£9.95 | €10.95 | $12.95

elektor MAG

design > share > earn

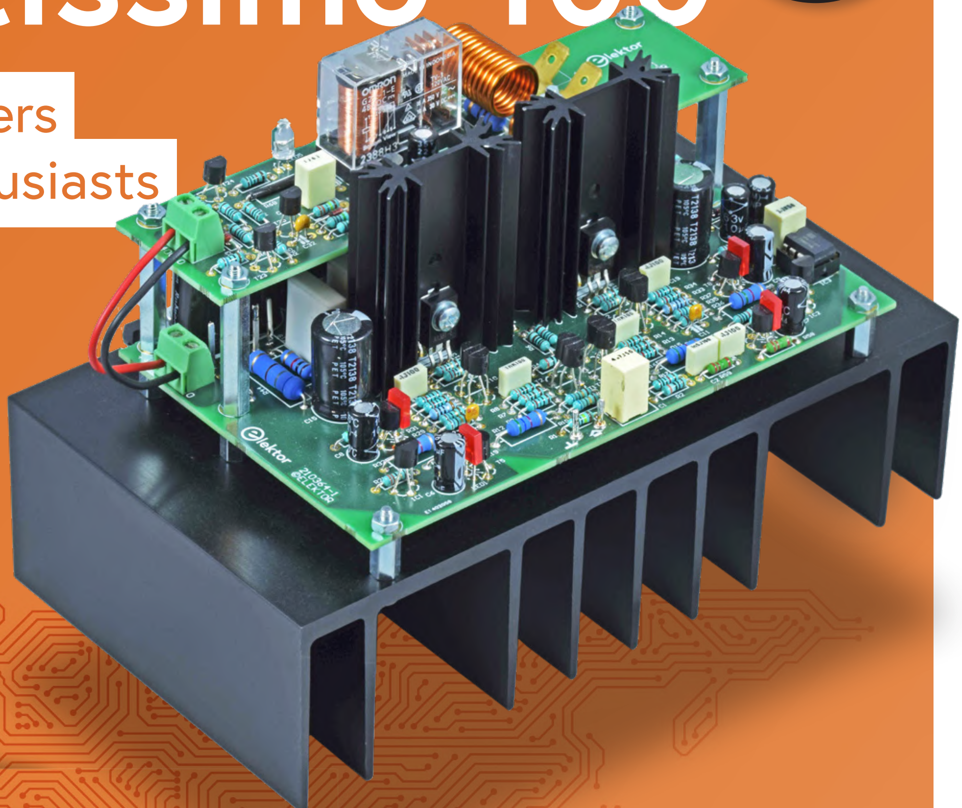
517
* SINCE 1961 *
NOVEMBER & DECEMBER 2022
ELEKTORMAGAZINE.COM

140 PAGES

High-End Amplifier Fortissimo-100

Project for both DIYers and high-end enthusiasts

p. 6



Visit us at

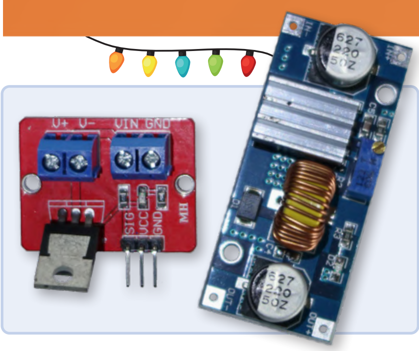
electronica
November 15–18 2022
Hall B4.440 Messe München

+ Special Section
WEEF 2022
Ethics in Action
Insights on Ethical Business

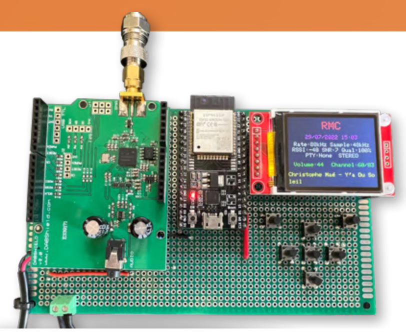
FOCUS ON
Production and Components

p. 24 **PCB Design**
Tips and Tricks

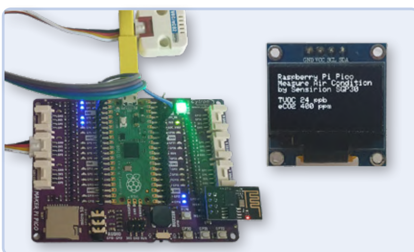
p. 56 **Did COVID Cause a Boost in Engineering Innovation?**



LED Garlands with ESP32 and FreeRTOS
Flashing and Variable Brightness
p. 38



FM/DAB+ Receiver
The Best of Both Worlds
p. 46



RP2040-Based Air Quality Measurement
Visualize Data with ThingSpeak
p. 120


electronica
ENGINEERING
A BETTER
WORLD
IMAGINE THAT.
WE CAN.
Let us take you on a journey of discovery. Whether you design, build or maintain, we have ingenious technologies and solutions to help engineer a better world for everyone.
So what are you waiting for? Come along to C2.179 to meet the team and explore how to take your project to the next level.
RS

COLOPHON

Elektor Magazine,
English edition

Edition 8/2022
Volume 48, No. 517
November & December 2022

ISSN 1757-0875 (UK / US / ROW distribution)

www.elektor.com
www.elektormagazine.com

Elektor Magazine, English edition
is published 8 times a year by
Elektor International Media

Head Office:
Elektor International Media b.v.
PO Box 11
6114 JG Susteren
The Netherlands
Phone: (+31) 46 4389444

Memberships:
E-mail: service@elektor.com
www.elektor.com/memberships

Advertising & Sponsoring:
Raoul Morreau
Phone: +31 (0)6 4403 9907
E-mail: raoul.morreau@elektor.com

www.elektor.com/advertising
Advertising rates and terms available on request.

EDITORIAL

Jens Nickel

International Editor-in-Chief, Elektor Magazine

High-End Device from the Elektor Lab

For the second time this year, you have in your hands an extra-thick, 140-page issue. Even our cover project is supersized: The Fortissimo-100 high-end amplifier is a fully symmetrical audio building block that boasts 100/190 watts. With its superlative specs, this amplifier joins the ranks of similar *Elektor* designs that we've published over the decades. For inspiration, Ton Giesberts turned to the medium-power AF Amplifier from our lab — a design from 1990 that's still being replicated today. I'm already sure that, in 30 years, we'll still be receiving questions and requests regarding the Fortissimo, for example at elektor-labs.com.

With its lengthy component list, the amplifier fits in with the main topic of our issue: production and components. It's no coincidence that, traditionally, we focus on this area of electronics in November. From November 15 to 18, *electronica 2022* — "the world's leading electronics trade fair" per their own advertising — takes place in Munich. Surely, it is not an exaggeration: In no fewer than 14 exhibition halls, we'll see components, boards, and modules presented, as well as software and development and production tools. You can get a taste of what's to come in our Industry section, starting on page 56.

Elektor will also be found in the heart of electronica, at Hall B4.440. As always, we'll be showing off interesting products and books, while Elektor editors will be reporting on the newest trends from location. Together with Messe München, we're organizing the Fast Forward award for start-ups. This year, we've sought out the most innovative young companies for you, and the field of participants runs from four-legged robots to autonomous bikes. Find out more on page 95!

Last, but not least, I'd also like to invite you to the 2022 World Ethical Electronics Forum (WEEF), which takes place on the first day of the fair (Hall B3). Together with *Elektronikpraxis* magazine, Elektor will be supporting ethics in electronics for the second time. Between 10:00 and 16:00, well-known experts in the field will participate in an "Ethics Talk Show" with our moderators, Stuart Cording and Johann Wiesböck. Questions and comments are welcome! Starting on page 106, we'd like to get you ready for this increasingly important event.

See you in Munich!

The Team

International Editor-in-Chief: Jens Nickel
Content Director: C. J. Abate
International Editorial Staff: Eric Bogers, Jan Buiting, Stuart Cording, Rolf Gerstendorf, Alina Neacsu, Dr Thomas Scherer, Brian Tristam Williams
Laboratory Staff: Mathias Claussen, Ton Giesberts, Luc Lemmens, Clemens Valens
Graphic Design & Prepress: Giel Dols, Harmen Heida, Sylvia Sopamena
Publisher: Erik Jansen

FIPP Connecting Global Media — Elektor is a member of FIPP, an organization that has "grown over almost 100 years to include media owners and content creators from across the world."

DEUTSCHE FACHPRESSE — Elektor is a member of VDZ (Association of German Magazine Publishers), which "represents the common interests of 500 German Consumer and B2B publishers."

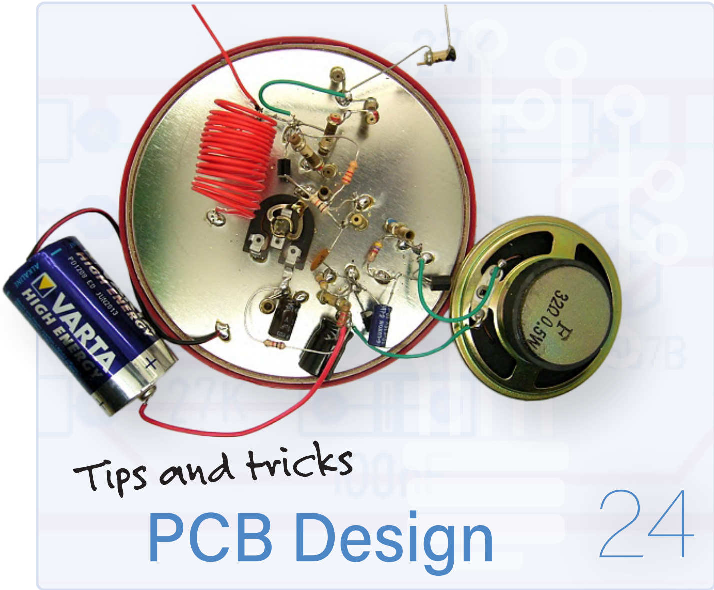
THIS EDITION

Volume 48, No. 517
November & December 2022

Regulars

Features

Industry electronica



WEEF 2022

Projects

Next Edition

Elektor Magazine Edition 1-2/2023 (January & February 2023)
As usual, we'll have an exciting mix of projects, circuits, fundamentals and tips and tricks for electronics engineers and makers. We will focus on audio and video electronics.

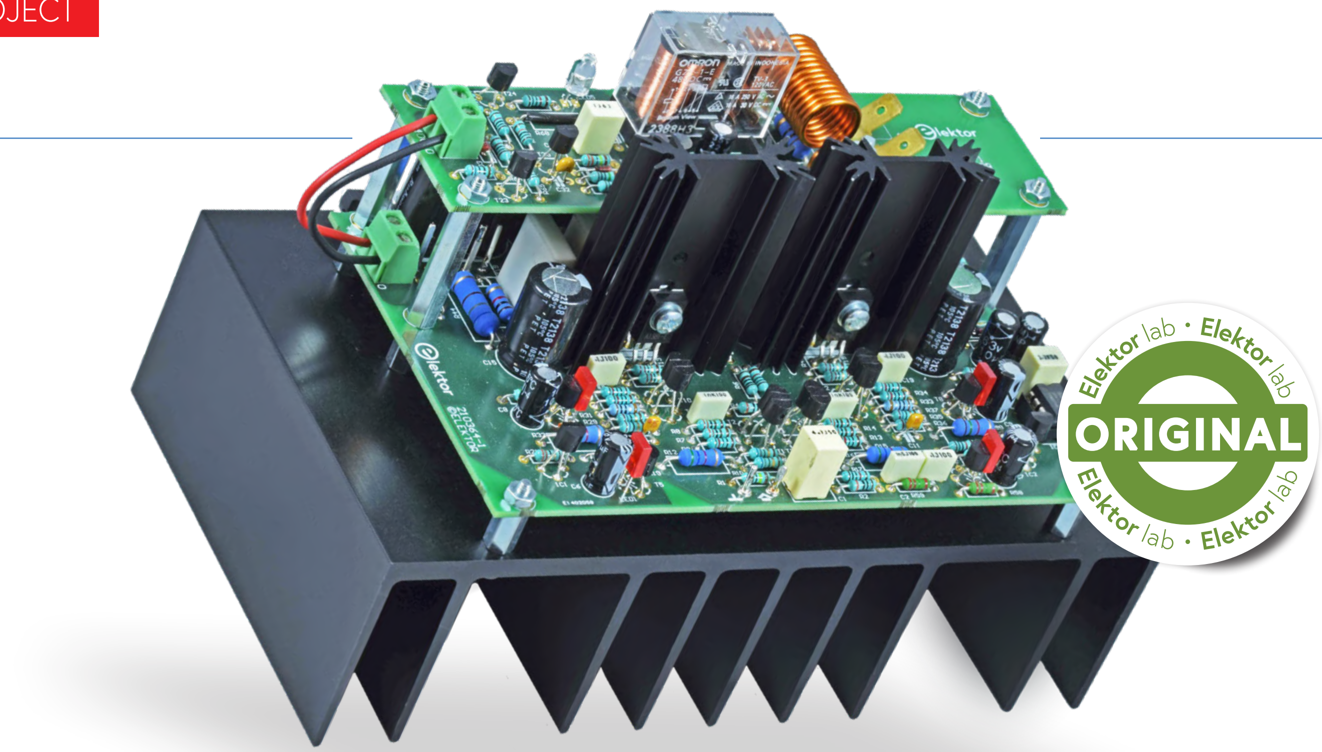
From the contents:

- Video output with microcontrollers
- ESP32 Camera
- 32-Ω Headphone amplifier
- Workshop: ESP32 Audio Development Framework
- Spacebee satellites for IoT communication
- Tube amplifier
- Poor man's ChipTweaker
- USB True random number generator
- ATX Power supply for Raspberry Pi

And much more!

Elektor Magazine edition 1-2/2023 (January & February 2023) will be published around January 5, 2023. The arrival of printed copies for Elektor Gold Members is subject to transport. Contents and article titles are subject to change.

FOCUS ON
Production and Components



Fortissimo-100 High-End Amplifier

Fully Symmetrical Audio Output Stage and 100/190 W

By Ton Giesberts (Elektor)

Digital amplifier modules can now be bought for little money, but high-end enthusiasts typically turn up their noses at the sound. On the other hand, people still like to build Elektor designs from decades ago. Our newest amplifier, the Fortissimo-100, will intrigue DIYers and high-end enthusiasts alike: THD+N: 0.000.8 % at 50 W at 8 Ω, maximum power 98 W at 8 Ω or 188 W at 4 Ω with THD ≤ 1 %. DIYers will find it convenient that only wired components are used. Curious? Then read on and preheat your soldering iron.

During the development of this high-end amplifier, I was inspired by an Elektor design that's over 30 years old, but is still very good: the *Medium-power AF amplifier* [1] from October 1990. Thanks to its sophisticated fully-symmetrical design, this amplifier is still respectable today and can certainly be regarded as high-end. The question is whether the circuit can actually be improved. My answer is the *Fortissimo*, which means "yes, indeed!"

Basics

Figure 1 shows the power portion of the old output stage (light yellow) and the new output stage (light blue). Like the old circuit, the new one operates in the proven Class-AB mode, but now with the driver stage implemented in a symmetrical bootstrap configuration. The key differences are marked in red. On the right-hand side of the figure, capacitors C15 (between the junction of R44/R45 and the output) and C16 (between the junction of R46/R47 and the output) provide significantly higher voltages at the bases of T17 and T18. The main advantage is that the power stage built around the output transistors can be driven harder, so the maximum output voltage is over 2 V higher without requiring higher supply voltages for the voltage amplifier stages.

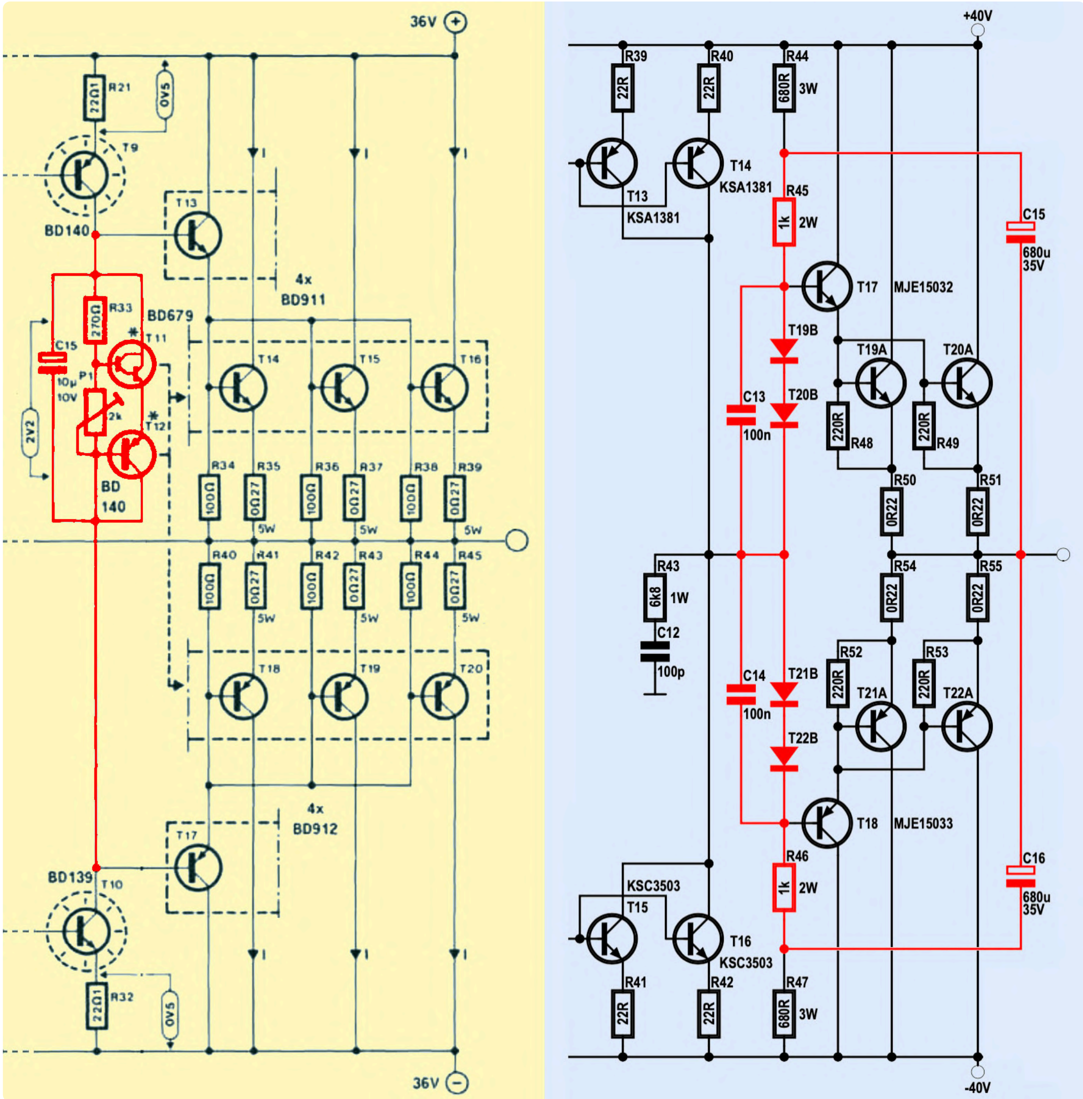


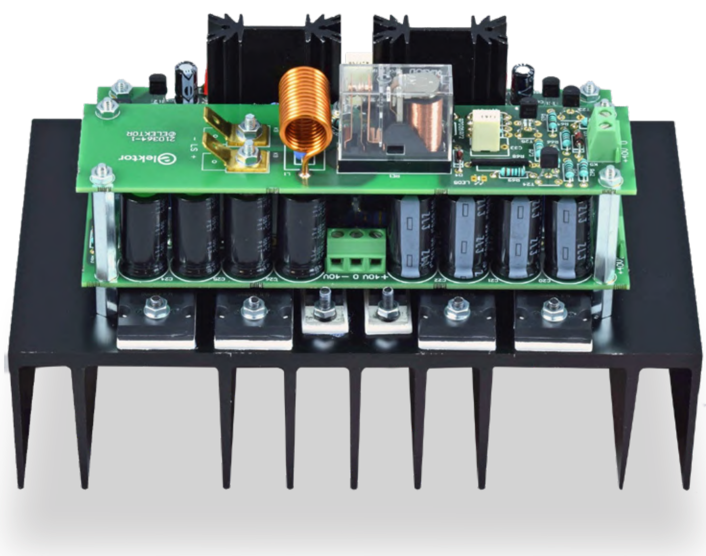
Figure 1: Differences between old (left) and new (right): quiescent current setting and symmetrical bootstrapping.

