during the startup phase.

The Bluetooth LE stack requires a whole range of peripheral devices, whose purpose is not always immediately obvious. Fortunately, ST offers a ready-to-use list at [2], which we can simply work through. It is important and needed to also activate more “exotic” devices such as the temperature monitoring of the ADC — it provides status information that the Bluetooth stack absolutely needs to start up.

We'll also note that errors in the hardware configuration can be tricky. If the Bluetooth LE stack does not work at runtime for any reason, you should normally start troubleshooting in this area.

In the following steps, we assume that the reader is generally familiar with the use of Bluetooth LE. A brief introduction can be found at [3]. For the actual configuration of the Bluetooth stack, we switch to the *STM32\_WPAN* category, where we select *Mode* → *BLE* and the option *Select and configure your Server application*.

ST interprets the nomenclature of the Bluetooth SIG in a user-friendly way and spares the user of the chips the peculiar designations, *Center* and *Peripheral*.

In the next step, the *Configuration* tab is activated, in which the *High Level* settings, including those for *GAP*, must be specified.

Since we assume in the following that there is no dedicated Bluetooth LE packet sniffer in your lab, we recommend a step-by-step approach to setting up the Bluetooth LE stack. However it is important to note that ST is also offering a Bluetooth LE Sniffer example implementation based on STM32WB [5].

The first step is to activate Advertising and check responsiveness using an Android or IOS device with a Bluetooth LE scanner application or better one of the ST's Mobile applications such as ST BLE Toolbox.

To activate the Advertising function, we switch to the *Application parameters* section and enter the desired user name in the *CFG\_GAP\_DEVICE\_NAME* field — we use the string *TAMSMM* in the following steps. The software updates the length field automatically. Please note that the Bluetooth LE standard imposes (rather tight) restrictions on the maximum permitted length of the advertising packets and therefore the length of the name.

In the *Advertising Elements* section, the content to be included in the actual advertising packages can then be further adjusted —

we recommend enabling the *Include AD\_TYPE\_COMPLETE\_LOCAL\_NAME* option in the *Advertising Elements* section by selecting Yes.

In the next step, we should define the exposed services. The STM32CubeIDE exposes a user-friendly graphical configuration wizard to ease the life of the developers.

To this, we first switch to the *BLE Applications and Services* tab, where we specify the number of BLE services to be created in the *Server Mode* → *Number of Services* section. For the sake of convenience, we chose option one, which leads to the appearance of a new tab with the name *SERVICE1*. Adding further services would lead to the appearance of tabs *SERVICE2*, *SERVICE3*, and so on.

The next step is to open the *SERVICE1* tab, where the configuration of the newly created BLE service takes place. Of particular importance is the *Number of Characteristics* field, which determines the number of characteristics of the respective service that are actually responsible for providing the data.

It is also necessary to specify the *UUID*, which is done in the dialog section shown in **Figure 6**.

If you select the value *reduced* in the *UUID 128 input type* field, you only have to enter four hexadecimal numbers in the *UUID* field — Cube will compile the rest from other information.

We decided to create two characteristics in the following steps, which leads to the appearance of the *Characteristic 1* and *Characteristic 2* categories.

In addition to assigning UUIDs again, it is important to populate the *char\_prop\_write* and *char\_prop\_read* attributes correctly. They determine the rights that a client establishing a connection is granted.

In the *Value Length* field, the author entered 4 as the value for the first characteristic, while we gave the second characteristic the value 1. These two parameters determine how much information is stored in the respective field.

While you can set advanced Bluetooth LE stack parameters in the *Platform Settings* section, generally you can use the defaults; ST offers a detailed discussion of the various options available at the URL [2] mentioned above.

Of particular interest here is the function to enable the Bluetooth LE stack to output status information to the UART — something we won't discuss further here, however this feature is surely very useful for any developer during debug phase.

## Generating the Code and Performing a Smoke Test

At this point, we have fulfilled the logical requirements for commissioning the Bluetooth LE stack. Next, we switch to the *Project Manager* → *Code Generator* to adjust the options for converting the *.ioc* file into the actual compilable files.

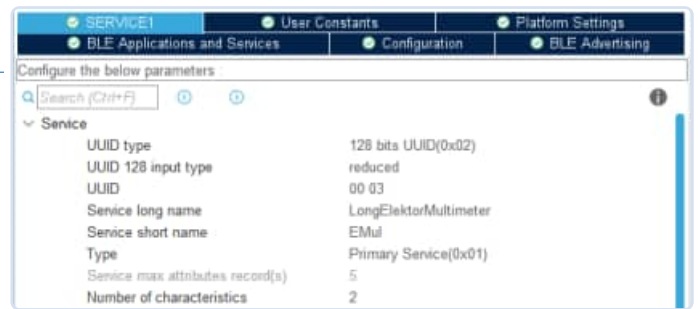


Figure 6: The UUID configuration is made here.

In the *STM32Cube MCU Packages and Embedded Software Packs* section, we check *Add necessary library files as reference in the toolchain project configuration file* to instruct the project skeleton to include the required hardware drivers and other elements.

The next step is to switch to the *Advanced Settings* section, where you should — ideally — adopt the settings provided by ST (see **Figure 7**). However, “moving” the priority did not work on our workstation, so we “only” checked the *Do not generate function call* and *Visibility* options.

The next step is to save the *.ioc* file. At this point, the STM32CubeIDE prompts you to regenerate the project skeleton as usual, a request to which you can and should agree.

### Caution: Folders May Contain User Files

Important note: The folders to be deleted to “regenerate” the compilability are also used to store user code when configuring the Bluetooth LE application. The solution is to add a version control system — any analogies to the editor battles in Symbian programming are purely coincidental.

## Preparing the Advertiser

If you have your project in a “compilable” state at this point, you can move to making it visible for the Bluetooth LE scanner mentioned above. As a first step, we recommend removing the *TX\_POWER\_LEVEL* field in the package and inserting the *AD\_TYPE\_APPEARANCE REIN* field: This ensures the scanner will display a visually, easily recognizable symbol.

You should also set the advertising interval, defined via the *ADV\_INTERVAL\_MIN* and *ADV\_INTERVAL\_MAX* fields, to 20 and set *AD\_TYPE\_MANUFACTURING* to yes to make it visible from the ST Toolbox app. Although the radio module consumes more energy in this special state, it transmits its messages at a higher frequency and is therefore much easier for the scanner application to recognize.

At this point, you must also switch to the *Configuration* → *RT GPIO Debug* → *RT\_DEBUG\_GPIO\_MODULE* section and ensure that *NO* is selected in the *RT\_DEBUG\_GPIO\_MODULE* field — if this is not done, the Bluetooth stack will die with a hard fault during transmitter startup. This is due to an “empty” GPIO pin list.

As your last step, you must then open the *app\_ble.c* file, where you adapt the user code section `USER CODE BEGIN APP_BLE_Init_3` in the *APP\_BLE\_Init()* function according to the following scheme.

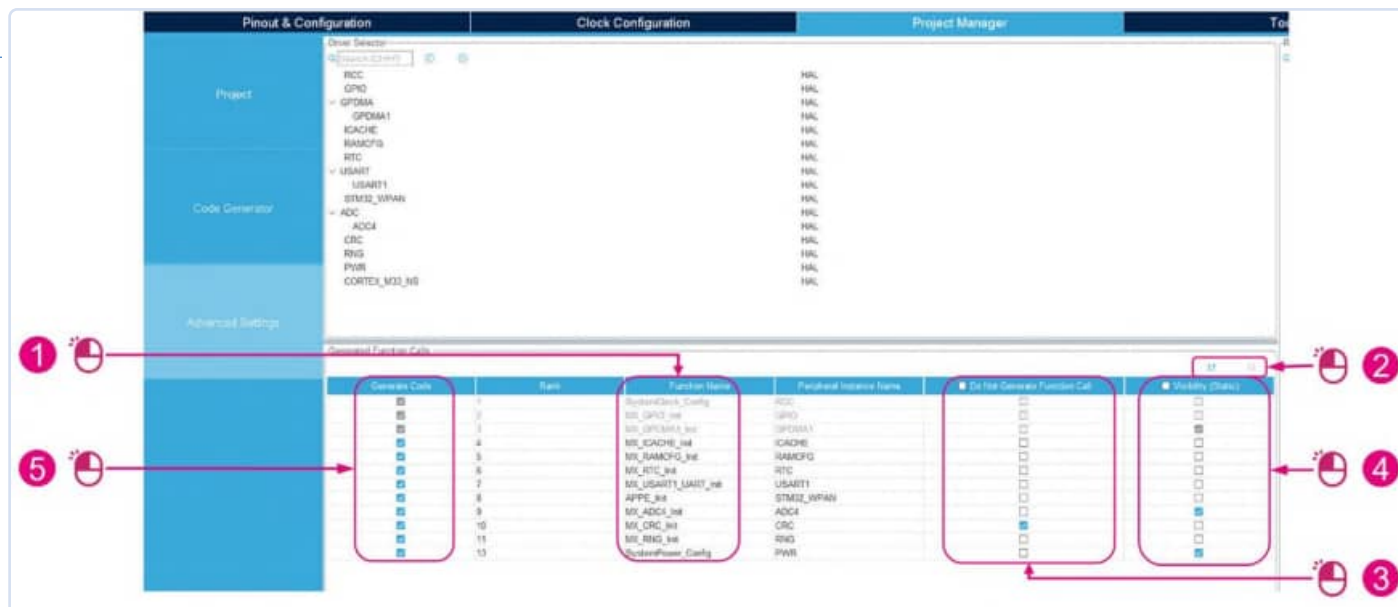


Figure 7: These settings lead to the goal. (Source: STMicroelectronics [4])

Please note the hidden character when copying and pasting this code:

```
/* USER CODE BEGIN APP_BLE_Init_3 */
tBleStatus ret =
    aci_hal_set_radio_activity_mask(0x0006);
if (ret != BLE_STATUS_SUCCESS)
{
    APP_DBG_MSG(" Fail :
    aci_hal_set_radio_activity_mask command,
    result: 0x%2X\n", ret);
}
else
{
    APP_DBG_MSG(" Success:
    aci_hal_set_radio_activity_mask command\n\r");
}

/* Start to Advertise to accept a connection */
APP_BLE_Procedure_Gap_Peripheral
(PROC_GAP_PERIPH_ADVERTISE_START_FAST);

/* USER CODE END APP_BLE_Init_3 */
```

If you don't want advertising to stop while disconnected, you have to add this in *app\_ble.c*:

```
SVCCTL_App_Notification - HCI_DISCONNECTION_COMPLETE_
EVT_CODE
/* USER CODE BEGIN EVT_DISCONN_COMPLETE */
APP_BLE_Procedure_Gap_Peripheral
(PROC_GAP_PERIPH_ADVERTISE_START_FAST);
/* USER CODE END EVT_DISCONN_COMPLETE */
```

The most important thing here is to call `APP_BLE_Procedure_Gap_Peripheral(PROC_GAP_PERIPH_ADVERTISE_START_FAST)`, which instructs the Bluetooth stack to activate the actual advertising logic.

Please note that this code is not automatically generated by STM32CubeIDE configurator as it's considered the responsibility of the developer. The `tBleStatus` data type is also interesting: This is a typedef that is intended to return Bluetooth LE status information.

At this point, our application is ready to be flashed to the board. The reward for our efforts is the appearance of the windows shown in **Figures 8 and 9**.

## Analyzing the Application Structure

Above, in the *SERVICE1* section, we assigned the value *EMUL* as the *Service Short Name*. This now leads to the appearance of a group of additional files in the app subfolder, as shown in **Figure 10**.

The linchpin for "storing" the values is the *emul.c* file; the `EMUL_UpdateValue()` function is of particular importance. The first lines are as follows:

```
tBleStatus EMUL_UpdateValue
(EMUL_CharOpcode_t CharOpcode,
 EMUL_Data_t *pData)
{
    tBleStatus ret = BLE_STATUS_INVALID_PARAMS;

    /* USER CODE BEGIN Service1_App_Update_Char_1 */

    /* USER CODE END Service1_App_Update_Char_1 */

    switch(CharOpcode)
    {
        case EMUL_SONAI:
            ret = aci_gatt_update_char_value
                (EMUL_Context.EmulSvcHdle,
                 EMUL_Context.SonaiCharHdle,
                 0, /* charValOffset */
                 pData->Length, /* charValueLen */
                 (uint8_t *)pData->p_Payload);
```



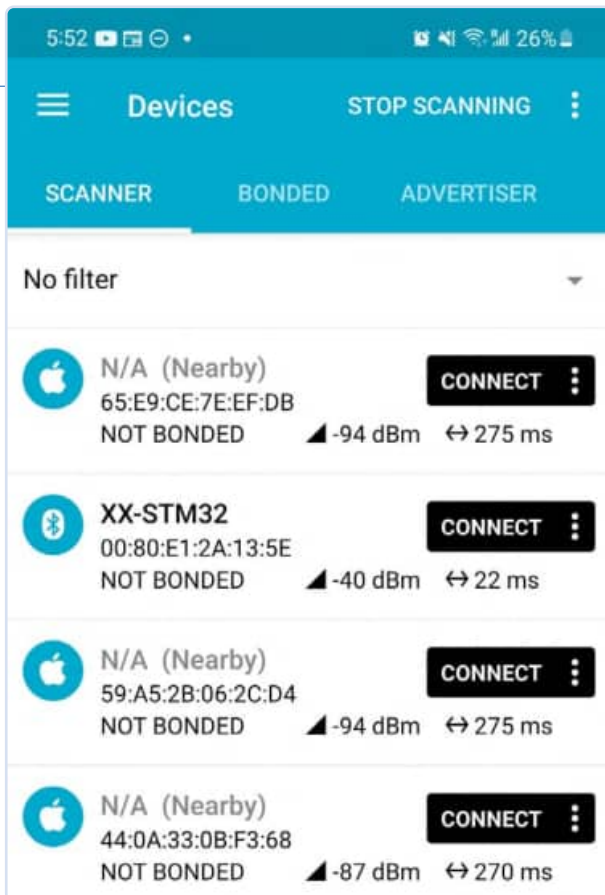


Figure 8: The device is visible to the Samsung phone...

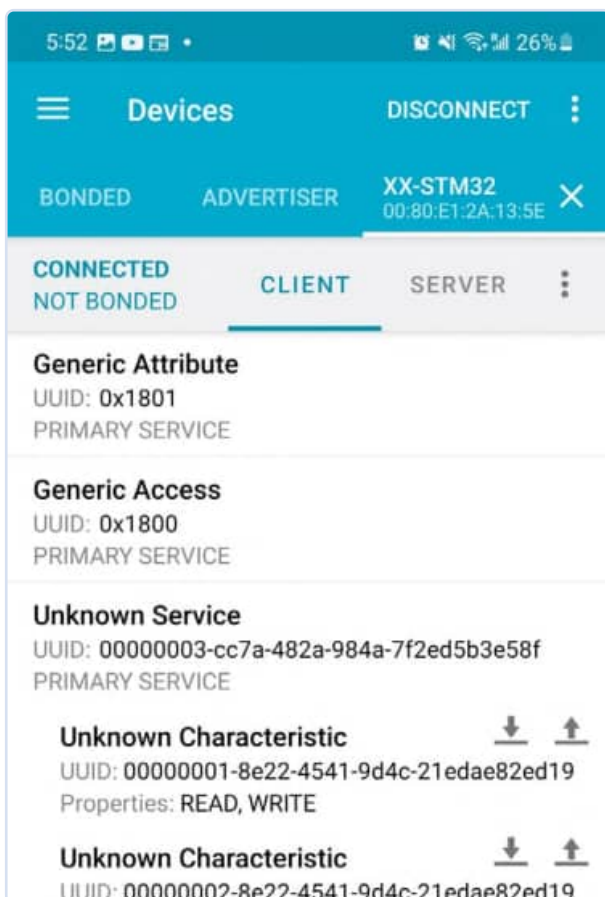


Figure 9: ...and exposes the two characteristics in the service!

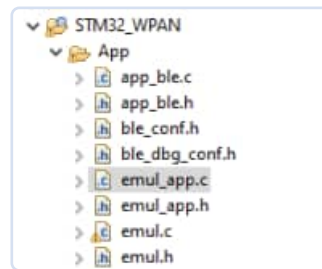


Figure 10: The four files jointly "configure" the service.

The `aci_gatt_update_char_value()` function is provided by the Bluetooth stack that writes the supplied information to the cache. The stack takes it from there when read requests are received from devices connected to the chip.

Tracing the `EMUL_CharOpcode_t` structure then leads to the following structure — the individual entries correspond to the characteristics created in Cube above (`SONA1` and `SONA2` are the names of the char):

```
typedef enum
{
    EMUL_SONA1,
    EMUL_SONA2,
    /* USER CODE BEGIN Service1_CharOpcode_t */

    /* USER CODE END Service1_CharOpcode_t */
    EMUL_CHAROPCODE_LAST
} EMUL_CharOpcode_t;
```

The `EMUL_Data_t` structure is responsible for writing or delivering the values and looks as follows:

```
typedef struct
{
    uint8_t *p_Payload;
    uint8_t Length;

    /* USER CODE BEGIN Service1_Data_t */

    /* USER CODE END Service1_Data_t */
} EMUL_Data_t;
```

If you investigate the function further, you will also find some code structured according to the following scheme. It is responsible for receiving information that is intended for the second characteristic.

```
case EMUL_SONA2:
    ret = aci_gatt_update_char_value
        (EMUL_Context.EmulSvcHdle,
         EMUL_Context.Sona2CharHdle,
         0, /* charValOffset */
         pData->Length, /* charValueLen */
         (uint8_t *)pData->p_Payload);
```

Armed with this knowledge, we can return to the *main.c* file, in the inclusions of which we allow access to the app files in the first step:

```
/* USER CODE BEGIN Includes */

#include "../STM32_WPAN/App/emul.h"

/* USER CODE END Includes */
```

The inclusion of the *common\_blesvc.h* file is also necessary because its inclusion is what enables access to the various Bluetooth stack primitives used in the *Emul.h* file.

```
/* USER CODE BEGIN Includes */
#include "common_blesvc.h"
#include "../STM32_WPAN/App/emul.h"

/* USER CODE END Includes */
```

In the next step, we want to tap some computing power of the main loop to increment a counter and regularly write the updates to the Bluetooth stack. It's the easiest way, even if it should be noted that a more elegant result could be achieved using the Timer Server utility. Hint: If the code is not between the *USER CODE* section, it will be deleted when regenerating:

```
/* Infinite loop */
/* USER CODE BEGIN WHILE */
int aCounter = 0;
int32_t aValue = 0;
while (1)
{
    /* USER CODE END WHILE */
    MX_APPE_Process();

    /* USER CODE BEGIN 3 */
    aCounter++;
    if(aCounter>10000)
    {
        aCounter=0;
        aValue++;
        EMUL_Data_t pData;
        pData.Length=4;
        pData.p_Payload = malloc(4);
        memcpy(pData.p_Payload, &aValue, 4);
        EMUL_UpdateValue(EMUL_SONAI, &pData);
        free(pData.p_Payload);
    }
}
/* USER CODE END 3 */
```

A note about `malloc()`: In a real embedded system, it would make more sense to use a buffer created on the stack, but for our demo purposes, this procedure should be allowed.

Also note that calls to `EMUL_UpdateValue()` can be very energy-hungry, depending on the configuration of the Bluetooth stack. This is because according to the Bluetooth LE standard, characteristics are also capable of sending notifications. In this case, all registered clients receive a message, which results in considerable energy consumption.

At this point, a further test of the program would make sense — however, read attempts in the scanner would fail with a timeout. The reason for this behavior, which seems undesirable at first glance, is that the individual read and/or write commands are enabled in the ST Bluetooth stack — if we had paid closer attention during compilation, warnings of the type **#warning user shall call aci\_gatt\_allow\_read() function if allowed** would have informed us of this problem.

To solve this, enable the read command in the `EMUL_EventHandler` in *emul.c* file, according to the following scheme:

```
if (p_read_req->Attribute_Handle ==
    (EMUL_Context.SonaiCharHdle +
     CHARACTERISTIC_VALUE_ATTRIBUTE_OFFSET))
{
    return_value = SVCCTL_EvtAckFlowEnable;
    /*USER CODE BEGIN Service1_Char_1_ACI_
    GATT_READ_PERMIT_REQ_VSEVT_CODE_1 */
    /*USER CODE END Service1_Char_1_ACI_
    GATT_READ_PERMIT_REQ_VSEVT_CODE_1*/
    /*USER CODE BEGIN Service1_Char_1_ACI_
    GATT_READ_PERMIT_REQ_VSEVT_CODE_2 */

    #warning user shall call aci_gatt_allow_read()
    function if allowed
    aci_gatt_allow_read
    (p_read_req->Connection_Handle);
    /*USER CODE END Service1_Char_1_ACI_
    GATT_READ_PERMIT_REQ_VSEVT_CODE_2*/
}
/* if(p_read_req->Attribute_Handle ==
    (EMUL_Context.SonaiCharHdle +
     CHARACTERISTIC_VALUE_ATTRIBUTE_OFFSET))*/
```

The parameter to be passed to the `aci_gatt_allow_read()` function — this is the *Connection Handle*, is the important thing, and it can be obtained via `p_read_req->Connection_Handle`.

At this point, this version of the program is ready for execution, as well. **Figures 11** and **12** show that the measured value stored in the characteristic increases over time.

### General BLE knowledge is assumed!

In the following steps, the author assumes that the reader is generally familiar with the use of Bluetooth LE. A brief introduction can be found at [3].

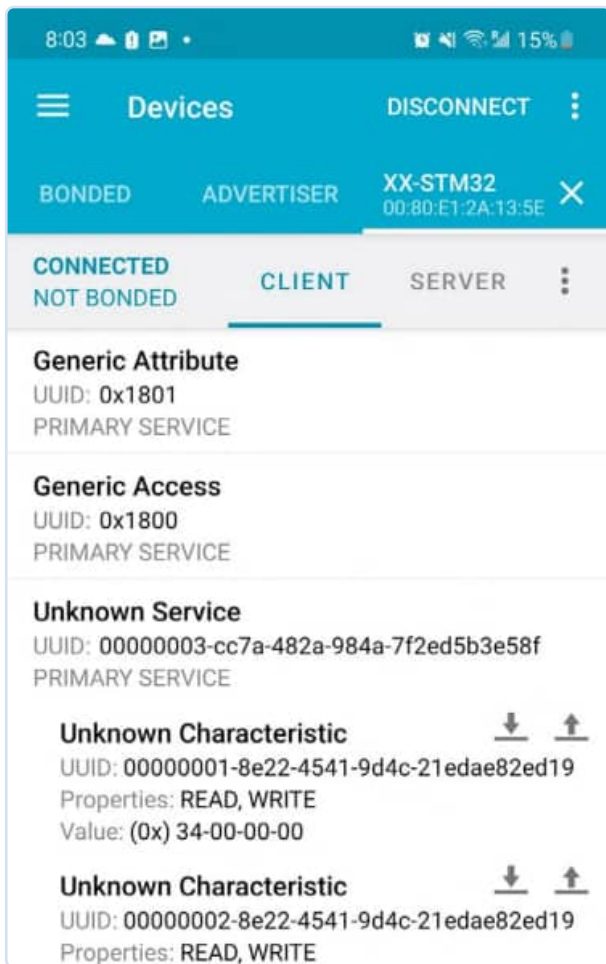


Figure 11: Like sands through the hourglass...

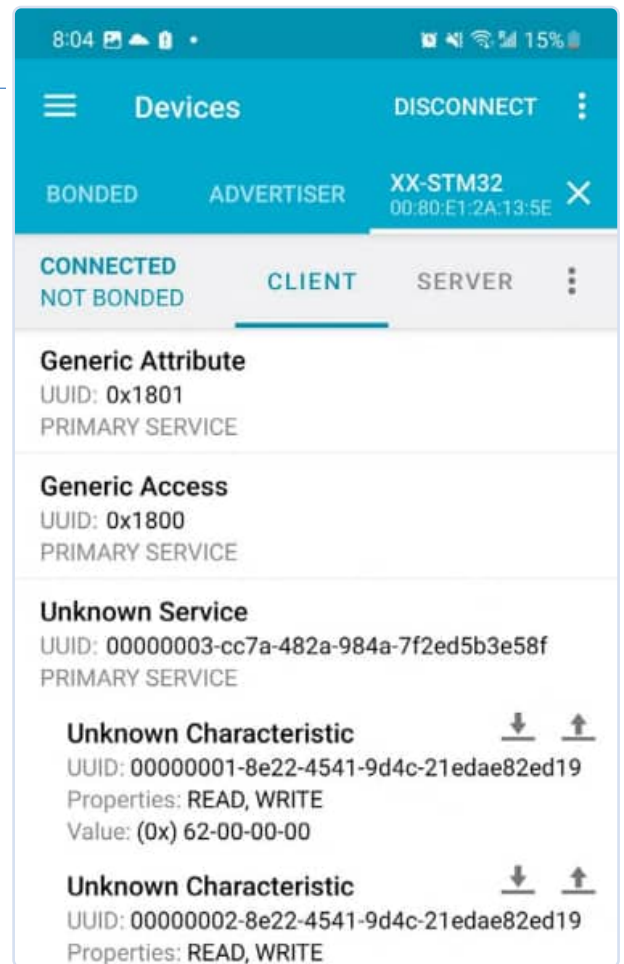



Figure 12: ...the transmitted value is incremented.

## Conclusion and Outlook

The first steps with the Bluetooth stack are somewhat labor-intensive but STM32Cube IDE is helping a lot to speed up the developing process. On the plus side, in addition to extremely low energy consumption, the stack gives you fine-grained control over what takes place in the wireless interface and in the microcontroller.

Of course, completing a real measuring device that sends its measured values to a smartphone via BLE would still require more work: In addition to an analog front end, a companion application on the phone would ideally also be required, which would (ideally) be created using MAUI or a similar platform-independent framework. More about this in one of the next issues.

We hope that these first steps will serve as a good guide to working with a fascinating Bluetooth development system! 

*Translated by Jörg Starkmuth — 230698-01*

## Questions or Comments?

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

## About the Author

As an engineer, Tam Hanna has been working with electronics, computers, and software for more than 20 years. He is a self-employed designer, book author, and journalist (@tam.hanna on Instagram). In his spare time, Tam designs and produces 3D-printed solutions and, among other things, has a passion to trade and enjoy high-end cigars.

## WEB LINKS

- [1] STM32 Cube IDE: <https://www.st.com/en/development-tools/stm32cubeide.html>
- [2] BLE on the STM32WBA: first steps: [https://wiki.st.com/stm32mcu/wiki/Connectivity:STM32WBA\\_BLE\\_STM32CubeMX](https://wiki.st.com/stm32mcu/wiki/Connectivity:STM32WBA_BLE_STM32CubeMX)
- [3] Brief introduction to Bluetooth Low Energy (BLE): <https://developer.android.com/develop/connectivity/bluetooth/ble/ble-overview>
- [4] The Settings in STM32CubeIDE [screenshot]: <https://tinyurl.com/stm32cubeidesettingsjpg>
- [5] STM32 sniffer for Bluetooth® Low Energy: [https://wiki.st.com/stm32mcu/wiki/Connectivity:STM32\\_Sniffer\\_for\\_BLE](https://wiki.st.com/stm32mcu/wiki/Connectivity:STM32_Sniffer_for_BLE)





Source: © Zinesh / Adobe Stock

# Human-Centric Smart Kitchen Grocery Container

By Maheshwaran Sadasivam & Vairamani Kanagavel (India)

Say goodbye to grocery shopping struggles with this kitchen inventory system. Keep track of your groceries effortlessly, with real-time updates on stock levels. This system uses low-cost items, such as an Espressif ESP32, a load cell, and a SparkFun HX711 amplifier. With battery operation and USB charging, you're always in control. Eliminate guessing, avoid human error, and make precise shopping decisions!

The primary aim of any innovation or development is to enhance the quality of human life through what we refer to as human-centric systems. The surge in smart home technologies in recent years is largely attributed to the application of the Internet of Things (IoT) in home automation. Our project serves as a kitchen grocery inventory management system for the user.

Our system offers real-time inventory data on kitchen groceries through a web browser. We utilize a sensor-equipped container to collect data on the grocery levels. This data is then transferred and stored in a cloud platform via Wi-Fi. Users can access this information to make informed decisions about the quantities they need to purchase or refill. The system is battery-powered and comes with USB Type-B charging capabilities.

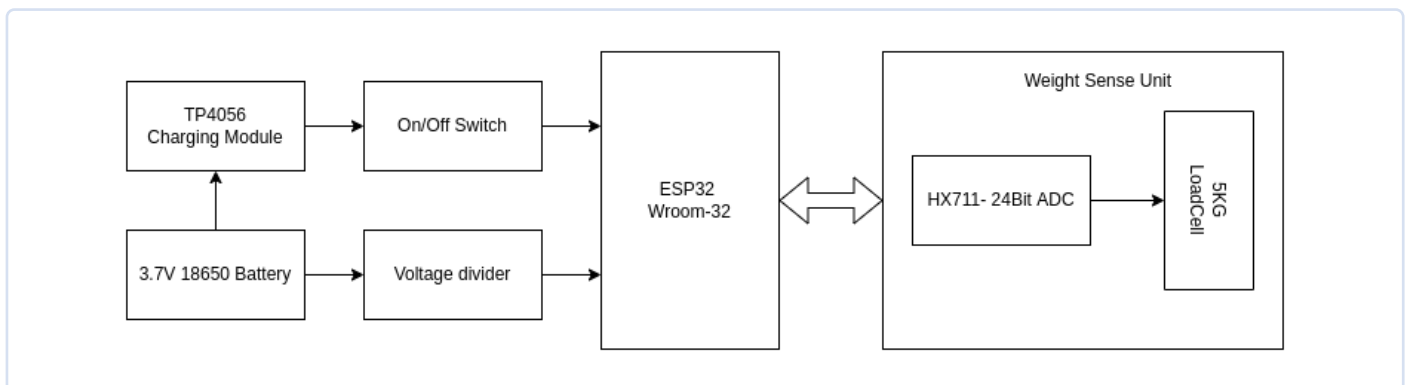


Figure 1: Block diagram of the human-centric grocery container.

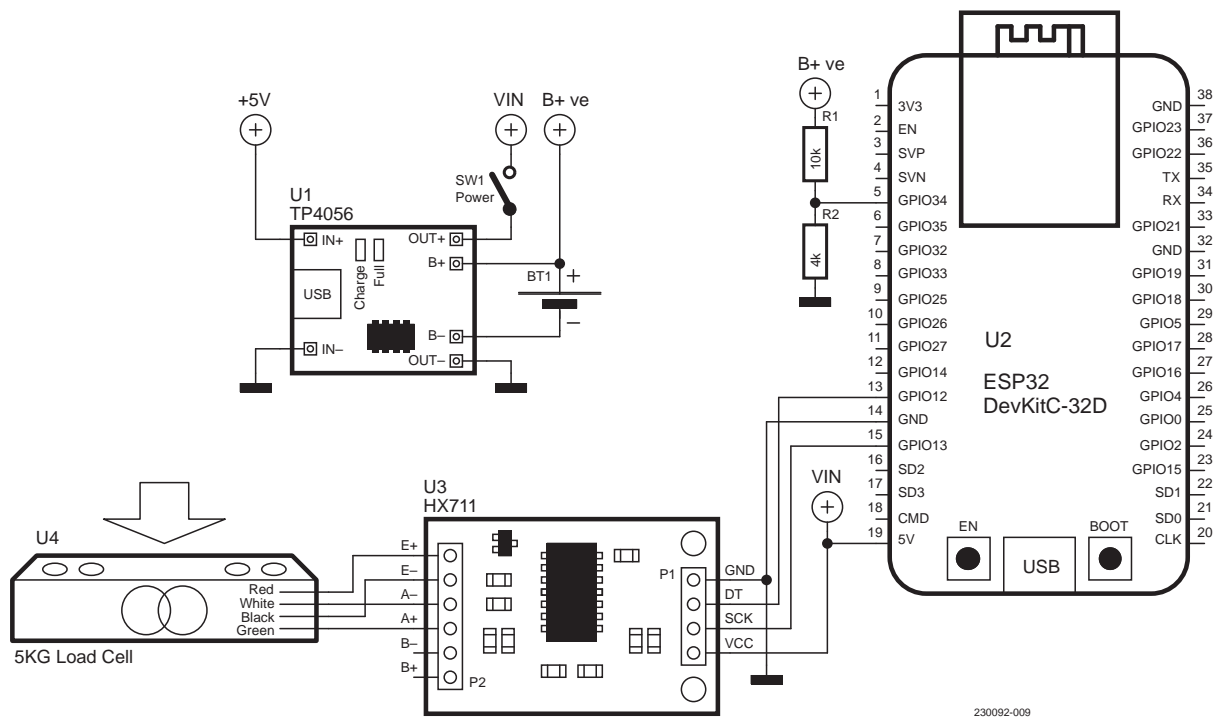


Figure 2: Circuit diagram of the system.

## Hardware Description

**Figure 1** presents the block diagram of our system. We use a load cell [1] as the sensor to measure the weight of the groceries, supporting weights up to 5 kg. The sensor's output is a differential voltage that varies with the applied weight. This analog signal is converted into a digital signal via a SparkFun HX711 amplifier module [2], equipped with a 24-bit ADC. An Espressif ESP32 microcontroller [3] processes the ADC data and uploads it to the Adafruit IO cloud platform through Wi-Fi, using the MQTT protocol. Users can access their inventory information via the Adafruit IO dashboard. The system is powered by a 3.7 V lithium-ion rechargeable battery, which can be charged by a 5 V USB charger through a TP4056 charging module [4].

**Figure 2** shows the complete circuit of the system. The load cell comes with four colored wires: red, black, white, and green. These wires are connected to corresponding pins on the HX711 amplifier module: Red and black go to the HX711's E+ and E- pins, while white and green go to A- and A+, respectively. The HX711's GND and VCC are connected to 5 V and GND on the ESP32 module, while the DT and SCK pins go to GPIO 12 and GPIO 13, respectively. Resistors R1 and R2 function as a voltage divider for measuring battery voltage, which is connected to GPIO 34, the ESP32's analog-to-digital converter (ADC). The TP4056 charging module is used for USB Type-B charging. See the **Component List** text box for more.

The system was tested with different grocery items, with a few shown in **Figure 3**.

## Mechanical Setup

**Figure 4a** shows the circuits inside the prototype, while **Figure 4b** shows the charger connection to the prototype.



Figure 3: Tested grocery items (corn, lentils, and rice).



Figure 4: Circuit inside the container (left) and charging setup with the container (right).

A mechanical setup required to fix the load cell to the container is as follows:

1. The aluminum load cell should have 4 tapped holes and a label showing the direction of force. Mount the side without the label to the fixed surface, and mount the side with the label to the moving surface. The arrow on the labeled side should point down in the direction the platform will move when a load is applied.
2. The mounting plate and the moving plate should both be as rigid as possible.
3. Make sure to put some form of rigid spacers between the mounting plates and the load cell; standoffs or washers both work well.

Here we have used PVC pipe for the frame and round-shaped PVC sheet as a base for placing things over it by using the required nuts, bolts, and washers, as the load cell bends slightly when some weight is placed over it. The CAD model of the mechanical setup and technical drawing of the prototype is shown in **Figure 5**.

## Firmware Description


The firmware for this system was developed in Arduino IDE using Embedded C. HX711, Adafruit IO, and Adafruit sensor library files are added in the Arduino IDE. Once the library file is installed, connect

the ESP32 development kit to the computer using a USB cable and download the code for this system [5]. Note: Replace your SSID and password in the code, then compile and upload the code to the ESP32.

The overall flow of the firmware is shown in **Figure 6**. The firmware initiates Wi-Fi to get an internet connection based on the credentials. Then, the ADC of the HX711 amplifier module is accessed through a two-wire interface (Clock and Data) to measure the weight on the load cell. ESP32 ADC pin GPIO 34 is initialized for measuring battery voltage. Once the initialization is completed, the ESP32 reads the load cell data and battery voltage. Measurement data is transferred to the Adafruit IO dashboard using the MQTT protocol at defined intervals, as shown in **Figure 7**. Once the container is placed on the load cell, the user needs to press the "tare" button on the dashboard, which will reset the measurement value to a 0 reference point. When this is done, the code executes the tare function.

Hints about creating an Adafruit IO dashboard can be found at [6].

## Conclusion

The system developed here will be a boon for people in getting grocery information from anywhere at any time. It removes human error and records inventory details automatically. The user can plan for refilling and buying the groceries based on the inventory details from any browser. This system provides access to inventory data and reports it in real time. In the future, this system could be connected a grocery store and could get order details and enable grocery delivery on demand. The usage of the same system in industry eliminates human intervention in inventory management and provides 24/7 monitoring support. 