A noteworthy feature of the new circuit is that it does not have an adjustable bias voltage to set the quiescent current. Instead, four diodes (T19B – T22B) are simply connected in series, with the voltage drop over these diodes corresponding with the voltage over the circuit's four BE junctions composed of T17 through T22A. As you may have guessed from the diode designations, these are additional diodes integrated into power transistors T19 through T22. The thermal coupling of these diodes is very good, resulting in a fairly stable quiescent current with an extremely simple circuit. This thermal coupling is why the complementary transistors, NJL3281D (NPN) and NJL1302D (PNP) [2], are called "ThermalTrak," and it is a nice feature.

For optimal output power, the amplifier requires regulated symmetrical supply voltages of ±40 V. With an 8 Ω load, the maximum power with THD ≤ 1% is nearly 100 W, and, with a 4 Ω load, it is almost twice as much (see the **Specifications** frame at the end of the article).

What's more, the PCB is double-sided and through-hole plated, simplifying construction of the amplifier. The six power transistors in the output stage are located halfway under the PCB, which, together with the protection circuit, is mounted on the heat sink. This results in a compact module (**Figure 2**). Only six 3 mm holes in the heat sink for the power transistors, plus another six for the stand-off posts, are needed for this arrangement. If you use the SK53-100-SA heat sink from Fischer Elektronik, you don't need to tap any M3 threads, because the required twelve holes fit perfectly between the heat sink fins. There

Figure 2: The fully-assembled compact amplifier module.



is even a bit of leeway for inaccuracies. The mechanical work is probably the most complicated part of building the amplifier. More about this later.

Circuit Design

The basic amplifier circuit (**Figure 3**) can be divided into three parts. First, there is the input stage with symmetrical differential amplifiers, followed by the push-pull stage, which, in turn, drives the output stage. The functions of the protection circuit are on top of this. All of these aspects are discussed in more detail below.

Differential Amplifiers

The differential amplifiers built around T1/T2, T3/T4, T9/T10, and T11/T12 are implemented using the well-known BC546B/BC556B-type transistors. These have a higher transition frequency than later types, such as the KSC1845/KSA992 pair. Replacing the BC546B and BC556B with other types may lead to problems, since their characteristics influence stability, and, in many cases, other types have different pin assignments. Other networks for frequency compensation would then be necessary, and possibly a whole different layout.

The rectangular red LEDs placed close to the individual transistors provide temperature-compensated voltages for the differential amplifiers' current sources. To limit power dissipation of current source transistors T5 – T8, 1 W resistors (R12, R18, R32, and R38) are placed in series with their collectors. The two integrated current sources, IC1 and IC2, together with resistors R21 and R24, stabilize the current through the LEDs at 2 mA. Although the integrated current sources' maximum-rated voltage is just enough for the 40 V used here, to be on the safe side, the two 10 kΩ resistors, R20 and R23, are connected in series to reduce the applied voltage to less than half.

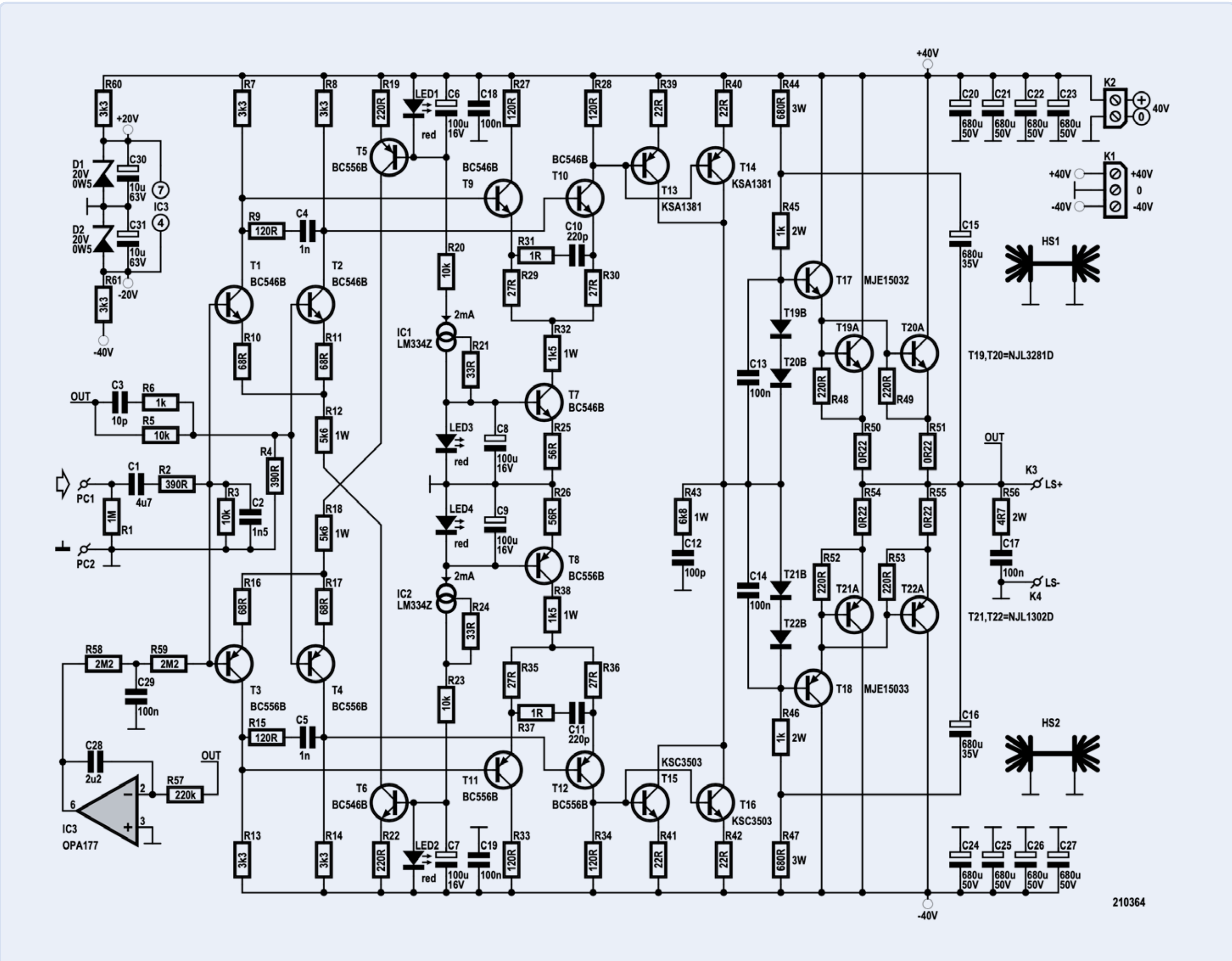


Figure 3: The circuit of the Fortissimo amplifier module is fully symmetrical.

The overall gain is set to 26.6 by negative feedback network R4/R5. Due to the small voltage drop over R2, it's reduced to approximately 25.6. Capacitor C2, together with resistors R2 and R3, attenuate high-frequency signals that the amplifier can't handle. The maximum input voltage for an unclipped output signal is slightly above 1 V. C3 and R6 in the negative feedback loop ensure high-frequency stability.

Also for stability reasons, RC networks R9/C4 and R15/C5 are placed between the collectors of the first differential amplifiers built around T1/T2 and T3/T4 to provide frequency compensation. The downstream differential amplifiers built around T9/T10 and T11/T12 provide a bit of additional gain. Their main task is to provide low-impedance drive to the subsequent push-pull amplifier stage built around T13 – T16. The networks, R31/C10 and R37/C11, also provide frequency compensation.

Collector resistors R27 and R33 are there to keep the collector-emitter voltages of the two transistors in the second differential amplifier equal. The voltage difference between R27 and R28 and between R33 and R34 should be ≤ 0.35 V (even better, ≤ 0.1 V), as, otherwise, the first differential amplifier's transistors' U_{BE} and h_{FE} would not be close enough to each other. Despite their tight positioning, the transistor pairs' thermal coupling is not as good as with a dual transistor, since they are not in the same package on the same die. Consequently, there may be measurable deviations.

These transistors cannot be purchased as matched pairs. This means you must first measure their characteristics and then select pairs with good matching. Simply measuring the h_{FE}, for example with a multimeter, is not good enough here. The U_{BE} values should differ by no more than 1 mV with the same collector-emitter voltage and the same collector current. If the U_{BE} of the NPN pair is not the same as that of the PNP pair, that's not a problem. The **Transistor Selection** frame (end of the article) describes the procedure for selecting matched pairs using the test circuit in **Figure 4**. Note that the measurements are strongly-dependent upon ambient temperature.

Push-Pull Stage

T10 and T12 drive a push-pull stage. Two pairs of driver transistors connected in parallel — T13||T14 (PNP) and T15||T16 (NPN) in TO-126 or SOT-32 packages — keep the collector current per transistor in the linear region even at maximum output, and this dual-driver current improves drive with regard to the output stage's parasitic capacitance. Complementary types KSC3503 and KSA1381 from ON Semiconductor (formerly Fairchild Semiconductor) are used here. They are very suitable for this purpose: with a V_{CEO} of 300 V they can not only handle high voltages, but also have an impressively low reverse-capacitance C_{re} of 1.8 pF (NPN) or 2.3 pF (PNP) and linear gain at collector currents of up to 50 mA (maximum collector current 100 mA).

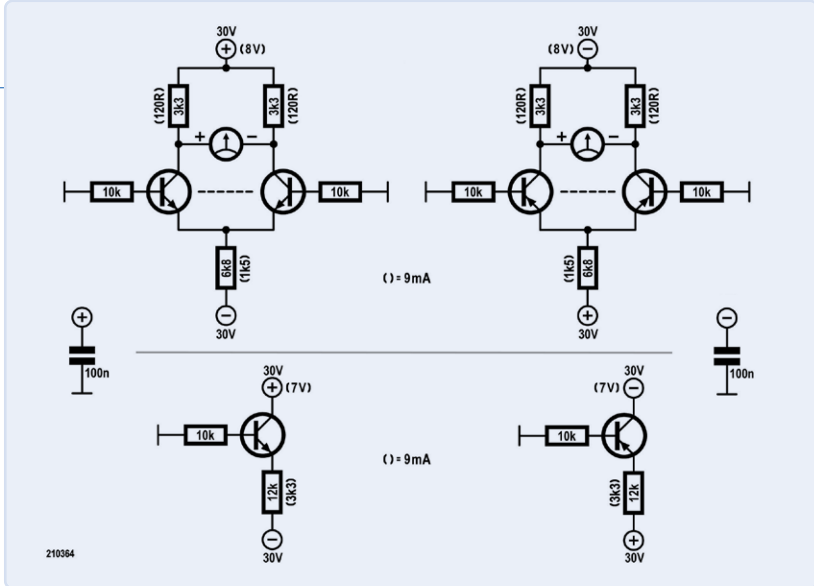


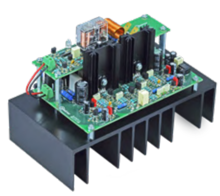
Figure 4: The test circuit for measuring the small-signal transistors to determine the best possible matched pairs can be built on a breadboard.

These transistors are available in h_{FE} classes C, D, E, and F. Unfortunately, ON Semiconductor can only supply NPN-type KSC3503 in Class-D (h_{FE} 60 – 120) and PNP-type KSA1381 in Class-E (h_{FE} 100 – 200). The NPN and PNP types should ideally be in the same class, but the emitter resistors R39/R40 and R41/R42 largely compensate for the different current gains. The current through each of the four transistors is set to approximately 13 mA. This matches the assigned task, and the transition frequency is highest at this current.

Under no-signal conditions, the power dissipation of each transistor is approximately 510 mW. To carry away the heat, each pair of parallel transistors is mounted to a heat sink. Heat sinks HS1 and HS2 are of type SK104 from Fischer Elektronik, which comes with holes for package types TO-220, SOT-32, or TO-3P. The TO-126 package also fits. The thermal resistance of the 50.8 mm-long SK104 is 9 K/W, so its temperature will be about 10 K above ambient temperature when the two transistors are mounted to it. Due to the package thermal resistance (17.8 K/W), the transistors' silicon will be another 9 K warmer. Although the heat sinks are at ground potential, no additional insulation is required for the transistors. A bit of thermal paste is sufficient, since they each have a full plastic package.

Output Stage

The output stage is built around transistors T17 – T22A. It is a complementary Darlington configuration for Class-AB operation. In most analog power amplifiers, including the previously-mentioned Medium-power AF amplifier, the power transistors' quiescent current is set by a transistor mounted on the same heat sink, in a circuit similar to a

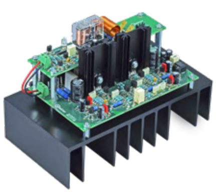


Zener diode (U_{BE} voltage multiplication) that provides temperature stabilization.

The Fortissimo is different: Here, each of the four power transistors (T19 – T22) has a galvanically-isolated diode integrated in its package, shown on the circuit diagram as T19B – T22B. These diodes sense the power transistors' junction temperatures fairly directly, which makes them better suited to setting these power transistors' quiescent current. With four power transistors, there are four diodes available, and they can simply be connected in series to compensate for all four effective base-emitter voltages of the power transistors, T19A||T20A and T21A||T22A, and their drivers, T17 and T18.

Although this method is better, it is not perfect due to the indirect sensing of T17 and T18, so it cannot entirely prevent the quiescent current from exhibiting temperature-dependent drift. However, this circuit does prevent thermal runaway. The current through the four diodes is set to approximately 23 mA by the four power resistors, R44 – R47. These resistors are also part of a symmetrical bootstrap circuit with C15 and C16, making the current through the diodes nearly independent of the voltage amplitude. Bootstrapping also allows a higher output-voltage amplitude. At full output, the voltage drop over resistors R39 – R42 and the saturation voltages of T13 – T16 are largely offset by the voltages over T19B - T22B.

Important: The power transistors' quiescent current depends on the current through resistors R44 – R47. This means that the ±40 V power supply must be regulated within a fairly tight range. A power supply consisting only of a transformer with a bridge rectifier and electrolytic filter capacitors is definitely not recommended for this amplifier. With that arrangement, the quiescent current would have a small ripple component and the supply voltage would change with the load, output power, and mains voltage, degrading the characteristics of the amplifier. Excellent switch-mode power supplies specifically designed for audio power amplifiers, such as the type SMPS800RE, are available now. Many other power supplies are designed for Class-D amplifiers and have an output voltage that varies with the mains voltage. These are definitely not suitable. A suitable switch-mode power supply must provide a stable symmetrical output voltage of ±40 V that does not collapse at the peak currents occurring in the circuit, even with a low-impedance load of (for example) 4 Ω.



The voltage at R45 and R46 is always a constant 23.4 V and is virtually independent of the output signal. The power dissipation of each resistor is approximately 550 mW. The DC voltage at R44 and R47 is approximately 15.9 V, but the AC voltage of the output signal is superimposed on this due the bootstrap capacitors, C15 and C16. The effective value of a sinusoidal voltage with a DC offset can be calculated using this formula:

$$U_{eff} = \sqrt{(U_{DC}^2 + U_{ACpeak}^2 / 2)}$$

If DC voltage U_{DC} is 15.9 V and the peak value of sine wave signal U_{ACpeak} is 39 V, the power dissipation over 680 Ω is 1.5 W. At full overdrive of the amplifier with maximum clipping, the waveform is a square wave with peak voltages close to the supply voltages. In that case, the power dissipation over R44 and R47 is 2.6 W each. This should actually never happen, but 3-watt types are used here to avoid burning out the resistors. For R45 and R46, 2-watt types are sufficient. The dimensioning of the power dissipation of these power resistors also depends on the ambient temperature.

DC Correction

Ideally, both input transistor pairs would have the same h_{FE}, so the base currents of T1 and T3 would offset each other. But, even if the h_{FE} values of the two transistor pairs are the same, the voltage drops over LED1 and LED2 would differ slightly because LEDs, like transistors and resistors, have tolerances. This leads to differences in the DC voltage setting, and even small differences are amplified. Measurements showed that the gain of a BC556B is greater than that of a BC546B, but even that depends on the manufacturer.

A difference in the base currents of the NPN and PNP transistors produces different offset voltages at R3 and R4, since their values are very different (10 kΩ and 390 Ω). The voltage drop over R4 can be ignored. The offset is subsequently amplified and must therefore be compensated. This is handled by the opamp, IC3. Selected type OPA177 has a very low intrinsic input offset. Acting as an integrator, the opamp measures the DC component of the output voltage via R57. The opamp's output voltage adds a very small negative feedback DC current to R3 via R58/R59/C29, which corrects the offset to nearly 0 V. Capacitor C29 filters out residual AC voltage components from IC3. The offset caused by the different base-emitter voltages of the input transistors is also compensated. Due to all the tolerances, the voltage on R3 will most likely not be exactly 0 V, even if the output voltage is close to 0 V. In practice, there will be a small offset over R3. In the prototype, the offset voltage over R3 was approximately 0.7 mV.

The symmetrical ±20 V supply voltages for the opamp are derived from the ±40 V supply via resistors R60 and R61 and Zener diodes D1 and D2.

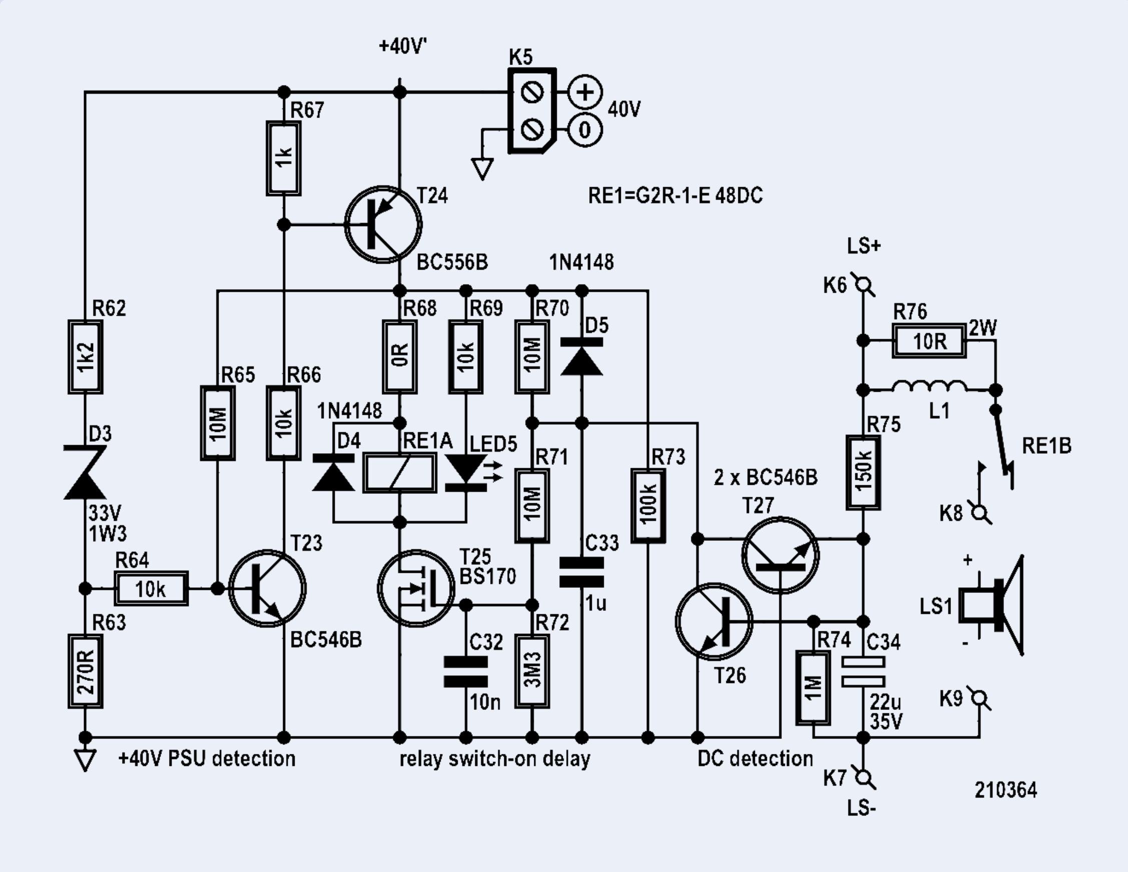


Figure 5: The Fortissimo's protection circuit prevents loudspeaker damage from DC voltages and loud switch-on noises.

◄

Protection

In the event that a DC voltage is present at the output or other malfunctions occur, it is a good idea to disconnect the loudspeaker. **Figure 5** shows the protection circuit. Transistors T26 and T27 are part of the DC-detection circuit. After a switch-on delay, T24 and T25 activate the loudspeaker through a relay. A relatively large DC voltage at R75 generates a collector current in T26 that discharges C33. Then T25 switches off the relay. A corresponding negative DC voltage at R75 generates an emitter current in T27 that discharges C33. Then, T25 switches off the relay. R75 and C34 form a low-pass filter so that low audio frequencies are not mistaken for DC voltages, even at maximum output.

To disconnect the loudspeaker when the amplifier is switched on or off, T23 switches off the relay via T24 when the supply voltage is too low. R65 provides a small hysteresis. Switch-on occurs at voltages ≥ 36.7 V, and switch-off at voltages less than ≥ 36.5 V. These voltages are defined by Zener diode D3. The current through D3 is set to approximately 5 mA at 40 V by R62 plus R63. The voltage at R63 is evaluated by the Schmitt trigger consisting of T23, T24, and R64 – R67. The hysteresis prevents relay chatter in the event of small disturbances or small variations in the supply voltage at high output power. MOSFET T25, in combination with the time constant network formed by R70, R71, R72, and C33, provides a switch-on delay that prevents any plopping of the loudspeaker, since the loudspeaker is only connected when the supply voltage is high enough and the amplifier has settled down. R73 and D5 discharge C33 quickly when T24 is switched off. This ensures a defined switch-on delay for the relay at the next switch-on or in the absence of a DC voltage at the output. The resistors at the gate of T25 have sufficiently high resistance that a relatively low value of C33 is enough for an adequate time constant. This allows a plastic-foil type to be used, which is preferable, since electrolytics usually have high leakage currents and age faster. With 1 µF for C33, the delay is approximately 3.5 seconds.

Relay type G2R-1-E DC48 has an operating voltage of 48 V, and its contacts are rated at up to 16 A. According to the data sheet, it can switch approximately 5 A at 40 V DC. The relay engages at 70% of the nominal coil voltage. This means that 34 V is sufficient to activate the relay. In any case, the available 40 V is more than enough. If another relay with a lower coil voltage (e.g. 24 V) is used, 0 Ω resistor R68 (or wire bridge) must be replaced by a resistor with a suitable value. For example, 24 V relay G2R-1-E DC24 has a coil resistance of 1.1 kΩ. The resistor value can then be calculated as follows:

$$R68 = (40\ V - 24\ V) / 24\ V * 1.1\ k\Omega = 733\ \Omega$$

The next-lower or next-higher value from the E12 series of resistors would be suitable. At 680 Ω, the coil voltage would be 24.7 V, and, at 820 Ω, it would be approximately 23 V. The voltage drop over T23 and T24 can be ignored here. The power dissipation of R68 is approximately 350 mW with a 680 Ω resistor, so the board layout allows fitting a 1 W resistor.

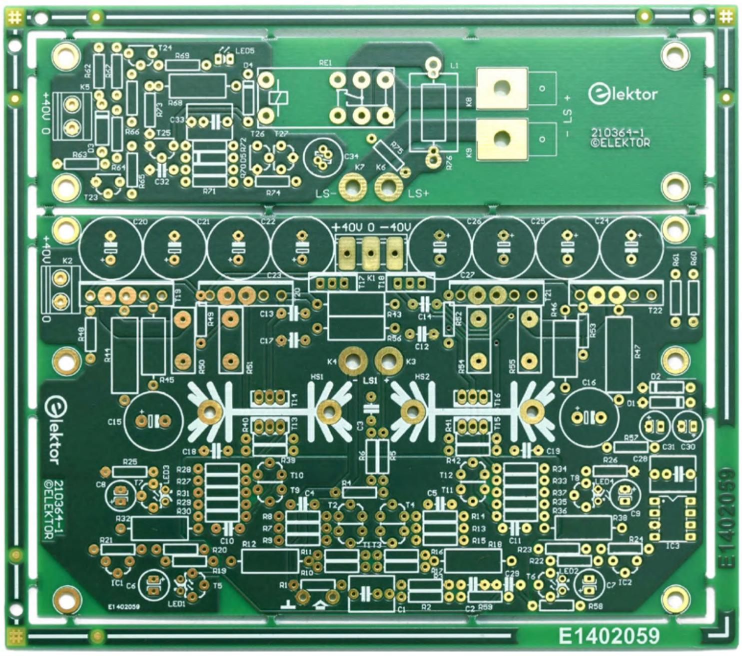


Figure 6: The double-sided, through-hole-plated circuit board of the prototype. The PCB layouts of the two separate boards are available for download [3].

Figure 7: Rear side of the large heat sink. The 12 black screw heads are hardly noticeable.

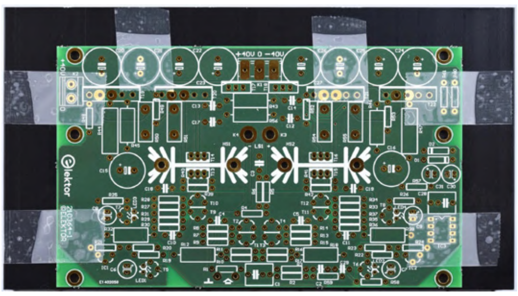


Figure 8: The amplifier circuit board secured with sticky tape acts as a template for marking the holes to be drilled.

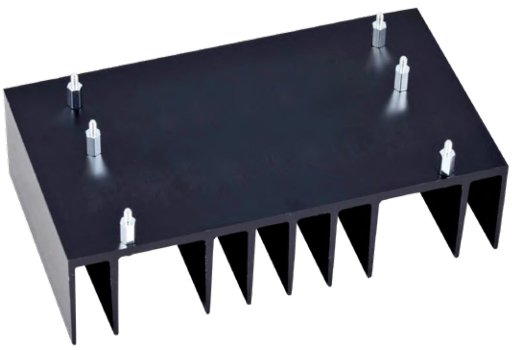


Figure 9: The large heat sink with six 10 mm standoffs for fitting the amplifier board.

Construction

Mounting of power transistors T17 – T22 and assembly of the circuit board are designed to make construction easy. The necessary mechanical work consists of drilling twelve 3 mm holes for mounting the transistors and the circuit boards (**Figure 6**) on the rear of the heat sink. There is enough room between the fins of the SK53-100-SA heat sink from Fischer Elektronik for the heads of the 3 mm screws. The amplifier board is fitted to the heat sink with six 10 mm metal standoffs with M3 threads. To achieve low thermal resistance, the transistors are insulated with ceramic pads (alumina). In the last stage of construction, a very thin coating of thermal paste must be applied to the rear of the transistors and the bottoms of the pads that rest on the heat sink. You should avoid getting this thermal paste on your skin, since many of them are toxic.

The protection circuit shown in Figure 5 is located on a second, smaller circuit board (upper part of Figure 6), which is mounted above the amplifier board on an additional six 30 mm standoffs. Pads K3 and K4 on the amplifier board connect the amplifier output to pads K6 and K7 on the protection board through two of these standoffs. From there, K7 is connected directly to K9 or to output terminal LS-. By contrast, K6 is connected through L1 to the relay contacts, and, from there, to K8 or output terminal LS+. Here, the tracks are routed on both sides of the board for low resistance. Blade connectors K8 and K9 provide low transfer resistance to the loudspeaker cable and support a high real damping factor.

The standoffs have an internal thread at one end and a threaded stud at the other. The internal thread faces the heat sink, and the threaded studs pass through the holes of the protection board. Finally, all screw heads should be located on the rear of the heat sink. Black screws are relatively inconspicuous on the rear of the heat sink (see **Figure 7**). Six M3x12 cross-head screws were used to mount the circuit board in the prototype. For the driver transistors in TO-220 packages, 12 mm screws were also sufficient, but at the time black screws were only available as M3x16 hex socket head screws from Conrad. There are surely other sources as well.

Heat Sink

First, lay the board on the heat sink as shown in **Figure 8** and secure it with sticky tape. The bottom edge of the board (where C1 is located) should be 1 mm away from the edge of the heat sink, with the board centered horizontally. The photo shows the board temporarily secured with sticky tape to act as a template for marking the hole locations for the six metal standoffs.

A 3.5 mm drill bit is suitable for marking the three holes on each side (left and right). Turn it by hand, *anti-clockwise*,

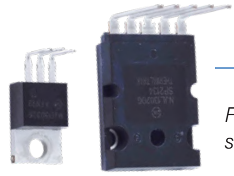


Figure 10: The leads of the power transistors should be bent, as shown here.

in the six holes while applying some pressure. This way you shouldn't damage the circuit board. However, please note that K3 and K4 are not marked. The board is laid out so that the holes are located between the heat sink fins with sufficient clearance. Next, drill the holes with a 3.2 mm drill bit and mount the six 10 mm standoffs firmly with screws. The assembly should look like the picture in **Figure 9**. If the board fits easily over the six threaded studs, everything is OK. If it doesn't, you can file out one or more holes to allow for the positions of the standoffs.

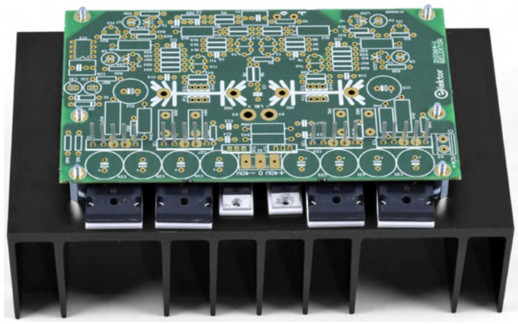


Figure 11: Marking the holes for the power transistors. To increase accuracy, the transistors are placed on top of ceramic pads.

Before mounting, bend all leads of T17 – T22 tightly-perpendicular toward the transistors' front sides (see **Figure 10**). To avoid applying too much force to the packages of large power transistors T19 – T22 when bending the leads, clamp the leads close to the package in a vise with a 2 mm drill bit between the vise jaws. With a suitable piece of sheet metal, you can then bend all the leads toward the front side of the transistor. The pins of smaller transistors T17 and T18 can be bent with pliers, taking care to bend them 1 mm away from where they become broader toward the package side.

Figure 12: The marked locations of the drilled holes for mounting the power transistors.

To mark the holes for the six transistors, place them on their thermal pads and insert their leads into the holes in the circuit board. The board must be on the six threaded studs for this. After a bit of adjustment of the positions, the assembly should look like **Figure 11**. Then, mark the positions of the six holes as before, using a 3 mm drill bit, also turned by hand *anti-clockwise*. With the prototype, the four holes for T19 – T22 were approximately 8.8 mm from the edge of the heat sink, and those for T17 and T18 approximately 11.5 mm. Of course, this depends on how precisely the transistor leads are bent, so it might be different in your case. **Figure 12** shows the marked locations of the six transistor mounting holes, and **Figure 13** shows these holes fully-drilled.

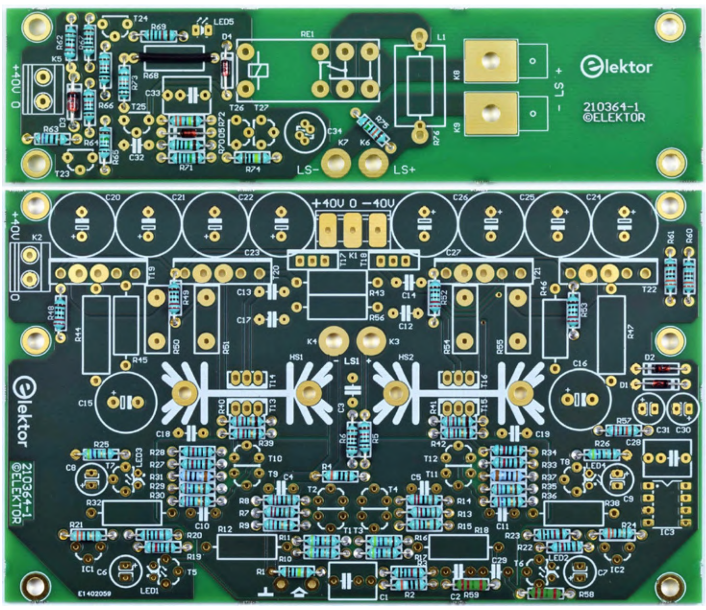
Figure 13: The finished holes for mounting the power transistors.

Next, secure the transistors and ceramic pads with screws. You should thread the nuts fairly loosely. Then, check that the transistor leads fit nicely into the circuit board's holes and that the board fits onto the six threaded studs. If necessary, adjust the leads' bends a bit.

PCB Assembly

After these preparations, almost all of the components can be fitted on the board. As usual, the sequence is based on component height. Start with the small resistors and diodes D1 – D5 (see **Figure 14**). Then, fit the power resistors and the socket for IC3. Next come the smaller capacitors, sorted by size: C3, C10, C11, C32, C4, C5, C12, C2, C13, C14, C18, C19, C29, C17, C33, and C28. After fitting the larger capacitors (C6 – C9, C30, C31, and C34), fit K5, and finally C1.

Figure 14: The low-profile components, such as small resistors and diodes, are fitted on the board first.



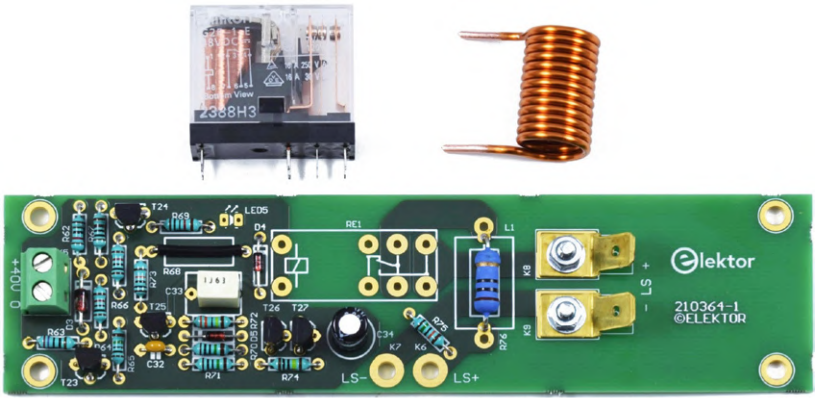


Figure 15: The fully-assembled protection circuit. Only the relay and the home-made copper coil have still to be soldered in place.

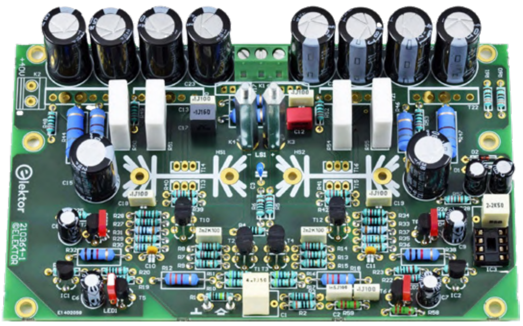


Figure 16: The two standoffs leading from K3 to K6 and from K4 to K7 are located in the middle of the amplifier board, next to each other.

▶

Figure 17: To avoid stress from thermal expansion, the leads of the driver transistors are bent slightly. This can be done very easily with the special pliers shown here, but it can also be done with round-nose pliers.

▶

Figure 18: Small heat sink with two transistors positioned opposite each other. Don't forget the washers.

▶

Next, assemble the protection circuit board by fitting transistors T23 – T27, the two blade terminals, K8 and K9 (secured with M3x8 screws and nuts with washers), coil L1 (13 turns of 1.5 mm copper wire with a 10 mm inner-diameter), and finally relay RE1. A 10 mm drill bit is perfect as a winding form for L1. The coil leads should be long enough to allow the coil to be positioned above R76. You can use a carpet knife or similar to scratch off the enamel on the ends of the leads. **Figure 15** shows the almost fully-assembled board (Relay, LED and coil are not mounted yet). If you wish, you can mount LED5 on the front of the amplifier enclosure later on and connect it using a small-diameter stranded wire.

Getting back to the amplifier board: Now it's time to fit T5 – T8 and LED1 – LED4. The visible chips in the LEDs should be at half the package height of the adjacent transistors. Bend the transistors and LEDs against each other after soldering, or, even better, while soldering, in order to achieve good thermal coupling.

After the previously-described matching of transistor pairs T1/T2, T3/T4, T9/T10, and T11/T12 for the same U_{BE} and h_{FE}, they can now be fitted on the board. When soldering the transistor pairs, make sure the flat sides are touching over the full surface area for good thermal coupling. Next, fit K1, power resistors R50, R51, R54, and R55, then capacitors C15 and C16, and finally capacitors C20 – C27.

Next comes the mechanical work. Secure the two standoffs connecting the outputs of the two boards at K3 and K4 to the top side of the amplifier board with M3x8 screws inserted from below. **Figure 16** shows the result.