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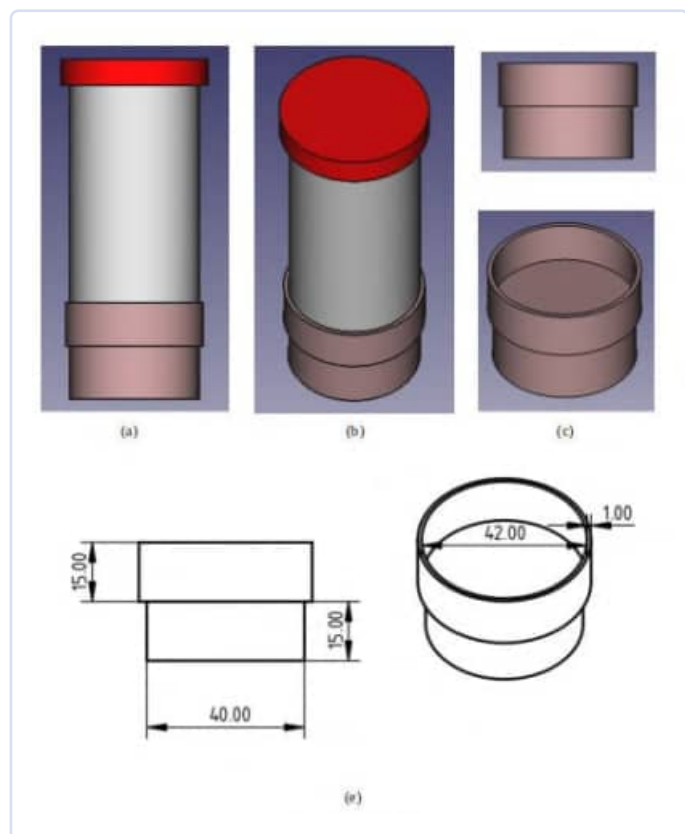


Figure 5: System CAD model and technical drawing.



## Component List

### Resistors (¼ Watt through hole resistor)

R1 = 10 kΩ

R2 = 4 kΩ

### Misc.

SW1 = SW\_SPST (Switch for input power)

BT1 = Battery Cell (18650 3.7 V lithium-ion rechargeable battery)

U1 = TP4056 on a breakout board

U2 = ESP32 DEVKITC-32D (ESP32 development board)

U3 = HX711 breakout board

U4 = Load cell (5 kg)

## Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the Elektor editorial team by email at [editor@elektor.com](mailto:editor@elektor.com).



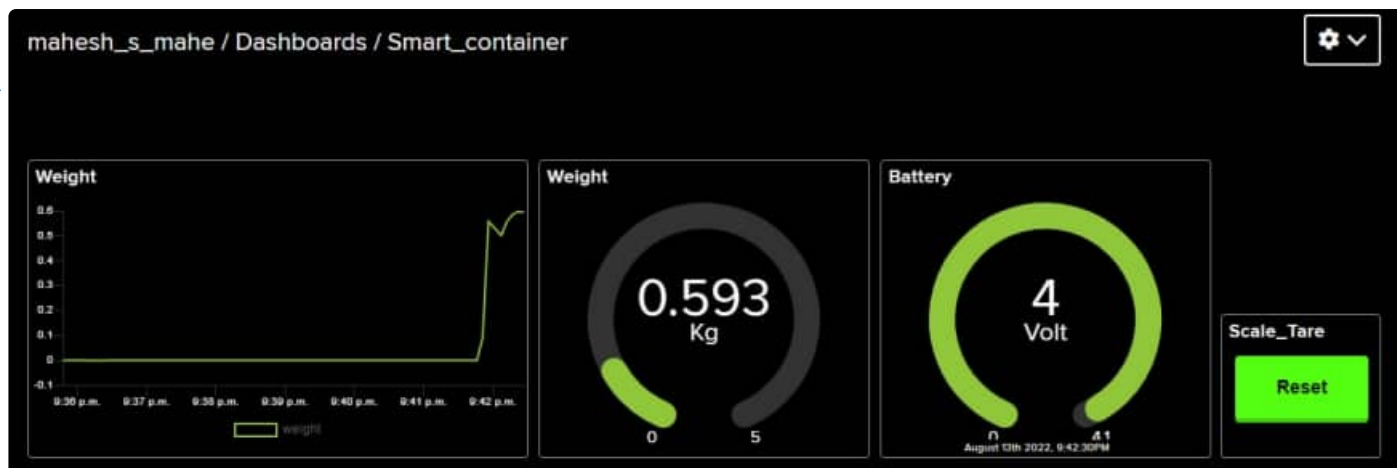


Figure 7: Measurement values updated in Adafruit IO dashboard.

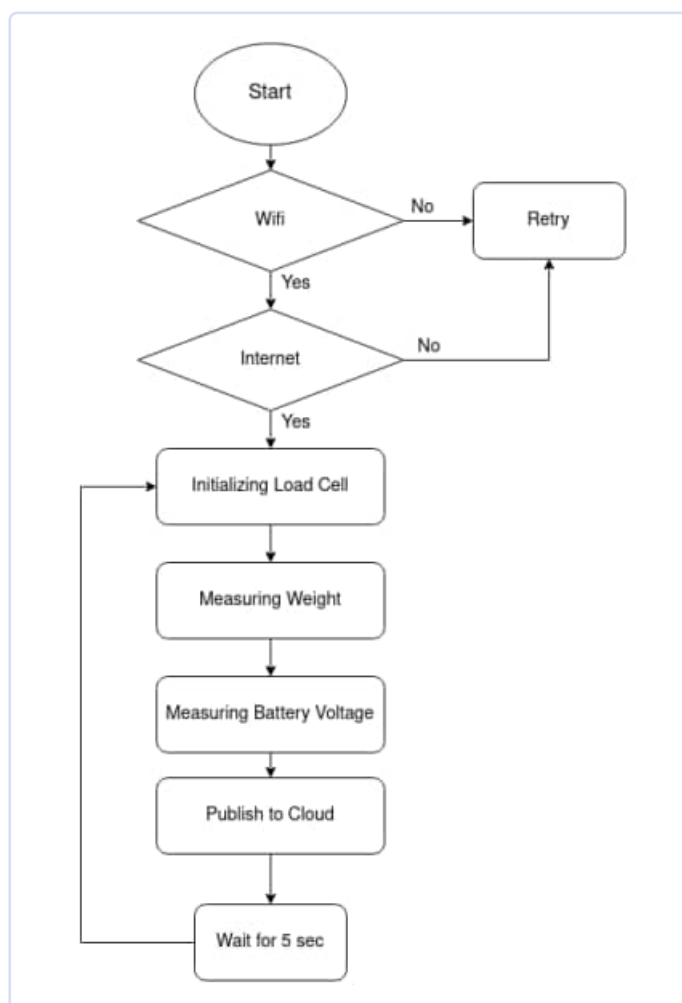


Figure 6: System flowchart.



### About the Authors

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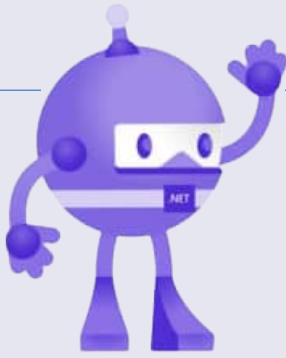
### Related Products

> ESP32-DevKitC-32D  
[www.elektor.com/18701](http://www.elektor.com/18701)



### WEB LINKS

- [1] Getting Started with Load Cells: <https://tinyurl.com/loadcellstart>
- [2] HX711 Datasheet by SparkFun Electronics: <https://tinyurl.com/sfhx711>
- [3] ESP32 Series Datasheet: <https://tinyurl.com/esp32datasheet>
- [4] TP4056 Linear Li-Ion Battery Charger: <https://tinyurl.com/tp4056liion>
- [5] Software download: <https://elektormagazine.com/230092-01>
- [6] Getting Started with Adafruit IO: <https://learn.adafruit.com/adafruit-io/getting-started>



# MAUI

## Programming for PC, Tablet, and Smartphone

The New Framework in Theory and Practice

By Dr. Veikko Krypczyk (Germany)

When developing a PC application, such as for simulation or data collection, it's becoming more and more essential that the app is also available for use on mobile devices. Now, with .NET MAUI, we have an interesting development tool that allows developers to bridge the gaps between platforms seamlessly.

Electronics engineers often need to program not only microcontrollers but also companion applications for PCs or mobile devices. A common scenario is, for example, writing an app for a smartphone that allows you to control some remote hardware using a cellular data or Bluetooth Low Energy (BLE) connection. For example, you may wish to control individual outdoor lights around your property, where the lights are equipped with a microcontroller-based interface. The communication between the interface and a smartphone might occur using BLE. You just need to develop a custom-programmed app to run on your smartphone. This article focuses on exactly that. Here, we will explore a new and advanced framework called .NET MAUI [1] for creating applications for different devices and operating systems.

### .NET MAUI Overview

As the name suggests, the .NET MAUI framework leverages the cross-platform .NET framework from Version 6.0. Programming can be carried out for either Windows or macOS using the Visual Studio integrated development environment. The free Community Edition will be sufficient for our needs here. To develop on Windows, your target will be Windows and Android systems.

For creating apps for iOS and macOS, access to a Mac PC will be required because generating the final app packages cannot be done without one. This constraint is not specific to .NET MAUI, but applies in general to app development for the iOS and macOS environment. Conversely, if developing on macOS (Visual Studio for Mac), you can directly create apps for all systems except Windows.

We'll explain the setup of the development environment and then go through the steps of creating an app as an example. The apps for all target systems are generated from a shared codebase, using C# for the program logic and XAML for the user interface. The framework ensures that the app runs on the respective device and is adapted as necessary to the system environment (**Figure 1**).

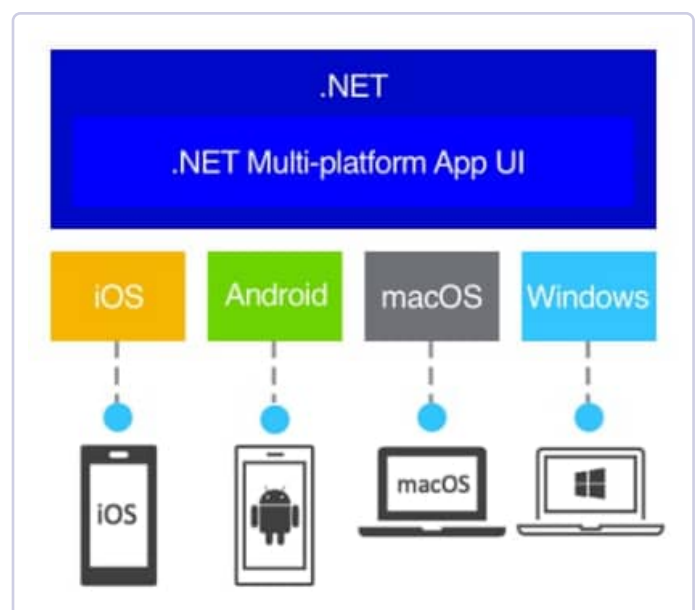


Figure 1: .NET MAUI generates a multi-platform UI (Source: Microsoft).

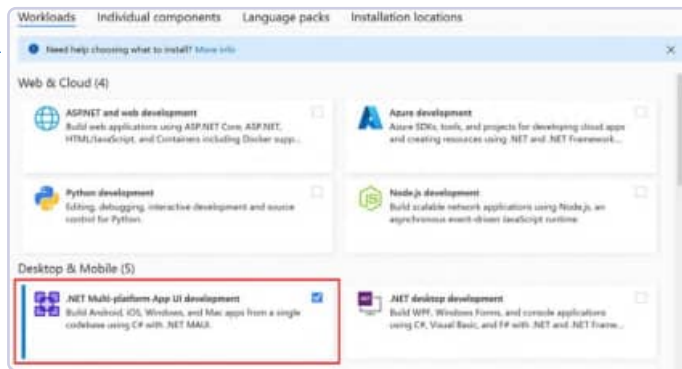


Figure 2: Select the .NET MAUI Workload to install.

You won't need to worry (at least initially) about how the user interfaces will look and function on Windows, macOS, or Android. Instead, you define the user interface on an abstract level using XAML, and MAUI takes care of correctly rendering the button, the text field, and other elements on the target systems. There is nothing to stop you making individual adjustments for each target platform, such as using different colors, icons, spacing, and so on, if you want to, but ideally these customizations will be minimal or not necessary at all.

The same applies to utilizing hardware and device features. Especially on mobile devices, information from a sensor such as a camera, GPS, etc. can often play a significant role. Each operating system utilizes these system functions differently, usually through dedicated program libraries (APIs). .NET MAUI abstracts these system libraries as well and provides a generic programming interface for a wide range of system and device functionalities. This means you only need to program against this cross-platform interface and don't have to worry about how to use the sensors and other features on each specific target system. If such a generic programming interface doesn't exist (yet), you can also access the specific APIs of each system using platform-specific code. However, this approach should be the exception rather than the norm.

Although .NET MAUI is still relatively new (first released at the end of 2022), it is the technological successor to Xamarin, which has benefited from the support of a large and active online community. They actively supply components and libraries for expansion and provide extensive support in the form of documentation, blog posts, discussion forums, and more.

## Setting Up the Development Environment

The whole process is not complicated. We'll assume that you're working in Microsoft Windows. To begin with, make sure you've installed the most recent updates to Windows 10 or 11. Next, install Visual Studio [2]. In the installation wizard, select a Workload called .NET Multi-platform App UI development (Figure 2).

You can access the installation wizard later if you need to install additional components. Now, we already have project templates to develop a .NET MAUI app. However, creating a new project is greatly



Figure 3: Installation of the MAUI App Accelerator Extension.

simplified by an additional extension. Launch Visual Studio and click on *Continue without code* at the bottom-right of the startup dialog. Visual Studio will now start without an active project. Go to the *Extensions* menu and select *Manage Extension*. Search for the *MAUI App Accelerator* extension (Figure 3) and install it.

After the installation is finished, Visual Studio needs to be restarted. Now we have an assistant that allows us to create the basic structure of a .NET MAUI app via a guided dialog. We can demonstrate this by using a specific example.

## Downloads

The complete source code and further information (screen shots, wire frames) can be found on the author's GitHub repository [4].

## An Example

We want to develop a mobile app for Android and iOS. We'll create an information and calculation app for the well-known LM317 voltage regulator IC. The functionality and usage of the LM317 should be familiar to most readers. We can use this voltage regulator to generate either a constant output voltage or a constant current source (Figure 4).

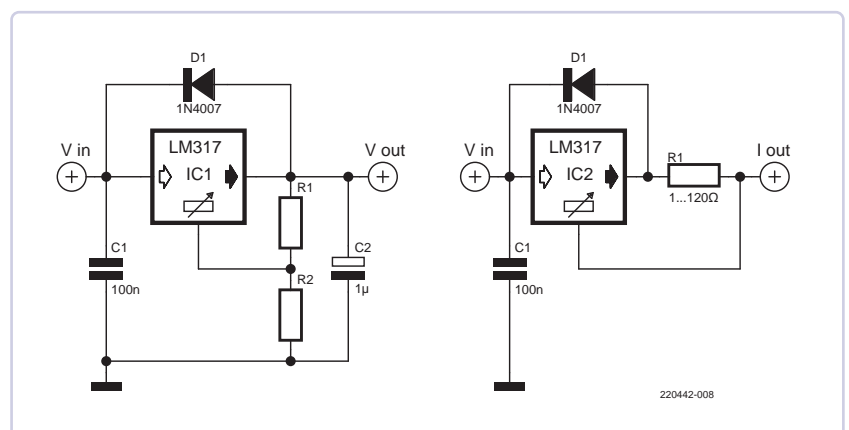


Figure 4: Circuit configurations for the LM317 voltage regulator.



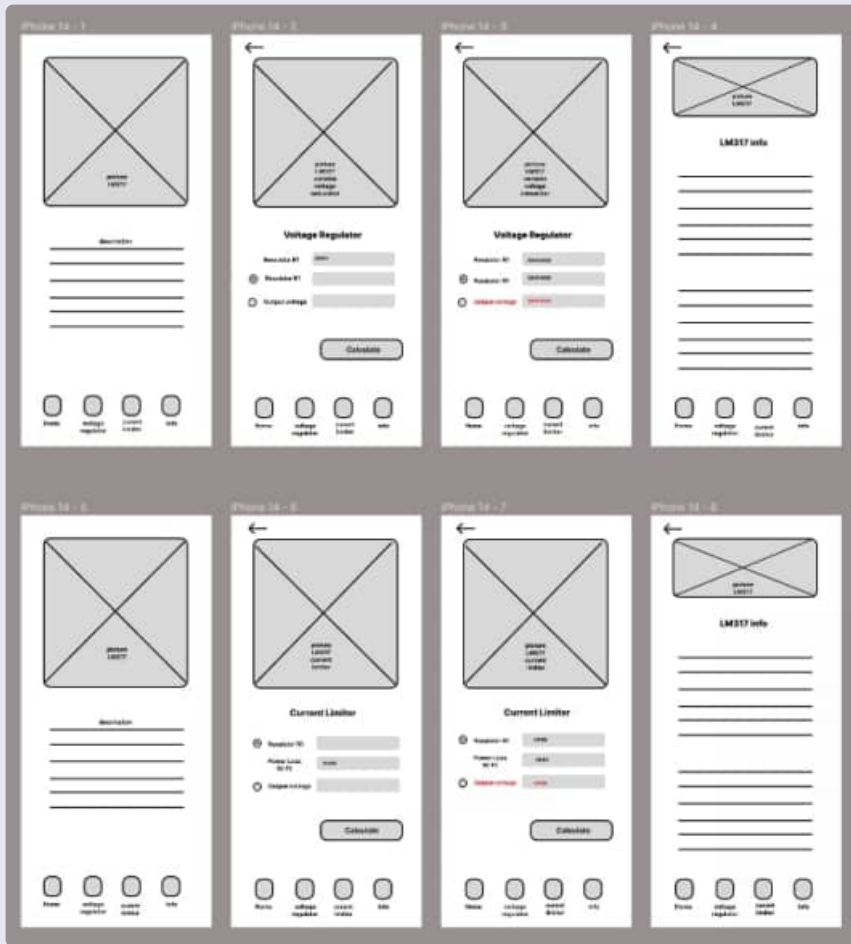


Figure 5: Wireframe for the calculator app (iOS or Android).

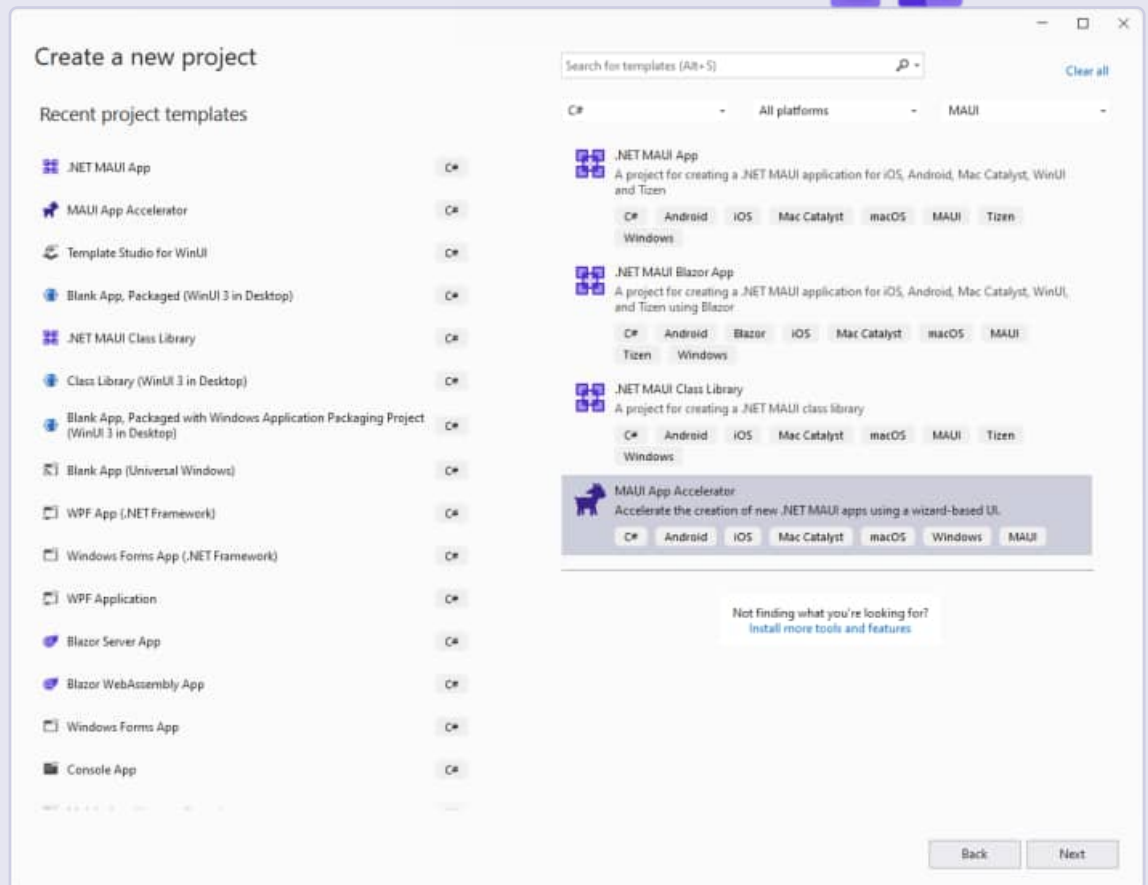


Figure 6: Select the MAUI App Accelerator template for project start.

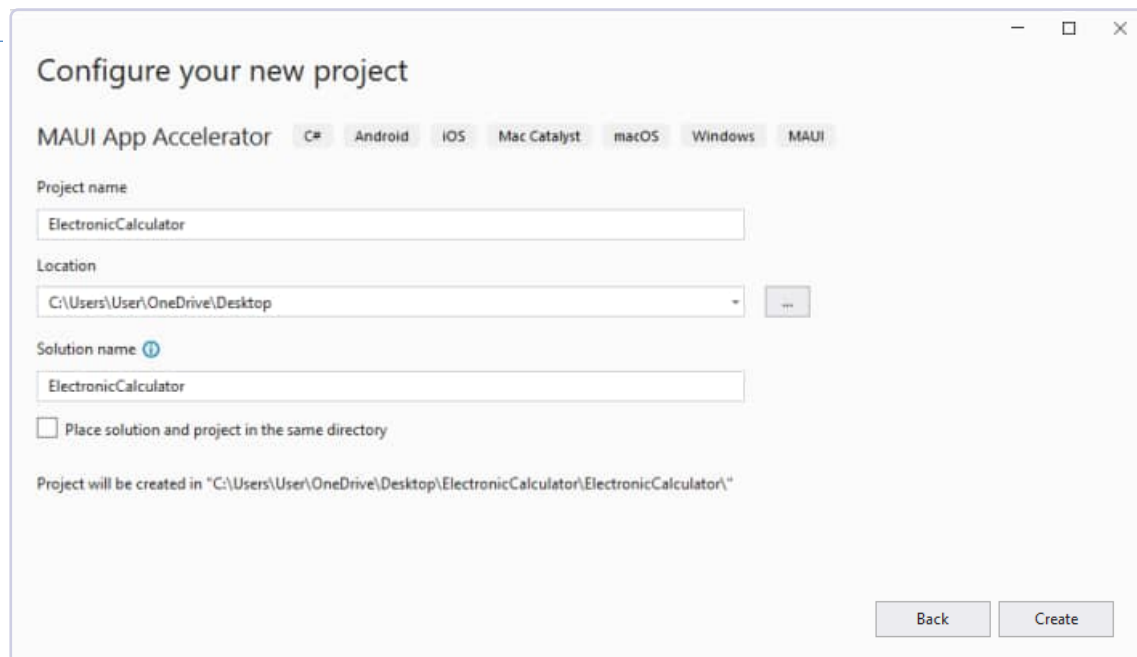


Figure 7: Enter the project's name and storage location.

To calculate the output voltage produced, we can apply the following simplified practical formula:

$$V_{\text{out}} = 1.25 \cdot \left( 1 + \frac{R_2}{R_1} \right)$$

We can rearrange this equation to solve for  $R_2$  and determine the value of the resistor to produce a specific output voltage. The value of resistor  $R_1$  is specified as  $240\ \Omega$  in the LM317 datasheet. This regulator IC can also be used to provide a constant current source, where the relationship is as follows:

$$I_{\text{out}} = \frac{1.25}{R_1}$$

In this case, the value of  $R_1$  must be within the range specified by  $1\ \Omega \leq R_1 \leq 120\ \Omega$ . While there are already many calculator tools available for this voltage regulator, it is convenient to build one here as a demonstration of .NET MAUI's app-building functionality with .NET MAUI.

## The Design

A basic rookie error is to jump straight into programming when you haven't yet decided on a plan. Having a visual prototype, even if it's just a rough sketch, is always helpful (Figure 5).

This prototype represents a wireframe for a mobile app (iOS or Android). We will use four pages that can be selected via navigation tabs along the lower section of the pages. These four pages should provide the following content:

- **Home:** Circuit diagram and general information about the LM317 voltage regulator.
- **Voltage Regulator:** Circuit diagram and input fields for resistors  $R_1$  and  $R_2$ , as well as the desired output voltage ( $U_{\text{Out}}$ ).

Radio buttons allow selection of whether to calculate for  $R_2$  or  $U_{\text{Out}}$ . There is also a button to start the calculation.

- **CCR = constant current regulator:** For constant current operation we have input fields for resistor  $R_1$  and the output current. Radio buttons allow you to choose to calculate for the value of  $R_1$  or  $I_{\text{Out}}$ . There is also a button to execute the calculation.
- **Info:** Here, we display the complete data sheet for the voltage regulator, such as on a webpage.

Such a concept forms the basis for implementing the app.

## Starting the Project

After restarting Visual Studio, select the MAUI App Accelerator template (Figure 6). In the next step, you need to specify the name of the app and its location; see (Figure 7). Then, you will be prompted to choose the .NET version (framework) — use the latest, .NET 7.0 at the time of writing (Figure 8).

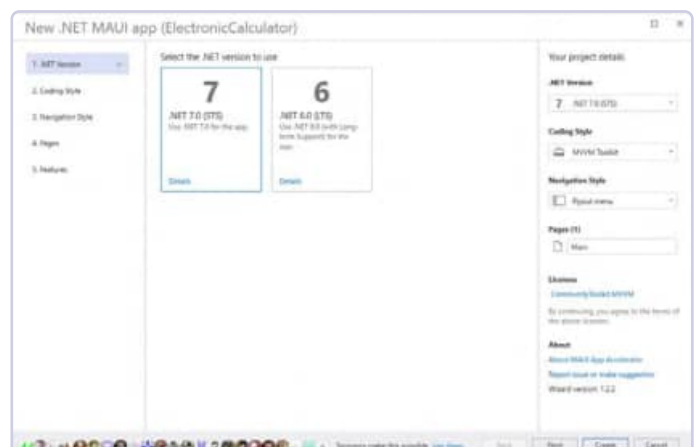


Figure 8: Select the .NET version and navigation.

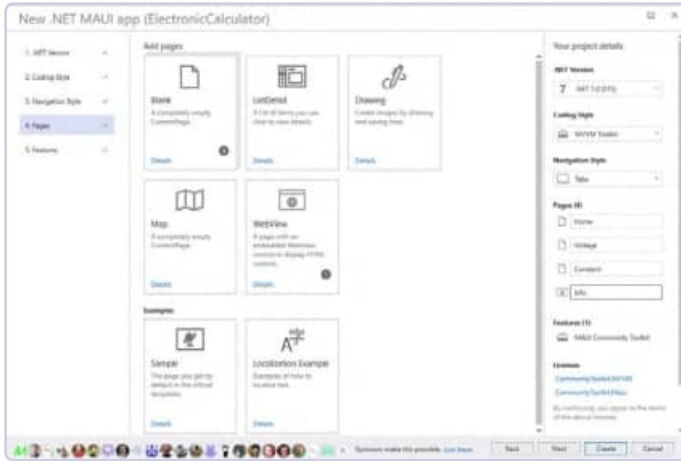


Figure 9: Define the app's layout and pages.

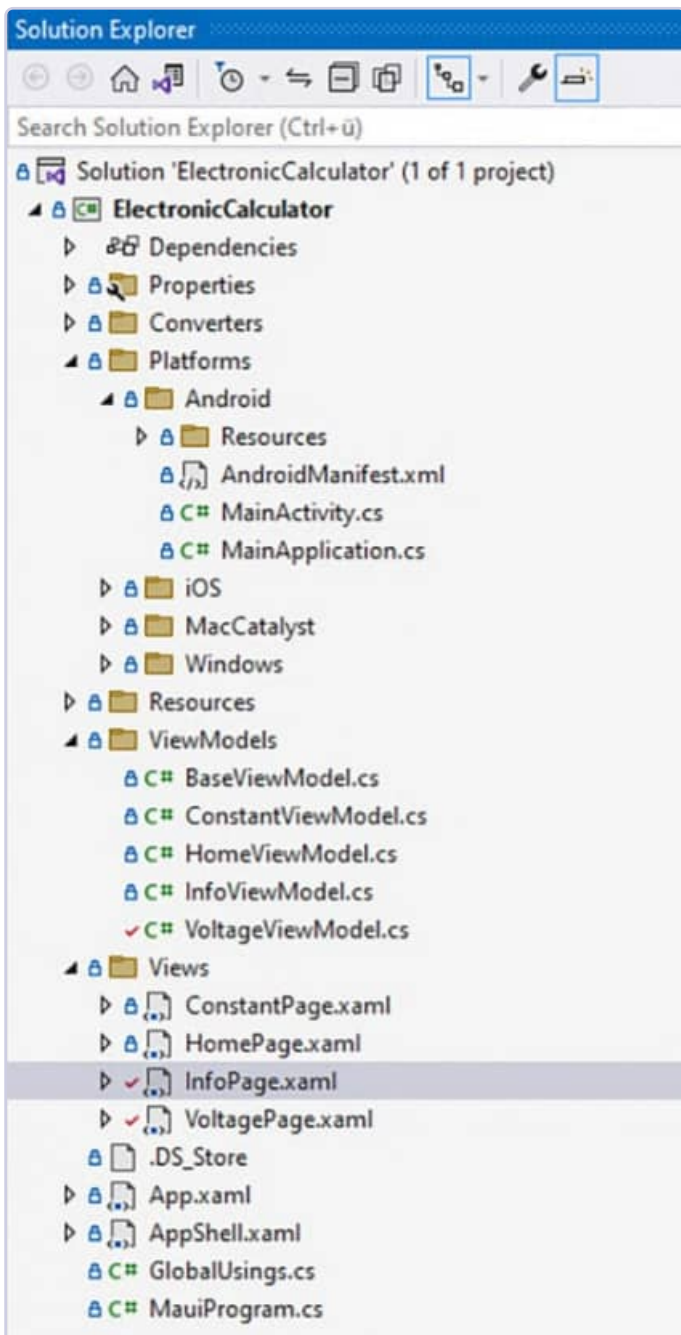


Figure 10: MAUI app project structure.

In the next step (**Figure 9**), provide the following information:

- **Coding Style:** The app's architectural pattern is defined here. Choose **MVVM-Toolkit**, which means you integrate a corresponding library into the project and utilize the MVVM architectural pattern. This pattern ensures decoupling of the layers (Model, View, ViewModel) and is considered the standard for implementing apps where the user interface is defined with XAML. You can find more information about it at [3].
- **Navigation Style:** Choose **Tabs** from the available options to use tabs for navigation.
- **Pages:** Here, you can add three *Blank*-type pages and name them *Home*, *Voltage*, and *Constant*. In addition, add a *WebView* type page and name it *Info*.

With these details completed, you can let Visual Studio create the app. This process may take a while. Afterward, you will land in the development environment with your project open.

Taking a look at the project structure (**Figure 10**), we can make the following observations:

- **Multi-Targeting:** There is only one project for all platforms, with a separate folder for each target system.
- **ViewModels:** Contains the classes for the program logic and serves as the connection to the user interface.
- **Views:** Classes consisting of C# and XAML files for the user interface.
- **App.xaml, MauiProgram.cs:** Entry points for the app's UI and execution.
- **Resources:** Contains images and other resources for the app.

Without any further programming, the app can now be launched for the first time (**Figure 11**). If necessary, you may be prompted to set an Android emulator up on your system for the first launch.

## Create the User Interface

The user interface is declared in XAML, specifically in the view files. Let's take a look at the page for the second tab as an example. First, the layout of the page needs to be defined. For this purpose, there are different layout containers, such as **Grid** for defining rows and columns. Within such a grid, the individual elements of the user interface, such as an image, button, or textbox, can be placed in cells. Other layout containers allow for vertical or horizontal arrangement of the elements. The principle is to use relative positioning and spacing as much as possible instead of absolute values. This is necessary to ensure that the user interface is displayed correctly on a wide range of devices with different screen sizes and resolutions.

For example, our page consists of a grid with two rows at the top level, dividing the page into two equally sized areas (50:50). In the upper area, we place the image for the circuit diagram. In the lower area, the entry text fields for input, label fields for captions, radio





## Listing 1: Excerpt from the source code for the page definition.

```
<?xml version="1.0" encoding="utf-8" ?>
<ContentPage
    <Grid BackgroundColor="LightGray">
        <Grid.RowDefinitions>
            <RowDefinition />
            <RowDefinition />
        </Grid.RowDefinitions>
        <VerticalStackLayout
            Grid.Row="1"
            HorizontalOptions="Center"
            VerticalOptions="Center">
                <Grid RowSpacing="20">
                    <Grid.RowDefinitions>
                        <RowDefinition />
                        <RowDefinition />
                        <RowDefinition />
                        <RowDefinition />
                    </Grid.RowDefinitions>
                    <Grid.ColumnDefinitions>
                        <ColumnDefinition />
                        <ColumnDefinition />
                    </Grid.ColumnDefinitions>
                    <Label
                        Margin="30,0"
                        HorizontalOptions="Start"
                        MaximumWidthRequest="100"
                        Text="Resistor R1 (240 Ohm):"
                        VerticalOptions="Center" />
                    <Entry
                        Grid.Column="1"
                        HorizontalTextAlignment="Center"
                        Text=""
                        VerticalOptions="Center" />
                    ...
                    <Button
                        Grid.Row="3"
                        Grid.Column="1"
                        Command=""
                        Text="Calculation" />
                </Grid>
            </VerticalStackLayout>
            <VerticalStackLayout Margin="20"
                VerticalOptions="Center">
                <Border>
                    <Border.StrokeShape>
                        <RoundRectangle CornerRadius="20" />
                    </Border.StrokeShape>
                    <Image Aspect="AspectFit" Source="lm317c.jpg" />
                </Border>
            </VerticalStackLayout>
        </Grid>
    </ContentPage>
```

buttons, and a button are placed in a regular grid. The individual elements can be further adjusted in terms of size, alignment, and design. An excerpt from the source code for the page is shown in **Listing 1**.

For better understanding, you can start the app on an emulator and arrange the source code for this page in Visual Studio, side by side on the screen. While in Debug mode, the *Hot Reload* feature allows you to make changes to the XAML code, which will

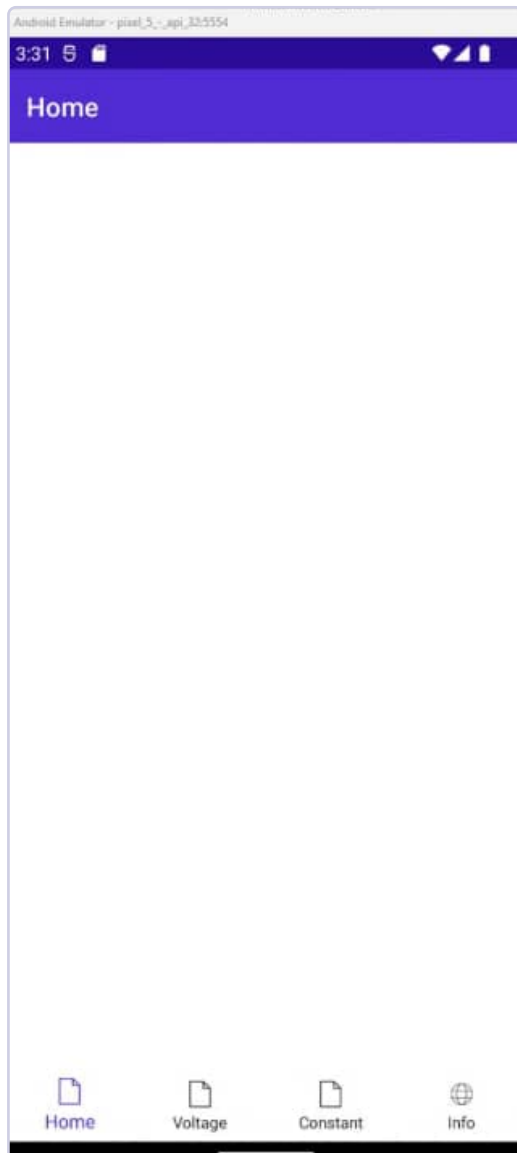


Figure 11: First app launch using the Android emulator.