Transistor Mounting

The next step is mounting the transistors T13 – T16 on the two small heat sinks, HS1 and HS2. To reduce the mechanical stress from temperature variations, form the transistor leads with small bends. **Figure 17** shows special type of pliers and a transistor with bent leads, and **Figure 18** shows a pair of transistors screw mounted on a heat sink with a bit of thermal paste. The bends must be close enough to the package to allow the transistor leads to pass through the circuit board. Fit a washer under the screw head to protect the transistors. Do not fully tighten the nuts yet. The screw head most be on the side of T13 or T15, respectively, as otherwise it cannot be reached later with a screwdriver. Now, fit the heat sinks and transistors on the board, first soldering both metal pins of the heat sinks. Then use small flat-nosed pliers to hold the M3 nuts from the rear (facing the thick capacitors) and tighten the screws from the front with a suitable screwdriver. Finally, solder the four transistors' leads. Now,

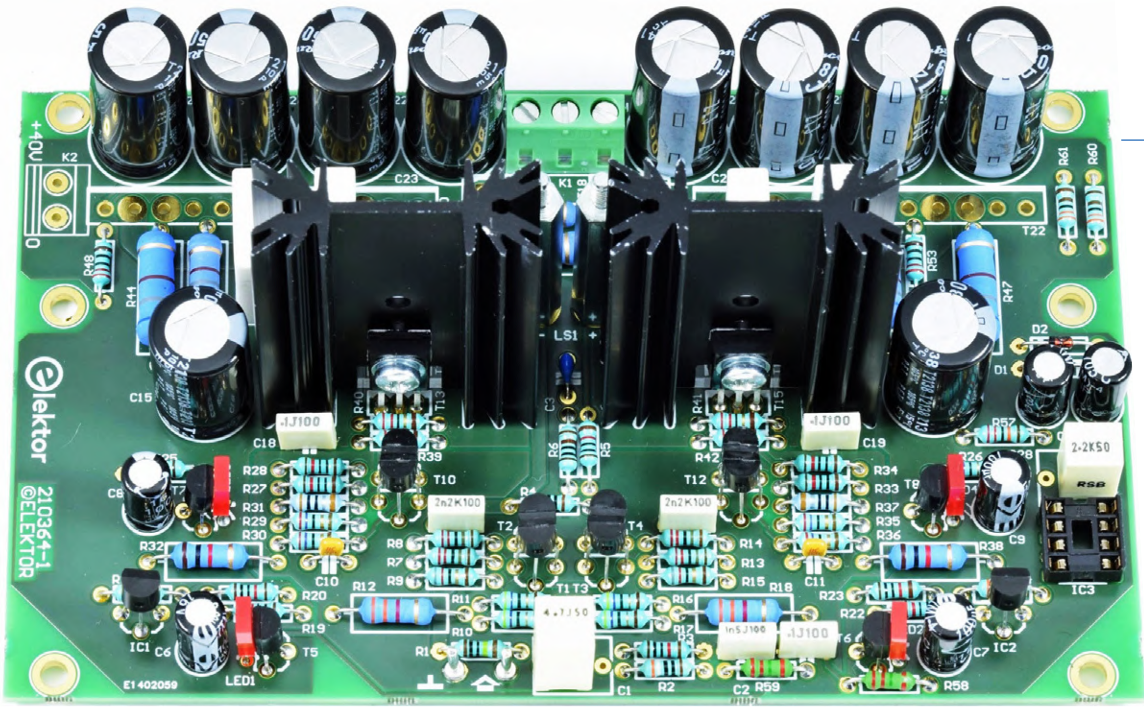


Figure 19: The two heat sinks with T13||T14 and T15||T16 are soldered onto the amplifier board.

the board should look like the picture in **Figure 19**.

Figure 20 shows transistors T17 – T22 provisionally attached to the heat sink with screws and nuts so they can be soldered in the correct positions. For this, also temporarily mount the board on the heat sink using the 10 mm standoffs, with the board held in place by nuts (or the 30 mm standoffs, as shown in the picture). Of course, the ceramic pads must also be underneath the transistors so that everything will fit later on. For T17 and T18, fit the small insulating bushes on the screws to ensure precise positioning.

Now solder at least the two outer leads of each transistor to the top side of the board. Take care when doing this to avoid burning nearby capacitors with the soldering iron. You should preferably solder all the leads on the top side straight away. A long, thin solder tip is helpful.

Then, remove all the screws from the transistors as well as the nuts holding the board. When removing the board, be careful to avoid bending any transistor leads. Now turn the board over and solder the transistor leads on the rear as well. The two-way screw terminal, K2, has not been fitted yet, to allow better access to the leads of T19. It should be fitted now.

Next, apply a very thin coat of thermal paste to the rear of the six transistors and to the side of each ceramic pad that will rest on the heat sink. Then, turn the heat sink upright so that the holes for the transistors are at the top. Insert the six M3 screws for the transistors halfway into their holes from the rear. This way you can place all six ceramic pads (with the coated side facing the heat sink) one-by-one onto the screws (see **Figure 21**).

Now place the board carefully on the standoffs, taking care that the screws pass through the holes of the transistors. Then, secure the board with the four 30 mm stand-

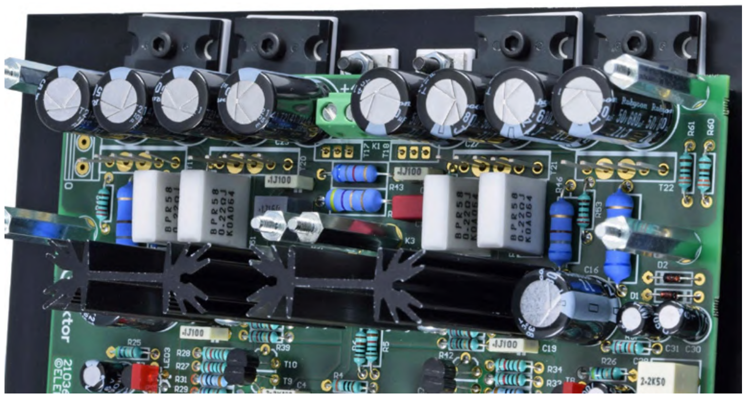


Figure 20: Transistors T17 – T22 temporarily mounted on the heat sink with ceramic pads. After provisional fitting of the circuit board, the leads of T17 – T22 are soldered on the top side of the board.

Figure 21: The ceramic pads are coated on one side with a thin layer of thermal paste and fitted over the partially-inserted screws. The heat sink must be positioned upright for this.

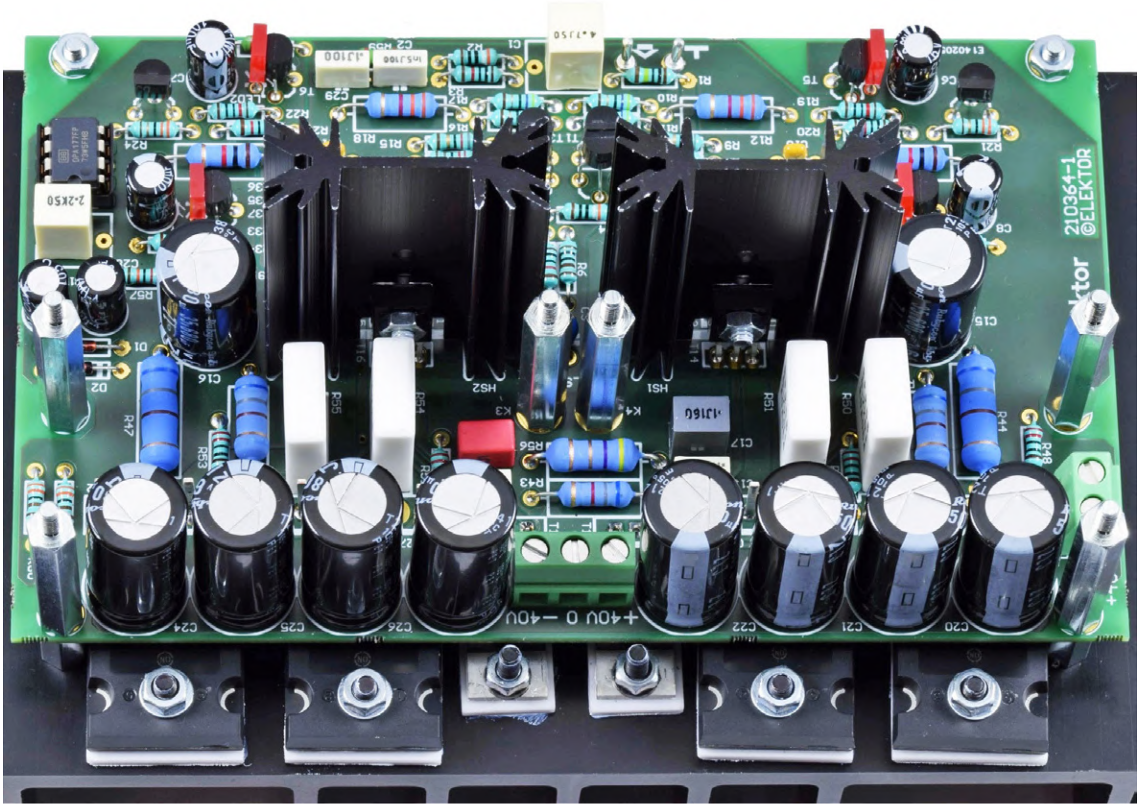


Figure 22: Now the board with the transistors is fitted on the heat sink and the transistors are firmly screwed in place as shown here.

offs (toward the transistors), thread M3 nuts onto the other two threaded studs, and tighten them. On the top sides of the four power transistors, T19 – T22, fit M3 washers to protect the packages. Also fit the insulating bushes for T17 and T18. Finally, tighten all the screws. **Figure 22** shows the fully-assembled output stage.

Final Assembly

Mount the fully-assembled protection board on the six 30 mm standoffs and secure the board with six M3 nuts. **Figure 23** shows the left and right views of the virtually complete amplifier module before connection to the power supply. Don't forget to connect K2 and K5. At this point, LED5 is not yet connected to the protection board. You may now begin with testing.

Measurements

Several relevant charts based on measurements from the prototype are described below.

Frequency Response

Figure 24 shows the frequency response, which refers to amplitude in dB versus frequency. The Fortissimo's -3 dB bandwidth is 3.3 Hz to 237 kHz – a wider range than the

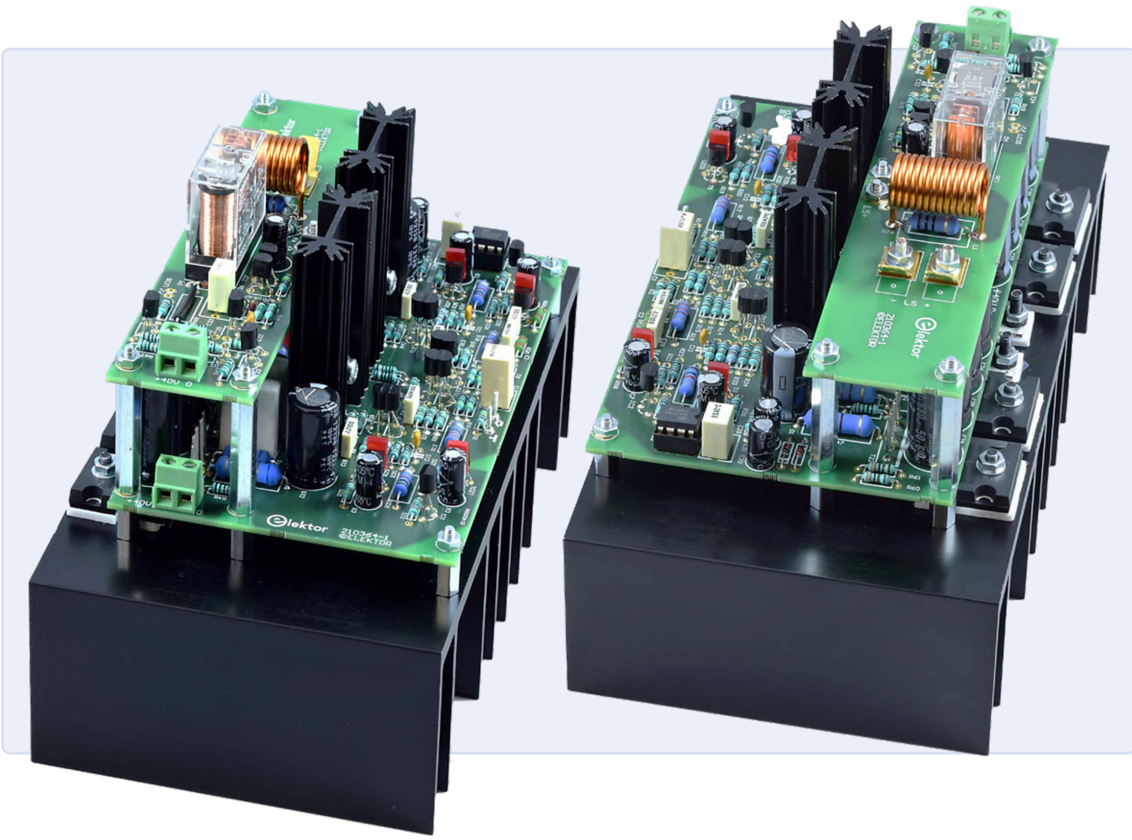


Figure 23: With the protection board mounted on top, the result is the compact module — shown here from both sides.

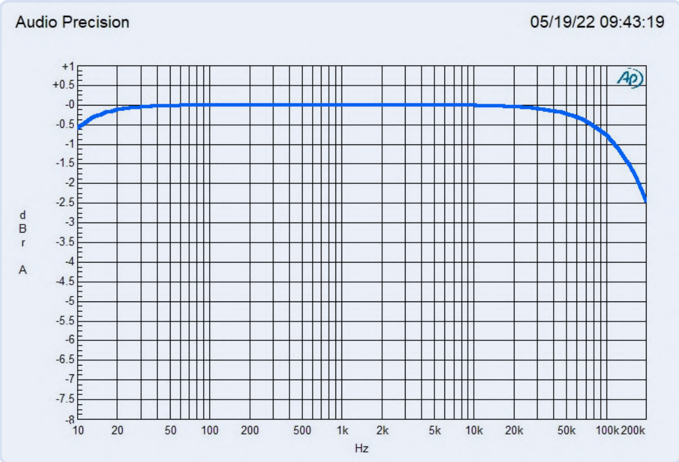


Figure 24: The measured frequency response: The -0.5 dB bandwidth extends from 10.8 Hz to 78 kHz.

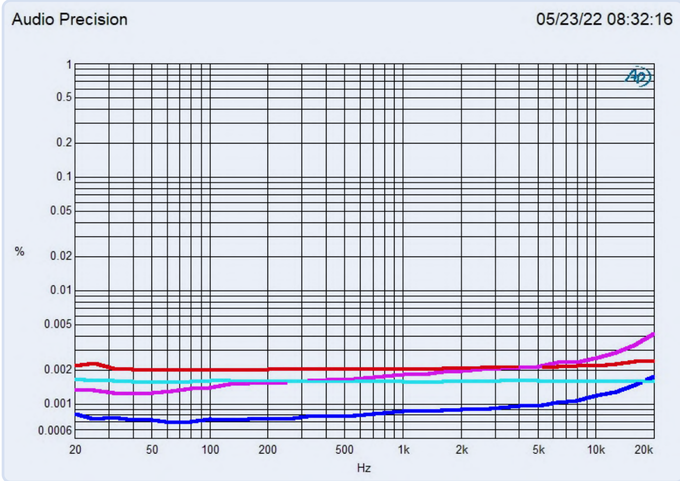


Figure 25: THD versus frequency with 4 Ω and 8 Ω loads and different power levels: Cyan: 1 W into 8 Ω; Red: 1 W into 4 Ω; Blue: 50 W into 8 Ω; Magenta: 100 W into 4 Ω.

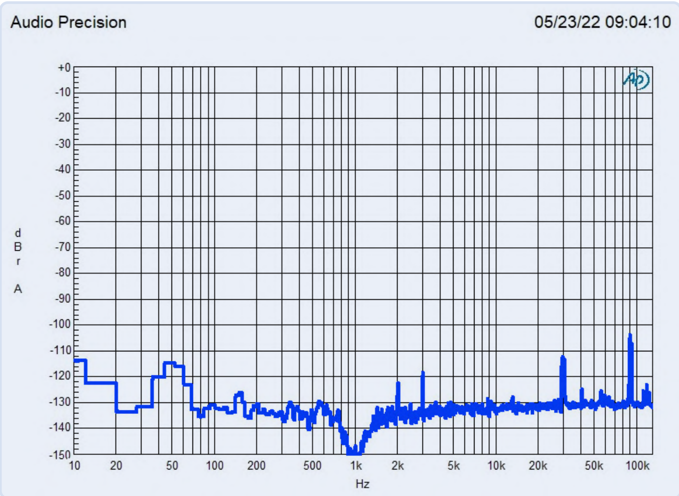


Figure 26: The harmonic spectrum with the amplifier driven by a 1 kHz sine wave with a power of 1 W into 8 Ω. The theoretical audible peaks at 2 kHz and 3 kHz are extremely small.

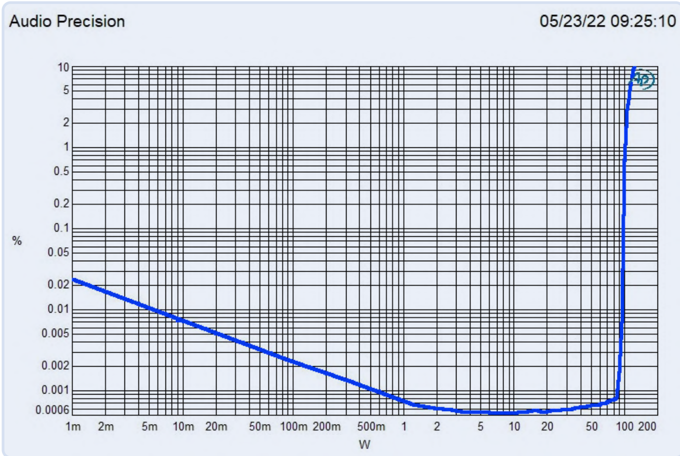


Figure 27: THD + noise versus output level with the amplifier driven by a 1 kHz sine wave with an 8 Ω load and a bandwidth of 22 kHz.

Audio Precision analyzer's generator can produce. The narrower -0.5 dB bandwidth extends from 10.8 Hz to 78 kHz.

THD+N Vs Frequency

The chart in **Figure 25** shows THD plus noise versus frequency with loads of 4 Ω and 8 Ω, in each case with 1 W or 50 W output power and a bandwidth of 80 kHz. The curve for 1 W into 8 Ω (cyan) consists predominantly of noise. With 1 W into 4 Ω (red) the output voltage is lower and the relative noise level higher. The influence of harmonics can also be seen at higher frequencies. The curve for 50 W into 8 Ω (blue) is extremely low below 1 kHz, at ≤ 0.0008%. Even at 20 kHz, the level rises to only 0.0018%. With 4 Ω and the same output voltage (100 W, magenta), the THD is higher but still excellent: 0.0023% at 1 kHz and 0.0042% at 20 kHz.

Spectrum

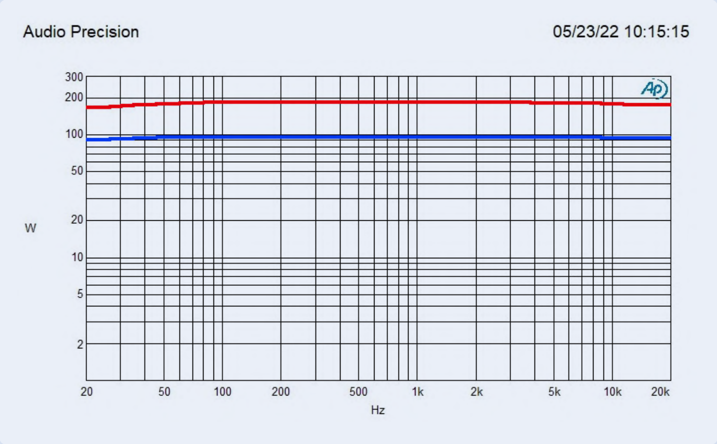
Figure 26 shows the frequency spectrum with the amplifier driven by a 1 kHz sine wave signal and a power of 1 W into 8 Ω. There are two harmonics visible in the audible range, at 2 kHz and 3 kHz. The former has a level of only -122.6 dB, and the second peak reaches -118.5 dB. The resulting THD is therefore only 0.00015% – an incredible 1.5 ppm. The peaks at 30 kHz and 90 kHz come from the residual ripple of the lab power supply used here, which explains why the THD with a bandwidth of 22 kHz is less than with a bandwidth of 80 kHz. At higher output levels, the power supply artifacts are no longer of any consequence.

THD+N Vs Power

The curves in **Figure 27** show the THD + noise versus output level with the amplifier driven by a 1 kHz sine wave with an 8 Ω load, measured with a bandwidth of 22 kHz. At 10 W, the THD is only 0.00052%. The THD is 0.0008% at approximately 85 W and rises sharply at higher power.