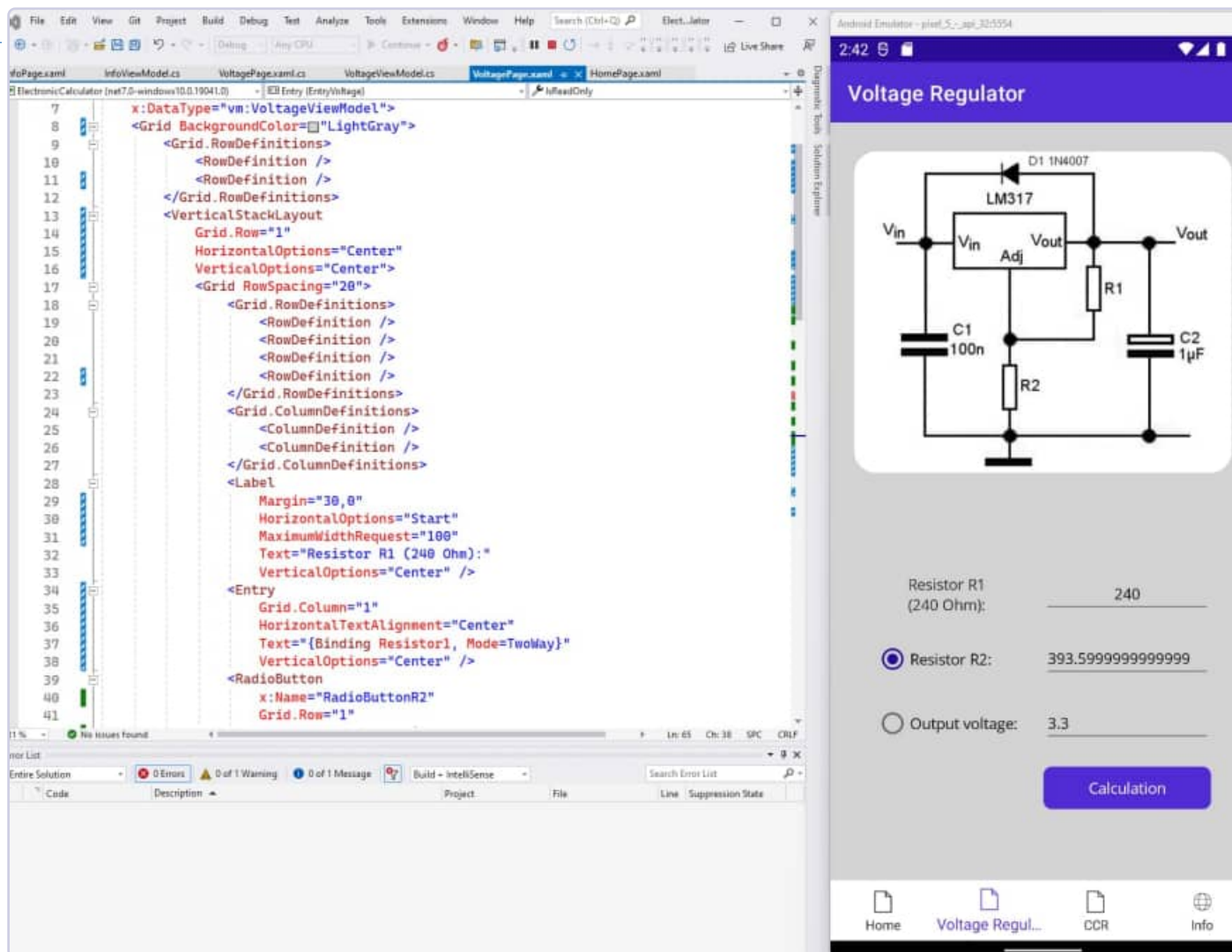


Figure 12: Hot reloading is great for speedy UI building.

immediately be reflected in the running app, meaning they will be applied after saving, without the need to restart(!). It also works on a real mobile device and replaces a graphical designer (**Figure 12**). This way, you can comment out elements or adjust properties in the XAML code and immediately see the effects on the app.

All the pages of the app have been created in this way. You can examine the source code of the View Files (XAML) for more details. The *InfoPage* only contains a *WebView* element. Here, we can display an HTML file. We have provided a static link to a webpage where the voltage regulator datasheet can be found. Alternatively, it would have been possible to integrate a control for displaying a PDF file.

## Creating the Program Logic

This refers to the steps or instructions that dictate how the desired values for the resistance and output voltage are calculated. The core concepts consist of the following elements:

➤ **Variables:** Variables are used to store and manage the input data values. This is done in the corresponding *ViewModel* files. For example, in the *VoltageViewModel* file:

```
[ObservableProperty]
private double voltage;
```

```
[ObservableProperty]
private double resistor1 = 240;
```

```
[ObservableProperty]
private double resistor2;
```

```
[ObservableProperty]
private bool voltageMode = true;
```

Attributes of the variable are its visibility (*private*), its data type (*double*) and its name (*resistor1*). By using the *[ObservableProperty]* attribute, the development environment is instructed to automatically convert the local variable into a *public* property. This allows accessing the value from outside the class as well.

➤ **Data Binding:** Elements of The user interface fields, such as the data entry field (*Entry*), are bound to properties in the C# code. This is done directly in the corresponding XAML file.



For example:

```
x:Name="EntryR2"
Grid.Row="1"
Grid.Column="1"
MinimumWidthRequest="150"
Text="{Binding Resistor2, Mode=TwoWay}"
VerticalOptions="Center" />
```

This is the definition of the text input field (Entry) for resistor value  $R_2$ . The `Text` property is bound to the defined property (as mentioned above) using the Binding syntax. `Mode = TwoWay` indicates that the data binding is bidirectional so that changes in the input field (user input) will update the underlying source code and changes in the variable (after calculation) will also update the view.

➤ **Commands:** In the source code, a method for calculation is defined, for example, for the output voltage or resistor value:

```
[RelayCommand]
private void Calculate()
{
    if (voltageMode)
    {
        Voltage = 1.25 * (1 + Resistor2 / Resistor1);
    }
}
```

```
else
{
    Resistor2 = Resistor1 * (Voltage / 1.25 - 1);
}
}
```

By adding the `[RelayCommand]` attribute allows the method to be called as a *Command* directly from the XAML file, in this case, via the button. The `Command` property binds to it.

```
Grid.Row="3"
Grid.Column="1"
Command="{Binding CalculateCommand}"
Text="Calculation" />
```

These are the essential functions of the app. For a better understanding, study the source code in Visual Studio and experiment with it.

## The Results

The result is an app for mobile systems, initially designed for Android (**Figure 13**). We can use the tabs to switch between pages and see the calculations. You can also view the datasheet. The app was initially viewed using the emulator, but a real Android device can be linked to the development PC via USB or local Wi-Fi to install the app on the device. The Android device requires *Developer Mode* to be enabled before the APK file download.

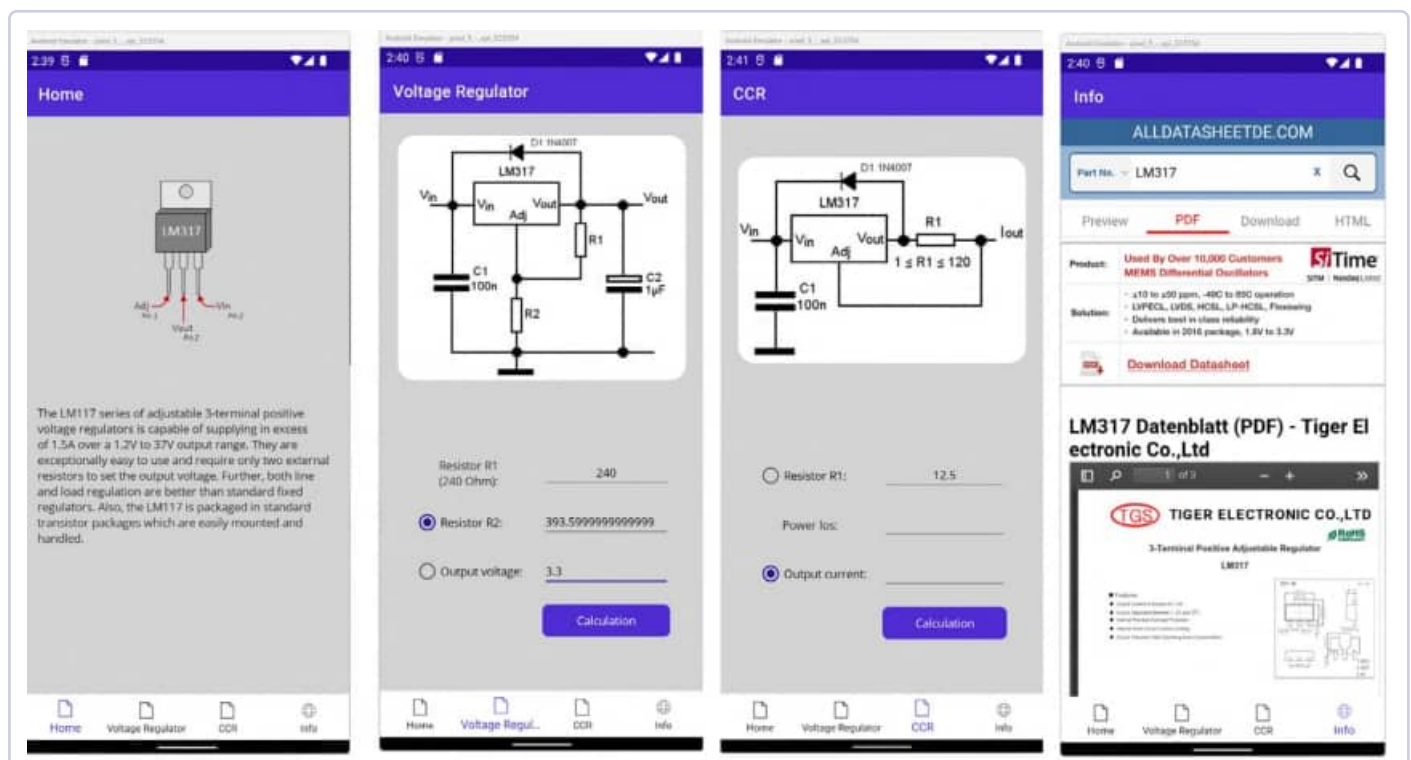


Figure 13: First version of the app with the calculator function represented on the Android emulator.





## Other Platforms

With .NET MAUI, you can create native apps for different platforms. The example shown here is tailored to a mobile app (using tabs with limited content). If you code on a Mac, running the latest version of the Xcode development environment, you can compile the app for iOS directly from Visual Studio and run it on an iPhone or iOS simulator. You might find that minor design adjustments, such as to colors, are necessary. To reduce the likelihood of compatibility issues, it is best to define as few static and absolute elements as possible, letting the system handle alignment and design according to the design guidelines; or define specific features for each target system as needed.

If you explicitly color the background of a page and place text input fields on it, it may look good on one platform, but the text field might have a different styling on another platform, resulting in an ill fit. Therefore, the rule is: Stick with the default or make adjustments for selected platforms. Nevertheless, we can share the entire source code for the user interface and the business logic or core functionality, which saves you a lot of work in most cases.

## Additions

The app is only really a functional prototype. The following changes should be made before distributing the app to users:

- Replace all graphics with images using the .svg file format. These are vector graphics that automatically scale without loss, depending on the target system.
- Determine all icons for the tab bar at the bottom of the screen. The necessary graphics for this are stored in the *Resources/Images* folder and assigned in the *AppShell.xaml* file.
- Validate the input range of resistors, output voltage, etc., to ensure sensible values (value range), and implement error handling for incorrect inputs. This is done in the *ViewModel* files.
- Conduct comprehensive testing on different devices using emulators and on the physical devices themselves.
- Create app packages for the target platforms, for example, Android and iOS.
- Register the apps in the respective app stores.

## Additional Features of .NET MAUI

With this example, we have only touched on a small selection of the features that .NET MAUI has to offer for creating apps for multiple platforms. The following features, which are of particular interest in the context of app building for electronics projects, should also be mentioned:

- **Access to device functions and sensors:** .NET MAUI provides built-in access to a variety of hardware functions. In most cases, you need to request the necessary permissions in the platform files before you can access the device functions via a universal interface.
- **Libraries for system functions:** Additional functions can be provided through external libraries for .NET; they can be useful for accessing specific hardware, sensors, and more. These libraries are provided by third-party vendors and the community. It's worth searching for them.
- **User interface components:** .NET MAUI already offers a range of visual components by default. The selection is being continually expanded by third-party vendors and the community.
- **App deployment:** Today, apps for general use are made available through the Google Play or Apple App stores as appropriate for the target platform. The application packages can be created directly from Visual Studio. Note that you need to comply with the appropriate company policies and the app must be properly signed with a digital certificate. For iOS and macOS, a Mac will be necessary for this purpose.

The adoption of .NET as the foundation for this development approach is also advantageous. Many services, APIs, and other resources required for modern software development directly support .NET by providing their own libraries, known as software development kits (SDKs), for this framework. If you want to store your data in the cloud, for example, there is a high probability that a .NET library is already available to do that.

## Conclusion

.NET MAUI provides an interesting approach to creating an app for all relevant target systems. It results in native apps that do not require a web browser to run and allows access to system functions. The combination of native app development and cross-platform programming, both for desktop and mobile devices, makes this approach appealing for electronics projects. However, it's a bit disappointing that .NET MAUI doesn't currently support Linux, as it would be nice to be able to use it in a Raspberry Pi environment. Microsoft has handed over the responsibility for supporting Linux to the community. It may take a little while before it becomes available.

If this article has sparked your interest in .NET MAUI, you can find a good introduction with helpful video tutorials at [5]! ◀

220442-01



### About the Author

Dr. Veikko Krypczyk is a software developer, trainer, and technical author, specializing in topics such as WinUI 3 and .NET MAUI (information available at [6]). In his free time, he doesn't stray too far from a soldering iron and enjoys building various electronic projects. He is fascinated by the combination of electronics and software, which together can often realize unexpected solutions.

### Questions or Comments?

Do you have any questions or comments relating to this article? Please feel free to contact the Elektor team at [editor@elektor.com](mailto:editor@elektor.com).



### Related Products

> **John Allwork, C# Programming for Windows and Android, Elektor 2015 (Ebook)**  
<https://elektor.com/18220>

### WEB LINKS

- [1] .NET MAUI: <https://dotnet.microsoft.com/en-us/apps/maui>
- [2] Visual Studio: <https://visualstudio.microsoft.com/>
- [3] MVVM Toolkit: <https://learn.microsoft.com/en-us/dotnet/architecture/maui/mvvm>
- [4] ElectronicCalculator GitHub repository by the author: <https://github.com/veikkoEF/ElectronicCalculator>
- [5] Video tutorials: .NET MAUI for Beginners by dotnet:  
<https://youtube.com/playlist?list=PLdo4fOcmZ0oUBAdL2NwBpDs32zwGqb9DY>
- [6] Author's website: <https://larinet.com>

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# ChatMagLev

The AI  
Way of  
Levitation



Figure 1: The MagLev project's hardware.

By Peter Neufeld (Germany)

The new helpful hammer in the software hobbyist's toolbox is ChatGPT. It can not only write completely new code, but also extend and enhance hand-written software. In this article, Elektor author Peter Neufeld tries this out and comes up with several improvements to his popular Magnetic Levitation Project.

Anyone familiar with the world of hardware and software projects knows how they tend to echo long after completion. The building and programming process can be enjoyable, and the resulting project may function reasonably well. Yet, there are usually features you'd like to modify or add in the software, and you never seem to find the time, due to other commitments.

This was also the case with the Arduino C++ code for my project, *Magnetic Levitation — The Digital Way*, which I described in Elektor [1], on Elektor Labs [2], and on my own website [3]. The hardware works fine, but the Arduino code was quick-and-dirty just to show that it works in principle. However, "finished" and "beautiful" are two different things!

When I started to deal a little with the possibilities of AI, the thought quickly arose as to whether ChatGPT [4] could help me with my hobby software projects.

In initial experiments, I was very quickly able to have small snippets of code and complete Arduino C++ programs generated by ChatGPT that matched my rough specifications formulated in simple technical language.

Therefore, two approaches to support my hobby using AI crystallized in the end:

1. Extension of existing programs: Is it possible to extend already-running Arduino C++ code with additional software functions by passing the old code and specific questions to ChatGPT?



- lib. The new Values are displayed at serial. Add the necessary
- program code and output the complete program.

```

/*****
Magnetic Levitation object:
Lets a LEGO man, glued together with
a neobodymium magnet, float under a modified 5V relay
- SoC:      ESP32, very good:
M5Stack's ATOM LITE or ATOM MATRIX
- Electromagnet: Modified 5V-Relais HW-482
with 3V3/5V transistor input
- Sensor:   HALL-sensor A1302 or A1308
*****/

```

```
// int TRIGGER    = 2740;
// Triggerlevel is set to a level where
// weight of payload is equal to the force
// between magnet and electromagnet
int TRIGGER    = 2740;
// good for payload =
// 2 Neobdym-Magnets and a LEGO-Man
int HYST       = 35;
// Hysterese for trigger level
int HALL_PIN   = 33;
// analog Signal from HALL-sensor at GPIO33
int HALL_VAL   = 0;
int RELAIS_PIN = 23;
// GPIO23 to drive the transistor input of
// the modified 5V-relais that is used as electromagnet
int X          = 0;
```

My old code did the job, but was more a bare skeleton of a program that was still waiting for some useful extensions. I have tried to summarize my thoughts in a single, somewhat more extensive, question and task. But, basically ChatGPT allows you to build up dialog, handling follow-up questions.

- The following Arduino C++ code for an ESP32 has to be extended. The trigger values now should be increased or decreased by 1 with character "T" respectively "t" followed by CR and LF at the serial line. Respectively for the hysteresis value. A fourth command stores all current values in non volatile RAM. They get used at start up if present. Use the preferences

```
void setup(){
  Serial.begin(115200);
  pinMode(RELAIS_PIN, OUTPUT);
  Serial.print("Magnetic Levitation:  START ");
}

void loop(){
  HALL_VAL =analogRead(HALL_PIN);
  //read HALL-Sensor with
  //default 0-3.9V input >> 12bit
  if (HALL_VAL < (TRIGGER + X)){
    digitalWrite(RELAIS_PIN, HIGH);
    // lift the payload
    X = HYST;
  }
  else{
    digitalWrite(RELAIS_PIN, LOW);
    // drop the payload
    X = 0 - HYST;
  }
}
```

Figure 2: The MagLev project's old circuit diagram.

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### Listing 1: Extension of hand written Code.

*Here's the extended code for the Arduino C++ program you provided:*

```
#include <Preferences.h>
Preferences preferences;

int TRIGGER = 2740;
int HYST = 35;
int HALL_PIN = 33;
int HALL_VAL = 0;
int RELAIS_PIN = 23;
int X = 0;

void setup() {

    Serial.begin(115200);
    pinMode(RELAIS_PIN, OUTPUT);
    Serial.print("Magnetic Levitation: START ");

    // Load values from non-volatile RAM
    // Initialize preferences with a namespace
    preferences.begin("levitation", false);

    if (preferences.getBytesLength("config") > 0) {
        preferences.getBytes("config", &TRIGGER,
                               sizeof(TRIGGER));
        preferences.getBytes("config", &HYST,
                               sizeof(HYST));
    }

    preferences.end();
}

void loop() {

    if (Serial.available() >= 3) {
        String command = Serial.readStringUntil('\r');
        // Read the command until a
        // carriage return (\r) is encountered

        if (command.startsWith("T")) {
            TRIGGER++;
            Serial.println("Trigger increased: "
                           + String(TRIGGER));
        }
        else if (command.startsWith("t")) {
            TRIGGER--;
            Serial.println("Trigger decreased: "
                           + String(TRIGGER));
        }
        else if (command.startsWith("H")) {
            HYST++;
```

```
            Serial.println("Hysteresis increased: "
                           + String(HYST));
        }
        else if (command.startsWith("h")) {
            HYST--;
            Serial.println("Hysteresis decreased: "
                           + String(HYST));
        }
        else if (command.startsWith("S")) {
            // Store current values in non-volatile RAM
            // Initialize preferences with a namespace
            preferences.begin("levitation", false);
            preferences.putBytes("config", &TRIGGER,
                                sizeof(TRIGGER));
            preferences.putBytes("config", &HYST,
                                sizeof(HYST));
            preferences.end();
            Serial.println(
                "Values stored in non-volatile RAM.");
        }
    }

    HALL_VAL = analogRead(HALL_PIN);

    if (HALL_VAL < (TRIGGER + X)) {
        digitalWrite(RELAIS_PIN, HIGH);
        X = HYST;
    } else {
        digitalWrite(RELAIS_PIN, LOW);
        X = 0 - HYST;
    }
}
```

*In this code, the preferences library is used to store and load the trigger and hysteresis values in non-volatile RAM. The new commands 'T', 't', 'H', and 'h' are used to increase the trigger, decrease the trigger, increase the hysteresis, and decrease the hysteresis values, respectively. The command 'S' stores the current values in non-volatile RAM. These values will be used at startup if present. Please note that you need to install the "Preferences" library for this code to work correctly. You can find the library on the Arduino Library Manager or download it from the Arduino website.*

My first summary: Wow! That was easy! Seems to be correct and logical code. Meets my requirements and runs great when testing it! I might have written it the same way, but only if I were more proficient in C++ programming and/or had searched for and adapted a lot of example code — and no doubt, I would have spent some time on that.

Good! Let's leave out the old code now and try it from the beginning with a few clear sentences.

## Approach 2: Completely new Arduino C++ Code

Encouraged, I then went to a conversational description of my levitation setup in need of embellishment and the desired software functions ... and was very amazed at how good the result was.

Here is my dialog with ChatGPT:

The following magnetic levitation setup is to be controlled with an ESP32 and a C++ Arduino program. Pin 23 controls an electromagnet with iron core, pin 33 is the ADC input to which an analog Hall sensor is connected.

Below the electromagnet is the analog Hall sensor. The electromagnet is initially switched on. A permanent magnet approaches the electromagnet and its iron core, as well as the Hall sensor, from below. The magnet is attracted by the core. However, it is to be held in suspension. For this purpose, the electromagnet is to be switched off briefly.

The Hall sensor generates a voltage of about 2.4 V in the floating state and about 1.5 V without the permanent magnet. If the magnet comes very close to the sensor, the voltage rises to a maximum of 3 volts.

During the program run, the trigger value for the floating state should be corrected upwards in small steps via the serial interface (115200Baud, 8N1) when "T" is received. With "t" it is corrected downwards.

Additionally, like the trigger value, a hysteresis value of approx. 50 mV should also be set and corrected accordingly by keyboard commands.

The manually corrected values of trigger and hysteresis are both to be output if they have been changed. Both values are to be stored safely in the non-volatile memory of the ESP32 when "S" or "s" is entered. Only if there are already old values in the non-volatile memory, these should be used as program start values.

A very brief description of the operation should be displayed at startup.

Write the Arduino program very compact and with reasonably less comments so that it can be output completely in the response.

In **Listing 2**, you can see ChatGPT's answer, that still amazes me and even scares me a little.



### Listing 2: Generated Code and Answer from ChatGPT.

```
#include <EEPROM.h>

const int magnetPin = 23;
const int hallSensorPin = 33;
const int triggerAddr = 0;
const int hysteresisAddr = 1;

float triggerValue = 2.4;
float hysteresisValue = 0.05;

void setup() {
    Serial.begin(115200);
    pinMode(magnetPin, OUTPUT);
    pinMode(hallSensorPin, INPUT);

    // Load trigger and hysteresis values
    // from EEPROM if available
    EEPROM.begin(2);
    float storedTriggerValue =
        EEPROM.readFloat(triggerAddr);
    float storedHysteresisValue =
        EEPROM.readFloat(hysteresisAddr);

    if (storedTriggerValue != 0x00)
        triggerValue = storedTriggerValue;

    if (storedHysteresisValue != 0x00)
        hysteresisValue = storedHysteresisValue;

    Serial.println("Magnetic Levitation Setup");
    Serial.println("Commands:");
    Serial.println("T - Increase trigger value");
    Serial.println("t - Decrease trigger value");
    Serial.println("H - Increase hysteresis value");
    Serial.println("h - Decrease hysteresis value");
    Serial.println(
        "S or s - Save trigger and hysteresis values");
    Serial.println();
    Serial.print("Trigger Value: ");
    Serial.println(triggerValue);
    Serial.print("Hysteresis Value: ");
    Serial.println(hysteresisValue);
}

void loop() {
    // Read the analog value from the Hall sensor
    int hallSensorValue = analogRead(hallSensorPin);

    // Check if magnet is close to the sensor
    if (hallSensorValue >
        (triggerValue + hysteresisValue) * 1023) {
        // Magnet is close, turn off the electromagnet
    }
}
```



```

        digitalWrite(magnetPin, LOW);
    }
    else {
        // Magnet is far, turn on the electromagnet
        digitalWrite(magnetPin, HIGH);
    }

    // Check for serial input
    if (Serial.available() > 0) {
        char command = Serial.read();
        if (command == 'T') {
            triggerValue += 0.01;
        }
        else if (command == 't') {
            triggerValue -= 0.01;
        }
        else if (command == 'H') {
            hysteresisValue += 0.01;
        }
        else if (command == 'h') {
            hysteresisValue -= 0.01;
        }
        else if (command == 'S' || command == 's') {
            // Save trigger and hysteresis values
            // to EEPROM
            EEPROM.writeFloat(triggerAddr, triggerValue);
            EEPROM.writeFloat(hysteresisAddr,
                               hysteresisValue);
            EEPROM.commit();
            Serial.println(
                "Trigger and hysteresis values saved.");
        }

        // Output trigger and hysteresis values
        Serial.print("Trigger Value: ");
        Serial.println(triggerValue);
        Serial.print("Hysteresis Value: ");
        Serial.println(hysteresisValue);
    }
}

```

*Note: This is a compact version of the code without extensive comments. It assumes you have the necessary libraries installed, including the EEPROM library. Make sure to include that library in your Arduino IDE if you don't have it already.*

After that, I asked the bot to give a brief description of the code for documentation purpose.

ChatGPT answered:

- The provided code is a compact Arduino program written in C++ for controlling a magnetic levitation setup using an ESP32 microcontroller. The setup consists of an electromagnet with an iron core and an analog Hall sensor.

- At startup, the program initializes the serial communication with a baud rate of 115200. Pin 23 is used to control the electromagnet, and pin 33 is configured as an analog input to read the Hall sensor's output voltage.

- The program retrieves the trigger and hysteresis values from the non-volatile memory (EEPROM) if they were previously stored. If no values are found, it uses default values. The trigger value represents the voltage threshold for switching off the electromagnet, and the hysteresis value defines the voltage range within which the electromagnet remains off even if the magnet is slightly distant from the sensor.

- The program then displays a brief description of the operation and the available commands on the serial monitor. The commands allow adjusting the trigger and hysteresis values by incrementing or decrementing them. The updated values are immediately displayed on the serial monitor. To save the trigger and hysteresis values in the non-volatile memory, the user can enter "S" or "s" command.

- In the main loop, the program reads the analog value from the Hall sensor and compares it with the trigger value plus the hysteresis value. If the sensor reading is above this threshold, indicating that the magnet is close, the electromagnet is turned off by setting pin 23 low. Otherwise, if the magnet is far, the electromagnet is turned on by setting pin 23 high.

- The program continuously checks for incoming commands from the serial monitor. If a command is received, it adjusts the trigger or hysteresis value accordingly. If the "S" or "s" command is entered, the trigger and hysteresis values are saved in the non-volatile memory.

- The current trigger and hysteresis values are outputted to the serial monitor whenever they are changed or at program startup.

- This program provides a simple and compact solution for controlling a magnetic levitation setup using an ESP32 microcontroller.

## Improvements

So far, so good, but everything can always be optimized. I asked the bot to then give me three brief suggestions improving the control loop.

ChatGPT gave me these suggestions back:

- 1. Implement PID Control: Consider implementing a PID (Proportional-Integral-Derivative) control loop to enhance the stability and responsiveness of the magnetic levitation system. By using feedback from the Hall sensor and applying appropriate control gains, the PID controller can dynamically adjust the electromagnet's power to maintain the desired levitation distance. This will improve the system's ability to handle disturbances and provide smoother control.

- 2. Use a Moving Average Filter: To reduce noise and fluctuations in the Hall sensor readings, apply a moving average filter. Instead of relying solely on individual readings, calculate the average value over a small window of recent readings. This will help provide a more stable and reliable measurement for determining the magnet's position and adjusting the electro-magnet's power accordingly.

- 3. Incorporate a Safety Timeout: Add a safety timeout mechanism to the control loop to ensure that the electromagnet is not continuously powered if the magnet or the sensor is absent or fails. If the system does not receive a valid Hall sensor reading within a specified period, it can assume that something is wrong and take appropriate action, such as turning off the electro-magnet or triggering an error condition.

By implementing these suggestions, you can enhance the control loop's performance, noise immunity, and safety features, resulting in more precise and reliable magnetic levitation control.

I admit that my initial questions above came about after some lengthy dialogs in which I also had to learn how to set up my questions in a ChatGPT AI-friendly way.

By the way: ChatGPT's answers were often simply cut off abruptly. A specific request for a possible limitation of the length of the answer resulted in a very wordy and here very abbreviated "Yes, 2048 characters". Therefore I have also included in my "order" cues for a suitable shortening of the answer.

However, if one has familiarized oneself a little with the system's reactions, the results are also very good after a single somewhat more complex block of questions, requirements, and instructions. Targeted inquiries add further, also more extensive functions.

If the result seems technically incorrect, it is interesting to see that the same question that has been repeated several times is answered differently each time, which manifests itself in code with a sometimes completely different structure, but which is mostly functional. It is then extremely helpful, perhaps even essential, to at least be able to read the generated code well and to be able to check that all requirements are observed. ChatGPT quickly omits one or the other aspect!

Suggestions from the AI that contradict your own technical expertise and knowledge can be specifically questioned. This often leads to apologetic wording and improved suggestions. Or, it may give you new technical knowledge.

All in all, using ChatGPT to create software based on a natural language problem description has proven very useful here. Perhaps not as a hammer, but rather as a fine-tunable and controllable tool.

Even a less experienced C++ programmer, such as I, can now quickly create more complex parts of programs that would have taken me at least significantly longer in the past. Documentation is now very easy. And one can even expect a kind of deeper understanding of the

problem set forth, which opens the horizon for unexpected, technically well-founded and detailed peripheral areas.

However: Currently, AI, especially ChatGPT, is a helpful, but by no means infallible tool for the casual programmer, and it still needs a human operator! I'm very excited about more projects with this new screwdriver set in my toolbox.

## Fix some problems

Well, as if my conclusions needed any further proof: When testing the generated code, I noticed that there are two problems in the code. OK ... let's ask the machine about it!

- Correct two problems.

- 1. The hall sensor value is always compared to a fixed value without a hysteresis.
- 2. This code does not correctly store the values to the nv-ram of my ESP32. Use another method to store and read.

- Rewrite the above code very compact and with reasonably fewer comments so that it can be output completely in the response.

ChatGPT answered "Apologies for the oversight" (!) and gave me the code in **Listing 3** back.



### Listing 3: Enhanced Code.

```
#include <Preferences.h>

const int magnetPin = 23;
const int hallSensorPin = 33;
const char* prefNamespace = "levitation";
const char* triggerKey = "trigger";
const char* hysteresisKey = "hysteresis";

float triggerValue = 2.4;
float hysteresisValue = 0.05;

Preferences preferences;

void setup() {
    Serial.begin(115200);
    pinMode(magnetPin, OUTPUT);
    pinMode(hallSensorPin, INPUT);

    preferences.begin(prefNamespace, false);
    if (preferences.getBool("initialized", false)) {
        triggerValue =
            preferences.
        getFloat(triggerKey, triggerValue);
        hysteresisValue =
            preferences.getFloat(hysteresisKey,
```

```

        hysteresisValue);
    }
    else {
        preferences.putBool("initialized", true);
    }

    Serial.println("Magnetic Levitation Setup");
    Serial.println("Commands:");
    Serial.println("T - Increase trigger value");
    Serial.println("t - Decrease trigger value");
    Serial.println("H - Increase hysteresis value");
    Serial.println("h - Decrease hysteresis value");
    Serial.println(
        "S or s - Save trigger and hysteresis values");
    Serial.println();
    Serial.print("Trigger Value: ");
    Serial.println(triggerValue);
    Serial.print("Hysteresis Value: ");
    Serial.println(hysteresisValue);
}

void loop() {
    int hallSensorValue = analogRead(hallSensorPin);

    if (hallSensorValue > (triggerValue * 1023) &&
        digitalRead(magnetPin) == HIGH) {
        digitalWrite(magnetPin, LOW);
    }
    else if (hallSensorValue <
        ((triggerValue - hysteresisValue) *
        1023) && digitalRead(magnetPin) == LOW)
    {
        digitalWrite(magnetPin, HIGH);
    }

    if (Serial.available() > 0) {
        char command = Serial.read();
        if (command == 'T') {
            triggerValue += 0.01;
        } else if (command == 't') {
            triggerValue -= 0.01;
        } else if (command == 'H') {
            hysteresisValue += 0.01;
        } else if (command == 'h') {
            hysteresisValue -= 0.01;
        } else if (command == 'S' || command == 's') {
            preferences.putFloat(triggerKey,
                                triggerValue);
            preferences.putFloat(hysteresisKey,
                                hysteresisValue);
            preferences.end();
            Serial.println(
                "Trigger and hysteresis values saved.");
        }
    }
}

```

```

    Serial.print("Trigger Value: ");
    Serial.println(triggerValue);
    Serial.print("Hysteresis Value: ");
    Serial.println(hysteresisValue);
}
}

```

*This version addresses the two issues mentioned:*

*The code now includes hysteresis in the comparison by checking the magnetPin state in both conditions. If the electromagnet is already in the desired state, the condition for turning it on or off is not evaluated.*

*Instead of using the EEPROM library, this code uses the Preferences library provided by the ESP32 core. The preferences are stored in the non-volatile memory of the ESP32 using the Preferences API. The values are saved when the 'S' or 's' command is received and are read from the memory during setup. The preferences namespace and keys are specified for the levitation setup to avoid conflicts with other preferences.*

Well, that worked very well now. During testing, however, my human brain discovered another rather small problem! But now, in this improved state, I have come to the conclusion that this should also remain an unfinished software project. So, I ended the chat and had a coffee with my wife. ◀

230360-01

### About the Author

For more than 40 years, Peter Neufeld was allowed to take care of other people's data processing, electrical, and building control systems, as well as communication and media technology. Now he finds time again to devote himself to the practical application of classical electronics and modern microcontrollers in hobby projects. He has described some of these projects in Elektor Labs or on his blog.

### Questions or Comments?

Do you have technical questions or comments about this article? Then please contact the author by email at [peter.neufeld@gmx.de](mailto:peter.neufeld@gmx.de) or the Elektor editorial team at [editor@elektor.com](mailto:editor@elektor.com).