Power Bandwidth

Figure 28 shows the maximum output power versus frequency at 0.1% THD. The blue curve represents an 8 Ω load, while the red is 4 Ω. With an 8 Ω load the output power at different frequencies is: 20 Hz: 89.5 W; 1 kHz: 94 W; 20 kHz: 92.4 W. With a 4 Ω load, the figures are: 20 Hz: 163 W; 1 kHz: 181 W; 20 kHz: 171 W. The exact values depend on the supply voltage. Any voltage drop over the



▲

Figure 28: Power versus frequency at 0.1% THD. The blue curve is for 8 Ω and the red for 4 Ω.

wiring from the power supply to the amplifier is noticeable. For this reason, two 10,000 µF electrolytic capacitors were placed near terminal K1 in the test setup. At 181 W into 4 Ω, the sine wave signal's peak current is 9.5 A, so, for maximum power into 4 Ω, the power supply must be able to deliver at least 10 A DC.

You'll Be Amazed

The Fortissimo amplifier demonstrates, in an impressive manner, that time has not stood still in the realm of analog audio amplifiers. With an optimized circuit and (in part) better semiconductor devices, the quality compared to the original Medium-power AF amplifier can be improved, and at a reasonable expense.

The building of this amplifier may not be suitable for beginners, but our individual steps have been described in so much detail that virtually any electronics hobbyist with a reasonable amount of experience should be able to reproduce it successfully. Another advantage is that absolutely no adjustment is required.

If you are uncertain, you can protect the amplifier by connecting a 100 W incandescent lamp in series with each supply lead for initial testing, assuming that you can still find incandescent lamps (halogen types are also suitable). Such lamps have a cold resistance of approximately 10 Ω. If they become noticeably warm or glow slightly in the dark, something is wrong. Before operating the amplifier without this form of series resistors, you can check the DC voltages on various components, as listed in the **Table 'DC Voltages,'** to see if there are any assembly errors. The voltages should be roughly within ±20% of the values measured on the prototype.

If everything is right, I hope you enjoy the first listening test. You'll be amazed!

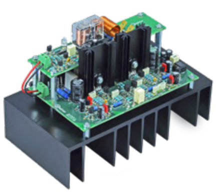
210364-01

Table: DC Voltages

R7	7.90 V
R8	7.85 V
R13	7.90 V
R14	7.96 V
R19	1.06 V
R22	1.05 V
R27	1.20 V
R28	0.90 V
R33	1.20 V
R34	0.95 V
R25	1.006 V
R26	1.007 V
R39	0.28 V
R40	0.28 V
R41	0.28 V
R42	0.28 V
R55	18.7 mV (cold) 28.3 mV (warmed up without output power)
LEDs	1.675 V (average)

Your Fortissimo-100 Kit

Elektor launched the Fortissimo-100 as a Jumpstarter project in July 2022. Refer to the Fortissimo-100 poster in this edition for additional details. Visit **www.elektor.com/20273** to order a kit.



Questions or Comments?

Do you have any technical questions or comments about this article? Contact the Elektor editorial team at editor@elektor.com.

Transistor Selection

For selection of the transistors for the differential input stages, simple circuits such as those in **Figure 4** can be built on bread board. The two transistors should be placed close together and clamped firmly against each other. The difference between the 3.3 kΩ resistors should be kept as small as possible. The 10 kΩ resistors serve as sense resistors for measuring the base currents. Although the h_{FE} values of the NPN and PNP pairs may differ slightly, ideally, they should be equal. The transistors are inexpensive, so you should buy more than you need and try different ones until you have found transistors with the least offset between the collector resistances. This way of making measurements is only slightly temperature-dependent. In the two upper measurement circuits, the collector current is 2.16 mA per transistor with the 6.8 kΩ resistor in the emitter circuit. If you want to measure precisely with 2.42 mA as in the circuit in Figure 3, simply set the negative rail voltage to -33.4 V.

A few things need to be adjusted for the second differential stage. The current must be increased to approximately 9 mA per transistor. For this, use the resistor values and voltages in parentheses.

A simpler method is to measure U_{BE} and h_{FE} separately for each transistor and use the resulting list of values to determine the best matches. However, the lack of thermal coupling makes this method significantly more temperature-dependent.

SPECIFICATIONS

The measurements were made with a ±40 V laboratory power supply. The supply voltages were buffered by two 10,000 µF electrolytic capacitors (rated voltage ≥ 50 V) close to terminal K1.

Input Sensitivity:
1.076 V for 94 W into 8 Ω at 0.1% THD

Input Impedance:
10 kΩ

Continuous Power (1 kHz):
94 W into 8 Ω at 0.1% THD
98 W into 8 Ω at 1% THD
181 W into 4 Ω at 0.1% THD
188 W into 4 Ω at 1% THD

Load Impedance:
≥3 Ω

Bandwidth:
3.3 Hz – 237 kHz; -3 dB at 1 W into 8 Ω
10.8 Hz – 78 kHz; -0.5 dB at 50 W into 8 Ω;
generator impedance 20 Ω

Bandwidth without negative feedback:
≈ 20 kHz

Open-loop gain:
≈ 140,000 into 8 Ω

Slew rate:
45 V/µs

Rise time:
1.5 µs

SNR:
103 dB with B = 22 Hz – 22 kHz
106 dBA at 1 W into 8 Ω

THD+N:
0.0008% at 1 kHz; 1 W into 8 Ω; B = 22 kHz
0.0016% at 1 kHz; 1 W into 8 Ω, B = 80 kHz
0.0016% at 20 kHz; 1 W into 8 Ω, B = 80 kHz
0.0008% at 1 kHz; 50 W into 8 Ω; B = 22 kHz
0.0008% at 1 kHz; 50 W into 8 Ω; B = 80 kHz
0.0020% at 20 kHz; 50 W into 8 Ω; B = 80 kHz
0.0012% at 1 kHz; 1 W into 4 Ω; B = 22 kHz
0.0020% at 1 kHz; 1 W into 4 Ω; B = 80 kHz
0.0025% at 20 kHz; 1 W into 4 Ω, B = 80 kHz
0.0023% at 1 kHz; 100 W into 4 Ω; B = 22 kHz
0.0023% at 1 kHz; 100 W into 4 Ω; B = 80 kHz
0.0042% at 20 kHz; 100 W into 4 Ω, B = 80 kHz

Intermodulation distortion (50 Hz:7 kHz, 4:1):
0.0012% at 1 W into 8 Ω
0.0015% at 50 W into 8 Ω
0.0024% at 1 W into 4 Ω
0.0041% at 100 W into 4 Ω

Dynamic IMD (3.15 kHz square wave with 15 kHz sine wave):
0.0016% at 1 W into 8 Ω
0.0010% at 50 W into 8 Ω
0.0019% at 1 W into 4 Ω
0.0021% at 100 W into 4 Ω

Damping Factor (at K8/K9):
570 at 1 kHz into 8 Ω
315 at 20 kHz into 8 Ω

Supply voltage detection (only positive rail):
≤36.5 V = Off
(slightly temperature dependent)
≥36.7 V = On
(slightly temperature dependent)

DC protection:
+0.54 V and -0.89 V

Switch-on delay (relay):
3.5 s

WEB LINKS

[1] T. Giffard, "Medium-Power AF Amplifier," Elektor 10/1990: www.elektormagazine.com/magazine/elektor-199010/32233
[2] NJL3281D/NJL1302D data sheet: www.onsemi.com/pdf/datasheet/njl3281d-d.pdf
[3] Circuit board layout download: www.elektormagazine.com/labs/fortissimo-100

COMPONENT LIST

Resistors
(default: metal film, 1%, 0.6 W)
R1, R74 = 1 MΩ
R2, R4 = 390 Ω
R3, R5, R20, R23, R64, R66, R69 = 10 kΩ
R6, R67 = 1 kΩ
R7, R8, R13, R14, R60, R61 = 3.3 kΩ
R9, R15, R27, R28, R33, R34 = 120 Ω
R10, R11, R16, R17 = 68 Ω
R12, R18 = 5.6 kΩ 5%, 1 W, metal film or metal oxide, max. 5 × 12 mm
R19, R22, R48, R49, R52, R53 = 220 Ω
R21, R24 = 33 Ω
R25, R26 = 56 Ω
R29, R30, R35, R36 = 27 Ω
R31, R37 = 1 Ω
R32, R38 = 1.5 kΩ 5%, 1 W, metal film or metal oxide, max. 5 × 12 mm
R39, R40, R41, R42 = 22 Ω
R43 = 6.8 kΩ 5%, 1 W, metal film or metal oxide, max. 5 × 12 mm
R44, R47 = 680 Ω 5%, 3 W, metal film or metal oxide, max. 5.5 × 16 mm
R45, R46 = 1 kΩ 5%, 2 W, metal film or metal oxide, max. 5 × 12 mm
R50, R51, R54, R55 = 0.22 Ω 5%, 5 W, metal film, radial, pitch 9 mm, max. 5 × 14 mm, Koa BPR58CR22J
R56 = 4.7 Ω 5%, 2 W, metal film or metal oxide, max. 5 × 12 mm
R57 = 220 kΩ
R58, R59 = 2.2 MΩ
R62 = 1.2 kΩ
R63 = 270 Ω
R65, R70, R71 = 10 MΩ
R68 = 0 Ω (wire bridge)
R72 = 3.3 MΩ
R73 = 100 kΩ
R75 = 150 kΩ
R76 = 10 Ω 5%, 2 W, metal film or metal oxide, max. 5 × 12 mm

Capacitors
C1 = 4.7 µF 50 V 5%, pitch 5 / 7.5 mm, PET, max. 7.6 × 9.7 mm
C2 = 1.5 nF 100 V 5%, pitch 5 mm, max. 2.5 × 7.2mm
C3 = 10 pF ±0.5 pF 100 V, pitch 5 mm, C0G/NP0 (TDK FG28C0G2A100DNT00)
C4, C5 = 1 nF 63 V 5%, pitch 5 mm, PET, max. 2.5 x 7.2 mm
C6...C9 = 100 µF 16 V 20%, dia. 6.3 mm, preferably 105°C
C10, C11 = 220 pF 100 V 5%, pitch 5 mm, C0G/NP0, max. 2.5 × 7.2 mm
C12 = 100 pF 100 V 5%, pitch 5 mm, PP, max. 4.5 × 7.2mm
C13, C14, C18, C19, C29 = 100 nF 100 V 5%, pitch 5 mm, PET, max. 2.5 × 7.2 mm
C15...C16 = 680 µF 35 V 20%, dia. 12.5 mm, pitch 5 mm, 5000 h at 105°C (Rubycon 35ZL680MEFC12.5X20)
C17 = 100 nF 160 VDC 5%, pitch 5 mm, PP, max. 5 × 7.2 mm (Kemet R79GC3100Z340J)
C20 – C27 = 680 µF 50 V 20%, dia. 13.5 mm, pitch 5 mm, 10,000 h at 105°C (Rubycon 50ZLJ680M12.5X25)
C28 = 2.2 µF 50 V 10%, pitch 5 / 7.5 mm, PET, max. 7.6 × 9.7 mm
C30, C31 = 10 µF 63 V 20%, dia. 6.3 mm, pitch 2.5 mm, preferably 105°C
C32 = 10 nF 50 V 10%, pitch 5 mm, X7R, max. 2.5 × 7.2 mm
C33 = 1 µF 63 V 5%, pitch 5 / 7.5 mm, PET, max. 7.6 x 9.7 mm
C34 = 22 µF 35 V 20%, bipolar, dia. 8 mm, pitch 2.5 / 3.5 mm

Inductors
L1 = 1.5 mm enamelled copper wire, approx. 60 cm, 13 turns, ID 10 mm

Semiconductors
D1, D2 = Zener diode 20 V 5%, 0.4 W, DO-35 (Nexperia BZX79-C20,113)
D3 = Zener diode 33 V 5%, 1.3 W, DO-41 (Nexperia BZV85-C33,113)
D4, D5 = 1N4148, DO-35
LED1 – LED4 = LED, red, 2 × 5mm rectangular (Multicomp Pro MCL453MD)
LED5 = LED, green, 5 mm
T1, T2, T6, T7, T9, T10, T23, T26, T27 = BC546B, TO-92
T3...T5, T8, T11, T12, T24 = BC556B, TO-92
T13, T14 = KSA1381, TO-126
T15, T16 = KSC3503, TO-126
T17 = MJE15032, TO-220
T18 = MJE15033, TO-220
T19, T20 = NJL3281D, TO-264, 5-lead
T21, T22 = NJL1302D, TO-264, 5-lead
T25 = BS170, TO-92
IC1, IC2 = LM334Z, TO-92
IC3 = OPA177FP, DIP-8

Other
K1 = 3-way screw terminal, pitch 0.2" (Phoenix Contact 1729131 or MKDSN 1,5/3-5,08)
K2, K5 = 2-way screw terminal, pitch 0.2" (Phoenix Contact 1729128 or MKDSN 1,5/2-5,08)
2 × solder pin 1.3 mm for input (Ettinger 13.14.419)
6 × metal standoff, 10 mm, M3 M/F
6 × metal standoff, 30 mm, M3 M/F
K8, K9 = blade terminal, PCB mount, hole 3.3 mm, blade 6.35 × 0.81 mm (Amp/TE Connectivity 42822-2 or similar)
RE1 = relay 16 A / 250 VAC / 30 VDC (Omron G2R-1-E 48DC)
4x M3 × 8 machine screw (for standoffs at K3/K4 and blade terminals at K8/K9)
8x M3 × 12 machine screw, black (for board standoffs and T17/T18 on heat sink, TR Fastenings M312 PRSTMCB100-)
4 × M3×16 machine screw, black (for T19/T20/T21/T22 on heat sink, Toolcraft 839672)
18 × M3 nut
8 × M3 washer, plain, steel
HS1, HS2 = heat sink, 9 K/W, length 50.8 mm (Fischer Elektronik SK 104 50.8 ST)
Heat sink, 0.6 K/W, 100 × 180 × 48 mm (Fischer Elektronik SK53-100-SA)
4 × ceramic thermal interface pad for T19...T22, 23 × 20 × 2 mm (Silfox SL-012-AL20)
2 × ceramic thermal interface pad for T17/T18, 18 × 12 × 1.5 mm (Silfox SL-019-AL15)
2 × insulating bush for T17/T18, TO-220 (Fischer Elektronik IB 6)
1 × IC socket, DIP-8, for IC3
PCB 210364-1 v1.1

Checking the Frequency of Tuned Circuits and Crystals

Tips & Tricks, Best Practices and Other Useful Information

By Lyle Russell Williams (USA)

A tuned circuit is the parallel connection of an inductor and a capacitor that resonates at a given fundamental frequency. A quartz crystal simulates the tuned circuit and has a very high Q. Tuned circuits and crystals are integral parts of receivers and other RF equipment. This article discusses building an oscillator into which the unknown tuned circuit or crystal is placed to determine its frequency of oscillation.

In what follows an oscilloscope is used to read the frequency of oscillation. If the oscilloscope does not have a built in counter, an inexpensive stand-alone frequency counter can be connected in parallel across the oscillator. I use a €250 dual trace digital storage oscilloscope with a 50 MHz bandwidth. Stand alone frequency counters are much cheaper, some kits are available for under €10.

We Need a Suitable Oscillator

The oscillator needed for our purposes must work over a wide range of frequencies and be free of spurious responses. For this and other projects, I evaluated a NAND gate (**Figure 1**) and an inverter type (**Figure 2**). However, my implementations of these oscillators suffered from the following problems: several spikes in front of the principal waveform, frequency jitter, noise, narrow frequency range, oscillating only with crystals, and oscillating at the wrong frequency. These problems make the digital logic oscillators unsuitable for our purpose.

The Dual-Gate Oscillator

A number of years ago, I built the circuit shown in **Figure 3**. It turns out that this circuit works very well for our purposes. It produces very little noise. The frequency range is from 839 kHz to 38 MHz. Actually, it may go above 38 MHz, but I didn't try to push it into the VHF range.

It is a simple circuit which is easy to build (**Figure 4**). A potentiometer allows adjusting of the bias for optimum oscillation. The board is provided with short wires terminated with small alligator clips to connect with the tuned circuit or crystal to be tested.

Several part numbers for the dual-gate MOSFET T1 can be used: 40673, NTE222, 3N200, 3N202, 3N211, and others. Check the datasheet of the chosen device for its connections. A design for a PCB together with a component list can be downloaded from [1].

This circuit will hereafter be referred to as the "dual-gate circuit."

The JFET Circuit

So, problem solved? Well, not quite. All of the dual-gate transistors listed above are hard to find and if they can be found they are expensive. Therfore, I decided to design a circuit that did not use the dual gate MOSFET. This circuit uses two JFETs in series instead of the MOSFET and the schematic is given in **Figure 5**. The inductor can be hand wound on a ferrite toroid, see [1]. Like the dual-gate circuit a bias adjustment is provided and connection to the unknown tuned circuit is made with short wires and small alligator clips. The circuit will operate at the same low frequency of 839 kHz but the output at that frequency is much greater. The high frequency is greater than 38 MHz like the dual-gate circuit. **Figure 6** shows the completed board. This circuit will be referred to as the "JFET circuit."

The operation of both of these circuits is simple. Connect the small alligator clips to the unknown circuit or crystal. Connect the probe of an oscilloscope to its terminals on the board. Turn on the switch. Turn the bias control until oscillation is maximum. Read the frequency on the oscilloscope.

What About Low-Q Circuits?

The dual-gate circuit and the JFET circuit work well with unknowns of reasonable Q. But what if the Q is low? **Figure 7** shows how to measure low-Q unknown tuned circuits (not crystals) such as a loop antenna. This method can also be used to measure tuned circuits of frequencies below 839 kHz.

The unknown is placed into an amplifier which will be described shortly. An RF generator is used to feed the amplifier. An oscilloscope probe is connected to the unknown. The generator is tuned until the magnitude of the signal across the unknown is maximum. The frequency is read out on the oscilloscope.

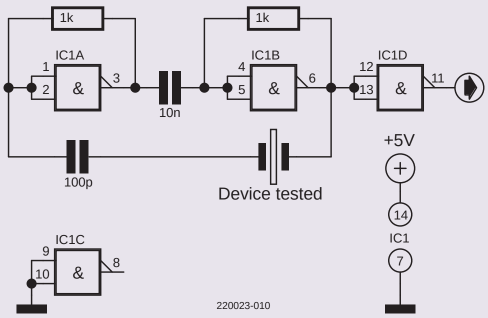


Figure 1: A NAND-gate oscillator using a 74LS00.

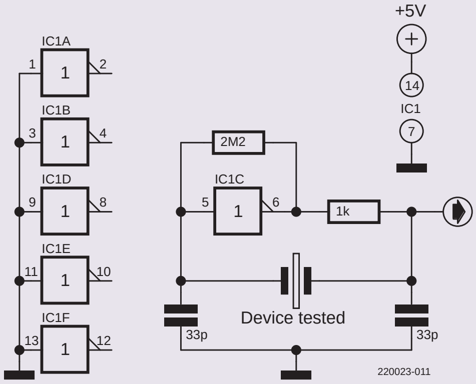


Figure 2: An inverter-based oscillator built with a 74HC04.

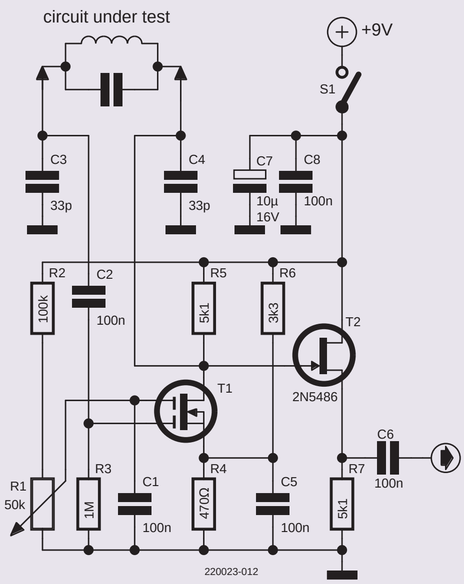


Figure 3: This oscillator with dual-gate MOSFET has a frequency range from 839 kHz to 38 MHz.