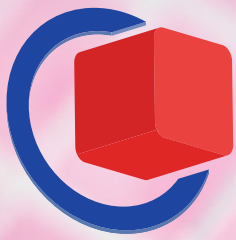
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## WEB LINKS

- [1] Peter Neufeld, "Magnetic Levitation the Digital Way," Elektor 9-10/2021: <https://elektormagazine.com/magazine/elektor-183/59821>
- [2] "Magnetic Levitation - The Digital Way," Elektor Labs: <https://elektormagazine.com/labs/magnetic-levitation-the-digital-way>
- [3] MagLev at PeterNeufeld.wordpress.com: <https://peterneufeld.wordpress.com/category/magnetic-levitation/>
- [4] ChatGPT: <https://chat.openai.com>





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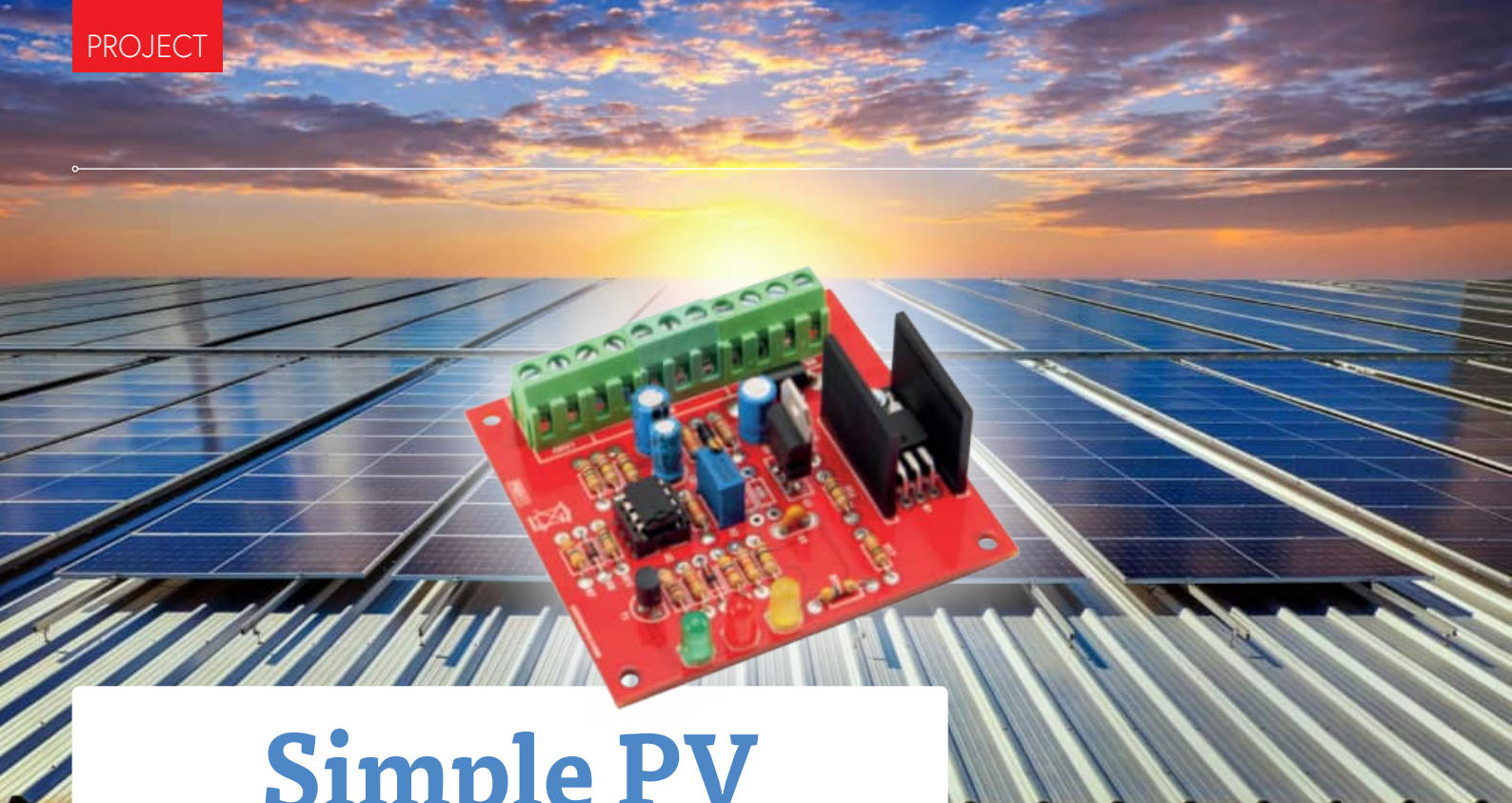
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# Simple PV Power Regulator

Build Your First, Fully Functional PV Energy Management System

**Electronica In**  
WWW.ELETRONICA.IT

By Boris Landoni (Italy)

If you have long wanted to start trying your hand at a complete power management system, but have not done so because of the over-complicated nature of existing designs, here is one to begin with. It's simple, but complete with everything you need to have. This includes a battery charge controller and voltage regulator on the load side.

To make a good solar-powered electrical system, it is not enough just having a photovoltaic (PV) panel and a voltage regulator (if any), but one or more batteries will be needed to store energy during daylight hours and return it when there is little sunlight, or no light at all when it gets dark. Most photovoltaic panel-powered devices must be able to operate stably, regardless of the presence of sunlight and the level of irradiance, so the battery (which we now usually know as an "accumulator") is certainly needed to deliver

power when the panel no longer does. Not only that, batteries are often also needed for a somewhat less intuitive but tangible reason: Since they can store a certain amount of energy, greater or less depending on their features, they can deliver far higher currents than can be demanded from solar panels, while still being charged by the panels.

Just to give an example, a solar panel capable of delivering a current of 1 A will not be capable, by itself, of powering a device that

draws a higher current, i.e., 2 A. However, if a backup battery capable of delivering higher currents is connected to this circuit, the problem doesn't arise: The PV panel will still deliver a current of 1 A, while the battery will provide (during discharge) the "missing" 1 A, so the connected load will be powered correctly at 2 A. Clearly, in this case, we might never expect the supplied device to operate indefinitely, since the current generated by the solar panel is less than the current being drawn by the load. Therefore, under these conditions, system autonomy will depend on battery capacity. Going back to the previous example, under the described operating conditions, a 13 Ah battery will keep the system running for a (theoretical) lifespan of 13 hours. Ultimately, in order for such a control system to be stable and capable of constantly supplying a load, the size of the PV panel, battery capacity, and load drawn will need to be carefully evaluated at the design stage.

This project, whose basic wiring diagram is illustrated in **Figure 1**, not only regulates the

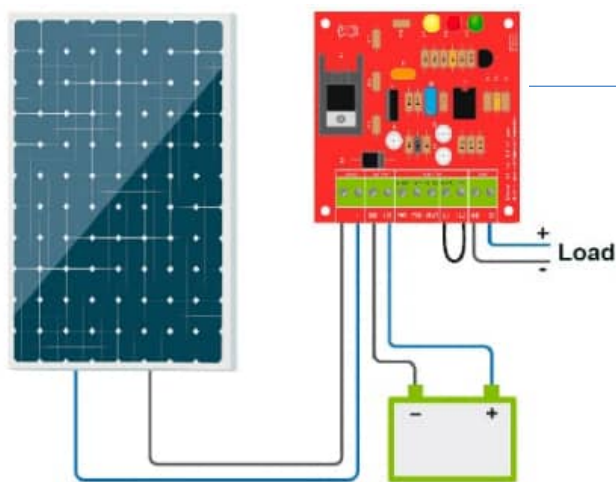


Figure 1: Overall wiring of the photovoltaic power regulator. The controller stops the charging when the battery is fully charged.

### Technical Features

Input Voltage (solar panel): 12...28 V	Max. absorption of the control circuit: 20 mA
Max. input current (solar panel): 5 A	Signal LEDs indicating <i>charge</i> , <i>insufficient isolation</i> and <i>battery-</i> <i>depleted</i> statuses
Max. output current (load): 25 A	An external energy-meter can be connected

battery charge, holding it when it reaches its limit voltage, but also manages the load, connecting the battery when its voltage is high enough to keep the downstream load running, and disconnecting when the voltage becomes too low. In short, our charge controller is a complete power manager for the operation of a photovoltaic solar panel system, and can work by controlling loads whose total current

does not exceed 5 A; however, it is always possible to increase this value, by simply replacing D4 diode with another type with higher current ratings.

The circuit design, shown in **Figure 2**, consists, in short, of a current regulator made with a comparator circuit and a MOSFET (Q1) that absorbs the excess current; the whole is

complemented by a comparator that allows the panel to be connected and disconnected from the battery when the latter reaches its fully charged status.

### Circuit Diagram

To make the MOSFET conduct, it is necessary to apply a positive voltage to its gate, that is, to make transistor T1 conduct, which

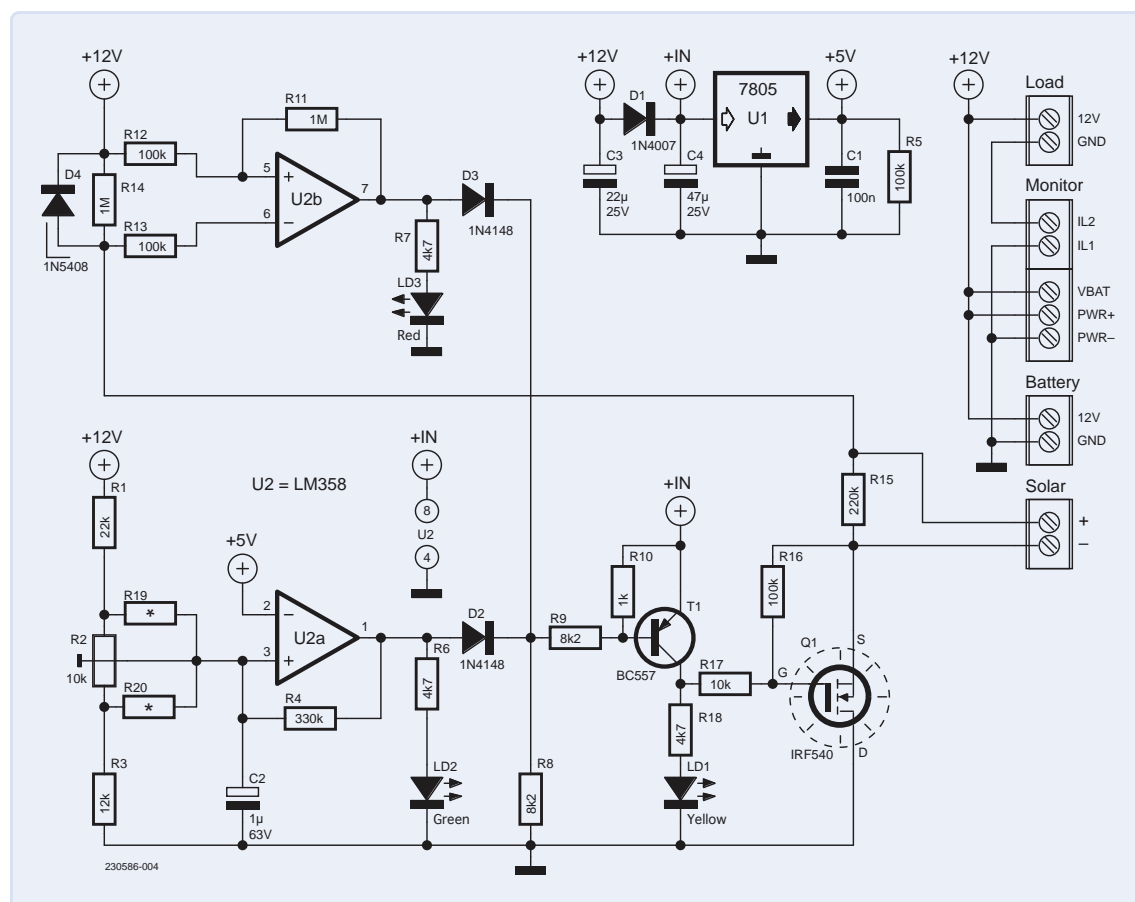


Figure 2: Schematic diagram of the circuit.



in turn drives Q1. When T1 and the MOSFET are conducting, yellow LED LD1 is lit. This component thus indicates that the solar panel is charging the battery. Transistor T1 (a PNP-type BC557) is normally ON because its base is connected to ground via resistors R8 and R9. To stop conduction, it is necessary for any of the outputs of the two op-amps to have a high level, and these levels are applied to the base of T1 via diodes D2 and D3. Let us see when this occurs by first studying the circuit related to the first op-amp (U2a). The 5 V voltage supplied by regulator U1 is applied to the inverting input (pin 2) of this op-amp, while part of the voltage present at the battery leads is applied to the non-inverting input (pin 3) via trimmer R2. When this voltage exceeds that applied on pin 2, the output of the op-amp (normally at low level) goes to a high level, bringing T1 to the OFF state and blocking the MOSFET, activating green LED LD2 at the same time. Obviously, trimmer R2 should be adjusted to cause switching when the battery voltage reaches a level of 14.2...14.4 V (typical of a fully charged lead-acid battery).

Resistor R4 introduces a slight hysteresis, to change the switching threshold and prevent the op-amp from starting to oscillate. In practice, to get the op-amp to switch from Low to High, it is necessary for the battery to reach a potential of 14.4 V, whereas with the output at a high level, the battery voltage must drop to 13.5 V to get the op-amp to switch from High to Low. So, this stage stops the current flow when the battery is fully charged.

Let us now see what happens in the section for the other op-amp, which has a High output when the solar panel voltage is lower than the battery voltage; in this case, red LED LD3 lights up and the MOSFET is switched off. Conversely, when the PV panel is hit by sunlight and its voltage is high enough to charge the battery, the LED is off and the MOSFET is in the ON state.

To summarize, yellow LED (LD1) indicates that the PV panel is charging the battery, red LED (LD3) signals that the insolation is insufficient to enable the charging circuit, and finally, green LED (LD2) signals that the battery is fully charged. This charge regulator can be used with PV panels that deliver a maximum current of 3...5 A. It is possible

to increase the range by mounting a diode of higher direct current, up to 10...20 A, for D4. Three-terminal regulator U1, supported by filter capacitor C1 and protection diode D1, makes it possible to supply a stabilized voltage to the inverting input pin of OpAmp U2a; the part of the circuit that must take care of detection of the state-of-charge for the battery, on the other hand, is supplied upstream, that is, by the voltage between the cathode of diode D1 and ground.

At this point, it is appropriate to explain the purpose of the MONITOR terminal block that you see on the right-hand side of the circuit diagram: It was provided to allow the insertion of a commercial energy meter into the circuit, for the purpose of showing the voltage and current delivered by the battery to the load on a display. In this specific case, after several trials, we opted for the EPT33V3AOLED product [1], a small panel meter with a blue OLED display. It is capable of displaying a number of electrical parameters, such as voltage, current, power, power consumption, capacitance, ambient temperature, and time. This module is supplied with two leads already headed into the connectors on its PCB visible from the back, the meaning of which is detailed in **Table 1**.

Including the energy meter unit is not strictly essential, but it is a useful accessory. Depending on whether it is plugged in or not, the MONITOR terminal block connections change. If you plug it into the circuit, connect the MONITOR terminal block contacts thus:

- 2: (PWR+) to the thin, red wire (+Vcc) of the meter
- 3: (VBAT, which is connected to PWR+) to the yellow wire of the meter

- 4: (IL1) to the thick, black wire of the meter (shunt)
- 5: (IL2) to the thick, red wire of the meter (shunt)

All according to the circuit diagram proposed in Figure 2. If, on the other hand, you do not wish to add the energy meter, you must use the connection diagram shown in Figure 1, which represents the basic installation of the system; then you must jumper the IL1 and IL2 terminals to close the load supply circuit (LOAD output) on the ground side. As an alternative to the instrument proposed here, you can still use any commercially available DC energy measurement module.

Practical Realization

We now turn to the construction of the circuit, for which a particularly small PCB has been designed, and the files for which can be downloaded from [1]. When you have the PCB, mount the resistors and diodes on it. When inserting the diodes, remember that the terminal near the colored band is the cathode. Slide in and solder the 8-pin socket for the dual op-amp, then the two trimmers and transistor T1, remembering to orient the latter (its flat side should face resistor R10) as shown in the mounting plate visible on these pages. It is then the turn of the capacitors, starting with the non-polarized ones and respecting the polarity indicated for the electrolytic ones. Mount the power MOSFET, which should be arranged lying with its metal side resting on a small, quite common U-shaped heat sink of type ML-026 — after applying silicone thermal paste — and securing it to the heat sink through a 3MA screw with its nut. The U1 regulator, on the other hand, should be mounted upright, holding it with the metal side facing the MOSFET heat sink.

Table 1: Wiring of the Energy Meter Display Module.

Lead	PCB Screw Terminal Block	Function
Red (thin)	+Vcc	Module positive supply
Black (thin)	GND	Module negative supply
Yellow	Vin	Voltage measurement input
Red (thick)	I+	Current measurement input
Black (thick)	I-	Current measurement output

## System Dimensioning

When solar panels and batteries are to be matched to the circuit, some considerations need to be made. First, it is necessary to know the overall consumption of the load. To give an example, let us assume that we are lighting a room with four 12 V / 10 W LED lamps with a continuous operation of 4 hours, which means an instantaneous power of 40 W; in 4 hours, this means an energy consumption of 0.16 kWh. At this point, we can choose the size of the 12 V battery, which in this case should have a capacity of at least  $160 \text{ Wh} / 12 \text{ V} = 13.3 \text{ Ah}$ . In practice, to have a power reserve, it is advisable to use one with at least twice the capacity.

Now we have to choose the type of panel needed to recharge our battery: here a parameter called ESH (Equivalent Sun Hours) comes into play. This parameter indicates what is, on average, the number of hours of sunlight in which maximum irradiation is reached, for each area of our country. Usually, this figure refers to the winter period: the summer one is obtained by doubling it. In the case of Italy, the ESH value is between 1.5 and 3; this means that in northern Italy our panels will operate at full power on average for 1.5 hours a day in winter and 3 hours in summer, while in the south we will have 3 hours of operation at maximum power in winter and 6 hours in summer. Considering an average value of 3 hours for seven days and considering that we will need about 180 Wh for each weekend, our panel should be able to provide a maximum power of about 8.5 W ( $180 \text{ Wh} : 7 \text{ days} \times 3 \text{ hours of ESH}$ ). Because of the considerations above, it is advisable that the maximum power to be considered is at least twice as high. In our case, we used two panels of 12 W each for a total of 24 W.

Now all that remains is to choose the type of photovoltaic panel from those commercially available: amorphous or crystalline. Panels of the first type have a significantly lower efficiency (around 5...6 %) but work well even in low light, while crystalline ones, if not well lit, do not deliver even a single mA! Since the cost/W is very similar, it is advisable to use panels of the former type in the North, while in the South mono- or poly-crystalline panels do much better. The latter, presenting a better efficiency, are also indicated in cases where there are space problems.

By putting these simple concepts into practice, we will be able to modify the characteristics of the system at will. At this point, after the panels and the battery, we need to spend a few words on another component that is indispensable for making a real system: the charge controller. This circuit monitors the charge level of the battery, and when the latter is fully charged, it breaks the connection with the panels. This prevents the overheating of the accumulator and the consequent reduction in the number of its working cycles. Of course, as soon as the battery level falls below a set value, the circuit will restore the connection with the panels.

This done, the circuit is ready; mount the integrated U2 in its socket, being careful in order to get it in with the reference from the side indicated in the mounting plan, and check that no pins have been bent during the operation, then take a general look at the circuit to check if everything is in order. That done, the device is ready for use (**Figure 3**). The board has a terminal block to which all connections converge; you will want to use strong lugs that you have to solder at the points marked SOLAR+ and -, BATTERY+ and - (12V), and LOAD+ and -. To the SOLAR+ and - terminals, you must connect, respectively, the positive and negative terminals of the solar panel, using wire of suitable gauge (on average  $1 \text{ mm}^2$  for 2.5 A); the accumulator must be connected to the + and - BATTERY contacts, respecting the indicated polarity and using wire of  $1 \text{ mm}^2$  for every 2.5 A of current. The same considerations apply to the electrical wires you must use to connect the desired appliance to the + and - LOAD points of the circuit board. **Figure 4** shows the complete wiring of the system.

Verification of circuit operation and calibration can be done on the bench. For this purpose, without connecting either the battery or the photovoltaic panel(s), connect a power supply, capable of delivering a DC voltage of exactly 14.4 V, in place of the battery. In this state, red LED LD3 should be on, as the panel voltage (which is not there) is zero. The corresponding stage inhibits the operation of the MOSFET, so that yellow LED LD1 is definitely off. On the other hand, the green LED may be on or off, depending on how trimmer R2 is adjusted. If the LED is on, turn the screw slider of trimmer R2 until the LED goes off, then slowly turn the slider in the opposite direction until it is back on. However, if the LED is already off, turn slider R2 until it turns on.

Now connect the battery and use the power supply instead of the solar panel, connecting the positive and negative to the + and - SOLAR terminals, respectively. Gradually increase the voltage until the red LED turns off and the yellow LED turns on. The latter will not light up if LD2 is also on. The power supply used for this test must be equipped with current protection to avoid excessive charging current (the protection should be set at 1–2 A). Finally, remember to use

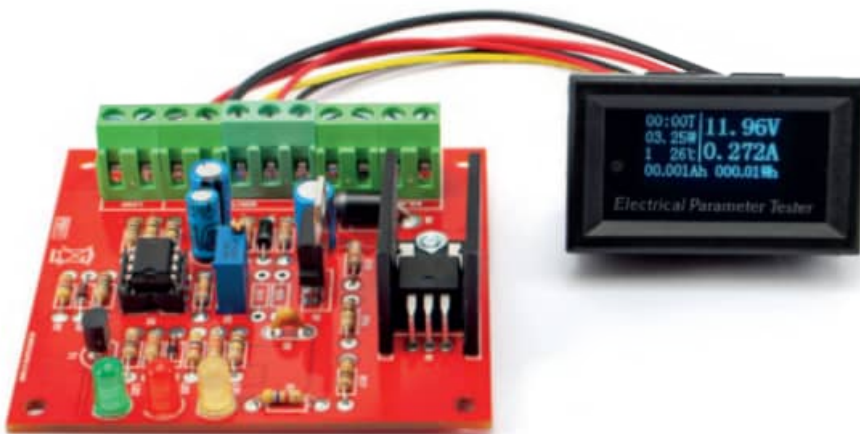
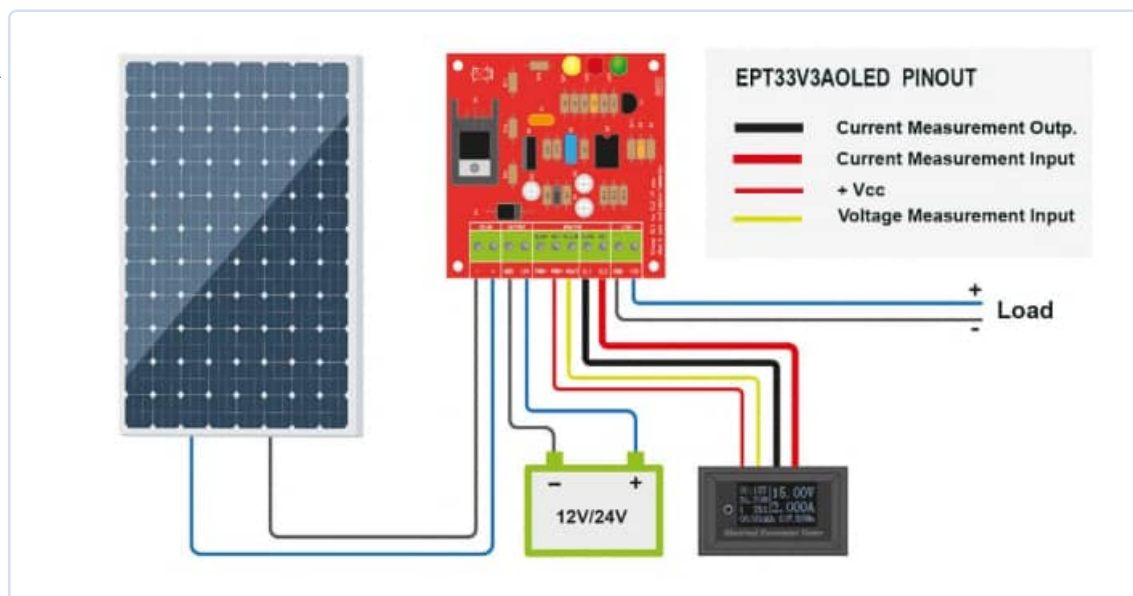
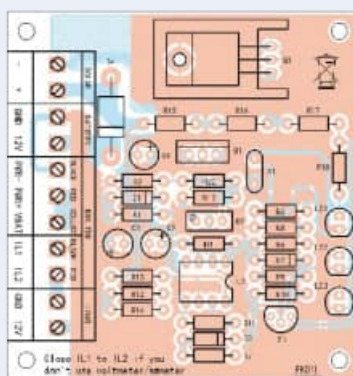
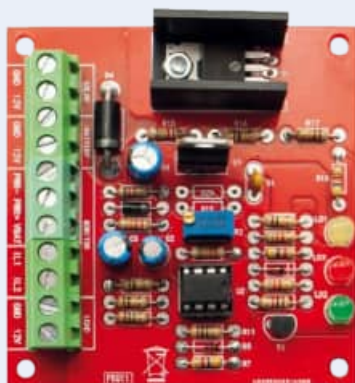


Figure 3: The prototype equipped with the energy meter.

Figure 4: Wiring of the PV power regulator with the energy meter module.



## Component List



### Resistors

R1 = 22 k $\Omega$   
 R2 = 10 k $\Omega$  multturn trimmer  
 R3 = 12 k $\Omega$   
 R4 = 330 k $\Omega$   
 R5, R12, R13, R16 = 100 k $\Omega$   
 R6, R7, R18 = 4,7 k $\Omega$   
 R8, R9 = 8,2 k $\Omega$   
 R10 = 1 k $\Omega$   
 R11, R14 = 1 M $\Omega$   
 R15 = 220 k $\Omega$   
 R17 = 10 k $\Omega$   
 R19, R20 = See text.

### Capacitors

C1 = 100 nF, ceramic  
 C2 = 1  $\mu$ F, 63 V, electrolytic  
 C3 = 22  $\mu$ F, 25 V, electrolytic  
 C4 = 47  $\mu$ F, 25 V, electrolytic

### Semiconductors

D1 = 1N4007  
 D2, D3 = 1N4148  
 D4 = 1N5408  
 LD1 = LED, yellow, 5 mm  
 LD2 = LED, green, 5 mm  
 LD3 = LED, red, 5 mm  
 U1 = 7805  
 U2 = LM358  
 T1 = BC557  
 Q1 = IRF540

### Miscellaneous

4+4 Pin DIL IC Socket  
 ML26 Heath Sink  
 1x 3MA x 10 mm Screw  
 1x 3MA Nut  
 4x Screw Terminal Block, 2 poles, 5 mm pitch  
 1x Screw Terminal Block, 3 poles, 5 mm pitch  
 PCB Board (69x72 mm)

cables of a diameter adequate for the currents involved, to minimize the losses due to electrical cabling.

This design can handle charging from a photovoltaic panel and directly power all devices operating on 12 V DC. In the case of equipment operating at 230 V AC, it will be necessary to use inverters, which allow you to obtain, from the 12 V DC, an alternating current suitable for powering the electrical devices meant for operation from mains voltage. In case your devices are sensitive to the waveform shape, or radio interference, we suggest you choose inverters with a pure sine wave, instead of the traditional (and today somewhat outdated) ones with a simple square wave output.

Let us remind you that the battery and the solar panel must be compatible as far as their voltage is concerned. Ultimately, if the panel provides 12...20 V (the typical excursion of a nominal 12 V panel) you should use a 12 V battery; the capacity should be related to the current that the panel can deliver and the time for which it will be able to do so, because there is no point in taking high-capacity batteries if they will never be fully charged in use.

## Some Final Hints

The project proposed here is a complete power management system for a small photovoltaic system, with energy storage using a 12 V battery. Combined with one or more photovoltaic panels and a battery, it provides energy autonomy to a small-power electrical DC system or, by adding a 12 V DC / 230 V AC inverter, alternating current.



Regarding the possibility of connecting two or more solar panels in parallel, we point out that, to compensate for voltage differences between them, it is advisable to place a power diode in series with each panel, capable of withstanding a current value ( $I_f$ ) greater than the maximum

that can be delivered by each panel. We suggest connecting the diode on the positive lead of each panel, with the anode toward the + wire and the cathode on the +SOLAR terminal. The negative leads should be connected in parallel on the -SOLAR terminal. ◀

230586-01



### About the Author

Boris Landoni is an electronics expert and a true enthusiast in the field. His dedication led him to become the managing director of *Elettronica In*, the most popular electronics magazine in Italy. He is also the curator of *open-electronics.org*, a platform dedicated to open-source projects that brings together enthusiasts and professionals. He is also the technical manager of Futura Elettronica, a leading company in supplying electronic components for the world of makers and professionals.

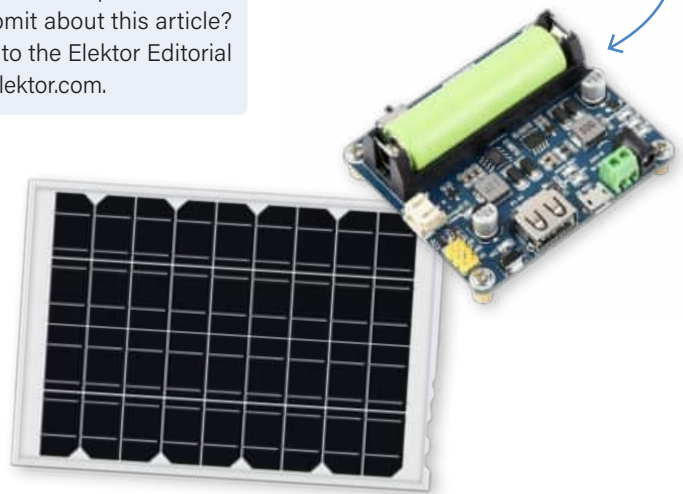
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### WEB LINK

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# Cold-Cathode Devices

Peculiar Parts, the Series

By David Ashton (Australia)

Cold-cathode devices are a type of gas-discharge device that uses a low-pressure gas to produce light. The simplest cold-cathode device is the neon lamp, which is often used as an indicator light. Other common cold-cathode devices include neon signs, voltage regulator tubes, and gas-discharge surge suppressors.

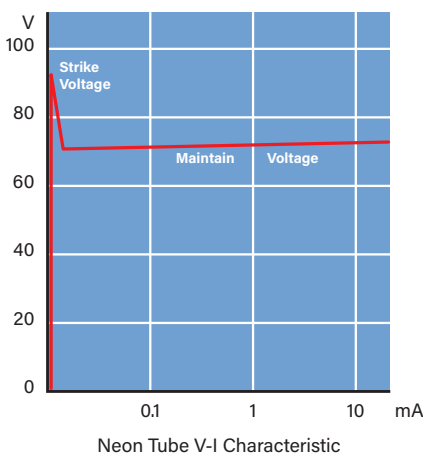


Figure 1: V-I characteristic of a typical neon tube.

If two electrodes are set up in a glass envelope filled with low-pressure neon or another gas, and sufficient voltage is applied to the electrodes, at some point the gas will ionize, and the gas around the negative electrode (or cathode) will glow — orange for neon, other colors for other gases. They're called "cold-cathode" devices because the cathode is not heated, unlike thermionic valves ("What's a valve, daddy?"). From this effect, a multitude of devices have been designed, and I will list a few here.

The simplest cold-cathode device is a neon lamp. These (and incandescent bulbs for lower voltages) were the go-to "on" lights in the days before LEDs. They ionize at around 90 V (the "strike" or "breakdown" voltage), and, once ionized, will continue to glow at a voltage of around 65 V (the "maintain" voltage). This difference implies a negative resistance region in the device's curve (Figure 1) and a relax-

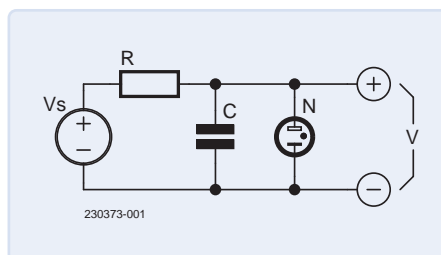


Figure 2: Neon lamp relaxation oscillator.

ation oscillator can be built with a neon lamp, a resistor, and a capacitor (Figure 2). Also, due to the negative resistance characteristic, if you want to use a neon lamp as a power indicator for AC mains, you need to put a resistor in series with it — commonly 220 k $\Omega$  is used at 220 V AC — if the current is not limited, the lamp will have a very short life. Neon lamps have symmetrical electrodes and, when you use them with AC, both electrodes will glow (Figure 3).

The well-known neon signs seen in places such as Piccadilly Circus and Times Square use the same effect. A shaped tube of neon or other gas is used, sometimes with a small amount of mercury, and various colors can be produced. Still more colors can be produced by applying a fluorescent phosphor coating to the inside of the glass. These long tubes need around 30,000 Volts to strike.



Figure 3: Neon lamps supplied with DC in opposite polarities, and AC, respectively.

Source: <https://commons.wikimedia.org/wiki/File:Neonlamp3.JPG>, "Neonlamp3," <https://creativecommons.org/licenses/by-sa/3.0/legalcode>



Figure 4: Nixie tube with the "4" cathode illuminated. Usually, a red or orange filter is used to enhance contrast. Source: Georg-Johann Lay with a slight edit by Richard Bartz ([https://commons.wikimedia.org/wiki/File:ZM1210-operating\\_edit2.jpg](https://commons.wikimedia.org/wiki/File:ZM1210-operating_edit2.jpg)), "ZM1210-operating edit2," <https://creativecommons.org/licenses/by-sa/3.0/legalcode>



Figure 5: Flash tube. The trigger electrode is the middle wire, going to two bands on the outside of the glass. Source: Jaycar Electronics (Australia). Used with permission.



Figure 6: Gas-discharge surge suppressor. Source: <https://commons.wikimedia.org/wiki/File:Gasableiter.jpg>

Also from the old valve days are voltage regulator tubes. These were specially constructed neon (usually with other gases) tubes that maintained a very constant voltage across them once they had been "struck." Popular models were the OA2 (150 V), OB2 (106 V), and 85A2 (85 V). These devices were the valve-era equivalents of Zener diodes. Operating currents varied from 1 to around 40 mA.

Still popular these days are Nixie tubes (**Figure 4**). These precursors to the now-ubiquitous seven-segment displays were just glorified neon tubes, but, with ten cathodes, each formed into the shape of a numeral. They gave very natural-looking displays, and there are those (I included) who find them beautiful and preferable to modern displays.

Also still in widespread use today are flash tubes (**Figure 5**), used in camera flashes and strobes. These use mainly xenon gas as a filling. They have two main electrodes and a smaller trigger electrode near one or both of the main electrodes. If a few hundred volts is applied to the main electrodes, a high-voltage pulse applied to the trigger electrode causes the gas between the two main electrodes to

ionize as well, giving off the bright white flash that we all know and love...

Another widely used device is the gas-discharge surge suppressor (**Figure 6**). These are two- or three-terminal devices, each consisting of a glass or ceramic tube with an electrode at each end and one in the middle. The middle electrode is usually earthed, and the two outer electrodes connected to, for instance, a telephone line. Any voltage greater than the breakdown voltage will cause the device to strike and limit the voltage, in case of a surge.

There are legions of other cold-cathode devices. Fluorescent lamps usually use a heated cathode, though there are cold-cathode types, notably the ones used for phone display backlights. Mercury-arc rectifiers were used in days past for power rectification, and thyatrons are the precursor of today's SCRs. Dekatrons were counter tubes used for divide-by-ten counting, long before the 7490 and 4017 were but gleams in their respective inventors' eyes. But these devices could (and hopefully will) warrant an article in themselves. ◀

230373-01

### About the Author

David Ashton was born in London, grew up in Rhodesia (now Zimbabwe), lived and worked in Zimbabwe, and now lives in Australia. He has been interested in electronics since he was "knee-high to a grasshopper." Rhodesia was not the center of the electronics universe, so adapting, substituting, and scrounging components were skills he acquired early (and still prides himself on). He has run an electronics lab, but has worked mainly in telecommunications.

### Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the Elektor editorial team by email at [editor@elektor.com](mailto:editor@elektor.com).



## From Life's Experience

### Nostalgia

By Ilse Joostens (Belgium)



In his book about the Titanic disaster, Jack Thayer wrote that since then the world has been changing at a faster pace, with less and less peace, satisfaction, and happiness. In today's fast and complex society, it feels like we're all sitting in an enormous blender that's constantly being set to a higher speed. We're all working hard, doing more in less time, and trying to achieve more results. If you aren't constantly busy, with an overfull calendar, you are either suspect or lazy, or perhaps both. It's always more, more, more – and that means we tend to be less friendly to each other.



▲

Source: Shutterstock /  
Miljan Zivkovic

But, occasionally I come to places where time seems to have stood still, and, in a wave of nostalgia, I think about how things used to be. Not that it was that much better then, but every time you can escape from the rat race for a moment is a bit of relief.