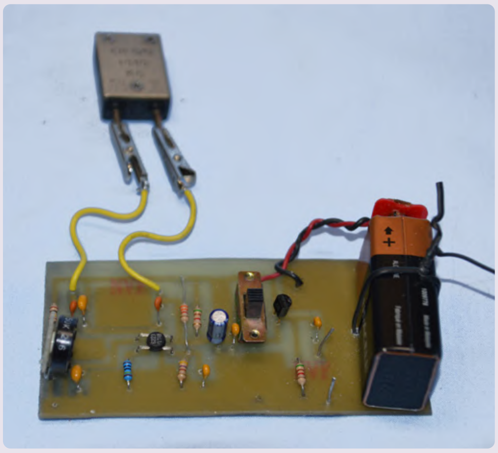


Figure 4: The dual-gate oscillator built on a printed circuit board [1].

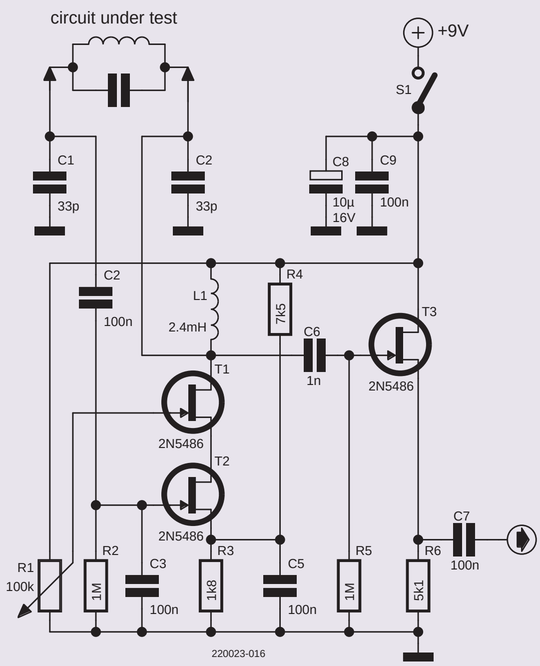


Figure 5: The JFET oscillator does not require hard-to-find dual-gate transistors.

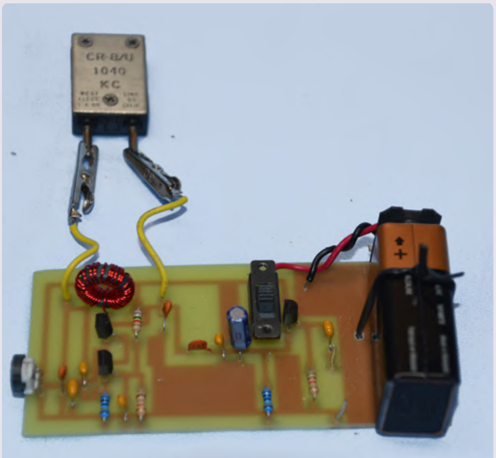


Figure 6: The JFET oscillator connected to an unknown tuned circuit.

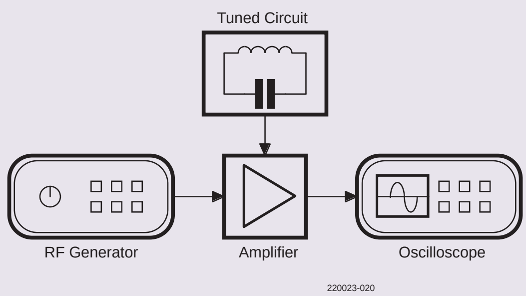


Figure 7: Overview of the low-Q frequency measurement setup.

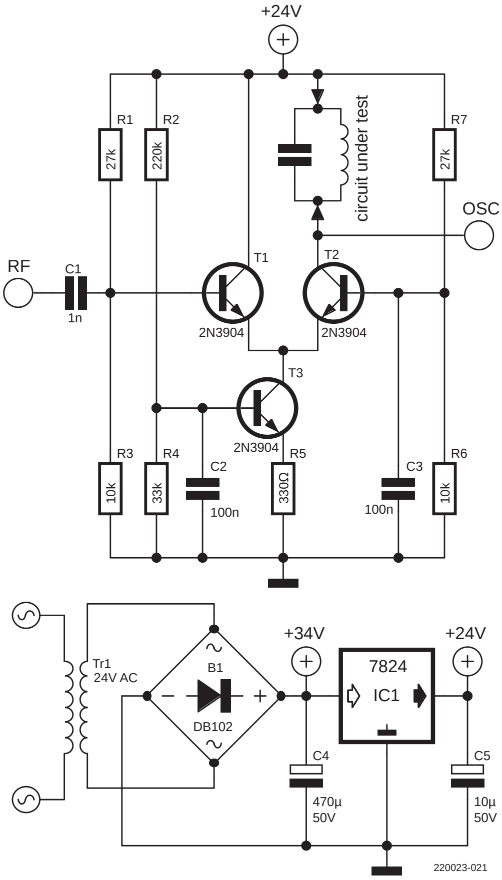


Figure 8: The low-Q amplifier circuit looks like a modulator.

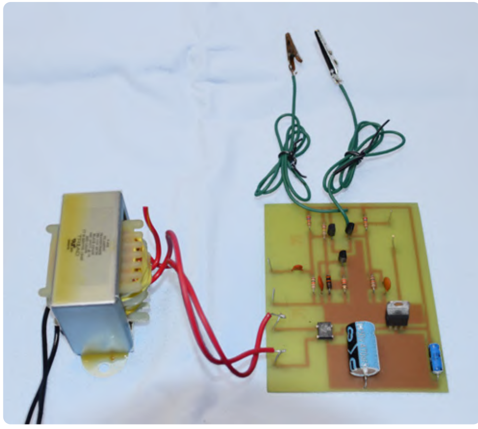


Figure 9: The test leads of the low-Q amplifier are about one meter long.

Figure 10: The low-Q amplifier used to measure the frequency of a loop antenna on an antique console radio.

With a dual-trace oscilloscope both the input and output to the amplifier can be displayed simultaneously. When the two signals are in phase, the amplitude of the output is maximum. As with the above circuits, if the oscilloscope doesn't have a counter function, then a stand alone counter can be connected in parallel with the oscilloscope probe. This will be called the "low-Q circuit".

The Low-Q Amplifier

The schematic for the amplifier for the low-Q set up is shown in **Figure 8**. Note the resemblance of this circuit to a modulator. It was originally developed for that purpose but it turns out that it works well for this application too. All the parts are easily obtainable. It is powered from the power line so no batteries are needed.

The output transistor gets its DC supply through the unknown so the latter must have a fairly low resistance to DC current. This is the resistance of the inductor of the tuned circuit. This rules out crystals which cannot pass a direct current. Connecting a crystal to this amplifier will probably damage the crystal.

As with the dual-gate and the JFET circuits, insulated wires terminated by small alligator clips are used to connect to the unknown. I have found that making the wires about a meter long is convenient (**Figure 9**).

Figure 10 shows a setup to measure the frequency of the loop antenna added to an antique radio. The loop is created by stapling two turns of wire to the back of the wooden console. By adding a parallel capacitor, the loop can be tuned to resonance at a frequency inside the AM broadcast band. I tuned the loop for the frequency of a low power transmitter used to provide vintage music to the antique radio. PCB designs and component lists for the dual-gate and JFET oscillators and the low-Q amplifier can be downloaded from [1].

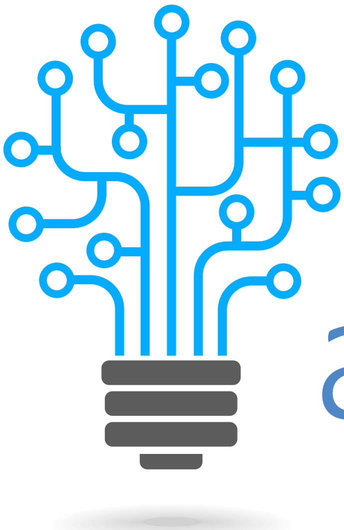
220023-01

Questions or Comments?

Do you have technical questions or comments about this article? Email the author at lyle0009@gmail.com or contact Elektor at editor@elektor.com.

WEB LINK

[1] Downloads for this article: https://www.elektormagazine.com/220023-01



PCB Tips and Tricks

By Burkhard Kainka (Germany)

You could say that almost every electronics project is not really complete until it gets its own PCB. Only then can you fully test the concept and maybe think about high volume mass production. However, the path to producing your own circuit board is often long and winding and not without its pitfalls.

Depending on your perspective, working style and previous experience, you might think that a custom PCB for a project should be ordered right at the start of the development process. You get an idea, draw a schematic, lay out the board, order it (or etch it yourself) and then assemble it. It's often the case, even though the PCB is perfect, you have overlooked a problem at a completely different level. Now you need to order another followed by a third or even fourth. Each iteration takes a bite out of the project budget and encroaches on deadlines. To avoid this, I usually put off committing to the first PCB for as long as possible.

Build a Proto-PCB!

The circuit itself needs to be checked and tested somehow. No matter how much your first test setup looks like a rats nest, it will still provide vital insights into whether everything is working as it should. Components wired up on a standard prototyping plug board will often do the job here. Alternatively, you could use strip board, but I sometimes prefer the "hedgehog" structure built on a tin lid (**Figure 1**). This gives you a decent ground plane, and the soldered connections mean you don't suffer intermittent faults from flaky connector contacts. Component values can be easily changed until everything works optimally. If the circuit proves to be unstable, you can work out the best place to site supply decoupling capacitors and small value capacitors to ground at points along the signal path.

When dealing with a microcontroller-based project, you would normally begin with an off-the-shelf development board. In this case you can connect external components to provisionally test the overall function and develop the firmware. It is often easy to see whether you will need to include precautions for interference immunity. EMC problems reveal themselves by generating interference signals that you can hear on a radio. You may have already noticed that the circuit reacts badly to nearby sources of interference. This will indicate that special attention to interference immunity will be required in the board layout.

In many cases I wire up the components on a breadboard to get a better idea of the finished board size and a possible placement of the components and any controls as well as sockets for power and signals. This can then become a handy prototype (**Figure 2**). A client could even use it to carry out initial tests and suggest changes that can then be easily tested. Once the circuit has been finalized you can then turn your attention to the PCB. Up till now wired components were probably used to build the circuit but the final PCB will most likely use SMDs. The breadboard layout has probably not been EMC-optimized because there is no ground plane but we now know what still needs to be improved.

Components and the Wiring Diagram

You probably already have circuit diagrams in the form of sketches. But all PCB design software tools require the input of the circuit diagram first. Each component needs to be specified very precisely. "Resistance 10 kΩ" won't do, you have to detail the package, e.g. an SMD resistor of size 0805. Choosing the right components is often very time-consuming because there are so many similar components. This applies above all to connectors, switches, potentiometers and the like. It's also necessary to determine that the chosen component is actually available and to be sure that its outline on the PCB layout is correct. It's so frustrating to find your beautiful pristine PCB has wrong hole-spacing and the USB socket will not fit on the board. Be very careful when selecting the components.

One thing I have found when working with SMD resistors and capacitors is they look so large and manageable on screen that it's easy to misjudge their actual size. This can be a problem if you intend to populate the board by hand. The smallest components are problematic, at least when soldering by hand. You should have a few examples of the parts at your desk to perform a quick reality check. I personally find the 0805 outline easiest to solder. I remember a project designed using 0402-size components to save space. It proved extremely difficult to solder the components to build the prototype but this situation can of course be avoided if the PCB is delivered assembled.

Once all the components have been selected, the circuit diagram can be drawn with all the connections. Incidentally, if an error occurs later when drawing the circuit board, you always have to go back to the circuit diagram and make the changes there first. The board layout software always ensures that PCB track layout matches the circuit diagram.

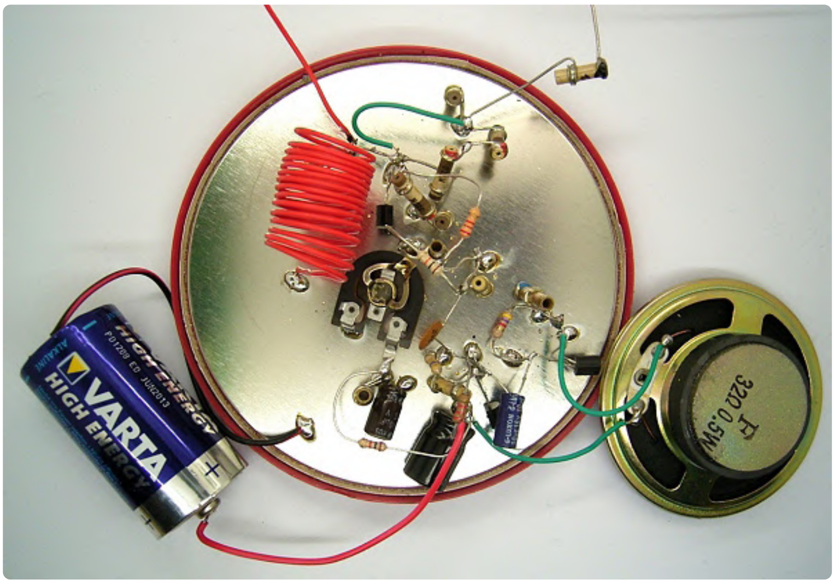


Figure 1: Test setup on a tin lid.

The PCB Layout

Now to the circuit board. First, you need to check the physical space into which it must fit to determine the dimensions and whether a double-sided circuit board will be necessary. You can now define features such as rounded corners and special outline shapes. You can change these later, but it's easier if you get the measurements right from the start.

Double-sided boards are usually standard. A single-sided circuit board has hardly any cost advantages, but it can it can simplify the process if you intend to etch it yourself. In most cases, at the first stage, I will just order five or ten samples from a PCB service provider to save myself the hassle. Some PCB suppliers also offer to assemble prototypes. In this case make sure in advance which components will be fitted and take this into account when creating the circuit diagram.

Once the outline is defined you can import all components from the circuit diagram and initially place them on screen next to the PCB outline. You can then move them one by one onto the circuit board and look for the right placement resulting in the shortest and most direct PCB track. Here it is an advantage if you have already built everything on a breadboard beforehand. You then already have an idea how to position the components with minimum number of crossing tracks so that vias to the other side can be avoided.

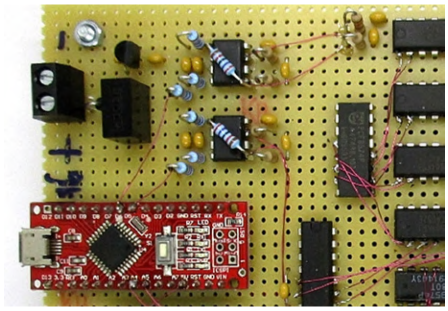


Figure 2: Test setup using a breadboard.

When all components are placed, you can start the auto router. The software then tries to connect all components as in the circuit diagram. However, it can then easily happen that the line routing is suboptimal from other points of view. There could be too long and tangled ground lines, or the "shortest" path between VCC and GND via a bypass capacitor becomes too long and forms an effective loop antenna. EMC problems are then inevitable.

You should at least lay the ground and supply lines yourself in advance and only then start the auto router. I go one step further and prefer to route all lines by hand. Above all, very simple circuits usually have a clear structure (**Figure 3**) and can be easily implemented.

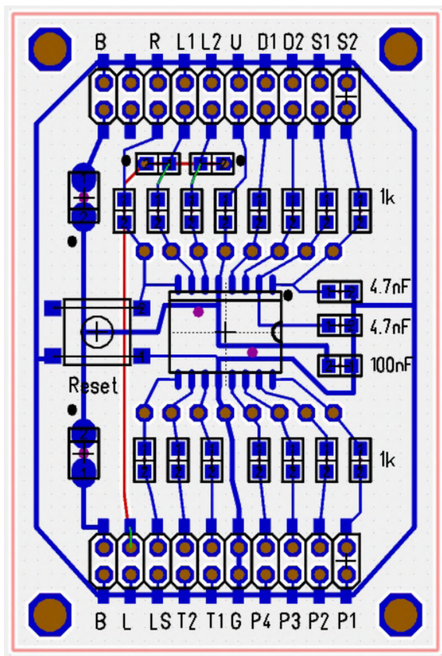


Figure 3: A ground track runs around the board perimeter.

Ground Planes

Continuous ground planes are a great help. For this you can create a continuous copper

Figure 4: The SDR shield.

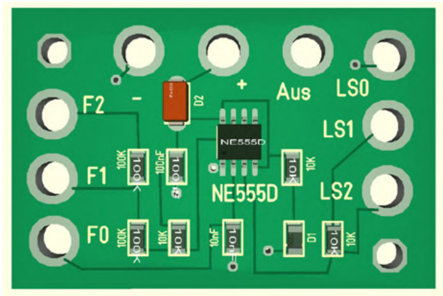


Figure 5: 4 mm diameter test points.

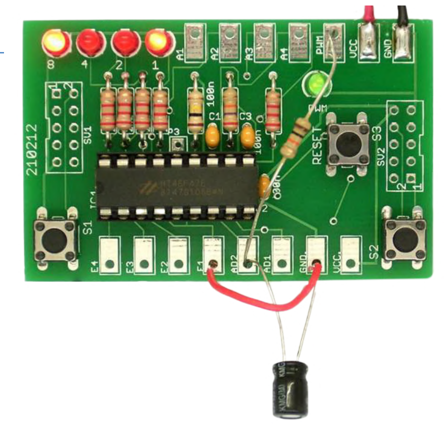


Figure 6: Experimental connector pads.

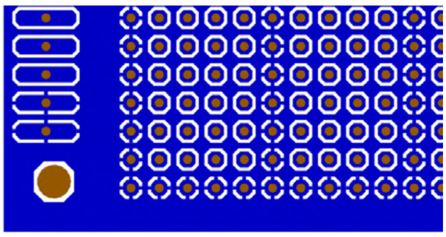


Figure 7: Matrix PCB prototyping board with ground plane.

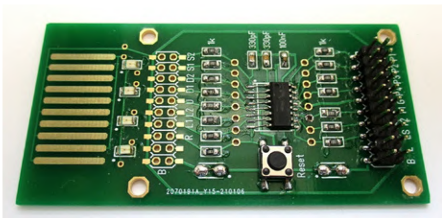


Figure 8: Doh! An outline error...

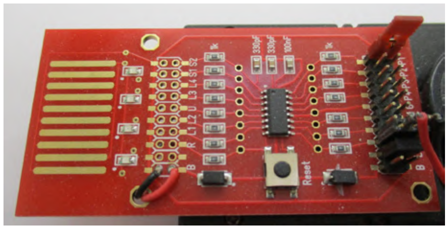


Figure 9: ... gets corrected.

surface on the underside of the circuit board connected to GND. All signal-carrying tracks stay on top as much as possible. Where it is unavoidable where two tracks cross, one track ends in a pad with a plated through hole (via) which routes the signal downwards to a small track on the lower plane and then upwards again at another point. It makes sense to establish a system with the track layout, perhaps running all the supply tracks horizontally and the signal-carrying tracks vertically as much as possible. Any break in the ground plane should be as short as possible to minimize voltage drops. Ultimately, a continuous copper plane helps to achieve the shortest possible route to ground over the entire board area; a through-hole connection is all you need when a component needs a connection to ground.

Ground planes can work wonders, as witnessed with the Elektor SDR-Shield (**Figure 4**) project. This circuit is a sensitive shortwave receiver so it's important to avoid any interference that would compromise its performance. The shield plugs directly over an Arduino Uno. At first I was worried that mounting it so close to a microcontroller might give trouble but it all worked out fine with trouble-free reception. A ground plane on the underside acts as a shield to signals from below and interference fields from above have less of an effect, because most field lines end directly at the ground and very few on the thin conductor tracks.

Connectors

Most circuit boards need some connection to the outside world. Post plugs or sockets are often used on the edge of the circuit board, as with the Arduino, or other standardized plug-in systems. When it comes to experimental projects or circuit boards for education , larger connection points are often more practical. Round, through-plated 4 mm holes will accept banana plugs directly as well as crocodile clips (**Figure 5**).

I like to specify double-sided, rectangular pads with through-plated holes spaced at 5.08 mm. These connection points do not add any additional costs and can be used very flexibly; you can solder wires, use crocodile cables or fit a screw terminal block. For very simple experiments, components can even just be plugged directly into the contact holes (**Figure 6**).

There are also PCBs that only consist of connection points. Then you don't need a circuit diagram and can start right away with the circuit board. For an HF-capable breadboard, I created a continuous ground plane on both sides. Most of the contact points are on isolated islands. But the points at the edge of the field and several continuous rows are connected to earth (**Figure 7**). In this way, the earth is easily accessible everywhere by a short route and you have a relatively good shielding surface.

Checking the Board Layout

Software used to make PCBs will run automated tests to find open circuits, short circuits and close parallel tracks. There are however other mistakes that can occur on a completely different level, which you will only be able to find out by yourself. The aim is that the first printed circuit board you order should be error-free but as you know, Murphy's Law applies here also. Looking back I estimate that every second PCB I received has had a least one error. Last minute changes are often the culprit here because they can generate a new unforeseen bug. There have also been errors made right at the project start which have somehow remained unnoticed.

To order a PCB, you have to convert the information into Gerber files. The software creates individual files for the different layers of the circuit board and for the drill holes. You can find various Gerber viewers on the web, which

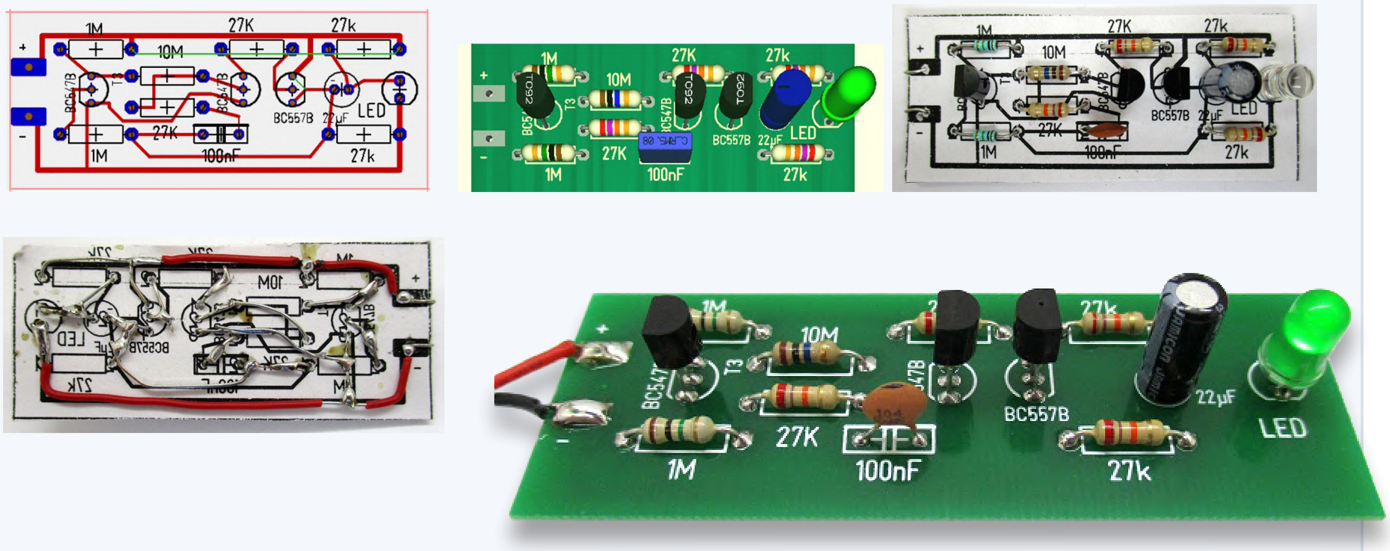


Figure 10: Draft, test setup and finished board.

you can use to view the result. You can then switch between layers and get a completely different view. This is another important stage in the verification process and has uncovered many a missed bug, even at this stage there is still some uncertainty as to whether everything will work properly in the end.

Another tip that can help to spot errors is to print out the layout and place the components over their outline. On one project I was working on I thought I could skip that because the PCB was so beautifully simple and clearly structured. With the freshly unwrapped PCB on the bench and the soldering iron up to temperature, it suddenly hit me: Wrong SO outline package for the microcontroller housing! This particular component is available in a narrow or wide outline. In this case, I still went ahead and assembled the PCB by extending all the pins of the controller on one side using small lengths of wires (**Figure 8**). That is so frustrating; I can however usually console myself by finding other tweaks that would benefit the layout (in this case better labelling) so that a new PCB iteration is not a complete loss (**Figure 9**).

When it comes to very simple boards with wired components, e.g. for training projects, you can go one step further and actually build a version of the board in advance: Stick a paper copy of the PCB layout onto a small sheet of cardboard and poke holes for the component leads. The components can then be plugged through the cardboard and soldered underneath. Short lengths of wire are then used in place of the PCB tracks. This gives you a good chance of spotting possible errors. In addition it leaves you with a usable prototype to test before committing to the final PCB layout (**Figure 10**).

Many of these strategies for designing simple circuit boards work really well with small, manageable, experimental projects, but obviously not so well with larger designs. The head of a large company may well lack understanding and pour scorn on cardboard layouts thinking they are amateurish, a waste of time and that any competent professional engineer should be able to get it right first time. Well in principle that's true but believe me - oversights and mistakes inevitably occur and multiple drafts are often required, each time adding to the costs and threatening project deadlines. I can only say the technique described here has worked well for me; the emphasis should be on preliminary trials and testing so that fewer versions of the board need to be ordered.

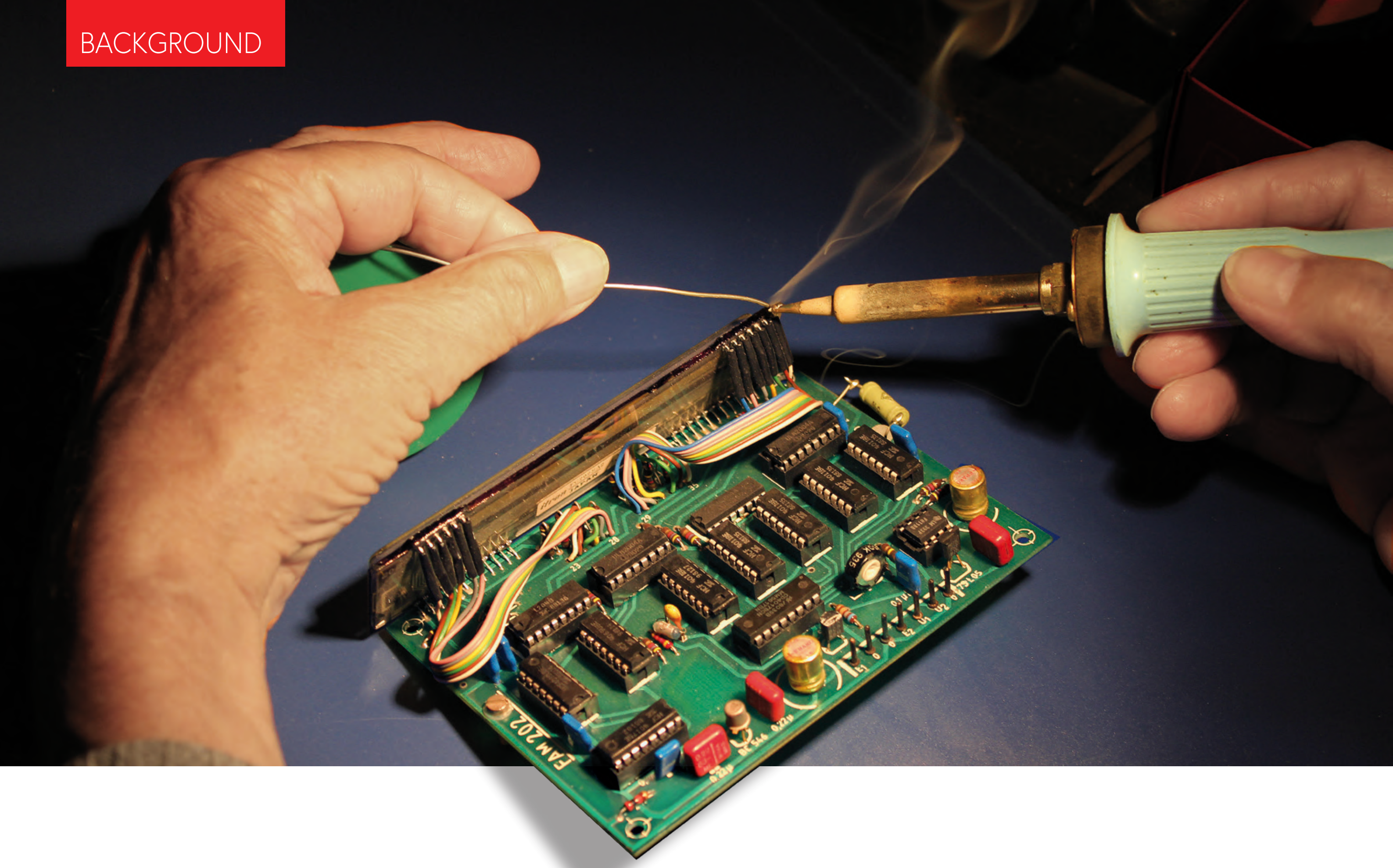
220226-01

Questions or Comments?

If you have any technical questions or comments about this article please contact the author at b.kainka@t-online.de or the Elektor team at editor@elektor.com.

About the Author

Burkhard Kainka worked as a physics teacher for many years before becoming self-employed as a developer and author in the field of electronics and microcontrollers in 1996. He runs the www.elektronik-labor.de and www.b-kainka.de websites where you will find many interesting small and large projects along with information on the basics of electronics. Burkhard is an avid radio amateur with the call sign DK7JD.



Soldering – *So What?*

A Closer Look at Current Soldering Technology

By Peter Beil (Germany)

Most people don't realize that soldering electronic components is a very complex activity with complicated thermal and chemical processes taking place in a very small space. However, if you follow some basic rules, you won't run into trouble.

Solder joints should do more than just make good contact – they also need to be mechanically strong and they shouldn't oxidize. In addition, they should be free of chemical residues, such as flux, since flux can attack nearby metallic surfaces as well as plastics.

Solders are generally divided into three categories: consumer, industrial, and high-end. The latter is used in areas such as automotive or environments where life or health is at stake. As makers, we are mainly interested in manual soldering for DIY construction and development.

Good Old Lead Solder

Lead solder was standard for many years. It has good wetting and flow characteristics and a relatively low melting point of around 183°C. Following the rule of thumb that
the working temperature at the soldering tip is equal to the melting point of the alloy plus 120°C,
this corresponds to a soldering temperature of approximately 300°C.

The flux in the solder wire is intended to dissolve oxides at the solder joint. The tin in the solder amalgamates with the copper (or other metallic layer) to produce an intermetallic diffusion zone consisting of an alloy of the two metals. This normally results in a well-formed solder joint, durable and with good mechanical strength.

Unfortunately, this is not always the case – sometimes you get a cold solder joint (**Figure 1**). Cold solder joints are caused by highly oxidized metallic layers, dirt, the wrong temperature, or early solidification during the melting process. Cold solder joints have excessive joint resistance and can even lead to the detachment of components. The electron microscope images in **Figure 2** show the deficiencies of a cold solder joint compared to a good solder joint.

In the days of lead solder, cold solder joints were clearly recognizable due to their dull matte surface, instead of the glossy surface of a good solder joint. Unfortunately, this is no longer true with lead-free solders. With the new alloys, solder joints usually have a matte surface depending on the specific composition, whether they are cold or good (see **Figure 3**).

Lead-Free in the New Millennium

The introduction of lead-free solder in 2006 has made manual soldering a bit more difficult. The new solders are designated as RoHS-compliant, which means they conform to the EU Directive on the *Restriction of Certain Hazardous Substances* [1].

Lead-free solders are not allowed to have more than 0.1% lead content. This is mainly intended to prevent the inhalation of toxic vapors, but the risk of this was actually fairly low because suitable extraction systems were available (assuming they were used).

For a long time, people were not aware of the hazards of working with lead. For example, in the old days, a professional typesetter would lose all their teeth within a few years due to the lead type.

Soldering Tips Are Hotter Now

Anyone who works with lead-free solder for the first time notices right away that the new solder needs a significantly higher temperature and has different flow characteristics. Many components do not like such high temperatures, so efforts have been made to counteract them by means of innovative fluxes and shorter soldering times. All this makes lead-free solder wire more expensive (see below).

This also means you should be on guard against especially cheap lead-free solder wire, which often is not what it claims to be. If you work with too high a temperature, you can easily damage a sensitive component or, what's worse, quickly detach a solder pad from the PCB.

Hobby developers and makers are still allowed to use lead solder, as long as they do not distribute their products on a commercial basis. This means that selling relatively large numbers of things you make in your home lab is not allowed. **Figure 4** shows that along with RoHS-compliant solder, 'makers' are still using lead solder.

What's in Solder?

Most of the lead-free alloys commonly used now have a significantly higher tin content. Previously it was approximately 63%, but now it is around 95%, depending on the manufacturer. This raises the melting point of the alloy to the range of 217°C to 227°C. Previously, the tin in the solder was the component that formed

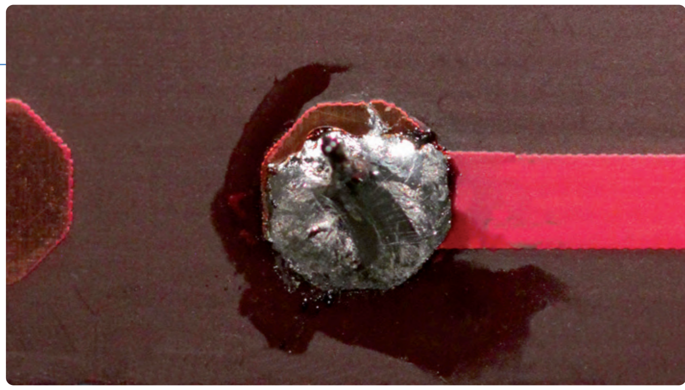


Figure 1: Bad news: a cold solder joint.

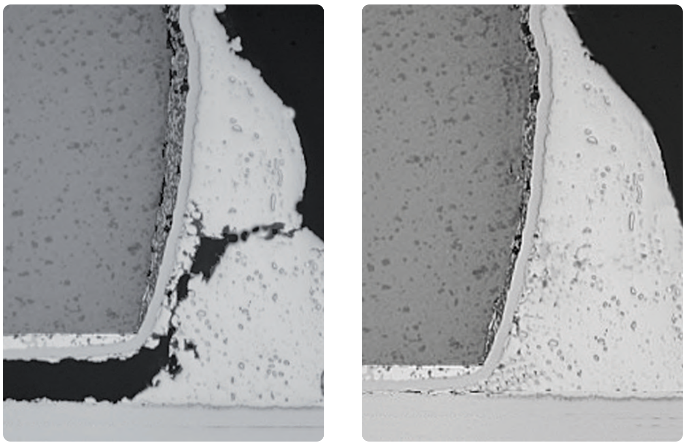


Figure 2: Electron microscope images of a cold solder joint (left) and a good solder joint (right) with good contact (source: Infineon).

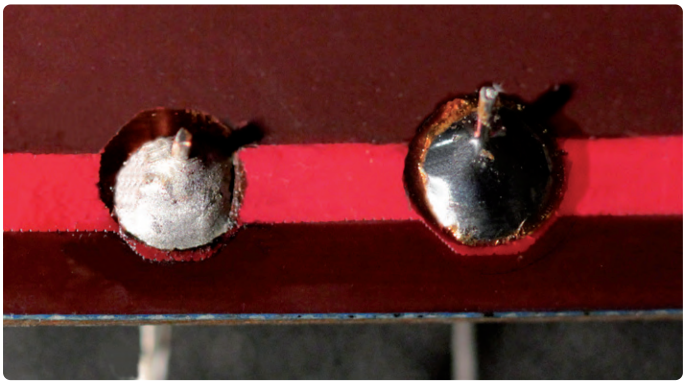


Figure 3: Different appearances: a lead-free solder joint (left) and a conventional lead solder joint (right).

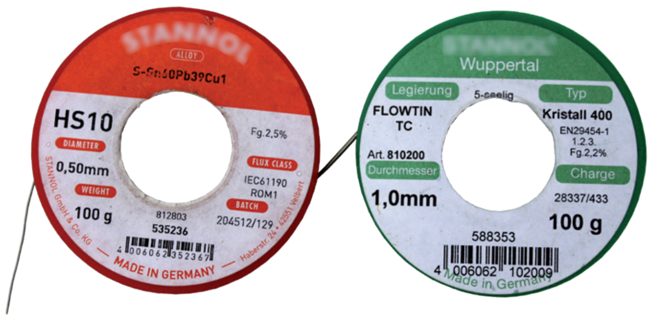


Figure 4: Lead and lead-free solder wire.

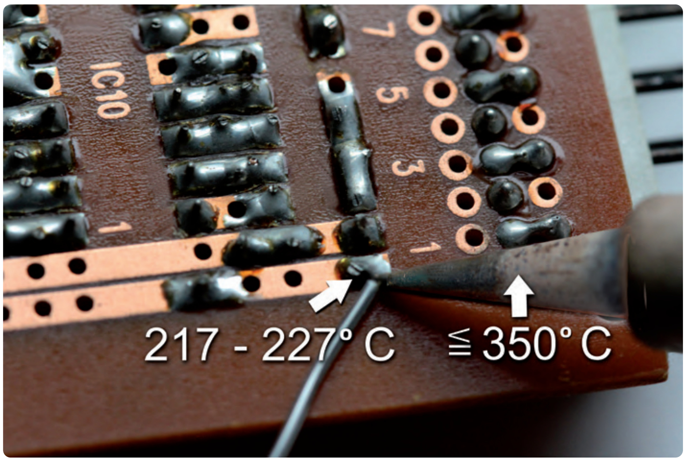


Figure 5: Some like it hot: Soldering iron temperatures for lead-free soldering.

Figure 6: Different soldering tips.

the intermetallic zone and was able to amalgamate with the solderable metal surfaces.

Lead was always the inactive component of the alloy, with the advantage that it made the solder wire cheaper and reduced the melting point of the tin from 232°C to 183°C. With more tin in the solder now, along with a higher soldering temperature, you have to pay a bit more attention to your tools and to component metallization. The solder not only amalgamates faster with copper surfaces but also strips copper from the surface faster.

Why Is Lead-Free More Expensive?

With standard lead-free alloys, the previously mentioned melting temperature of 217°C, one of the lowest possible melting temperatures, can only be achieved in the usual composition with an alloy consisting of 95.5% tin, 0.7% copper, and around 3.8% silver. This alloy has the advantage of a relatively low melting point, but the disadvantage is that the silver content of slightly less than 4% can easily make the solder wire twice as expensive.