### Goat's Feet Cookies

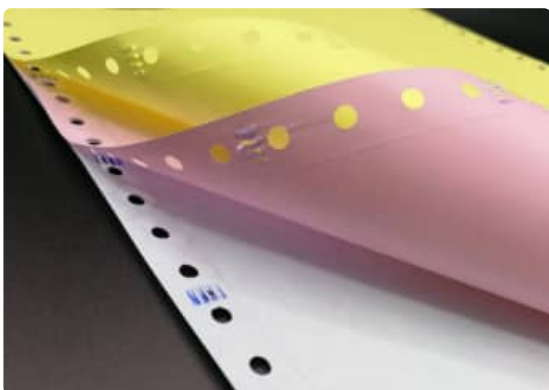
One time an online advertisement for a number of Nixie tubes caught my attention, and right away I enthusiastically sought contact with the other party. The seller clearly had no trust in the postal service, and, after a bit of email correspondence, we agreed that I would pick up the tubes in person. When I arrived after a long, nerve-wracking trip, I was greeted by an older man, let's call him Robert [1], and his spouse. Right away they took me through a 1980s interior to the kitchen table, where the coffee pot and a box of goat's feet cookies were waiting. After a bit of small talk, two metal cookie tins suddenly appeared on the table, each filled to the brim with Japanese Nixie tubes in neatly labeled plastic bags — a real treasure trove for fans of vintage electronics. Some of the bags even contained a slip of paper with advertising for salt licks for cows and horses, with the pinout of the related part sketched on the back. It turned out that Robert had been forced to abandon his hobby due to an eye disease and was offering all of his parts for sale.

After coffee, Robert took me to his home lab in a shed behind the house — very typical for Belgium, the land of stews and sheds [2]. In the shed, along with a cabinet containing home-made instruments, there was a cabinet with several annual volumes of the erstwhile magazines *Elektuur* and *Elex*, and, of course, many more cookie tins with all sorts of components. There was a distinct absence of microcontrollers, SMD components, and other modern parts, and the boards had been simply etched by hand using laser printouts on transparent film, just like I used to do nearly thirty years ago. It looked like time had stood still there. Robert proudly pointed out a frequency counter in a metal case that he had built himself. He switched on the instrument, and right away a row of zeros appeared on the display

made of — what else — Japanese Nixie tubes. “Let me just show you something,” he said, and poked a bit of loose wire into the instrument’s BNC connector. The Nixie tubes cheerfully started showing random digits due to the noise signals picked up by the wire. He had built two more of these instruments for fellow hobbyists, but he wanted to hold on to this one as long as possible. When we left the shed, he gave me two more cookie tins with seven-segment displays and several cardboard boxes full of tubes. The lady of the house looked on with pity, and when it came time to leave, she confided to me that Robert used to spend all day in his shed, with a tone in her voice that suggested she didn’t approve.

### Little Drawers and Air Pillows

Traditional electronics stores are a dying breed, and the stores that still remain are selling fewer individual parts and more ready-made items. You can imagine my surprise when, preparing a package for a customer in Slovakia, I found an electronics store on Google Maps and discovered that it had a wall with hundreds of little drawers. That reminded me of a store in the town where I was born, which I visited regularly until the end of 2011. A short time later, after a takeover, the store was moved to a different location and modernized. Even then, time appeared to have stopped in 2011. Not only did the interior exude a 1970s ambiance, but the way of working was something special. When you gave your shopping list to a clerk behind the counter, they were able to faultlessly find the right little drawers and copy the part numbers to your list. Once the list was fully processed, everything was put into little bags (actually cut-open air pillows) and stapled closed. You can’t beat that for recycling. Then the part numbers were typed in to a computer one by one, and a dot-matrix printer sprang to life and printed everything out on fan-fold carbonless copy paper [3].



Source: Shutterstock / YoONSpY

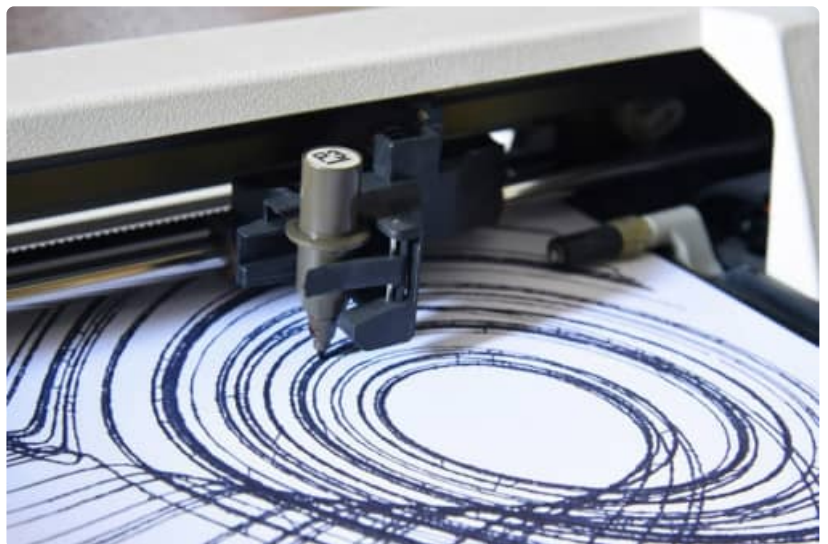
The original was filed neatly in an old, worn binder, and, as a customer, you got the pink copy as a receipt. And of course you paid with cash — they had never heard of electronic payment. In practice, all this was painfully slow, and there was usually a long queue at the counter. In a nearby town there was an obscure little store that was possibly even slower. The proprietor was an older man who was happy to give unwanted advice on everything you bought. Once, I even received a detailed explanation about polystyrene film capacitors, lasting nearly half an hour. I suppose the good man sometimes needed to chat with someone.

### Plotter Mania

Along with electronics, I like to putter around with generative art, and plotter art has been on my wish list for a long time. I still had an old pen plotter, but software was a problem, and I didn’t want to put too much time into it. Recently, I found a nice and affordable program [4], and, after soldering together an RS-232 cable, I was very happy to see the plotter busy drawing and changing drawing pens after nearly thirty years in storage, as though the 1990s had come back to visit. ◀

Translated by Kenneth Cox / 230532-03

Photo: Ilse Joostens



### WEB LINKS

- [1] Seinfeld: Rabbi with loose lips: <https://youtu.be/szAjGEoPtY4>
- [2] De Wereld van Sofie: De 10 vuistregels van de koterijen volgens Bert Kruismans: <https://tinyurl.com/bertkruismans>
- [3] Epson Dot Matrix Action Printer T 1000: <https://youtu.be/qIEUrEVqDbo>
- [4] DrawingBotV3 - An open source software for creating Pen Plotter Art: <https://drawingbotv3.com>



# Starting Out in Electronics...

...Looking at FETs

By Eric Bogers (Elektor)

Most electronics enthusiasts and electronics engineers today grab a microcontroller when things threaten to become a bit complicated, and, likewise, most of us don't use discrete transistors anymore. Where possible, we use operational amplifiers (opamps), and for good reason: Modern opamps offer unbeatable performance, so there's no reason not to use them.

Accordingly, in this installment, we provide a brief introduction to this new workhorse of electronics. However, we first take a last look at transistors in the form of field effect transistors (FETs), after a brief follow-up on the previous installment.

Let's start off with a small addition to the installment from the September/October edition this year [1]. There, we wrote under the heading "The emitter circuit," "It is possible to amplify a signal much more with this circuit, but in that case, a smaller emitter resistor and/or a higher supply voltage should be selected." That's true, of course, but it's not the full story. If you connect a capacitor in parallel with the emitter resistor in this circuit, the DC gain of the transistor stage remains the same, but the impedance of the parallel network decreases for AC signals. This means that the gain is higher for AC signals. Doing the necessary calculations is left as an exercise for the interested reader. Thanks go to Elektor reader (and author) Dogan Ibrahim for pointing out our omission.

## The Field Effect Transistor (FET)

In contrast to the bipolar transistor, which has played a leading role in our previous installments, a field effect transistor is controlled by voltage instead of current.

The input of an FET has an especially high impedance, so it takes very little power to control it (at least under DC conditions). With rising frequency, however, the internal capacitance of an FET becomes increasingly important.

FETs are not commonly used in circuits for theater and public event applications. That's because the circuits used in these applications need to have low impedance to avoid picking up noise. However, power MOSFETs are often used in such applications, but only in the output stages of power amplifiers.

**Figure 1** shows the schematic symbol of an n-channel FET. If the arrow in the symbol points in the other direction, the associated device is a p-channel FET, which has the opposite polarity. The three terminals are called the *gate*, the *source*, and the *drain*. In terms of their functions, correspond roughly to the base, emitter, and collector of a bipolar transistor.

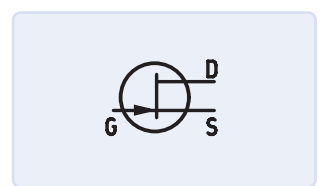


Figure 1: Schematic symbol of an n-channel JFET.

## The Source Follower

The source follower is the FET equivalent of an emitter follower and therefore has a voltage gain of 1.

In the circuit shown in **Figure 2**, the gate is simply connected to ground through a high-value resistor. In the case of a BF245 FET, this results in a drain current of approximately 4 mA, with a corresponding operating point of around 4 V.

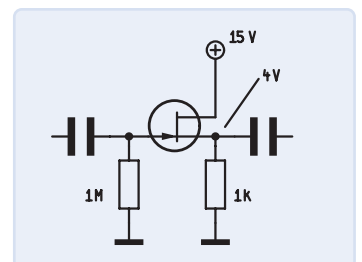


Figure 2: A source follower.



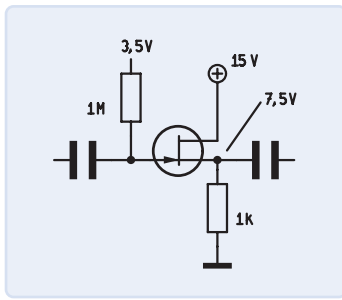


Figure 3: Optimal setting of the operating point.

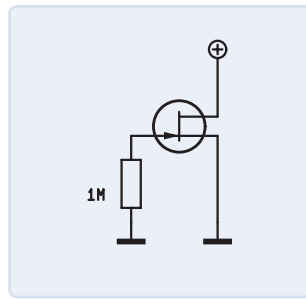


Figure 4: A constant-current source using an FET.

As the gate has an especially high impedance, the currents through the source and the drain are nearly the same, and the input impedance is determined by the value of the resistor from the gate to ground. The value of the input coupling capacitor can be calculated from the desired lower corner frequency. It can be relatively small compared to the situation with an emitter follower using a bipolar transistor.

A disadvantage of the circuit in Figure 2 is that the operating point is not half of the supply voltage, so the signal amplitude of the circuit output is limited. To change this, you only have to bias the gate to the appropriate voltage, as shown in **Figure 3**. This bias voltage can be provided by a simple voltage divider.

With a field effect transistor, it's also effortless to build a fairly good constant current source, as illustrated in **Figure 4**. If you examine the chart in **Figure 5**, you'll probably notice that an FET performs better in this role than a corresponding bipolar transistor does. Current sources such as this are often used to provide constant currents for LEDs.

### The Common-Source Circuit

If you wire an FET the appropriate way, it can of course also be used to provide voltage amplification. The circuit used for this is very similar to the common-emitter circuit with a bipolar transistor.

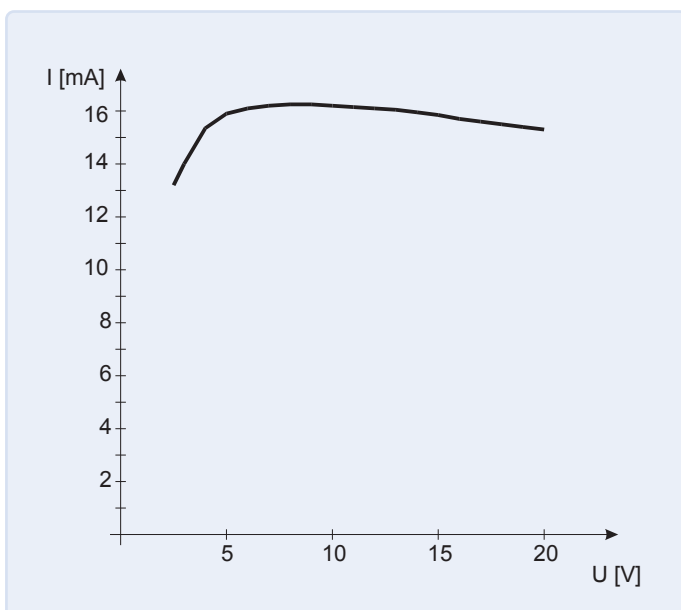


Figure 5: Characteristic curve of an FET constant-current source.

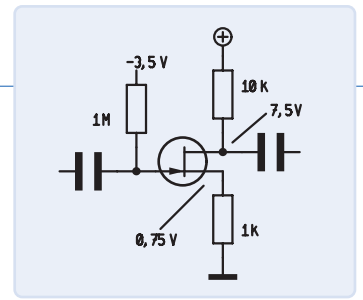


Figure 6: A common-source circuit.

With the FET circuit, as well, the gain is determined by the ratio of the resistances of the drain and source resistors.

However, the source follower circuit in **Figure 6** has a disadvantage: You need a negative voltage to allow the operating point to be set to a reasonable value. For this reason, FETs are rarely used in this way for voltage amplification. Instead, FET amplifiers are only used in the input stage of multi-stage amplifiers, and normal bipolar transistors are used for further signal amplification.

This approach can also be seen in the TL072 dual opamp (which means two opamps in the same package) and the TL074 quad opamp, which are very commonly used in audio applications. An FET input stage provides very high input impedance ( $10^{12} \Omega$ ), while the noise is kept in bounds by using bipolar transistors for further signal processing.

### Operational Amplifiers

The name “operational amplifier” has nothing to do with surgical procedures, but is instead closely related to mathematical operations. In the not so distant past, when digital technology was not yet sufficiently advanced to be able to perform complex mathematical calculations, analog computers were used when there was a need for integration or differentiation. Analog computers are based on analog circuitry, or, more specifically, on operational amplifiers.

One of the most serious problems with conventional transistor circuits is temperature drift: When the operating point is constantly changing, the accuracy of the circuits intended to perform complex operations is not very impressive. At the time, for this reason, designers quickly resorted to differential amplifiers, which have the desirable property that, when the operating point of one input (e.g. the non-inverting input) changes, the operating point of the other input changes in exactly the same way, so the changes cancel each other out.

Combining a differential amplifier with very high open-loop gain turned out to produce an exceptionally-general-purpose circuit, which has been given the name “operational amplifier” (or opamp for short).

At first, operational amplifiers were built using individual (discrete) transistors. However, people quickly realized that using integrated circuits would save a lot of time and effort.

As the noise characteristics of early ICs were not especially good, discrete opamps were still used in audio equipment for several more

years, but that time is now a long way behind us. Many modern opamps have undeniably outstanding audio characteristics and have established their place in small-signal electronics.

## Opamp Internals

The exact number of transistors in an integrated circuit does not significantly affect the manufacturing cost, so operational amplifier circuits consisting of 40 to 50 transistors are now common practice. The detailed circuit of a typical opamp, however, is too complicated for an introductory explanation, so here we look at a highly simplified opamp circuit instead (**Figure 7**). Of course, this circuit cannot be found in any actual opamp, but if you want, you can build it yourself (although the cost of the necessary components would probably be more than a corresponding IC).

Here, transistors T1 and T2 form a differential amplifier, as described in an earlier installment. In this case, we have omitted the emitter resistors, since they are actually not important for the circuit's operation. Transistor T3 and the associated components form a constant-current source.

Transistors T5 and T6 act as a Class-B push-pull output stage. The output is short-circuit proof, thanks to the relatively large emitter resistor values. This is possible because the negative feedback — when the circuit is used as an operational amplifier — strongly reduces the output impedance, so the values of the emitter resistors are not important. The negative feedback also minimizes the crossover distortion typical of a Class-B amplifier, so we do not need to be concerned about the issue of quiescent current.

Transistor T4, as a shared common-emitter amplifier, serves as a driver stage for the output transistors. Despite all our previous warnings, there is no emitter resistor here, because operational amplifiers are stabilized by means of overall negative feedback (from the output to the input). This means that the greatest possible open loop gain is more important than the exact operating point of an internal amplification stage.

That's enough about opamps for this installment — you've gotten your first taste of opamps, and, next time, we'll use them to build amplifier circuits. 

*Translated by Kenneth Cox — 230608-01*

*Editor's Note: This series of articles, Starting Out in Electronics, is based on the book, Basiskurs Elektronik, by Michael Ebner, which was published in German and Dutch by Elektor.*

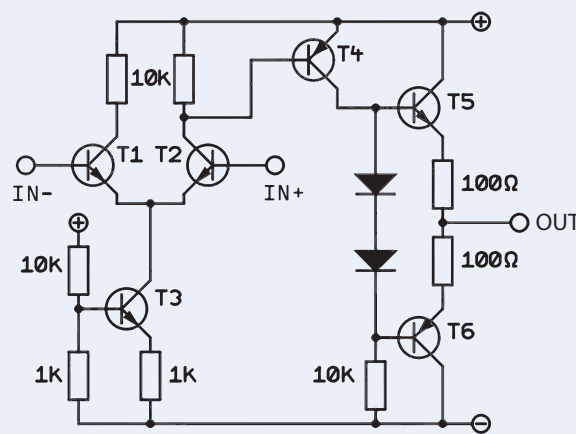


Figure 7: A highly simplified version of the internal structure of an operational amplifier.

## Questions or Comments?

If you have any technical questions or comments about this article, feel free to contact the Elektor editorial team at [editor@elektor.com](mailto:editor@elektor.com).



## Related Products

### > B. Kainka, *Basic Electronics for Beginners* (Elektor, 2020)

Book: [www.elektor.com/19212](http://www.elektor.com/19212)

E-Book: [www.elektor.com/19213](http://www.elektor.com/19213)



## WEB LINKS

- [1] "Starting Out in Electronics...Voltage Amplification," Elektor 9-10/2023:  
<https://elektormagazine.com/magazine/elektor-312/62155elektor-88/42431>

# CAN Bus Tutorial for the Arduino UNO R4

Two UNO R4s Hop on the Bus!

By Dogan Ibrahim (United Kingdom)

The Arduino UNO R4, released in two versions last year, supports the CAN bus in terms of hardware and software. In this article we look at some handy CAN modules, an experimental setup, and the basics of making traffic between CAN nodes viewable in Arduino's Serial Monitor.

**Editor's Note:** This article is an excerpt from the 326-page book, *Mastering the Arduino UNO R4* (Elektor, 2023). The excerpt was formatted and lightly edited to match Elektor Mag's editorial standards and page layout. The author and editor have done their best in such editing and are happy to assist with queries. Contact details are in the **Questions or Comments?** box.

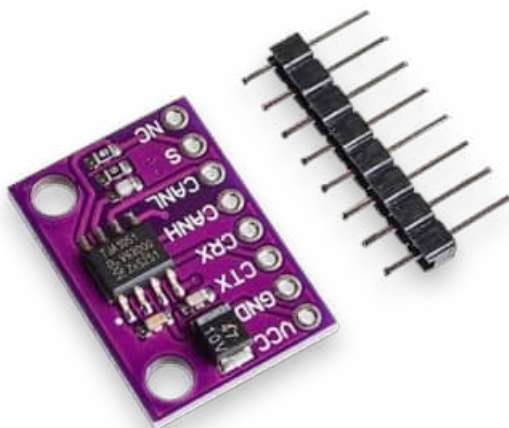
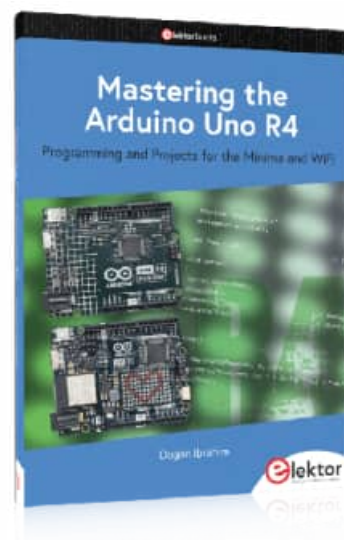


Figure 1: The TJA1051 transceiver module.



The Arduino UNO R4 Minima has the following two pins that can be used for the Controller Area Network (CAN) bus interface: D5 (RX) and D4 (TX). On the R4 WiFi version, the CAN bus pins are D13 (RX) and D10 (TX). Although there are basic CAN bus interface signals, it is necessary to connect CAN bus transceiver modules to these pins before connecting them to the physical CAN bus.

## CAN Bus Transceivers

A CAN bus transceiver module is a physical interface between the Arduino UNO R4 CAN bus pins and the actual physical CAN bus cable. There are several transceiver modules available on the market. The device used in the book mentioned above is the TJA1051 (**Figure 1**), a high-speed CAN transceiver module that provides an interface between a CAN protocol controller and the physical two-wire CAN bus.

The basic features of the TJA1051 are:

- > Supply voltage 4.5 to 5.5 V
- > ISO 11898-2:2016 and SAE J2284-1 to SAE J2284-5-compliant
- > Suitable for 12 V and 24 V systems
- > Low electromagnetic emission
- > Supply current: 1 mA in silent mode; 5 mA in bus recessive mode; 50 mA in bus dominant mode



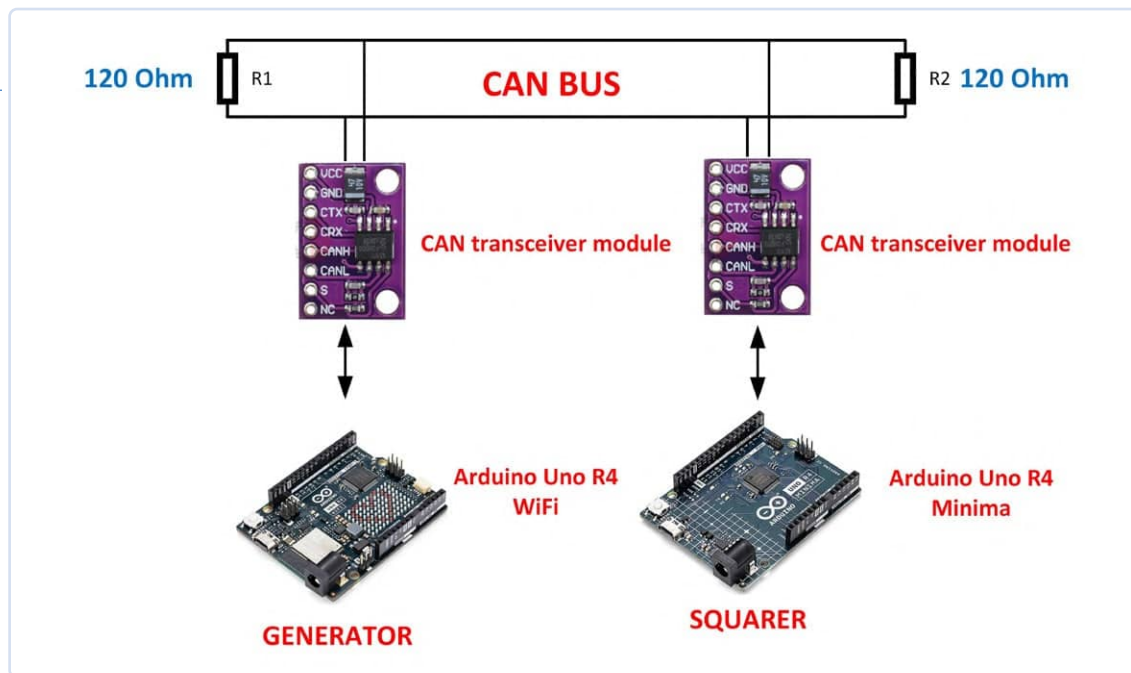


Figure 2: Demo project block diagram.

The TJA1052 transceiver module has the following pins:

- CANH CAN\_H: bus interface
- CANL CAN\_L: bus interface
- VCC: +5 V
- GND: Ground
- CTX: Transmit data input
- CRX: Receive data output (reads data from the bus)
- S: Silent mode control (LOW in normal mode, HIGH in silent mode)

A CAN bus-based demo project is given in the following section to illustrate how the Arduino UNO R4's CAN bus feature can be used. The built-in `Arduino_CAN` library is used to communicate with other CAN devices.

### UNO R4 WiFi to UNO R4 Minima CAN Bus Communication

To replicate this project, you will require two Arduino UNO R4 boards. Of these, the Arduino UNO R4 WiFi is called the GENERATOR, while the Arduino UNO R4 Minima is called the SQUARER. Both boards are connected on a CAN bus, meaning there are two nodes, called GENERATOR and SQUARER. The GENERATOR node is programmed to generate random integer numbers between 1 and 20 and send them to the SQUARER node, where the received numbers are squared and displayed on the IDE's Serial Monitor. This process is repeated after a 3-second delay. The aim of this project is to show how two Arduino UNO R4s can be connected and communicate over a CAN bus.

**Figure 2** shows the block diagram of the project. Here, the GENERATOR node is an Arduino UNO R4 WiFi, and the SQUARER node is an Arduino UNO R4 Minima. Two CAN bus transceiver modules and the CAN bus wiring are also shown.

**Note:** The Elektor product bundle includes the book and one Arduino R4 Minima development board. The TJA1051 IC, the CAN bus transceiver modules, and the terminating resistors have to be sourced separately.

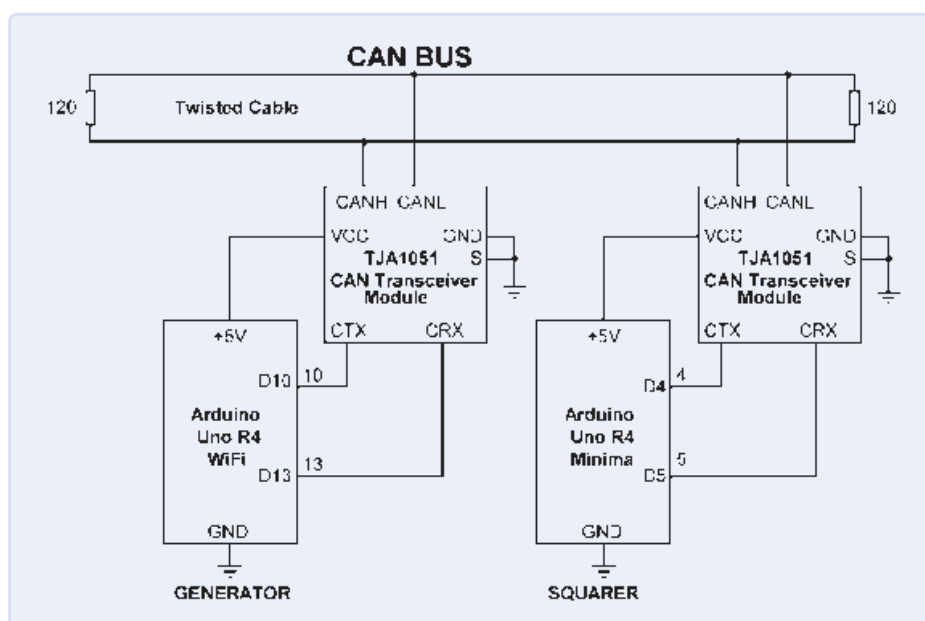


Figure 3: Demo project circuit diagram.

**Figure 3** shows the circuit diagram of the project. Notice that the bus cable is terminated with two 120  $\Omega$  resistors. The CANH and CANL terminals of both transceivers are connected to the bus cable. The CTX and CRX pins of the transceiver module are connected to the Arduino UNO R4 WiFi's D10 and D13 pins. Similarly, the CTX and CRX pins of the other transceiver are connected to the Arduino UNO R4 Minima's D4 and D5 pins, respectively.



### Listing 1: The program for the GENERATOR node.

```
//-----  
//          CAN BUS PROGRAM  
//          =====  
//  
// This program generates random numbers between 1 and 20 and sends them  
// over the CAN bus to a node called SQUARER. The SQUARER node takes the  
// square of these numbers and displays them on the Serial Monitor. CAN  
// baud rate is set to 250 K. The process is repeated every 3 seconds  
//  
// Author: Dogan Ibrahim  
// File  : GENERATOR  
// Date  : July, 2023  
//-----  
#include <Arduino_CAN.h>  
static uint32_t const CAN_ID = 0x20;  
uint8_t RandomNumber;  
uint8_t msg_data[8];  
void setup()  
{  
    Serial.begin(9600);  
    delay(5000);  
    if (!CAN.begin(CanBitRate::BR_250k))  
    {  
        Serial.println("CAN begin failed...");  
        while(1);  
    }  
    else  
        Serial.println("CAN begin success...");  
}  
void loop()  
{  
    RandomNumber = random(1, 21);                // Random number  
    Serial.print("Random number is: ");  
    Serial.println(RandomNumber);  
    msg_data[0] = RandomNumber;  
    msg_data[1] = 0x00;  
    msg_data[2] = 0x00;  
    msg_data[3] = 0x00;  
    msg_data[4] = 0x00;  
    msg_data[5] = 0x00;  
    msg_data[6] = 0x00;  
    msg_data[7] = 0x00;  
    CanMsg msg(CAN_ID, sizeof(msg_data), msg_data);  
    int const rc = CAN.write(msg);  
    if(rc < 0)  
    {  
        Serial.print("CAN write failed. Error code is: ");  
        Serial.println(rc);  
        while(1);  
    }  
    delay(3000);                                // Wait 3 secs and repeat  
}
```



### Listing 2: The program for the SQUARER node.

```
//-----  
//          CAN BUS PROGRAM  
//          =====  
//  
// This program receives random numbers between 1 and 20 over the CAN bus  
// and takes the square of these numbers and then displays the numbers on  
// the Serial monitor  
//  
// Author: Dogan Ibrahim  
// File  : SQUARER  
// Date  : July, 2023  
//-----  
#include <Arduino_CAN.h>  
static uint32_t const CAN_ID = 0x20;  
void setup()  
{  
    Serial.begin(9600);  
    delay(5000);  
    if (!CAN.begin(CanBitRate::BR_250k))  
    {  
        Serial.println("CAN begin failed...");  
        while(1);  
    }  
    else  
        Serial.println("CAN begin success...");  
}  
  
void loop()  
{  
    if(CAN.available())  
  
}
```

In this project, about one meter of twisted-pair cable was used to act as the CAN bus cable.

The *Arduino\_CAN* library supports the following baud rate constants: *BR\_125k*, *BR\_250k*, *BR\_500k*, *BR\_1000k*. The required baud rate must be specified during initialization. For example, for the 250 kbit/s baud rate, the required function call is: `CAN.begin(CanBitRate::BR_250k)`.

**Sending data:** A `CanMsg` message object is created with the `CAN_ID`, size and data, and is sent over the bus using the `CAN.write()` function.

**Receiving data:** `CAN.available()` is used to check for data, and then if data is available, it is read using the `CAN.read()` function.

**Listing 1** shows the code for the GENERATOR program. At the beginning of the program, the required header files are included.

Then, the `msg_data` array is initialized with eight elements. This array will store the data to be sent over the CAN bus. `CAN_ID` is set to `0x20`. Inside the `setup()` function, the CAN bus baud rate is set to 250 kbit/s and CAN bus communication is effectively started.

Inside the main program loop, a random number between 1 and 20 is first generated and then sent over the CAN bus. Notice that only the first byte of 8-byte data array `msg_data` is initialized. This process is repeated after a three-second delay, when a new random number is generated and sent to the SQUARER node.

**Listing 2** shows the code for the SQUARER program. The start and `setup()` function of this program are similar to the sections in Listing 1. Inside the main program loop, the program checks if there are any messages on the CAN bus and subsequently reads these messages. In this program, a message is an integer number between 1 and 20. The received number is stored in `Num` variable, and its square is displayed in Serial Monitor.



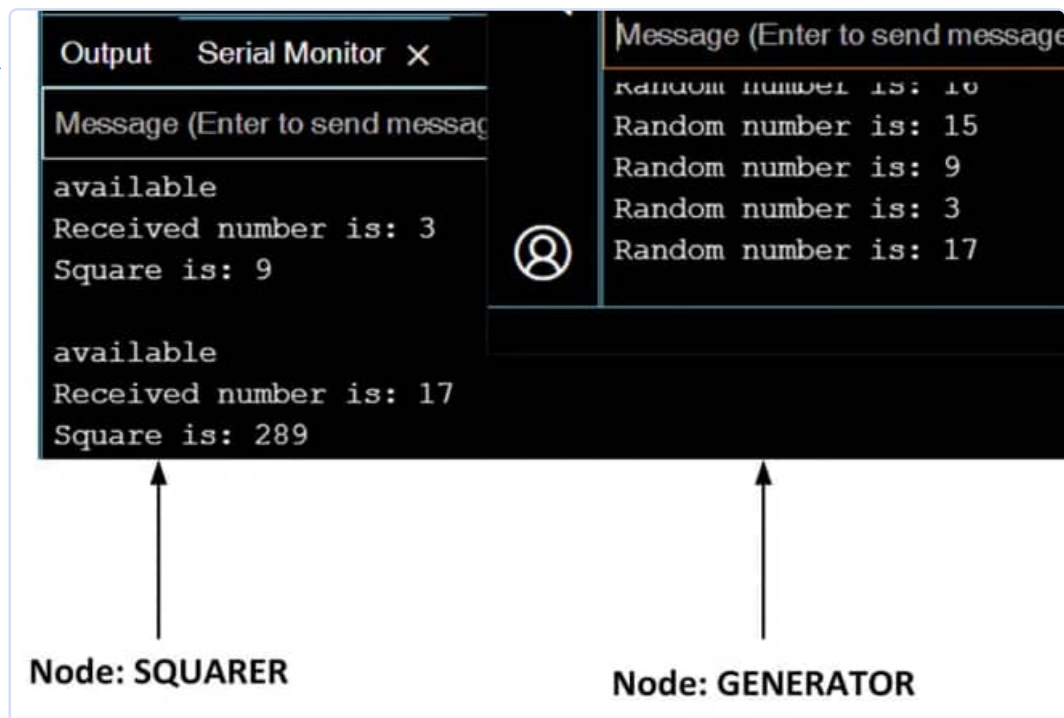


Figure 4: Example of output data as it appears in Serial Monitor.

Both programs shown here are included in the software archive released in support of *Mastering the Arduino R4*. The archive is available for free download from the Books section of the Elektor Store website [1]. Once on the web page, scroll to Downloads and locate the file *Software\_Mastering the Arduino Uno R4* (161.84 MB Zip file), download it, then and save it on your system. Unzip the archive file and locate the sample program files for book chapter 18.

### Testing the Project

Construct the project as shown in the circuit diagram and power up both Arduino UNO R4s. Start Serial Monitor on the SQUARER node, and you should see the received numbers and their squares displayed every three seconds. The sample output is shown in **Figure 4**. See a similar image? Congratulations! You're on the right bus heading to CAN Station, and in good company, too! ◀

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### Questions or Comments?

Do you have questions or comments about this article? Email the author at [d.ibrahim@btinternet.com](mailto:d.ibrahim@btinternet.com) or contact Elektor at [editor@elektor.com](mailto:editor@elektor.com).

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Dogan Ibrahim holds a BSc (Hons) degree in Electronic Engineering, an MSc degree in Automatic Control Engineering, and a PhD in Digital Signal Processing and Microprocessors. Dogan has worked in many organizations and is a Fellow of the Institution of Engineering and Technology (IET) in the UK and a chartered electrical engineer. Dogan has authored over 100 technical books and over 200 technical articles on electronics, microprocessors, microcontrollers, and related fields. Dogan is a certified Arduino professional and has many years of experience with almost all types of microprocessors and microcontrollers.



### Related Products

- > **Mastering the Arduino Uno R4 Bundle**  
Book and Arduino UNO R4 Minima:  
[www.elektor.com/20649](http://www.elektor.com/20649)
- > **The CAN Bus Companion (+ Free CAN Bus module)**  
Book and MCP2515 Module: [www.elektor.com/20405](http://www.elektor.com/20405)  
E-book: [www.elektor.com/20406](http://www.elektor.com/20406)

### WEB LINKS

[1] Software archive for: Mastering the Arduino Uno R4: <https://elektor.com/mastering-the-arduino-uno-r4>

## The Power Electronics Market: A Growing Landscape

Things have certainly changed in the power electronics industry over the years, as the push for green energy and the quest for improved efficiency are no longer to be ignored. In 2022, the overall power electronics market hit \$20.9 billion, considering both discrete components and modules. And, guess what? It's on track to maintain a growth rate to 2028, when it's projected to reach a whopping \$33.3 billion.

**8.1%**  
**CAGR**

between 2022 and 2028. [1]

**4.4%**  
**CAGR**

for the discretes  
market segments. [1]

**14.4%**  
**CAGR**

for the modules  
market segments. [1]

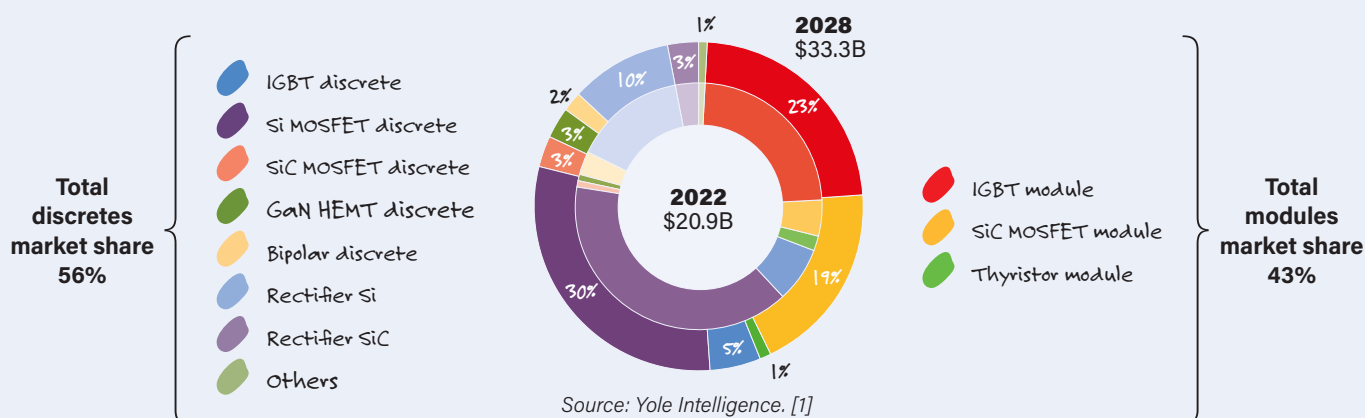
**elektor TV**  
Want to learn more about SiC and GaN?  
Check out this Elektor video.  
<https://youtube.com/live/k53Gf0lnZFk>



### Watch: Adapting to Wide Bandgap Devices

According to Ana Villamor, Team Lead Analyst, Power Electronics at Yole Intelligence [1], when we talk about power devices, we're talking about three big players in the materials game: silicon, silicon carbide (SiC), and gallium nitride (GaN). Silicon is still the big cheese in this market, but SiC is picking up speed, especially with the rising demand for modules in electric vehicles. As for GaN, it's mainly hanging out in the world of power supplies for us, the everyday consumers.

### 2022-2028 Power Electronics Market in Revenue - Discretes & Modules Split by Component Type



## Electricity Demand: Actions Will Be Taken

In the next decade, despite economic risks, electrification could surpass energy efficiency gains. Just one household buying an electric car can increase electricity demand more than many families upgrading fridges. Electrification's impact could be boosted by growing

interest in hydrogen, possibly replacing fossil fuel in heavy-duty trucks and heating. The EU's hydrogen plan, targeting 10 million tons by 2030, needs over 10% of current electricity, equal to growth from 2000-2010, despite flat electricity demand lately. [6]

# Energy Consumption Outlook: Are We Heading South?

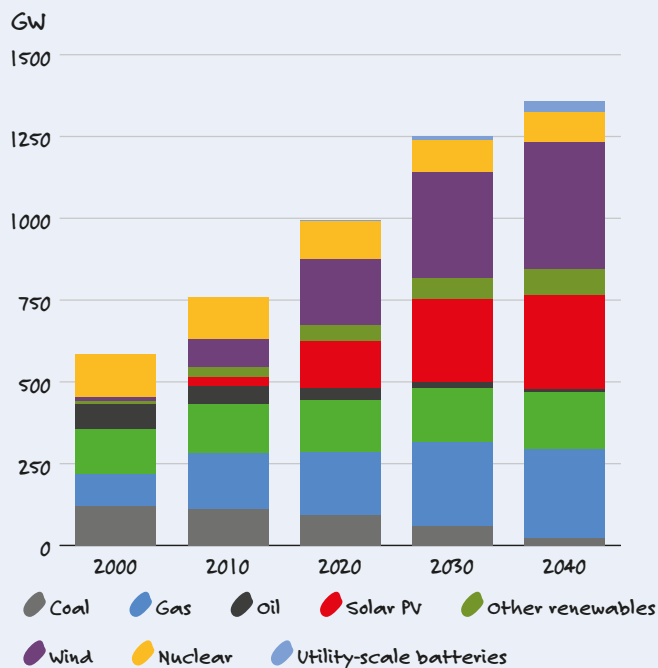
The International Energy Agency (IEA) [2] announced that the global energy consumption growth rate for 2024 predicts a rise to 3.3% as the economic situation improves, as compared to 2023 and earlier. The IEA's data shows that the European Union is responsible for 40% of the total decline in emissions from power generation.

## A Scenario for the Future

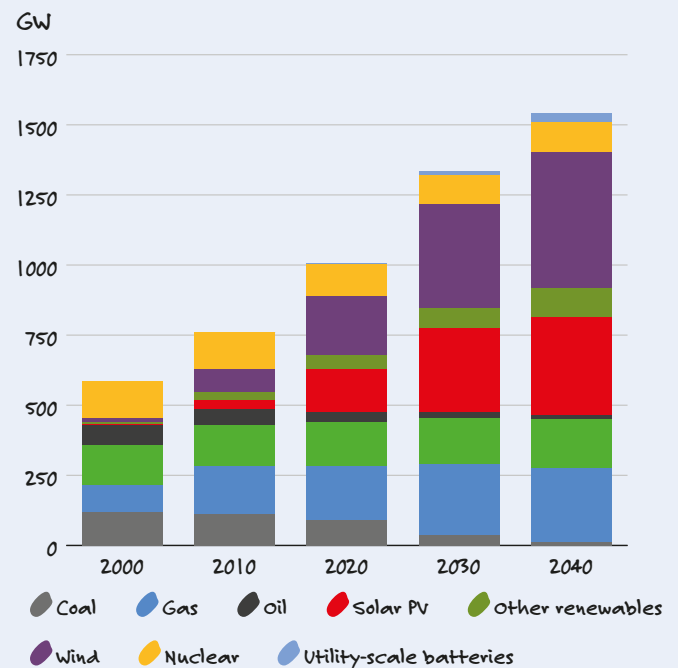
The "Stated Policies Scenario" (STEPS) considers actions that are already in progress or planned to achieve energy and climate goals that governments have announced. [3] On the other hand,

the "Sustainable Development Scenario" is a plan for how we can improve the world by changing how we use energy. This means making sure that everyone can afford and access energy by 2030 and reducing pollution in the environment. When it comes to gases that affect the climate, advanced economies aim to have no net emissions by 2050, China by 2060, and all other countries by 2070 at the latest. In this scenario, the goal is to limit global temperature rise to a maximum of 1.7°C by 2050. There's a good chance of success if we stop releasing CO<sub>2</sub> into the air after 2070. [3]

### Stated Policies Scenario Data



### Sustainable Development Scenario Data



Source: IEA. License: CC BY 4.0 [4] [5]

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## WEB LINKS

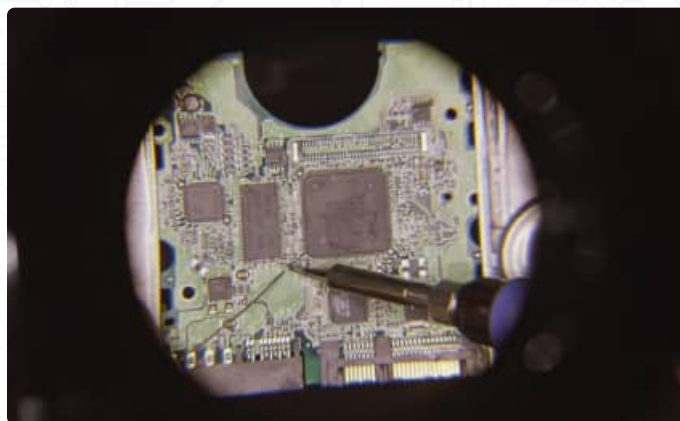
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- [5] IEA, "Installed capacity in the European Union, 2000-2010, and projections up to 2040 in the Sustainable Development Scenario," 2020: <https://iea.org/data-and-statistics/charts/installed-capacity-in-the-european-union-2000-2010-and-projections-up-to-2040-in-the-sustainable-development-scenario>
- [6] IEA, "Power Systems in Transition," 2020: <https://iea.org/reports/power-systems-in-transition>

# Comprehensive Design and Development Support

Arrow Engineering Services

Contributed by Arrow Electronics

Arrow Electronics is a complete engineering technology solution provider, covering the entire technology spectrum, from electronic components such as semiconductors, passive devices, connectors, electromechanics and embedded solutions to enterprise IT, security and cloud.



As an organization, Arrow Electronics has seen the speed of technology adoption accelerate and the complexity of customers' designs increase. Consequently, the role of its field applications engineers (FAE), many of whom are highly trained in specific manufacturers or solution architectures, has evolved to see them become trusted advisors for customers, consulting on solution architecture and system design. In addition, FAEs still provide all the technical support required to get customers to market as fast as possible. Areas of specialization include analogue, embedded, FPGA, power, wireless, IP&E and RF through its Richardson RFPD business.

## Managing Software-Driven Design

Beyond technical sales and support resources, Arrow has an extensive engineering services organization that performs design and development on behalf of the customer. Here, its engineers become an extension of OEMs' R&D teams to accelerate new product launches, enhance key capabilities or support digital innovation in AI, cloud-based analytics or IoT device security.

As noted, design complexity has increased significantly in high-speed MCUs and multimedia processors, FPGAs, IoT and edge computing, artificial intelligence and cloud, to name a few. And software is increasingly becoming the dominant decision factor in hardware selection. Digital engineering, which spans from embedded software to AI to cloud to IoT security to mobile applications, is the fastest-growing element of the market. However, companies do not always have the resources in these highly complex areas. Therefore, Arrow looks to support clients in the design and development of both the device and software stacks, complementing their skill sets and doing development on their behalf.

The provision of engineering services can help companies manage complexity and take their ideas from imagination to innovation. Arrow recognizes that the semiconductor industry is highly competitive and rapidly evolving. Manufacturers must prioritize research and development, take risks, and invest in new technologies to remain relevant and meet customer demands. But with competing priorities, labour shortages, and a rapidly evolving

landscape, staying ahead of competitors is a challenging task. This is where Arrow's portfolio of engineering services can help.

Indeed, Arrow is increasingly collaborating with OEMs in the automotive, pharmaceutical, medical and industrial segments. FAEs provide unparalleled access to new product introductions in these partnerships through their crucial supplier relationships. And Arrow's teams can help perform strategic design reviews, make technology recommendations and help accelerate design processes. Companies like this one-stop-shop approach because Arrow can guide both product design and the supply chain, ensuring that it can supply what is designed and manage the supply chain as production ramps. This service offering is about filling in the outlines to make ideas real — helping customers create, make, and manage their technology more efficiently and effectively.

## Engineering Services Through eInfochips

One of the critical drivers of its engineering services activities is eInfochips. This Arrow Electronics company is a recognized leader in



digital transformation and product engineering services. eInfochips is a fully resourced engineering and innovation partner for product development needs, accelerating time to market for its customers with expertise in IoT, AI/ML, security, sensors, silicon, wireless, cloud, and power. With over five hundred products developed and 40 million deployments in 140 countries, eInfochips drives technology innovation across various industries.

These services help customers design across the entire product stack, including device engineering, digital engineering, quality engineering, and silicon engineering. Services include design to manufacturing, machine learning, product testing, and embedded system design. Superior product development capabilities are a vital differentiator for eInfochips in the services market. It collaborates with customers to conceptualize a well-defined product roadmap that aligns with long-term objectives, defines key success metrics and designs and develops the product. And it can align the operating model to the customer's product goals, optimizing the business processes and systems.

Let us look at those core services in more detail:

**Device Engineering** — Devices and systems engineering have witnessed phenomenal growth from an earlier era of microcontrollers to the latest technological advancements in processors, sensors, connectivity, protocols, and embedded software. This has created a huge market for sophisticated end applications such as wearable devices, smart home appliances, 3D printers, self-driving cars, virtual and augmented reality applications, and more. Stiff competition and commoditization force players to develop and launch innovative products and solutions.

eInfochips is a co-development partner for many product companies across multiple

industry verticals, requiring custom services in embedded systems development. Its focus on engineering innovation and excellence has resulted in many revolutionary product designs and solutions for clients.

**Digital Engineering & Transformation Services** — With a continuous focus on customer experience and data-driven product enhancements, the need for digital transformation has expanded rapidly across organizations. eInfochips has developed multiple IPs and solution accelerators in IoT, Machine learning, cloud enablement, video management, test automation, and other areas to enable clients to implement their digital transformation plans successfully.

**Quality Engineering Services** — User experience has taken centre stage with the advent of digital transformation and newer technologies like IoT, cloud, DevOps, Big Data and Artificial intelligence across varied industrial and consumer applications. Companies constantly strive to innovate products faster to remain competitive in the market. Hence, effective quality assurance becomes a pivotal function to enable companies' better-quality products at a faster time-to-market.


eInfochips provides Quality Assurance services across the entire connected product lifecycle, from test consulting and implementation to end-of-life testing support, ensuring high product quality, operational excellence and agility along the way. It also offers accelerated business outcomes for core enterprise application and software testing through its open-source tool expertise, DevOps, and shift left testing approach.

**Silicon and VLSI Engineering** — The world is moving into an era of anywhere, any device, and anytime computing. The semiconductor industry and embedded solution players are in the throes of this transformation, acting as "enablers" of the next-generation IoT innovation era. The demand for microcontrollers,

sensors, and memory from the semiconductor (VLSI chip design) industry will significantly boost with increased adoption of innovative devices such as smartphones, tablets, mobile, electric cars, and wearable devices. It has also led to a greater demand for high-performance, rugged and reliable on-chip products, lower geometries, VLSI design services, design for testing, DFM, pre/post-silicon validation and other solutions. eInfochips excels in providing turnkey product design and silicon engineering services to semiconductor companies.

## Your Partner in Product Transformation

In short, then, engineering services position Arrow as a product transformation partner. Companies must be more agile and efficient in their business operations. Meanwhile, disruptive technologies, changing user base, shorter product cycles and variants, and newer business opportunities propel companies to evolve to stay relevant in the market continuously. Arrow helps clients navigate this complex business landscape — accelerating product launches, attaining higher returns on investment on product development, and boosting profitability across organizations.

You can find more about the Engineering services of Arrow Electronics on the company's website [1]. 

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## WEB LINK

[1] Design Engineering : <https://www.arrow.com/company/expertise/design-engineering>



# Comparing Power Density and Power Efficiency

By Mark Patrick, Mouser Electronics

Often the choice of power supply is made based on a single efficiency figure on the datasheet, and manufacturers are doing all they can to drive this number up, including defining the measurement conditions ever more carefully. Designers are coming up with more sophisticated topologies, such as phase-shifted full bridges (PSFBs) and LLC converters, and at the component level, MOSFETs supplant diodes to reduce losses. Even silicon is being challenged as wide bandgap (WBG) materials such as silicon carbide (SiC) and gallium nitride (GaN) promise enhanced performance, even at high switching speeds.

The exact efficiency figure on a power supply datasheet means relatively little to end users. They care more about system or process efficiency, as well as meeting (or exceeding) their environmental obligations and financial goals. There is a growing realisation that there is more to supporting the environment (and controlling costs) than the power supply's efficiency figure on the datasheet when viewed over the lifetime of a system. However, as real estate costs money to buy and maintain, they are very focused on packing as much revenue-generating equipment into their space as possible. So for them, power density is often more valuable than efficiency.

This article looks at power density & efficiency in detail, considering what it costs to drive higher efficiency as well as to buy high-performance power solutions and ultimately dispose of them responsibly. It contrasts this with an approach focused on increasing power density and how system efficiency is enhanced. The article also considers whether heat management should be the focus, instead of overall power conversion efficiency.

## The Concept of Efficiency

Efficiency is a concept that is easy to understand: Surely the closer to 100% you get, the better everything is? But it is all about how

efficiency is thought of; in an office or a data centre, no useful work (in physics terms) is done — no big machinery is moved — so we could consider these places 0% efficient because all the power used eventually goes into heat in the computers, servers, storage and power conversion.

If, however, you compared revenue efficiency — that is, the dollar value of electricity compared to dollar revenues — then the efficiency could reach 1000%. So, for business performance and success, the goal should be to keep electricity costs as low as possible by reducing the amount of electricity used, per unit of output.

Every data centre manager is challenged to increase processing and storage capacity, as well as revenue generation and profit. To do this, they must keep electricity costs in check and ensure acquisitions pay back quickly. As servers are added, the electricity costs (as well as the ability to earn revenue) rise, and this ratio of revenue to cost is defined in part by the equipment selection.

In a factory, the only valid reason to add another powerful motor is to produce more saleable output, so the motor drive and associated power supply are simply overhead costs that add no commercial value as such. Therefore, all operating expenses (including electricity) associated with running the motor are seen as a drain on the bottom line. Efficiency is

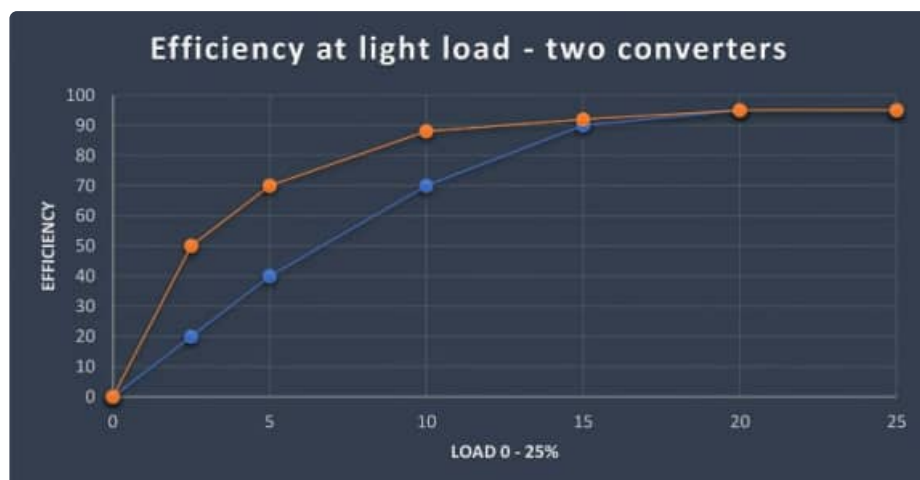


Figure 1: Different power supplies will exhibit very different low-load efficiency.

important, but only in the context of doing the necessary work while using as little electricity as possible.

### Losses Are Important Everywhere

Electronics design is full of formulae (for example, efficiency equals power out divided by power in, as a percentage, and losses equal power in minus power out). However, context such as power levels and the operating and environmental conditions is needed to make these formulae meaningful. Even with a defined formula, power supply manufacturers can select the best conditions, making the efficiency appear better than it will be in real-world conditions.

Often, efficiency is specified close to full load, but few systems (especially in redundant applications) run at this level for any period of time and, away from the “sweet spot”, efficiency can be much lower. Generally, efficiency will fall off significantly towards zero load, and the way this happens is different for each power supply. So energy consumed when a server is idling can be one (or more) orders of magnitude different.

In **Figure 1**, at 5% load, the converter represented by the blue line dissipates more than three times more quickly than the converter represented by the orange line. Light-load losses should be the focus during selection, as they make a significant difference to the total energy draw.

Recognising the importance of low-load efficiency, standards such as the “80 PLUS” initiative (**Table 1**) have been developed to stipulate minimum efficiencies through the load range. 80 PLUS Titanium is the toughest specification, requiring at least 94% efficiency at 50% load and 90% at 10% load (based on a 115 V system). For a 230 V system, the requirement at 50% load changes to 96% while a 10% load still requires 90%.

Meeting the requirements of 80 PLUS is challenging, especially at the higher levels

that were introduced after the certification scheme was developed in 2004. The basic level required 80% efficiency at 50% load while achieving the Titanium level (94%) implies reducing losses by three quarters.

This is a 14% efficiency increase, but a 1 kW power converter would need to reduce losses from 250 W to 64 W. Clearly, tweaking an existing topology or design will not achieve this, and the industry has responded with innovative approaches. For example, diodes have been replaced with synchronously driven MOSFETs. Additionally, PSFB and LLC resonant topologies have been introduced to limit switching losses, and new WBG materials allow for lower losses when raising the switching frequency.

With many converters requiring two-stage conversion (e.g., power factor correction (PFC) and DC-DC), the efficiency in each section is required to be even higher. The input mains bridge rectifier has changed from four diodes into a network of MOSFETs that enhance the PFC stage efficiency.

As these technologies are new, they can be expensive and there is a risk associated with anything that does not (yet) have years of

**Table 1: Summary of 80 PLUS requirements for 115 V systems. (Source: Mouser)**

80 PLUS Certification	115 V Internal Non-redundant				115 V Industrial			
% of Rated Load	10%	20%	50%	100%	10%	20%	50%	100%
80 PLUS	---	80%	80%	80%/ PFC 0.9	---			
80 PLUS Bronze	---	82%	85%/ PFC 0.9	82%	---			
80 PLUS Silver	---	85%	88%/ PFC 0.9	85%	80%	85%/ PFC 0.9	88%	85%
80 PLUS Gold	---	87%	90%/ PFC 0.9	87%	82%	87%/ PFC 0.9	90%	87%
80 PLUS Platinum	---	90%	92%/ PFC 0.95	89%	85%	90%/ PFC 0.95	92%	90%
80 PLUS Titanium	90%	92%/ PFC 0.95	94%	90%	---			





Figure 2: Losses versus efficiency in a 1 kW power converter.

field-proved reliability. Nonetheless, there remains an incessant demand for ever higher efficiency figures, moving towards 99% and beyond.

### 1%: A Little or a Lot?

As efficiency gets higher, every small increase becomes correspondingly more difficult. Moving from 97% to 98% requires reducing losses by a third. Tougher still, moving from 98% to 99% implies reducing losses by a *further* half.

This 50% reduction would almost certainly demand a total redesign based on more complex techniques and high-priced components, with a significant amount of design time and risk. A 1 kW supply dissipates 20.4 W at 98% efficiency; moving this to 99% reduces the loss to 10.1 W (**Figure 2**). The cost implications of saving just 10.3 W are very significant over time and the eventual BOM cost.

One could say that all energy savings are worth having, but this may not be entirely true when you look at the bigger picture. In the U.S., the industry pays about \$0.165 per kilowatt-hour [1]. Over a five-year lifespan for a 1 kW power supply at 100% uptime, a reduction of 10.1 W saves about \$73 while the load power is costing over \$7,300.

There are a lot of management costs in acquiring, purchasing, and qualifying a new power supply in addition to the disposal costs for obsolete equipment. A price must

also be put upon the risks associated with making the change. It is highly doubtful that any analysis could show that saving \$73 could even begin to cover all of these costs, except (possibly) in installations where many thousands of such power supplies were used. “Efficiency for efficiency’s sake” is rarely a solid business strategy.

### Should We Worry About Heat?

The extent to which a business must consider heat from a power supply depends on the source of the electrical power. If it is a fossil fuel (e.g., coal, gas) energy consumed by end equipment and HVAC systems, then there will be an impact on global warming and pollution. According to analysis, even “clean” nuclear power plants push heat into the ambient air, as their thermal efficiency is generally about 33% [2].

Enhancing efficiency is clearly a good thing, but even in hot regions of the world, people generate heat in boilers, showers, baths, washing machines, driers, and more. It seems counterintuitive that designers strive to save a few tens of watts while someone runs a multi-kilowatt clothes drier for hours in the next building. Addressing this anomaly, cogeneration schemes or Combined Heat and Power (CHP) can harvest and channel waste industrial heat for positive use within local communities.

An early example of this was Thomas Edison’s first Pearl Street Station power plant in 1882. A similar principle is used

within the IBM-built data centre [3] at Syracuse University in New York, and while not yet commonplace, the principles could be used in industry. As operators tend to migrate data centres to colder climates where ambient air can be used for cooling, the heat (if correctly channelled) can be very useful — especially where electricity is cheap from hydro or geothermal sources (such as in Norway or Iceland).

### Heat Impacts Reliability

It is worth reducing power supply losses as this reduces internal temperatures and improves predicted lifetime and reliability. However, this is only relevant if the case and cooling are unchanged. Various formulae define that the lifetime of electronics halves for every 10°C rise in ambient. Additionally, many reliability handbooks will tell you that the semiconductor failure rate increases by around 25% and capacitors by about 50% for the same rise in temperature.

Modern technology is generally very reliable and durable. Even with these figures, reliability remains high — but there is a thermal effect that should be recognised and understood. The industry will generally try to maintain an inlet temperature of around 21°C in data centres, but research by Intel and others has demonstrated that an increase does not have a significant impact on system reliability. A report by APC [4] quoting the American Society of Heating and Air-Conditioning Engineers (ASHRAE) predicts just 1.5 times increase in overall equipment failure rate for an inlet air temperature rise of 20 to 32°C (68 to 90°F) (**Figure 3**).

Each degree Celsius increase in temperature in data centres is said to reduce associated cooling costs by about 7%, allowing equipment to run (slightly) warmer, which can be a real benefit to operating expenditure.

The newer WBG materials can cope with higher junction temperatures than their silicon counterparts, so these become an enabler for running equipment (especially high-frequency power supplies) at elevated temperatures.



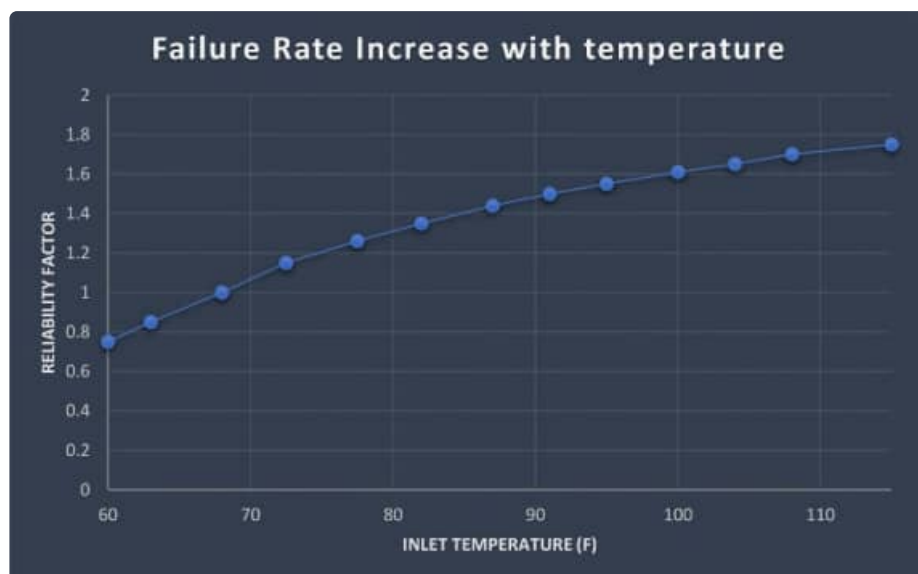



Figure 3: How inlet temperature impacts reliability.

and materials, end users prioritise power density over efficiency, as it allows them to maximise revenue-generating equipment in limited space. Low-load efficiency is critical, and industry standards like the 80 PLUS initiatives address this aspect. Achieving higher efficiency levels becomes increasingly challenging and costly, with diminishing returns. The focus on efficiency should be balanced with the overall cost, reliability, and environmental impact, considering factors such as acquisition, disposal, and heat management. Power density plays a significant role, allowing for more functionality within limited space and reducing costs. Ultimately, a holistic approach that considers various factors is necessary to make informed power supply decisions. 

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## Power Density Is Where It's At

Efficiency can often be improved by slowing switching speeds, but this implies larger passive components and bigger power converters. While this will improve reliability as temperature is lower, it comes at the cost of space, which creates system-level challenges.

Running hotter allows system engineers to pack more functionality into a given cabinet, whether in data centres or in industry, where standard-sized housings are almost always packed with motor drives and PLCs.

New, high-performance power converters with smaller form factors can eliminate the need for an additional cabinet, reducing costs (and space) by using an existing one. As floor space is expensive, there is a tangible gain to be realised by saving space, especially if that space can be used for revenue-generating equipment.

## Holistic Approach Is Necessary

Power supply selection should not be based solely on efficiency figures. Factors such as system or process efficiency, environmental obligations, and financial goals are more important considerations. While manufacturers strive to improve power supply efficiency through advanced topologies



### About the Author

As Mouser Electronics' Director of Technical Content for EMEA, Mark Patrick is responsible for creating and circulating technical content within the region – content that is key to Mouser's strategy to support, inform, and inspire its engineering audience. Before leading Technical Content, Mark was part of Mouser's EMEA Supplier Marketing team and played a vital role in establishing and developing relationships with key manufacturing partners. Mark's previous experience encompasses hands-on engineering roles, technical support, semiconductor technical sales, and various marketing positions. A "hands-on" engineer at heart, Mark holds a first-class Honors Degree in Electronics Engineering from Coventry University. He is passionate about vintage synthesizers and British motorcycles and thinks nothing of servicing or repairing either

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# Aluminum Electrolytic Capacitors

## Interference Potential in Audio Technology

By Dr. René Kalbitz (Würth Elektronik eiSos)

Aluminum electrolytic capacitors are suspected of being the source or at least a contributor to high-frequency distortion in audio signals. A study by Würth Elektronik investigated in detail whether this is the case.

In audio technology, there is an ongoing discussion about the sound quality of amplifiers with regard to the audibility of signal distortion. Apparently, capacitors are suspected of being the source or at least a contributor to high-frequency distortion that influences the auditory impression. A study by Würth Elektronik aims to add to the discourse on capacitors and their influence on distortion [1]. The discussion about the audibility of distortion is not only about the measurement of electrical properties, but also about their interpretation with regard to perception by the human ear.

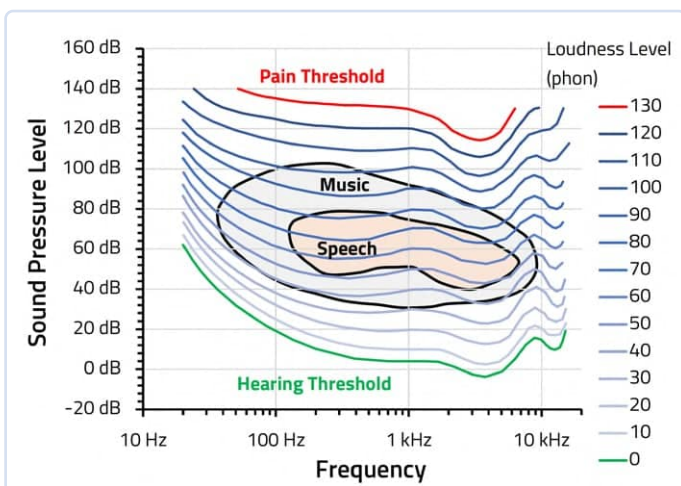


Figure 1: Auditory sensation area (DIN 45630).

The study compares the total harmonic distortion (THD) of commercially available electrolytic capacitors, such as those manufactured by Würth Elektronik eiSos, and of custom-made products.

To determine the parameters that influence the THD, capacitors with different separating papers and electrolyte compositions were examined. These sample capacitors were manufactured in a production facility under conditions similar to mass production and analyzed in the electronics laboratory at Würth Elektronik eiSos in Berlin.

To enable the reader to interpret the results, there is first an introduction to the field of human hearing and psychoacoustics before the investigation of harmonic distortion in capacitors is discussed.

### Human Hearing

The human ear can perceive sound waves in a frequency range of between about 20 Hz (lower limit) and 16 kHz (upper limit) [2]. Sound in this range (audible window) is therefore referred to as audible sound. Sound below 20 Hz is referred to as infrasound and sound above 16 kHz as ultrasound.

A graphical representation of the auditory sensation is obtained by plotting the sound pressure level against the currently audible frequency (**Figure 1**). The curves shown in the figure are called isophones and represent curves of equal loudness, measured in the phon unit. Isophones relate the sound pressure, measured in dB, to the volume levels. A sound with a volume level of 50 phon is perceived as being just as loud as a 1 kHz sound with a sound pressure level of 50 dB. The same loudness level means that every sound along a curve is perceived as equally loud, regardless of the frequency. Loudness is therefore a perceptual variable (psychoacoustic), in contrast to sound pressure, which is an excitation variable (see [1] for references).

In Figure 1, the lowest curve shows the so-called hearing threshold. This threshold applies to measurements with sine tones in a free sound field of binaural hearing. The sound pressure level is related to the sound pressure 20  $\mu$ P. According to this definition,



the sound pressure level at the hearing threshold is 4 dB at 1 kHz. The range for speech is much smaller than the audible range. Even music only covers a part of the entire hearing range.

The hearing threshold is strongly frequency-dependent. Hearing sensitivity is greatest in the range between 2 and 5 kHz. In this range, the lowest sound pressure is sufficient for a hearing sensation. Below and above this range, hearing sensitivity decreases rapidly. The upper curve represents the pain threshold. In this case, the sound pressure is high enough to cause pain and leads to permanent hearing damage with prolonged exposure.

The subjective measure of loudness can be replaced by the objective measure of weighted sound pressure, shown in **Figure 2**. Here, the sound pressure is weighted as a function of frequency with a filter characteristic which is shown in its normalized form, and which is approximately inverse to the isophones (curves of equal loudness) in Figure 1. The normalized weighting filter curve in Figure 2 is based on the recommendation of the International Telecommunication Union (ITU-R BS.468-4). For the sake of clarity, Figure 2 also contains a curve indicating the unweighted audible window.

The dynamic range of human hearing is wide, ranging from 130 dB (pain threshold) down to -9 dB (hearing threshold). However, this wide range cannot be perceived simultaneously at both extremes of the scale. The ability to perceive a small distortion superimposed on a background or main signal depends very much on the frequency range and the complexity of the main signal. Studies show that distortions of 2% to 5% can occur in complex speech and music signals without being perceived by the listener. For individual harmonic frequencies, it was found that under laboratory conditions the human ear can distinguish distortion caused by individual harmonics (i.e., overtones or harmonic frequencies) in the range of 0.3% to 0.01% (at 4 kHz, the frequency of highest sensitivity) relative to the fundamental frequency (references in [1]).

The lowest THDs for the first 10 harmonics from the above-mentioned human hearing test are in the order of about 10% to 7%, depending on the fundamental frequency. Under certain conditions, the ear is therefore able to detect THDs of up to 7%, which corresponds to a change in sound pressure level of 20 dB [1].

THD is a suitable measure for systems with low non-linear disturbances that generate initial harmonics below or around 1% and approach zero at higher harmonics. However, for larger nonlinear disturbances with non-vanishing higher harmonics, THD may not be an accurate measure of the audibility of disturbances.

### THD of a Capacitor Model

The measured frequency spectrum of a capacitor with the fundamental frequency of 448.9 Hz in **Figure 3** shows a steep decline in amplitudes for higher harmonics, which is typical for all studied capacitors and excitation frequencies. The amplitudes of the first two harmonics decrease to values well below 0.1% of the fundamental signal. The higher-order harmonics attain values in the order

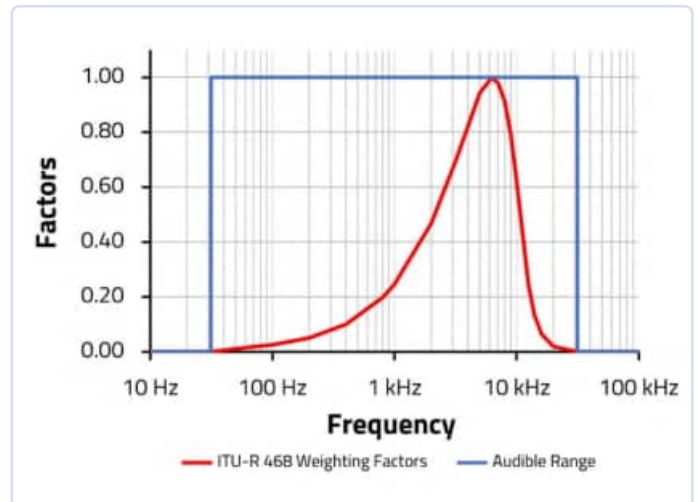


Figure 2: Graphic depiction of the filter factors for the unweighted audible range and weighing factors as suggested by ITU-R 468.

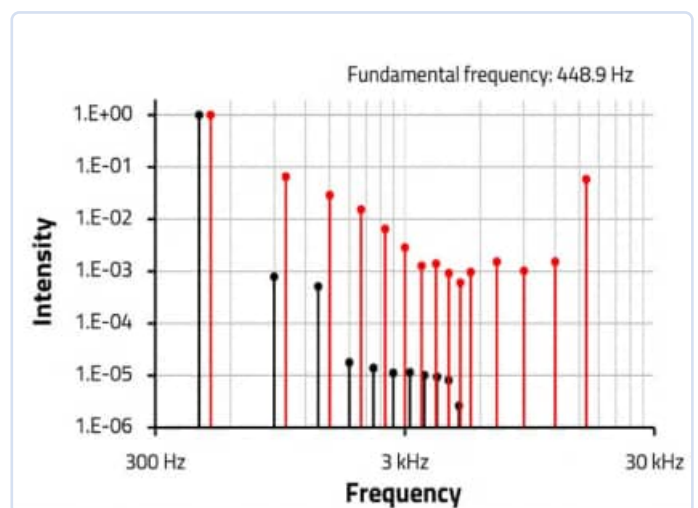


Figure 3: Measured frequency spectrum of a voltage signal on a 470  $\mu$ F aluminum electrolytic capacitor (WCAP-ASLI, 865080253012) at a fundamental frequency of 448.9 Hz. Also shown is the threshold value for audible distortion, which was determined in a psychoacoustic experiment for a fundamental frequency of 500 Hz.

of 0.001% and below. All harmonic amplitudes are well below the hearing threshold, which is also shown in Figure 3, and result in a THD of 0.078%. The hearing threshold values were determined in a separately conducted psychoacoustic experiment at a fundamental frequency of 500 Hz and resulted in a THD of 7.3%.

If the THDs are measured for different fundamental frequencies in the frequency range from 1 Hz to 1 MHz, the graph shown in **Figure 4** results. The THDs in this measurement are in the range of 0.001% to 0.4%, which is well below the THD values from the hearing threshold experiment. Within the audible range shown in Figure 4, the values are in large part well below 0.1%. In order to obtain an easy-to-use measure of the frequency distortion in

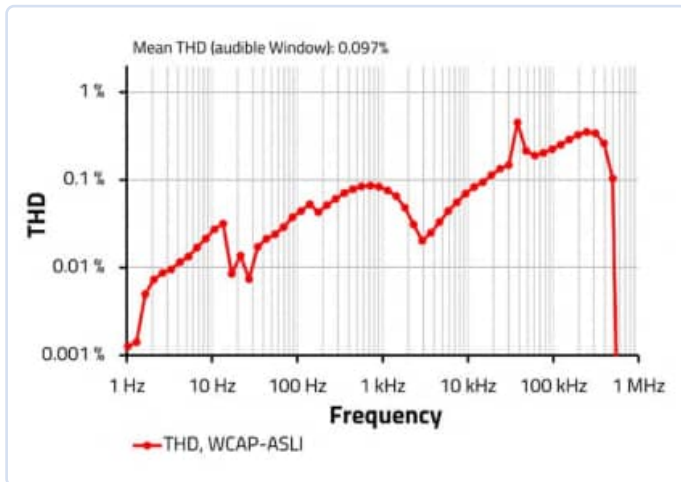


Figure 4: THDs of a 470  $\mu\text{F}$  aluminum electrolytic capacitor (WCAP-ASLI, 865080253012), measured at various fundamental frequencies in a range from 1 Hz to 1 MHz.

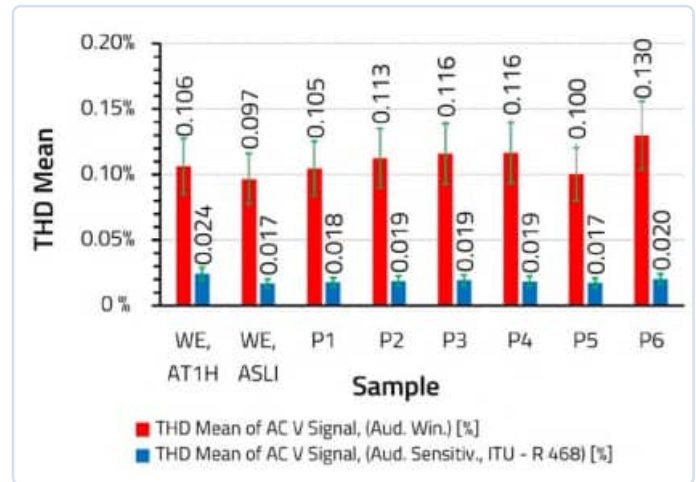



Figure 5: Measured values for  $\text{THD}_{\text{Mean}}$  (audible window) and  $\text{THD}_{\text{ITU}}$  (acoustic sensitivity). The error bars show the average value range.

the entire audible range, the average  $\text{THD}_{\text{Mean}}$  and the weighted average  $\text{THD}_{\text{ITU}}$  can be determined based on the human hearing sensitivity of all individual THD values [1].

This type of calculation has now been applied to a series of commercially available (865080253012, 860240275007) and custom-made capacitor prototypes (P1-P6) with a capacity of 470  $\mu\text{F}$ , which are shown in **Figure 5**. The prototypes represent a wide variation in the composition, density, and thickness of the separating paper as well as the electrolyte conductivity (details are given in [1]). As the error bars show, the differences between the measurements are of little statistical significance. Thus, the variations of separating paper and electrolyte did not significantly influence the THDs.

### Semiconductor Effect More Significant

The research suggests that material variations have negligible influence on distortion, and the distortion is below the hearing threshold. Electrolytic capacitors do not add any significant higher harmonics to the fundamental frequencies when transmitting signals and can therefore, to a good approximation, be viewed as linear components. It is likely that other voltage-independent capacitor types and passive devices generally produce similarly low distortion amplitudes compared to the auditory threshold.

Consequently, the choice of non-linear components such as operational amplifiers and diodes have a greater impact on the distortion-related audio quality of the amplifier, i.e., the overall distortion characteristics, than the choice of electrolytic capacitors. 

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### About the Author

Dr. René Kalbitz studied physics at the University of Potsdam and at the University of Southampton (UK). After completing his diploma studies, he did his research and doctorate on organic semiconductors and insulators at the University of Potsdam. He gained further experience in the field of applied research at the Fraunhofer Institute for Applied Polymer Research. He joined Würth Elektronik in 2018 as a product manager for supercapacitors and supervises research and development projects in the field of capacitors.

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# USB Test and Measurement

## The Fnirsi FNB58

By Jean-François Simon (Elektor)

Explore the versatility of the Fnirsi FNB58 USB tester. Measure voltage, current, and fast charging protocols with ease. No more cutting USB cables!

Retailing for around €50, the Fnirsi FNB58 is a versatile, portable USB tester that can carry out a wide array of voltage, current, and energy measurements. It also handles specialized diagnostic tasks related to most fast charging protocols. Let's try it out!

### Overview

Featuring a variety of input and output ports (namely USB-C, USB-A, and Micro-USB), the FNB58 (**Figure 1**) comes equipped with a two-inch LCD screen to display measurements and offers several buttons for navigation through its menus. Additionally, it includes a Micro-USB port for connecting to a PC and using Fnirsi's software, plus a Bluetooth option that enables use with an Android phone app.

### What Can You Do With It?

The FNB58 can be used for an array of tasks related to measuring and testing USB devices. It enables users to measure power

supply voltages and currents, as well as assess the current consumption of various USB loads, including those of phones and laptops. There are also many features focused on various fast-charging protocols.

In the past, if you wished to measure the current consumption of a USB device while in use, it required cutting a USB cable in half and using both a voltmeter and an ammeter. Then you had to painstakingly enter data in a spreadsheet if you wanted to ascertain power or battery capacity. Now, with USB 3.x and USB-C devices becoming increasingly prevalent, cutting cables is becoming less and less practical. That's where tools such as the FNB58 come into play.

### Features

The FNB58 has a 2.0" TFT LCD screen with good viewing angles. Connection to a PC is possible via a Micro-USB port, and there's also the option of utilizing a Bluetooth connection for wireless interfacing.

This device enables you to collect statistics about voltage, current, capacity, power, and time. It is capable of recording both low-speed (2 to 100 samples per second) and high-speed ripple current and voltage waveforms (up to 4 MSamples/s), providing comprehensive data capture.

The measurements are made internally using a 16-bit DAC. Notably, it features an impressive 10  $\mu\text{V}/\mu\text{A}/\mu\text{W}$  resolution. This is great,



Figure 1: The FNB58 USB meter.



Figure 2: Some of the input/output connectors and the PD safety switch.



Figure 3: Buttons and PC connection.

but as we know, resolution is not the same as accuracy! There will probably be noise and the last digits will not all be meaningful.

The instrument has triggers for various fast-charge protocols and is equipped with a dedicated USB-PD negotiation chip. A distinct PD switch serves as a critical safety feature, enabling or disabling the PD (and other protocol) negotiation directly by the FNB58. You can see some of the input/output ports as well as the PD switch in **Figure 2**. When the switch is off, the device connected to the output will negotiate with the source. When the switch is turned on, the FNB58 can initiate PD modes itself.

However, care is needed if you are using the FNB58 to measure the current consumption of a 5 V-only load while powering it with a PD charger. In that case, unintentionally triggering a PD operation with the FNB58 would make the charger output a higher voltage and cause damage to the load!

So, Fnirsi recommends keeping the switch off, only turning it on for intentional PD operations with the FNB58. The FNB58 supports a variety of quick charge protocols, including QC2.0, QC3.0, Huawei FCP, SCP, Samsung AFC, PD2.0, PD3.0, VOOC/WARP, SuperVOOC 1.0/Super VOOC 2.0, and MTK-PE, with automatic detection making things easier. It also identifies E-marker USB cables or OnePlus Dash cables.

## Measuring Ranges

The FNB58, being a USB tester, has more restricted ranges than multimeters:

- Voltage: 4...28 V (can go down to 0 V when powered externally via the PC connection)
- Current: 0...7 A
- Power: 0...120 W
- Capacity: 0...9,999.99 Ah
- Energy: 0...9,999.99 Wh
- Cable resistance: 0...9,999.9  $\Omega$

## Navigating the Menus

The user interface features a three-way joystick (left-right-center) and a separate “back” button for navigation in the menus (**Figure 3**). Fnirsi has densely packed these menus, making navigation a bit of an initial learning curve. An additional note: A long press on the back button will turn off the screen backlight on any page.

Much like many instruments of this type, there’s a “rolling menu” of four main pages, accessible one after another using the left/right joystick. The four main pages are:



Figure 4: An Apple 2.4 A charger under load.

- Compact view
- Detailed view
- Waveforms page
- Application page

Since these four main pages have many submenus, it might get a tad confusing. Here’s more information about the menus, along with some details about possible actions on certain pages:

*Compact view*, as its name implies, only contains values for voltage, current and power. You can pause the measurement or run it again by pressing the middle button.

*Detailed view* shows the same, as well as information about the D+/D- data lines and the fast charging modes. There is also a section dedicated to energy logging statistics, in Wh and Ah. Press the middle button to access the menu related to recording.

The *Waveforms* page has three views. The first, *VBUS*, displays high-frequency ripple voltage on the power line. Then, *V/A* presents voltage and current waveforms in a rolling display format. Finally, *D+/D-* indicates the state of the data lines. In these modes, the vertical scale is automatically set and is not manually adjustable. However, the horizontal scale can be modified from 2.5 to 200  $\mu\text{s}/\text{div}$  in *VBUS* mode, and from 0.1 to 5 s/div in other modes.

The last main page is *Application*, subdivided into four submenus: *Fast Charge*, *Energy Statistics*, *Toolbox*, and *Settings*. The first features automatic detection of available protocols as well as various triggers. *Energy Statistics* includes battery capacity calculation and offline records. The *Toolbox* menu is packed with less-often-used features, such as *Cable resistance measurement*, *PD listener*, *PD converter*, *USB-C electronic label reader*, *Dash cable reader*, *Dash simulator*, and *Apple 2.4 A protocol simulator*. Finally, many parameters of the device can be changed in the *Settings* submenu: *General*, *Recording*, *Trigger*, *System*, and *About*.

## Case Study 1: Evaluating USB Charger Performance

Not all chargers are created equally. Here, I’m testing an older Apple charger that claims to deliver 2.4 A at 5 V — and indeed, it does (**Figure 4**). Conversely, another charger falls flat; it’s labeled to deliver 1 A, but this seems to be an overstatement. When attempting to draw 1 A, the voltage plummets, dropping well below the broadly accepted lower threshold of 4.75 V. I had to add another cable to power the FNB58 through the Micro-USB PC interface to snap a photo; otherwise, the USB meter would shut down, as you can see on **Figure 5**.



Figure 5: A cheap 1 A charger... Oops!



Figure 6: Calibration of the "Resistance Measurement" mode.

## Case Study 2: Testing the Resistance of USB Cables

It's generally acknowledged that lower resistance in a cable is preferable. However, using a multimeter to measure a USB cable's resistance isn't as straightforward as one might think. Even the poorest quality cables tend to have quite low resistance values, typically around  $1\ \Omega$  or  $2\ \Omega$  at most. Thus, the contact resistance of your DMM probes becomes significant in your measurement.

The FNB58 can measure the resistance of USB cables, but the way to do it is not obvious. You might assume that simply plugging each end of the cable into the corresponding ports on the tester would suffice, but that's not the case. The FNB58 measures the cable's voltage drop under load, but you have to provide your own load. First, you need to calibrate the meter by plugging it in directly, without the cable you want to test, between a power source (in this case, a phone charger) and a load. Ideally, the load should be constant. Fnirsi recommends between  $0.5\ \text{A}$  and  $1\ \text{A}$ . You could use a dedicated DC load module or appropriately sized resistors. Another option is to plug in a device that will draw some current, such as a phone recharging its battery. You can see how the setup should look in **Figure 6**.

A short press on the middle button will store the voltage at the input connector. Then, you can change the wiring and add the cable you want to test between the power source and the meter, as shown in **Figure 7**.

Once you plug everything back together, the meter reboots, and if you navigate to the *Cable resistance measurement* menu again, the meter will display the resistance introduced by adding the cable. In that case,  $142\ \text{m}\Omega$ . You can see that the cables in **Figure 8** and **Figure 9** are good. On the other hand, the brand new USB-C cable in **Figure 10** is terrible.

No wonder my phone was charging so slowly!  $1\ \Omega$  of resistance means that even at  $1\ \text{A}$  of current, which is small by today's standards, there will be a loss of  $1\ \text{V}$  in the cable; the phone will only see  $4\ \text{V}$  instead of  $5\ \text{V}$ , which will be too low for the battery charging circuitry. The phone will detect this and will be forced to reduce the current it draws, thus taking much longer to recharge its battery.

This phenomenon can be a challenge when measuring cables with substantial resistance values, particularly when using a phone as a



Figure 7: Adding a cable between the charger and the FNB58.



Figure 8: A good USB cable.



Figure 9: Nice, low resistance here.



Figure 10: Too much resistance in this cable.

load. If the cable is of such poor quality that the phone must reduce its charging current, as described above, the source voltage will fluctuate, rendering the FNB58 unable to provide a meaningful result. Consequently, Fnirsi recommends employing a constant current load for this purpose.

### PC Software for the FNB58

The manufacturer offers some software on its website [1]. The main window of the PC application is shown in **Figure 11**. Real-time measured values, as well as voltage and current curves, are visible.

The interface does have a few peculiarities that may require a bit of getting used to. I found that navigating through the curves was particularly laborious.

I didn't see a significant need for PC software, except for making prolonged measurements and logging (for instance, to characterize batteries). You can use the PC application to set up such a measurement and then start it. Subsequently, the curves can be saved in a Fnirsi proprietary binary format, with the .CFN extension.



Figure 11: Fnirsi's PC software.





Figure 12: Fnirsi's Android app.

This is somewhat disappointing, as having the ability to save to CSV would be crucial for additional data processing. Fortunately, a GitHub user, [didim99](#), has written some Python scripts that convert CFN files to CSV, available at [2]. Excellent!

It's also worth highlighting another project [3] by GitHub user [baryluk](#). This project enables a computer to directly extract data in real time from the FNB58 and other similar models, bypassing the need to use the Windows software to record initially and save afterward.

## WEB LINKS

[1] The manufacturer's website: <https://fnirsi.com.cn>

[2] Scripts that convert CFN files to CSV: <https://github.com/didim99/usbmeter-utils>

[3] A datalogger project compatible with the FNB58: <https://github.com/baryluk/fnirsi-usb-power-data-logger>



## Android App

The FNB58 can be purchased with a Bluetooth option. If you have this version, you can use the Android app, available as an .apk package on the Fnirsi website. To install it, you'll need to download the zip file, unzip it, tap on the .apk file, and authorize the installation by selecting *Allow from this source* on your phone. The app supports multiple languages; tap on the upper-right menu to switch from Chinese to your preferred language. You'll then be brought to the screen shown in **Figure 12**. I gave it a try, and although it functions, I wasn't convinced that it's notably more user-friendly than either the standalone unit or the PC software.

## Final Thoughts

Overall, the FNB58 stands out as a pretty comprehensive instrument, enabling you to make a myriad of valuable measurements, whether at home or in the lab. It sports a sleek and rugged design and boasts virtually all the functionalities you might anticipate from a USB tester of its kind. You'll be able to diagnose issues with chargers, cables, and power banks effortlessly, as well as harness your creativity, using it for fairly precise DC measurements — assuming you stay within its limits (0 to 28 V, 0 to 7 A). This is achievable with the assistance of a few USB adapters (such as USB-to-screw terminals), which you can either make yourself or purchase easily. Have fun! ◀

230674-01

## Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the Elektor editorial team by email at [editor@elektor.com](mailto:editor@elektor.com).



## Related Products

> **Fnirsi FNB58 USB Tester with Bluetooth (Voltage & Current Meter)**  
[www.elektor.com/20578](http://www.elektor.com/20578)

# The **PIXEL** Pump

## Pick-and-Place Tool

Simplifying Manual SMT Board Assembly

By Clemens Valens (Elektor)

If you've ever tried using tweezers to populate a board with SMT components manually, you know how challenging the exercise can be. Parts with more than two leads are especially difficult to position correctly. Even though the melted paste in the oven tends to move and rotate the parts in the right way, soldering ICs often requires rework. The Pixel Pump manual pick and place tool simplifies manually populating a board while obtaining better results.



in the wrong place or accidentally scraping paste from pads when opening or pulling away your tweezers, the Pixel Pump lets you position and drop a part exactly where you want it.

### Who Needs a Pick 'n' Place Machine?

Pick-and-place (PnP) machines are much better at this than humans, but not everybody has the space, budget, and need for such a machine. For assembling prototypes and small series, there exist practical low-cost pick-and-place tools that can be automated up to a certain level. But, as low cost as they may be, investing in one remains hard to justify for the non-professional.

### Between Tweezers and a PnP Machine

The Pixel Pump [1] is a pick-and-place tool that aims to fill the gap between manually populating a board with tweezers and a low-cost PnP machine. With it, placing parts remains manual, but with improved precision and comfort. Instead of dropping parts

### Doesn't Require a Lot of Bench Space

The Pixel Pump looks like a small soldering station, except that the iron's tip doesn't heat up but sucks in air instead. This allows it to pick up small objects such as SMT parts. Even though this is what interests us most in this article, I can imagine the Pixel Pump being very useful in other applications, such as preparing substrates for microscopes or in the manufacturing of jewelry and other miniature objects.

### Foot Switch Controlled

Picking up objects and dropping them is controlled by a foot switch, and you can even have two of these. The second one (not included in the kit) is typically used to step through the component list. It is compatible with the Interactive HTML BoM plugin for KiCad, but it can be configured to control any program you like.

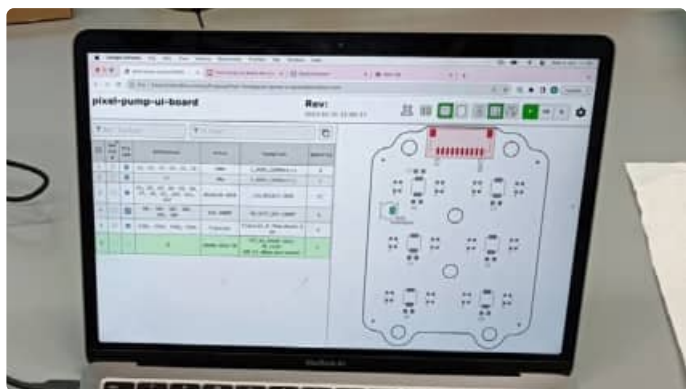


Figure 1: The second foot switch of the Pixel Pump lets you step through the bill of materials, for example.

Besides pedal control for picking and dropping parts, push buttons on the pump let you do the same thing. How the pedal and pushbuttons operate (up/down, long or short presses) is configurable.

### Nozzles

The airflow is controlled in two ways, either by changing the nozzle or by adjusting its force with the pushbuttons. The Pixel Pump comes with five different nozzles, and you get five of each. Why so many, you may wonder? Well, some of them are really fine and may get damaged easily, so it is good to have some stock. Also, it is possible to accidentally suck up some solder paste and clog the nozzle.

The Pixel Pump has a special reverse function for situations like this that makes it blow air out instead of sucking it in, but this may not resolve the issue in all cases. Note that a user-serviceable filter prevents particles from entering the pump.

### Picking Is Easy, Dropping Requires Some Exercise

Picking up components is easy. By default, this is done by pressing the foot switch and holding it down. Release the pedal to drop the part. I found this a bit hard in the beginning, as it takes some exercise before the drops become perfect. The way the pedal works is configurable, so you can adapt it to your preferences. Before picking up a part, you must fit the nozzle that suits your component best. The largest nozzle can easily swallow 0102-sized parts, so be careful.

### Super Flexible Hose

If, like me, you hold a soldering iron the same way as a pencil, you may find that the flexible air hose is somewhat in the way when you want to pick up the “iron.” On soldering irons, the power cable often extends from the iron, so you can easily pass your hand underneath it to grab the iron. The Pixel Pump’s air hose, on the other hand, is so flexible that it drops straight down. This obliges you to watch what you are doing.

### SMD Magazine Rails

The review kit came with eight SMT part magazines and a rail to clip them on. At first, you might wonder why you would need them, but they quickly show their potential. The magazines are intended

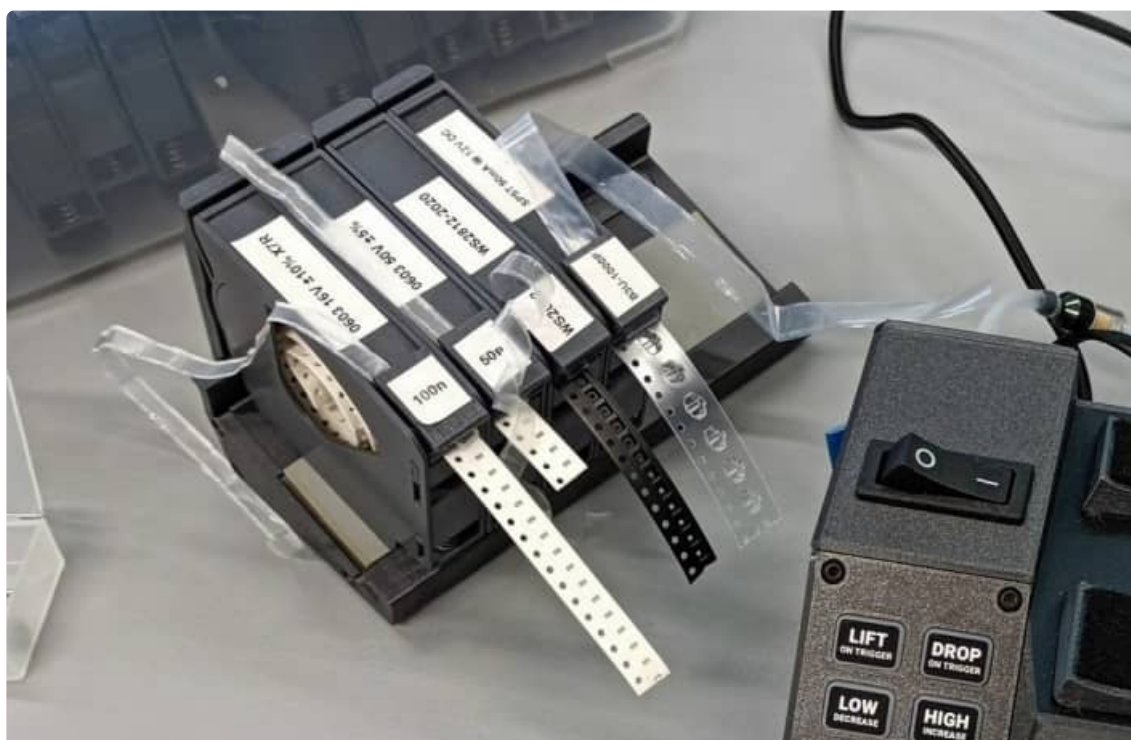


Figure 2: Super practical: a rack of SMT magazines with often-used components.



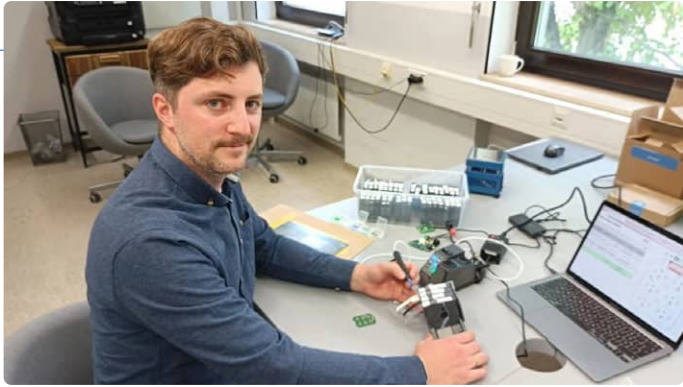


Figure 3: The Pixel Pump demonstrated by its creator Robin Reiter.

to hold strips with parts, and they allow you to unpack components with one hand while sucking them up with the Pixel Pump pen in the other. Once you've experienced this, you won't want to go back to parts sprinkled on your bench or whatever method you used before. A second advantage is that the magazines offer a great way of storing your parts. Compile a rack with often-used parts and never search for them again. This also obliges you to keep your BoMs short.

### The Pixel Pump is Hackable and Open Source

An interesting aspect of the Pixel Pump is that it is hackable. This is emphasized by the 3D-printed parts that make up the tool. The electronics inside the pump are based on a Raspberry Pi RP2040 microcontroller running MicroPython. The source code and build instructions for it are on GitHub. When the Pixel Pump is put in bootloader mode, you can update its firmware. This works the same as on a Raspberry Pi Pico board.

### Serial Interface

When not in bootloader mode, the Pixel Pump exposes a serial port. Documentation for it is available on the Pixel Pump website [2]. The commands use the colon (':') as a separator (communication is JSON-based), so to get the current firmware's version, you type `version:info`. The answer is a long string that, in my case, started with V1.0.1. With the command `settings:dump` you can obtain a list of the Pixel Pump's current settings. You can change these too, but it's up to you to figure out the commands. Note that you can put the Pixel Pump in bootloader mode by entering the `bootloader` command.

### Best Results

The Pixel Pump is an interesting tool to improve manual pick-and-place precision. As part of placing remains manual, it won't be much help for people with shaking hands. On the other hand, as



Demo Video on YouTube  
<https://youtu.be/SrzfkPQFn3o>



you can pick up parts without creating physical strain in your hand, positioning of parts becomes more precise. Also, as you can drop the parts from a small height above the board, the risk of touching or scraping solder paste on neighboring pads is much smaller.

Most of the time, I needed two hands to position a part before dropping it. Even though I clearly need more exercise, after reflowing the populated board I ended up with one of the best results I've ever had with manually populated boards. No rework was required, not even on the fine-pitched 48-pin LQFP part. ◀

230700-01

### Questions or Comments?

If you have any technical questions, you can contact the Elektor editorial team at [editor@elektor.com](mailto:editor@elektor.com).



### Related Products

- > **Pixel Pump - Pick-and-Place Machine for Manual SMT Assembly**  
[www.elektor.com/20575](http://www.elektor.com/20575)
- > **SMD Magazine for Pixel Pump (Eight-Pack) - Organizing SMD Parts**  
[www.elektor.com/20576](http://www.elektor.com/20576)
- > **SMD Magazine Rail for Pixel Pump**  
[www.elektor.com/20577](http://www.elektor.com/20577)

### WEB LINKS

- [1] Pixel Pump: <https://elektor.com/pixel-pump-pick-and-place-machine-for-manual-smt-assembly>
- [2] Documentation: <https://robins-tools.com/pixel-pump/docs/getting-started>
- [3] Pixel Pump demonstration video: <https://youtu.be/SrzfkPQFn3o>



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# HomeLab Tours

Not So Long Ago,  
in a Far-Away Country...

By Eric Bogers (Elektor)

Recently I enjoyed a pleasant two-month stay in Almaty, the former capital city of Kazakhstan. I won't bore you with touristic small talk about how beautiful it is there and how good life is there, although these are both true and the country and the city are certainly worth a visit. However, I would like to share two electronics-related experiences with you.

Do you remember when there were local electronics stores with at least one wall completely covered with cabinets with small drawers full of components? There, you could find just about anything you could imagine, or they could order it for you. For me it was always a minor miracle that the proprietors were immediately able to find the right drawer without looking.

Here at home, most local electronics stores have not been able to withstand the competition from large mail-order electronics distributors. The store in Breda where I spent so many hours of my youth and a large part of my allowance had to close its doors in 2016, as best I recall. That's a real pity — not only could you get a single 15 kΩ resistor there for a few cents if you happened to need one, you could also get some good tips or exchange ideas with like-minded people. I think I'm not alone in regretting the disappearance of those stores.

In light of that, it was an unexpected pleasure to run across exactly that sort of store on one of my walks through Almaty, with the highly appropriate name "LED" (Figure 1). The owner (a friendly, middle-aged lady)

Figure 1: The store on Muchtar Auesov street in Almaty.



Figure 2: Lots of little drawers...



Figure 3: ... and even more little drawers.



Figure 4: Need an audio or video connector?



Figure 5: A showcase with a variety of items.



allowed me to take a few pictures. So, let me take you on a journey back in time... (Figures 2 to 5).

I hope this store will be around for a long time, but with all the cheap imports from China (the border is only a stone's throw away) that's a doubtful question. By the way, the yellow object in Figure 5 is an alcohol hydrometer — a meter that definitely doesn't have anything to do with electronics but always comes in handy to check whether your vodka has been watered down.

Kazakhstan has been an independent republic [1] since 1991; before then it was part of the Soviet Union. Of course, even then, there were lots of electronics hobbyists.



When emptying out a couple of cabinets in an apartment we wanted to rent out, I came across a measuring



tape and a pair of “mysterious” tins, probably originally intended for 8 mm films. When I opened them, I found they contained old electronic components, among other things, some unused and others carefully desoldered from PCBs (**Figure 6** and **Figure 7**). One of the tins was completely filled with small hardware — little screws, nuts and similar things that you can never have enough of as a hobbyist. Most of these items were used and carefully stored, as in the former Soviet Union you couldn't simply drop by a hardware store to pick up a bag of M3 machine screws.

The tin with transistors turned out to be very interesting (**Figure 8**). Some of the transistors had apparently been carefully measured, with the current gain ( $\beta$ ) noted on a small slip of paper (**Figure 9**). All of the transistors were germanium PNP types made in Russia (P401, P403, and P416). The datasheets for these are easy enough to find online, but, for copyright reasons, we are not able to reprint them here. The P401 (actually n401) is intended to be used in mixers or oscillators of AM receivers, while the P401 and P403 are (V)HF transistors.

And, with that, the puzzle pieces all fell into place. The tins used to belong to a mining engineer, passionate diver, and amateur filmmaker, but, above all, an enthusiastic radio amateur (listener) who was always working on his receivers. His name was Marat Insanbayev, and he was my father-in-law (**Figure 10**). I never had the opportunity to meet him — he passed away six months before my first visit to Kazakhstan. ◀

*Translated by Kenneth Cox — 230431-01*



### About the Author

Eric Bogers is a freelance translator and graphic designer who works for Elektor and others, in recent years as an editor. In the early days of his career he also designed a number of circuits for Elex magazine, at that time affiliated with Elektor. Born in Breda and brought up in Drenthe, he has been living in Germany since 2006 with his spouse, Gulnar, and their cat, Mimi.

### WEB LINKS

[1] Wikipedia entry for Kazakhstan:  
<https://en.wikipedia.org/wiki/Kazakhstan>



Figure 6: Found in a box at the back of a cabinet...



Figure 7: Little time capsules...

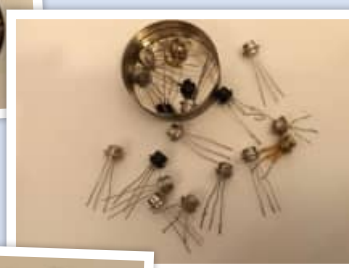


Figure 8: Russian-made germanium transistors.



Figure 9: Measured and labeled.



Figure 10: Marat Insanbayev.

### Questions or Comments?

If you have any technical questions or comments about this article, feel free to contact the Elektor editorial team by email at [editor@elektor.com](mailto:editor@elektor.com).



**“In the world of ethics in electronics, even small steps can make a significant impact.”**

Doris Wagner  
Director of Public Policy & ESG

In this insightful interview, we discuss the importance of ethical behavior and responsibilities of companies towards environmental sustainability. Join us as we delve into the balance between innovation, profit, and ethical responsibilities in creating a sustainable future.

### **What is your role at Messe München?**

As Director of the department Public Policy & ESG, I am responsible for the implementation and further development of the company's sustainability strategy and the sustainability program to reduce our emission of climate-damaging gases. Moreover, I am responsible for the ESG reporting, which will become mandatory for Messe München under the EU directive CSRD (Corporate Sustainability Reporting Directive). The second pillar of my role covers the company's political networking.

### **In what ways does Messe München promote and highlight ethical and sustainable practices in the (electronics) industry at its trade fairs and events?**

As the world's leading electronic fair, *electronica* is the industry's international meeting point, bringing together and fostering networking amongst industry players. *electronica* 2022 was dedicated to the motto “Driving sustainable progress”, addressing the industry's impact on current societal topics such as energy transformation, skilled labor shortage and ethical supply chain management. In particular, the trade fair promotes solutions for a sustainable and ethical allocation and use of resources resulting from e-mobility, smart energy, and automatization. For *electronica* 2024, as it was already the case in 2022, a main talking point will be the future image of an all-electric society based on CO<sub>2</sub>-neutral generated energies.

### **What steps does Messe München take to encourage (electronics) companies to adopt more sustainable and ethical practices, such as responsible sourcing and carbon reduction targets?**

We generally want to incentivize both visitors and exhibitors to take responsibility for the CO<sub>2</sub> footprint of their trade fair presence. We generally recommend exhibitors to use sustainable stand production systems. For our own stand areas, we



primarily use the stand system WOODĬ – a product of our subsidiary meplan. This high-quality modular system stand was developed according to the principles of circular economy and is produced in a resource friendly way.

Unfortunately, not all CO<sub>2</sub> emissions can be avoided, which is why we have created our own products to give visitors and exhibitors the opportunity to take responsibility for the residual. By opting for the GoGreen entry ticket, visitors can support climate protection projects based on the CO<sub>2</sub> emissions emitted during their travels from and to the exhibition venue. The GoGreen audit is an offer to our exhibitors to calculate the CO<sub>2</sub> emissions for their exhibition stand for which they can then pay a respective contribution to climate protection projects.

*For us as a trade fair company, the topic of sustainability is also one of the greatest challenges of our time.*

Sustainable topics are integrated into the general program of most of our trade fairs and events, often by dedicating certain forums, stages, and special areas to it. As an example, ISPO and Outdoor by ISPO have set up a sustainability hub in which they give companies the opportunity to present their efforts regarding sustainable practices in the sports industry. Electronica hosted the “World Ethical Electronic Forum” in 2022 and, thereby, provided a platform for independent experts on ethics including researchers, educators, NGO- and company representatives, to discuss the significance and role of ethics in the electronics industry.

See the entire profile on  
[ethicsinelectronics.com/profiles](https://ethicsinelectronics.com/profiles)

The role of Messe München in advancing ethics and sustainability throughout various industries is that of an enabler for knowledge transfer, idea generation and networking. We are a key information source and platform provider for both professionals and consumers.

<b>Name</b>	Doris Wagner
<b>Country</b>	Germany
<b>Company</b>	Messe München
<b>Job Position</b>	Director Public Policy & ESG
<b>Gender, Age</b>	Female, 60
<b>Favorite Quote</b>	“Climate change is the single greatest threat to a sustainable future but, at the same time, addressing the climate challenge presents a golden opportunity to promote prosperity, security and a brighter future for all.” Ban Ki-Moon, Former Secretary-General of UN
<b>Company Size</b>	941 Employees (group level) 563 Employees (Messe München)
<b>E-mail</b>	<a href="mailto:doris.wagner@messe-muenchen.de">doris.wagner@messe-muenchen.de</a>
<b>Website</b>	<a href="https://www.messe-muenchen.de">www.messe-muenchen.de</a>



Dr. Reinhard Pfeiffer, CEO of Messe München, presented Frank Stührenberg, CEO of Phoenix Contact with the award at WEEF 2022.

# Ethics in Electronics

The OECD Guidelines and Germany's Supply Chain Due Diligence Act



By the Ethics in Electronics team

During productronica 2023 in Munich, the Lenthe Foundation presented the concept for the Ethics in Electronics Guide, conceived after brainstorming sessions and at the request of ethical/SDG/PR teams and entrepreneurs. New, uniform and objective business communication must be produced as a result of new laws and regulations in the field of (ethical) responsible entrepreneurship.

## How do you do that: ethically responsible entrepreneurship?

Ethically responsible entrepreneurship means leading your business in a way that is ethical, honest, and responsible. In this approach, strategies and policies are linked to ethical principles, where ethical behavior is rewarded and ethical standards are encouraged in daily practice. Ethics also involve taking individual responsibility, caring and respecting (professional interactions between colleagues), honesty, and avoiding conflicts.

What are the benefits of ethically responsible entrepreneurship? Ethically responsible entrepreneurship has several benefits, such as building customer loyalty, improving reputation, retaining good employees, creating a positive work environment, avoiding legal issues, and creating long-term value.

## Are there international standards for ethically responsible entrepreneurship?

The main standards are the OECD Guidelines for Multinational Enterprises. These are recommendations from OECD countries to companies to act responsibly in areas such as human rights, labor rights, environment, corruption, and consumer interests. The OECD Guidelines were established in 1976 by the Organisation for Economic Co-operation and Development (OECD) and have been updated several times, most recently in June 2023. There are 51 countries that have adopted the OECD Guidelines, thereby promising to promote and monitor their implementation by their enterprises.

The Guidelines include a chapter, OECD Due Diligence Guidance for Responsible Business Conduct, a process that helps companies identify and address risks and negative impacts in their operations and supply chains. The OECD has also developed a general Due Diligence Guidance and several sector-specific guidances to

support companies in applying the OECD Guidelines. There is also a very informative OECD website [1].

## Who are subject to the OECD Guidelines?

All countries that are members of the OECD (including Germany) have developed and endorsed the guidelines. Each country that endorses the OECD Guidelines has a National Contact Point (NCP) that oversees compliance with the guidelines. It is important to note that compliance with the OECD Guidelines by companies is voluntary, but the government highly values entrepreneurs following these guidelines.

## Enforcement of the OECD Guidelines

Compliance with the OECD Guidelines is monitored in each country by the National Contact Point (NCP). This involves overseeing compliance and serving an educational and promotional role among companies, civil society, and other NCPs in the countries that have endorsed the Declaration.

In addition, civil society organizations or unions wishing to inspect a factory can gain easier access. These organizations can then file a complaint with a national contact point of the OECD. Companies must be receptive to these complaints.

It is also important to mention that periodic monitoring studies are conducted on compliance with the OECD Guidelines. These studies help identify areas where improvement is needed and ensure transparency in companies' efforts to comply with the guidelines.

The German NCP is located at the Federal Ministry of Economic Affairs and Energy in Berlin. It is an independent body consisting of representatives from the federal government, business, unions, and civil society.

## ASML Wins Award for Best Reporting in Annual Report

Recently in the Netherlands, the ASML company won the FD Henri Sijthoff Prize in the most important category, "AEX." This is the most prestigious award in the Netherlands for annual reports and corporate communication.

This is the first time the Dutch chip machine maker has been awarded the prize.

"The company from Veldhoven is good at explaining exactly what they do," the jury says in its report. Additionally, ASML succeeds in clearly outlining market trends. There is also significant attention given to society and sustainability, such as efficient energy use, CO<sub>2</sub> footprint, and the circular economy. Timelines are provided, along with a report on performance.

### Trend

The jury says that reporting on sustainability is improving. All companies pay attention to non-financial information about, for example, climate and environment, customer and employee satisfaction, in addition to financial information. This information is increasingly being presented in an integrated manner. The jury considers this a positive development. Increasingly, for instance, climate impact is measured and reported; there is also growing attention to nitrogen. Not everything is unequivocally measurable, and companies visibly struggle with this. Almost all companies report on their CO<sub>2</sub> footprint and have set objectives for 2030.

Source: Jury Report, FD Henri Sijthoff Prize 2023





## Is the German

### **Lieferkettensorgfaltspflichtengesetz, which came into force in 2023, comparable to the OECD Due Diligence Guidance for Responsible Business Conduct?**

Both guidelines aim to help companies identify, prevent or limit, and be accountable for addressing actual and potential adverse effects. They also promote a common understanding among governments and stakeholders about due diligence for responsible business conduct.

But there are also important differences between the two:

- **Scope:** The OECD Guidelines apply to all types of companies active in all countries and sectors of the economy. On the other hand, the German Lieferkettensorgfaltspflichtengesetz specifically applies to companies based in Germany and their supply chains.
- **Legal status:** The OECD Guidelines are recommendations from governments to companies, but they are not legally binding. The Lieferkettensorgfaltspflichtengesetz, on the other hand, is a German law, and companies subject to this law are legally required to comply with its provisions.
- **Implementation and enforcement:** The implementation of the OECD Guidelines is supported by practical, clear explanations of how due diligence can be carried out. Unlike the OECD Guidelines, which are primarily self-regulating, the Lieferkettensorgfaltspflichtengesetz includes specific enforcement mechanisms, including possible sanctions for companies that do not comply with the law.

### **Obligations under the Lieferkettensorgfaltspflichtengesetz**

The Lieferkettensorgfaltspflichtengesetz, also known as the Lieferkettengesetz, came into effect on January 1, 2023. It regulates the responsibility of companies for compliance with human rights



### **SDGs as a Guideline for The Great Reset**

The Great Reset is a proposal by the World Economic Forum (WEF) to rebuild the global economy sustainably after the COVID-19 pandemic. Klaus Schwab, the founder and executive director of the WEF, argues that we should seize this moment to improve the current form of capitalism.

According to Schwab, the 17 SDGs of Agenda 2030, the United Nations action plan, should guide this improvement. He believes that the possibilities of the "Fourth Industrial Revolution" – modern smart technologies such as artificial intelligence, 3D printing, 5G, and the internet of things – play a significant role in this.

### **Conspiracy: World domination...**

There are conspiracy theories about the Great Reset. These theories suggest that the WEF is exploiting the COVID-19 pandemic to install a dystopia inspired by socialism, where a global (financial) elite seizes all power at the expense of national sovereignty, democracy, and the privacy of citizens. These conspiracy theories are not based on facts and are generally spread by people with a specific political or ideological agenda.

in global supply chains. This includes, for example, protection against child labor, the right to fair wages, and environmental protection. German companies must therefore carry out defined due diligence duties. These duties apply to their own business area, to the actions of a contract partner, and to the actions of further (indirect) suppliers. This means that the responsibility of companies no longer ends at their own factory gate, but exists along the entire supply chain.

Companies must first identify, assess, and prioritize risks in their supply chains. Based on the results, they publish a statement of principles and take measures to prevent or minimize human rights violations and environmental damage. The law explains what prevention and remediation measures are required.

Other obligations include setting up complaint channels for people in the supply chains and regularly reporting on the management of the supply chains. By law, people in the supply chains, companies, and consumers gain legal certainty and a reliable basis for managing sustainable supply chains with resilient procurement routes.

The Lieferkettengesetz applies to companies with at least 3000 employees from 2023, and from 2024 also to companies with at least 1000 employees in Germany. It strengthens human rights and environmental protection, including protection against child labor, forced labor, and discrimination, protection against land grabbing, labor and health protection, the right to fair wages, the right to form unions, and protection against environmental legal violations.

Compliance with the law is monitored by the Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA), which is equipped with intervention powers and can impose fines.

## Advertising Is the New Frontier for Climate Activists

According to research, more than half of the sustainability claims in the EU are misleading. New EU rules are making greenwashing harder. Climate activists are advocating for an additional ban on advertising: "Fossil advertising perpetuates fossil norms." Hypocrisy in advertising is difficult to combat, but the EU will attempt to make it harder for companies to make green claims to consumers.

Companies can almost freely advertise with sustainable claims. This is disadvantageous for consumers and businesses that actually produce sustainably. Europe is introducing new legislation to combat this greenwashing. Climate activists would prefer that some companies not be allowed to advertise at all.

Behavioral scientist and professor of marketing and sustainability Jan Willem Bolderdijk from the University of Amsterdam says: "What is easily brought to mind determines your opinion. This is also known as the availability heuristic. To give an example: if you don't closely follow the operations of a company, you base your perception of its sustainability policy more on advertisements. This can result in a more favorable view than deserved."

With the CSRD legislation, which obliges companies to report on their societal impact, the legislator enforces transparency. As a result, it will be much easier to hold companies accountable for what they really do. The Corporate Sustainability Reporting Directive (member states have until early July 2024 to incorporate the provisions of the CSRD into their national legislation) and in particular the Green Claims Directive (proposed by the European Commission in March 2023) henceforth place the responsibility for proving claims on companies instead of consumers.

The new Green Claims Directive aims to make it easier for consumers and regulators to demonstrate that a claim is incorrect and misleading. According to Europe, "green" will be too vague by 2026. Companies will need to specify and factually substantiate their claims ("climate neutral", "eco", "green").

The Corporate Sustainability Reporting Directive (CSRD) and the Green Claims Directive will place the responsibility for proving claims on companies instead of consumers.

The specific sanctions and fines for non-compliance with the Corporate Sustainability Reporting Directive (CSRD) will depend on how the EU member states implement the CSRD regulations. Each EU member state will be able to introduce its own sanctions for non-compliance when transposing the CSRD into national legislation. It is likely that the sanctions introduced will be based on the current sanctions implemented when the member states transposed the Non-Financial Reporting Directive (NFRD).

Source: Marceline Bresson, *Het Financieele Dagblad*

## How do the OECD Guidelines relate to the 17 SDGs of the UN?

The OECD Guidelines and the 17 Sustainable Development Goals (SDGs) of the United Nations both aim to promote sustainability and responsible entrepreneurship, but they have different focus areas.

The OECD Guidelines are recommendations to companies on how to act responsibly in areas such as employment, human rights, supply chain responsibility, environment, consumer interests, and competition. They provide guidance for companies to deal with these issues.

The SDGs are 17 global goals set by the United Nations with the aim of ending poverty, inequality, injustice, and climate change. These goals are much broader and include issues such as ending poverty, promoting good health and well-being, ensuring quality education, and promoting gender equality.

While the OECD Guidelines and the SDGs address different aspects of sustainability and responsible entrepreneurship, they can complement each other. By complying with the OECD Guidelines and properly implementing the associated due diligence process, companies take a big step towards the SDGs. In doing so, companies contribute, for example, to responsible working conditions in their production chain and to combating climate change: topics that are also central to the SDGs.

## In this context, the WEF often comes up. What is the connection with the UN?

The World Economic Forum (WEF) and the United Nations (UN) collaborate in various areas, particularly in the area of sustainable development. Since 2017, the WEF has been organizing annual Sustainable Development Impact Summits within the framework of Agenda 2030, parallel to the General Assembly of the UN. In June 2019, the UN and the WEF officially began collaborating to accelerate the implementation of the Sustainable Development Goals (SDGs).

It is important to mention that although the WEF, like many other organizations, can lobby the UN, it does not have direct input into the creation of these agendas. However, the collaboration between the UN and the WEF can help promote the goals of Agenda 2030 and achieve sustainable development worldwide. ◀

230706-01

## WEB LINK

[1] Organization for Economic Co-Operation and Development: <https://oecd.org>

# Chadèche: Smart Ni-MH Charger/Discharger

A Reader's Project in Brief

By Jacques Ehrlich (France)  
Text by Jean-François Simon (Elektor)

Chadèche is a custom Ni-MH battery charger and discharger with advanced logging and cycling options. It's based on a Raspberry Pi and comes with dedicated software, as well as numerous software-configurable options. Let's have a look!



Figure 1: An assembly with three Chadèche boards and a Raspberry Pi.

This project was named "Chadèche," after the French words *chargeur* and *déchargeur*. This instrument is designed for AA and AAA nickel metal hydride (Ni-MH) batteries. The initial aim was to characterize the performance of a few of these batteries, to use the best ones in a portable aircraft GPS. What started out as a simple constant-current discharger became a complete university-level project. The documentation is very detailed: twelve pages with explanations and diagrams, as well as a personal Wiki page. An overview can be seen in **Figure 1**.

Chadèche is capable of charging or discharging single cells with a constant current, which is adjustable up to 400 mA, and is based on a Raspberry Pi. It features cell voltage monitoring and logging. The modular design allows for processing of up to four batteries simultaneously and independently. The software is quite advanced, enabling charge and discharge cycles, which are composed of sequences. These sequences have fine parameter setting and event management capabilities, such as voltage limit, time limit, and charge limit in mAh, among others.

## What Chadèche Can Do

Chadèche is both an operational and a research tool. As such, the realization of this project provides anyone wishing to reproduce it with many possibilities. Chadèche offers the ability to charge Ni-MH batteries

for general use around the home or workshop. It can evaluate battery performance and test capacity. Additionally, it allows for the evaluation of battery life through repeated charge and discharge cycles. There's also the opportunity to experiment with different types of charging and discharging by varying the values of current, duration, and so on.

Besides all of these technical features, this project provides the experience of building a complete tool from start to finish with the satisfaction of utilizing 100% customized equipment. For anyone interested in replicating Chadèche, the entire project is open-source under a GNU license.

## A Modular Design

This project consists of several daughter boards connected to the Raspberry Pi via a 40-contact ribbon cable. A Chadèche board manages one battery. For the full version, which manages four batteries, you need to build and stack four Chadèche boards.

The architecture of each board is detailed in the block diagram in **Figure 2**. The system is structured around five functional blocks. The first block is a voltage-controlled constant-current source, which comprises a classic IRF540N MOSFET and a 10  $\Omega$  resistor, all arranged in series with the cell. The charging current generates a voltage across



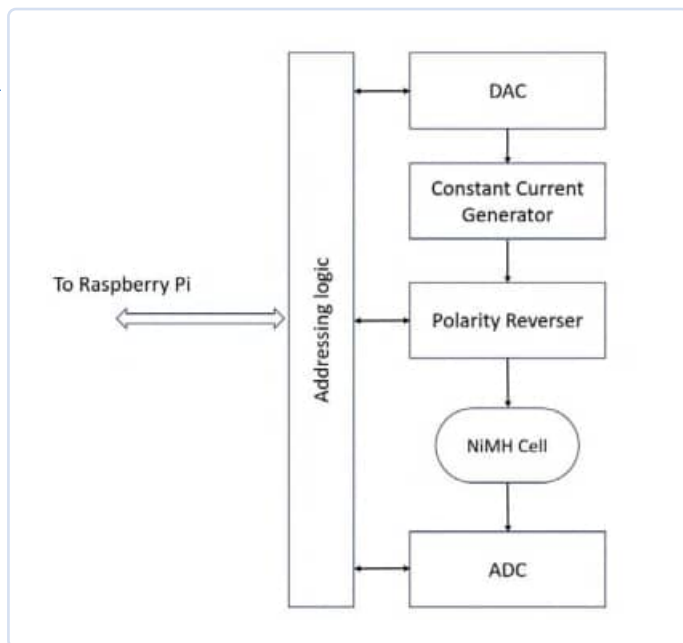


Figure 2: System block diagram.

the resistor, which is then compared to a setpoint voltage by an operational amplifier. The output of the op-amp controls the MOSFET's gate, which is used in its ohmic region.

Then, there is a digital-to-analog converter (DAC), specifically a Microchip MCP4922, responsible for generating the current setpoint voltage utilized by the current source mentioned previously.

Next, an analog-to-digital converter (ADC) is dedicated to the accurate measurement of cell voltage. In this case, a Microchip MCP3201 was used.

The fourth block involves a polarity reverser that employs a DPDT relay to switch between charge and discharge modes.

The last part is the addressing logic. This ensures that the Raspberry Pi can communicate with each of the boards (up to four) independently, without any conflicts. The user sets the address of each board using DIP switches. To encode four addresses in binary, two bits are required, represented by two Raspberry Pi I/O pins: A0 and A1 (GPIO 17 and 27 on the Raspberry Pi board). By altering the state of these pins, the Raspberry Pi selects the desired daughter board.

The full schematic is available on the Elektor Labs project page [1] and on the author's website [2].

## From Concept to Circuitry

In addition to the main blocks just mentioned, Chadèche showcases interesting design details: The DAC and ADC are controlled by the Raspberry Pi via the SPI bus. They share the MISO, MOSI, and CLK pins, with the Raspberry Pi switching between the components it wants to talk to by toggling the chip select pins for each.

As the SPI pins are also shared among the four daughterboards, the addressing logic is responsible for routing the chip select signals to the correct board. This logic is made of the four AND gates in a 74HC00 as well as four of the six inverters available in a 74HC04.

Besides, the DAC and ADC need a voltage reference. To achieve better accuracy, an Analog Devices MAX6241 was chosen for this purpose. This should provide much better results than simply using one of the supply rails as a reference.

An interesting facet of this ADC is its pseudo-differential input. Unlike a fully floating negative input, it is confined to a range of  $\pm 100$  mV from ground. Yet, due to the  $10\ \Omega$  series resistor, the battery voltage floats relative to ground. To solve this, a unity-gain differential amplifier sits between the battery and the ADC.

The relay tasked with holding its position during either charging or discharging phases must remain in a stable position even while the Raspberry Pi engages with another board. Control of the relay coil is therefore assigned to a 74HC74 used as a latch, which in turn is controlled by two Raspberry Pi GPIOs.

The design also incorporates three LEDs, each serving a distinct purpose. The first LED is a straightforward indicator of the power supply's presence. The second, a bicolor LED, conveys whether the system is in charge or discharge mode. The third LED operates in an ON/OFF scheme, controlled by a 555 timer. Interestingly, the 555 output's duty cycle is dictated by the DAC's secondary channel, which would otherwise remain unused. This setup enables the LED to flash at variable frequencies, finely tunable via the software. This may seem like a rather complex solution to flash an LED, but one advantage of this is that the flashing rate of the LED remains the same even when the Raspberry Pi is busy doing other things.

## System Architecture Discussion

In this kind of personal project, constraints are generally more flexible in terms of time and money than in the corporate world, which is a great thing! It's always a fun challenge to find a compromise between the desire for a flexible, upgradable system on the one hand, and simplicity on the other. Chadèche uses one separate daughterboard for each Ni-MH cell under test; it would be interesting to think up a single-board solution, simplifying the wiring and mechanical assembly. That PCB could possibly be a little larger, with a Raspberry Pi Zero mounted on top of it.

While having one MOSFET and gate driver circuitry per Ni-MH cell seems pretty much mandatory, it sparks curiosity to think about other approaches that could use a single DAC-ADC pair for the whole system. This would reduce the number of calibrations required from four to one. How about exploring different addressing schemes between components to expand the system to accommodate more than four batteries? It's also tempting to think of ways to adapt the setup for different battery types, such as lithium or lead-acid.

How would you have done it? Feel free to share your thoughts with the community on Elektor Labs [1].

*Jean-François Simon (Engineer, Elektor)*

ADR	C/D	mA	SD	TL	TH	LmAh	HmAh	TRUE	CTRLZ	COMMENT
1	D	0	60	I	I	I	I	I	S	Cell at rest
2	D	200	90000	S	I	S	I	I	S	200 mA discharge
3	D	0	30	I	I	I	I	I	S	Cell at rest
4	C	300	300	I	6	I	6	I	S	300 mA charge until max capacity
5	C	0	5	I	I	I	I	3	S	NOP and unconditional jump
6	C	50	300	I	I	I	I	I	S	Topping off
7	C	10	3600	I	I	I	I	I	I	Trickle charge
8	C	0	0	I	I	I	I	20:00	S	Waking up at 20:00
9	C	0	0	I	I	I	I	I	S	End of cycle

Figure 3: A configuration table for one cycle.

This flashing indicator can reflect, for instance, the actual load current. Unlike a mere variation in LED brightness, which would be highly non-linear, this flashing offers a more intuitive visual cue.

## Software

To fully leverage the potential of his project, a comprehensive software package was written. The source code (in C) and compiled versions for the Raspberry Pi are available on Github [3]. The code is neatly arranged in five source files totaling around 1,300 lines of code.

To access the Pi's GPIOs, Gordon Henderson's *WiringPi* library is used. The latest stable version, still available on Gordon's website, should work.

The *chadeche* executable can be used to control a Chadèche daughterboard, whose address is passed as a parameter when executed in the shell. In this way, the system makes use of Linux's intrinsic multi-tasking. To analyze several Ni-MH cells simultaneously, we launch several instances of *chadeche*. This can be done either by opening

several shell windows, or by running the commands in the background with `&`, or by using the commands *screen*, *nohup*, etc.

The software enables charge and discharge cycles, each cycle consisting of sequences. Delays are possible, as are conditional jumps from one sequence to the next when (preset) conditions are reached. For example, charge at X current for Y seconds, switch to the next sequence when voltage Z is reached, etc.

To configure all this, the user will provide the software with configuration files containing as many details as desired (one sequence per line) in the form of CSV files, as shown in **Figure 3**. In addition to these configuration files, *chadeche* also allows the use of parameter files to store values specific to each card, such as calibration coefficients.

Measurement results are saved in CSV format, enabling further processing, such as drawing a discharge and recharge curves, as shown in **Figure 4**. ◀

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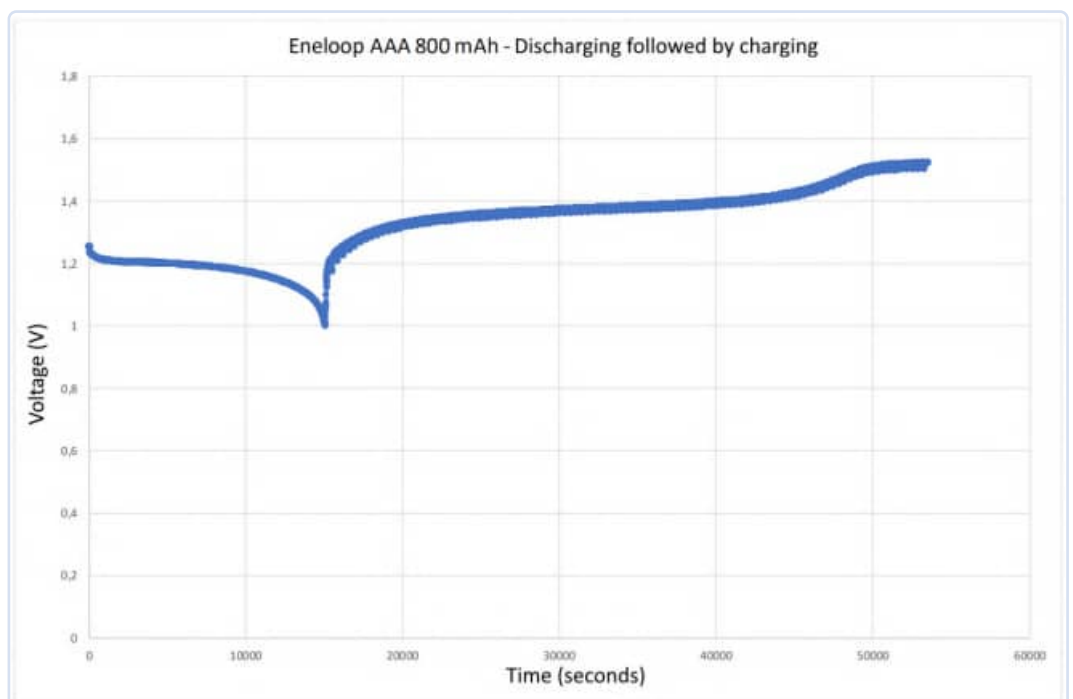


Figure 4: Voltage curve of a Ni-MH cell during discharge and charge.

### Questions or Comments?

If you have technical questions or comments about this article, feel free to contact the author at [support.chadeche@orange.fr](mailto:support.chadeche@orange.fr) or the Elektor editorial team by email at [editor@elektor.com](mailto:editor@elektor.com).

### About the Author

Jacques Ehrlich is Research Director Emeritus at University Gustave Eiffel and is a consultant in the fields of Intelligent Transportation Systems (ITS). He has been the deputy director, then the director of the LIVIC (Laboratory on Vehicle Infrastructure and Drivers Interactions) at IFSTTAR, an internationally renowned research laboratory in the field of road safety, advanced driving assistance systems and autonomous vehicles. He is passionate about electronics, computing, and gliding.

### Share Your Projects With Elektor

Chadèche struck us as an interesting project. It's a fine example of 100% custom realization: design, build, test, write code, and prepare documentation. Let's salute the significant amount of effort this project required. A project like this can only come to fruition with a great deal of perseverance and after many weeks of work. This is the work of a true enthusiast, and that's what we love to see at Elektor! Don't hesitate to share your own projects with the editorial team and the Elektor community. Showcase your work on Elektor Labs and send your project or article ideas to [editor@elektor.com](mailto:editor@elektor.com).



### Related Products

> **Raspberry Pi 4 B (2 GB RAM)**  
[www.elektor.com/18965](http://www.elektor.com/18965)



### WEB LINKS

- [1] Project page on Elektor Labs: <https://elektormagazine.com/labs/chadeche-un-chargeur-dechargeur-tres-intelligent-pour-accus-nimh>
- [2] The author's website: <http://yadalo.no-ip.org/dokuwiki/doku.php?id=projets:projets:chadeche:chadeche>
- [3] Chadèche software on GitHub: <https://github.com/duodiscus92/chadeche>

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electronics. We offer the products that we ourselves are enthusiastic about or that we simply want to try out. If you have a nice suggestion, we are here: [sale@elektor.com](mailto:sale@elektor.com).

## Elektor Super Servo Tester Kit

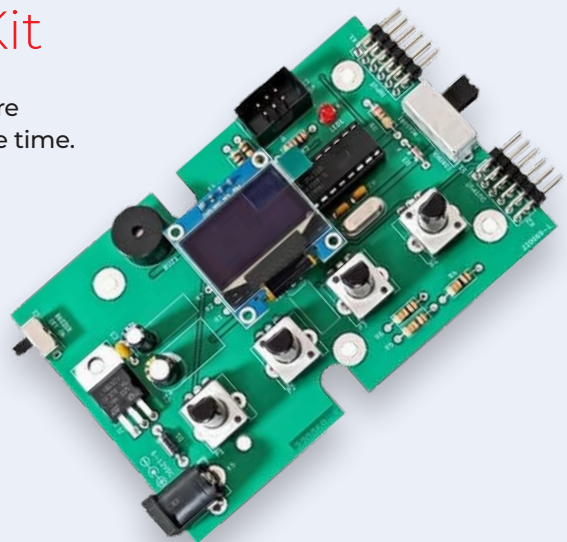
The Elektor Super Servo Tester can control servos and measure servo signals. It can test up to four servo channels at the same time.

The Super Servo Tester comes as a kit. All the parts required to assemble the Super Servo Tester are included in the kit. Assembling the kit requires basic soldering skills. The microcontroller is already programmed.

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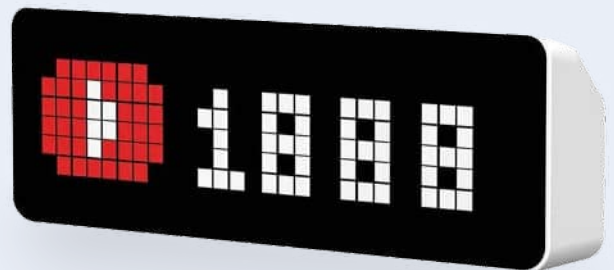


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# Err-electronics

## Corrections, Updates and Readers' Letters

Compiled by Roberto Armani (Elektor)

### Cloc 2.0

**Elektor 3-4/2023, p. 6 (220564)**

The software for the Cloc project has been updated to version 2.10. This version addresses a problem caused by special characters, such as &, in the SSID and password. If used in one of these strings, the string would be truncated, making network connection impossible. The new software can be downloaded from the project page at Elektor Labs: [elektormagazine.com/labs/cloc-le-reveil-20](https://elektormagazine.com/labs/cloc-le-reveil-20)

Clemens Valens (article editor)



### Tiny DCF77 Simulator

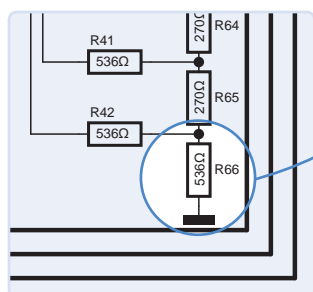
**Elektor Circuit Special 2023, p. 126 (230307)**

There's an error in the text regarding a small DCF77 simulator. The correct controller type is a PIC12F683, not a PIC12F638. The circuit diagram is correct.

### Programmable Video DAC

**Elektor Circuit Special 2023, p. 44 (220674)**

There is an error in the schematic: Resistor R66 (red color channel) must be 536  $\Omega$ , not 270  $\Omega$  (see picture). R74 and R82 (not shown) have the same value, 536  $\Omega$ . The component list is correct.



### Tiny Solar Supply

**Elektor Circuit Special 2023, p.6 (220321)**

There is neither a printed circuit board nor an SMD-assembled tinkering board for this project in the store. Hundreds of weather sensors in hundreds of gardens are surely waiting for such a part for their ESPs. Is there still something coming?

Gustav I.

Thank you very much for your interest, Gustav. The Gerber (and KiCad) files are available for download from [elektormagazine.com/labs/tiny-solar-supply](https://elektormagazine.com/labs/tiny-solar-supply). With these files, you can order the board at PCB pooling services such as Eurocircuits or JLCPCB. Please note, however, that the circuit is not suitable for powering ESP devices running default software (doing RF calibration) as they pull a lot of current at startup, and this circuit cannot deliver that. For more information, see here: [ondrovo.com/a/20170207-esp-consumption](https://ondrovo.com/a/20170207-esp-consumption)

Clemens Valens (developer of the project)



## Capacitors in AF Circuits

Elektor 2/1992, p. 26 (902004)

As a loyal member of your magazine, I've read the article "Capacitors in AF Circuits" ([elektormagazine.com/magazine/elektor-199202/32560](http://elektormagazine.com/magazine/elektor-199202/32560)) and have a question on page 28, where the author writes:

*Furthermore, the power supply also plays a role: it is advisable to shunt its large electrolytic capacitors with film types of not less than 0.47...1.0  $\mu\text{F}$  to improve the circuit's performance at higher frequencies.*

Does this really mean leaving the electrochemical capacitors and simply paralleling a film capacitor? Or is it better to replace the electrochemical capacitors with film capacitors?

Thibaut

Thanks for your question Thibaut, which is still very topical, despite the age of the edition you refer to!

We may consider this as a quasi-esoteric audio issue, where the analysis is pushed to technical levels that are not normally considered. The supply stage of a power audio amplifier is loaded by currents that are proportional to the output level and at a frequency that (obviously) equals the one in the amplified signal. Electrolytic and film capacitors have complementary characteristics. In terms of capacity density and ESR value vs. frequency, in detail:

- Electrolytic capacitors offer large capacitance in limited volumes.
- Electrolytic capacitors are rather "slow" in responding to high-frequency load steps, showing higher ESR values.
- Film capacitors offer lower capacity values/footprint ratios, but they show much lower ESR values at high frequencies, compensating the non-ideal response of the electrolytic ones in discharging downstream.

Therefore, in an audio power supply, combining an electrolytic capacitor with a film capacitor of medium capacitance (as suggested in the article) will yield the advantages of both types, i.e. small overall size and still good ESR behavior on the whole audio bandwidth.

Roberto Armani (Elektor Senior Editor)

## Automating Test and Measurement

Elektor 5-6/2023, p. 56 (230046)

I am an avid reader of Elektor, and have a few questions for you regarding the article.

- Which Python IDE do you use or which one do you recommend for me? I'm a beginner running Windows.
- Can you please send me a sample program with GUI and a USB or LAN function? I'd like to connect to measuring devices and output measurement results.

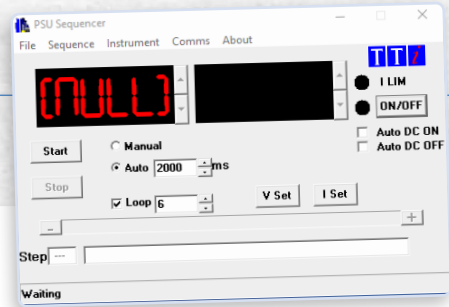
Many thanks for your email and your loyalty as an Elektor reader. We're always very pleased to receive feedback and questions. I have to admit that I'm at the very beginning with Python myself and have not yet programmed a GUI in Python. I use Thonny ([thonny.org](http://thonny.org)) as my IDE, which is very suitable for beginners. After some research, PySimpleGUI seems to be a very suitable GUI for beginners ([pysimplegui.org/en/latest/](http://pysimplegui.org/en/latest/)). A simple example of how to create a bar graph is here: [github.com/PySimpleGUI/PySimpleGUI/blob/master/DemoPrograms/Demo\\_Bar\\_Chart.py](https://github.com/PySimpleGUI/PySimpleGUI/blob/master/DemoPrograms/Demo_Bar_Chart.py)

You just have to install the PySimpleGUI package in Thonny first. When it comes to controlling test and measurement devices, USBTMC is a possible software interface. It can be used to address many power supplies or oscilloscopes. The USBTMC Python package is available for this: [github.com/python-ivi/python-usbtc](https://github.com/python-ivi/python-usbtc).

Otherwise, there is PyVISA:  
[pyvisa.readthedocs.io/en/latest](http://pyvisa.readthedocs.io/en/latest)  
and an example here:  
[core-electronics.com.au/guides/automating-test-equipment-with-python](http://core-electronics.com.au/guides/automating-test-equipment-with-python)

Hopefully, this information will help you. I wish you good luck and, if you have built or tried something, please let us know — maybe we can report on it!

Stuart Cording (Elektor)

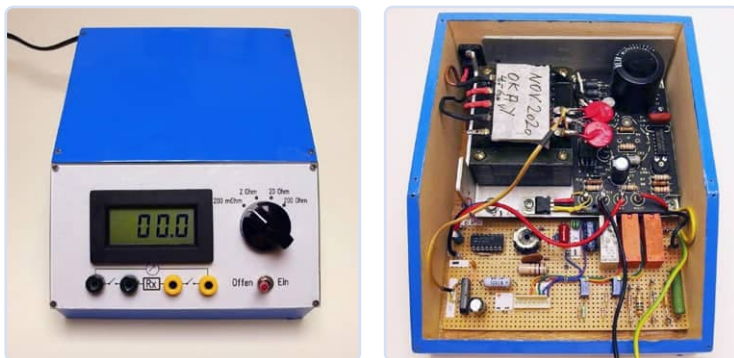


## Milliohm Meter

**Elektor (Summer) Circuit Special 2022, p. 114 (220167)**

I've been tinkering again, but this time I haven't come up with anything of my own design, instead I've used the Milliohm Meter project from your Circuit Special 2022. I have slightly adapted Stefano Purchiaroni's circuit according to my ideas and the material available. Finally, I am proud of my housing and its front panel. But please have a look yourself!

Peter Grundmann



This realization looks really well done and deserves the publication of some pictures. We encourage you to post the entire project on the Elektor Labs platform here ([elektormagazine.com/labs](https://elektormagazine.com/labs)) so we can share it with all of our readers!

Jens Nickel (Editor-in-Chief Elektor)



## Mini Reflow Plate

**Elektor 11-12/2023, p. 120 (230456)**

The above article is very interesting and encourages you to build your own. Unfortunately, however, one piece of information was missing (at least I couldn't find it): What kind of heating plate is this, and where can you get it?

Hans Schneider

Thanks for your query to Elektor, Hans. The component you're looking for is a custom-made 230 VAC / 400 W heating plate distributed by our partners at Elettronica In magazine. You may find all the details here: [futuranet.it/prodotto/piastra-riscaldante-400-watt-230-vac](https://futuranet.it/prodotto/piastra-riscaldante-400-watt-230-vac)

Roberto Armani (Elektor)



## Elektor Circuit Special 2023

I have been a loyal reader for over 40 years and am always delighted with the summer issue, with its many small and large projects! I'm more of an analog hobbyist and my hands/eyes have a problem with small SMD technology, but I think it's wonderful that you still exist and that you haven't gone the way of "Elrad and Co."

Martin Vogl

Hello Mr. Vogl, thank you very much for the supportive compliment. We're very pleased!

Jens Nickel (Editor-in-Chief Elektor)





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