This silver-containing alloy can basically be made more economical by reducing the silver content to 3%. Then, the alloy will have a melting temperature range of 217–223°C, which is not especially noticeable for soldering or for the life expectancy of the solder joint.

More economical alloys consist, for example, of 99.3% tin and 0.7% copper, resulting in a defined melting point of 227°C. For this, it is not absolutely necessary to raise the temperature of the soldering tip by 10°C compared to an alloy containing silver (**Figure 5**).

Temperature Limits Should Be Respected

In theory, the soldering iron temperature would have to be set to 350°C for the last-mentioned lead-free solder. If you need 10 to 20°C more to input a certain amount of heat in a short time, that's certainly possible, but temperatures above 380°C usually damage the board and the components more than they help with soldering. The flux in the solder wire core also burns significantly faster and can only do its job for a certain time at a certain temperature. Each 10°C increase in temperature cuts the active life of the flux in half; the time available to remove the oxides gets shorter, and at some point, it's not long enough.

The above-mentioned alloys naturally differ from one manufacturer to the next, and they can certainly contain additional components. For patent-related reasons, manufacturers usually do not disclose that information.

Soft soldering always involves inputting the required amount of energy and reaching a certain minimum temperature. The solder must be liquid and have a certain temperature above the melting point. This enables the amalgamation of the metallic layers to form a strong solder joint. All of the previously mentioned lead-free alloys are sufficiently durable. Very roughly speaking, the solders containing silver are better suited to applications with stronger temperature cycling, which is often accompanied by persistent mechanical stress or vibration. This applies, in particular, to the previously mentioned high-tech deployment in automotive electronics or medical equipment.

The Solder Should Flow Well

Solder wire consists not only of an alloy but also of the previously mentioned flux. In the very early days, there was no solder wire with a flux core, so people made do with solder pastes or even homemade flux. A common recipe consisted of trichloroethylene mixed with rosin, which went by the name 'soldering honey'.

The task of a flux is to remove the oxides from the parts concerned:

the component, the circuit board, and, of course, the liquid solder. This should happen for as long as possible, in order to give the longest possible time window for soldering.

A distinction is made between halogenated and non-halogenated flux. Both types remove oxides by means of an acid–metal oxide reaction. With lead-free solders, this reaction must take place at higher temperatures, and it must be active longer at higher soldering temperatures. The flux must be able to flow ahead of the solder in sufficient quantity, remove the oxides, carry the resulting salts away from the solder, and leave the liquid solder with a nice, clean, purely metallic surface. On the other hand, there should not be too much flux present, so that excessive residues do not have to be removed afterwards. Solidified flux is not only unattractive but (contrary to popular opinion) it usually remains chemically active, so you should, in any case, be careful.

Lead-Free Solder Needs a Bit More Energy

More energy is needed for a lead-free solder joint than for a conventional lead solder joint. As the required amount of energy is higher, you should regard heat transfer to the solder joint as an important aspect of soldering. Every soldering task requires a soldering tip with a suitable heat transfer surface so that the higher energy needed to melt the lead-free solder does not have to be achieved solely by raising the working temperature.

Selecting the right soldering tip (**Figure 6**) is, therefore, an important consideration, as is continual cleaning of the tip, since it also oxidizes and becomes covered with scale under high heat stress. The contact surface of a soldering tip also tends to get hollowed out after long use. This significantly reduces the effective heat transfer.

Studies have shown that when using lead-free alloys, raising the temperature (for example from 360°C to 410°C) has a nearly exponential effect on soldering tip wear and significantly shortens the lifetime of the soldering tip. For this reason, it is generally advisable to use a slightly longer soldering time or contact time instead of increasing the working temperature. A soldering station rated at 80 W or higher would be the right choice.

Summary

Lead-free soldering is not more complicated; it's just different. First of all, you need to become familiar with the different spreading and wetting characteristics of lead-free solder. You also need a slightly longer soldering time, to avoid raising the soldering temperature unnecessarily. Actually, not that much has changed. It's advisable to try a number of different solders to find the one you like best. Generally speaking, solders with relatively high silver content are preferable, even if they cost more.

Now we're no longer exposed to lead vapors, but the actual fumes come from the flux, and nobody knows exactly what is in the flux. A solder vapor extraction unit (even a small one) is, therefore, still a good investment.

210653-01

Further Reading

Some well-known manufacturers of soldering products offer an amazing amount of general information on the subjects of lead and lead-free solder wire, fluxes, soldering tips, instructions and practical tips, and much more, all for free download.

www.felder.de/downloads/allgemeine-informationen.html [German]
www.stannol.de/en/downloads.html
www.almit.de/index.php#Goodtoknow
www.almit.de/soldering-tips-and-working-life

Questions or Comments?

Do you have technical questions or comments about this article? If so, please contact the Elektor editorial team at editor@elektor.com.

WEB LINK

[1] RoHS Directive: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32002L0095

Low-Latency Bluetooth **Garage Door Control**

Take Control with Short BLE Messages from a Smartphone

By Stephan Lück (Germany)

I often want to open my garage door, but I rarely have the 433-MHz remote control transmitter in my pocket. Thus, I built a small Bluetooth Low Energy (BLE) receiver that can be controlled by an Android app on my smartphone.

A particularity of this project is that BLE advertising Protocol Data Units (PDUs) are used, thereby avoiding connection setup delays. The system thus responds as quickly to a remote control command as a classical hardware garage door transmitter/receiver combination would do. There is one-way communication from the smartphone to the receiver only, which is secured by HMAC [1]. The idea was to keep everything simple, both the hardware as well as the software.

I share this project in the hope that you might find it useful or use it as a basis for similar projects. The source code is available on GitHub [2].

The Protocol

To transmit a command, BLE advertising PDUs are used, which are described in Volume 6, Part B, Section 2.3 of the Bluetooth specification [3]. For compatibility reasons, the short (legacy) advertising PDUs are used that contain an *AdvData* field of at most 31 bytes. The *AdvData* field contains a sequence of Advertising Data (AD) elements [4] (cf. Volume 3, Part C, Section 11 of the Bluetooth specification). One possible AD element is the *Service Data* AD element (cf. Bluetooth Core Specification Supplement, Part A, Section 1). The *Service Data* AD element includes a *Service UUID* followed by an arbitrary number of bytes.

This *Service Data* AD structure is used to transmit a remote control command. The *Service Universal Unique Identifier (UUID)* with 128 bits corresponds to a unique transmitter ID. In other words, each transmitter defines a specific BLE service. The data appended to the UUID are structured as follows, and can be seen simplified in **Figure 1**:

```
typedef struct {
uint8_t cmd; /* command (currently
always 0) */
uint8_t seq_no[3]; /* sequence number
(big endian) */
uint8_t digest[4]; /* first four
octets of HMAC-SHA256 */
} gd_message_t;
```

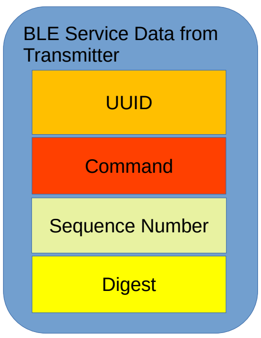


Figure 1: Simplified data structure.

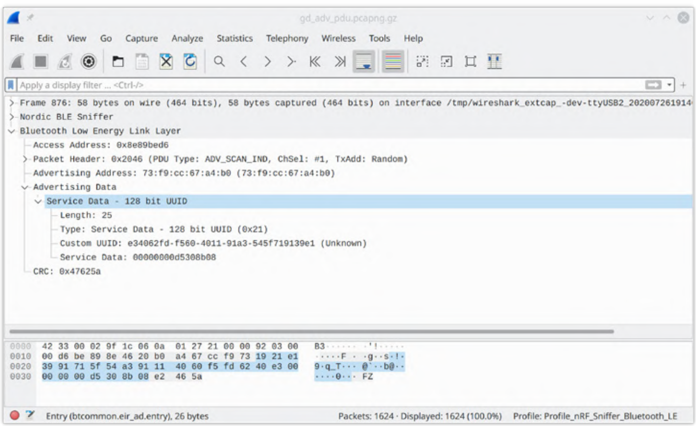


Figure 2: PDU captured by Wireshark.

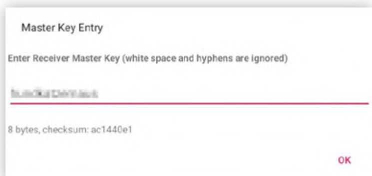
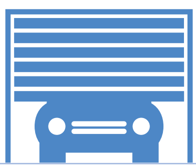


Figure 3: App start and key generation.



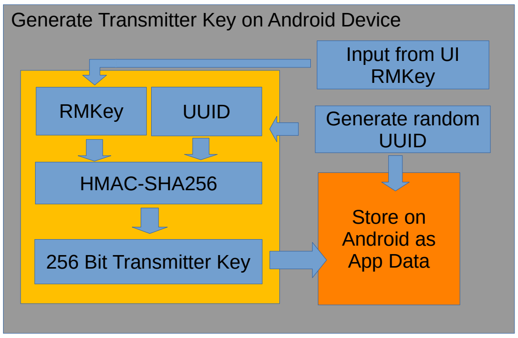


Figure 4: Flow for Transmitter Key calculation.

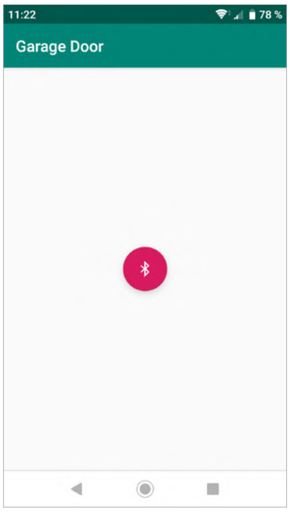


Figure 5: App is ready to be used.

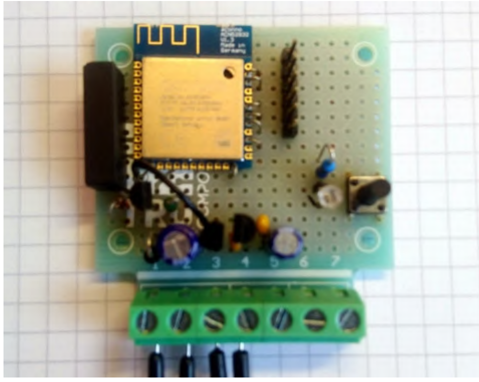


Figure 6: Prototype ready.

The digest authenticates the message. The sequence number allows to detect duplicate PDUs and prevents replay attacks. Since BLE advertising PDUs are not encrypted, it is possible for others to receive both the UUID as well as the additional data.

The digest is calculated based on a transmitter key. The transmitter key is derived from a receiver master key (RMkey) stored in the receiver, based on the transmitter UUID.

```
transmitter_key = HMAC-SHA256(RMkey,
transmitter_UUID)
```

An example of an advertising PDU is shown in the attached Wireshark screenshot (**Figure 2**).

The Transmitter

The transmitter is a simple Android App requiring API level 21 (corresponding to Android 5 “Lollipop”). When first started, the App calculates a random UUID and shows a setup dialog to enter the RMkey as a base32-encoded string (see **Figure 3**). The setup dialog shows the length of the key and a CRC32 checksum to help the user in avoiding typos when entering the key. The App calculates the transmitter key from the UUID and the RMkey and then throws the RMkey away. The tuple (UUID, transmitter key), corresponding to a transmitter identity, is then persistently stored. The transmitter identity is lost when the App is uninstalled or application data is manually deleted. A principle for the calculation is shown in **Figure 4**.

Once set up, the App shows a red button (see **Figure 5**). When clicking the button, a BLE advertising procedure is configured to repeatedly transmit the above-described *Service Data* AD structure during an interval of a few seconds.

The Receiver

The receiver has been built on a prototyping board around the aconno ACN52832 BLE module [5] (**Figure 6**). It has a Nordic Semiconductor NRF52382 microcontroller, a push button, an LED and a relay to be connected to a garage door drive. The receiver needs a 9V to 24V DC power supply. If possible, the supply voltage can be taken from the garage door driver. Otherwise, a simple wall power supply would do as well. You can find the schematic at **Figure 7**.

When building the software for the microcontroller, a Python script creates the file *rxm_key.bin* that contains the 20 byte RMkey. Moreover,

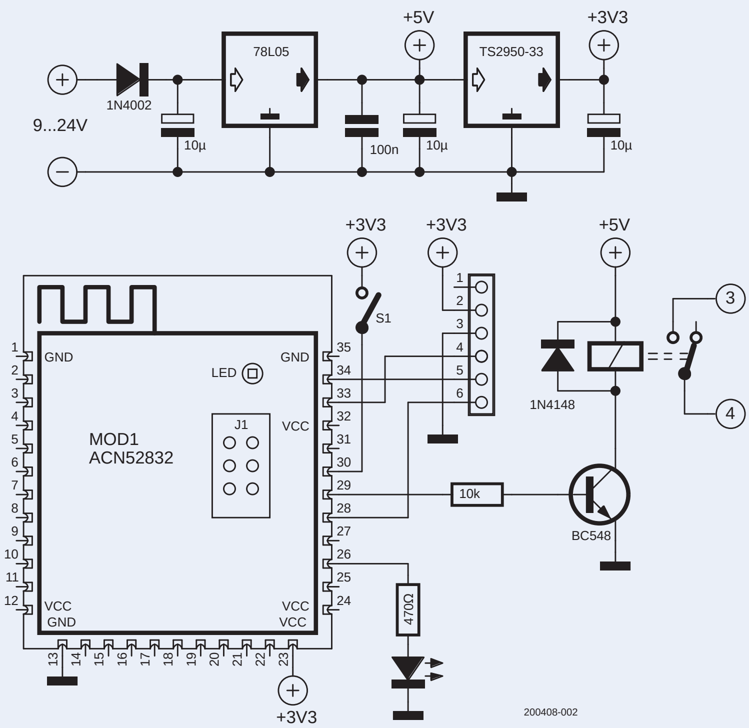


Figure 7: Receiver schematic.

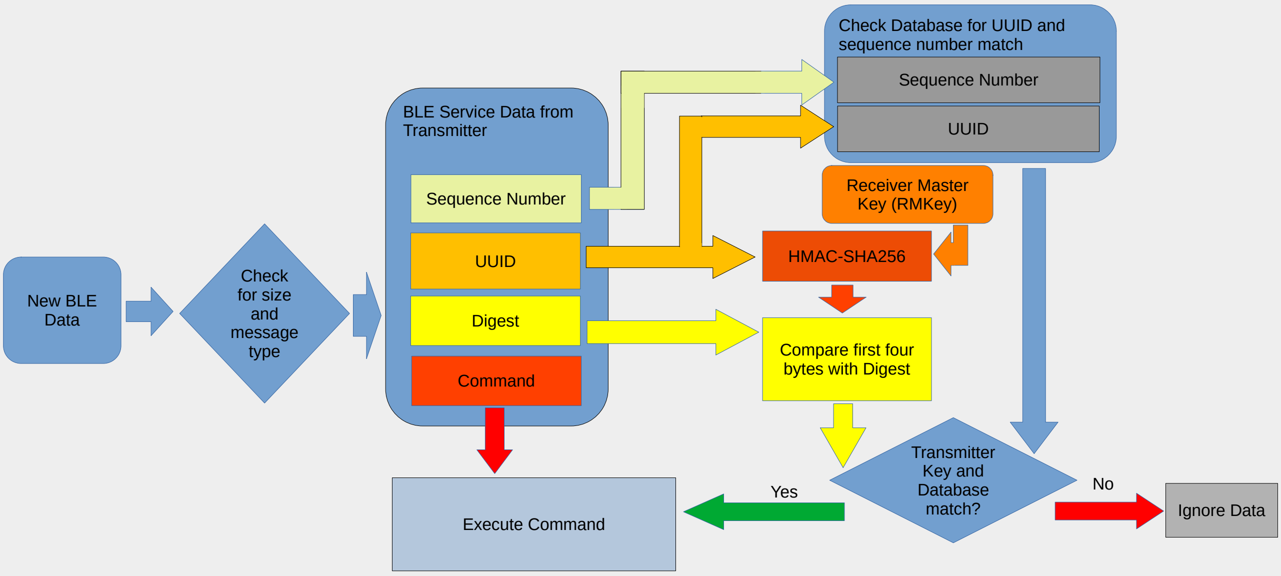


Figure 8: Flow for receiving BLE data.

a textual representation of the key is generated and stored in *_build/rxm_key.txt*. The latter contains the information to be entered into the transmitter App when first started.

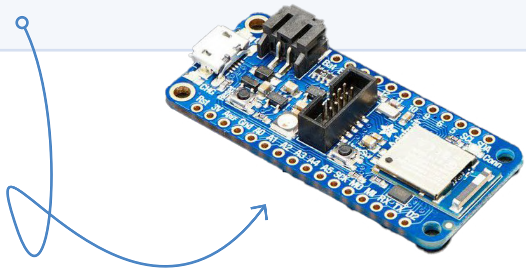
The receiver maintains a database of transmitter UUIDs and sequence numbers. To add a new transmitter, the button must be pressed and then the transmitter to be added must be activated. When the button is pressed for more than five seconds, the database is cleared and the receiver will not respond to any transmitter anymore.

When the receiver gets an advertisement PDU containing the above-described *Service Data* AD structure, it checks the digest, whether it knows the transmitter UUID and whether the sequence number is correct (**Figure 8**). If all checks succeed, the relay will be activated for one second.

200408-01

Questions or Comments?

Do you have technical questions or comments about this article? Contact the author via GitHub [2] or contact Elektor at editor@elektor.com.



WEB LINKS

[1] HMAC (Wikipedia): https://en.wikipedia.org/wiki/HMAC
[2] GitHub Repository: https://github.com/kiffie/ble-garage-door
[3] Bluetooth SIG: https://www.bluetooth.com/
[4] Bluetooth Advertising Data Basics, Silicon Labs: https://bit.ly/silabs-bluetooth-ad
[5] ACN52832 by aconno: https://aconno.de/products/acn52832/

Ideal Diode Controller

Diode Circuits with Low Power Dissipation

By Rainer Schuster (Germany)

Reducing power dissipation from diodes is essential in all situations where high currents flow at relatively low voltages (e.g., when solar panels or lithium-ion batteries are connected in parallel). Ideal diode controllers have been developed to minimize power dissipation in such cases.

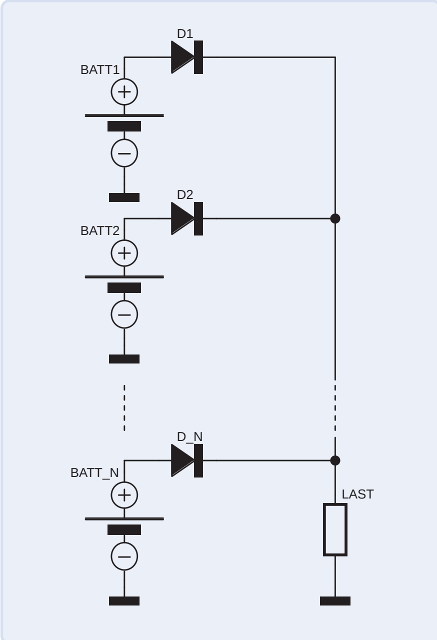


Figure 1: Low power dissipation is important when solar panels or batteries are connected in parallel.

A typical diode use case is shown in **Figure 1**. There the diodes are required to prevent current from flowing from one battery or solar panel into another battery or solar panel. But if you consider the power dissipation of silicon diodes, for example a type 1N5404, the data sheet says that the forward voltage is 1 V at 3 A (**Figure 2**). This means the power dissipation at 3 A is a hefty 3 W.

Things are a bit better if you use a Schottky diode such as the 1N5822, which can also handle 3 A. At this current level the voltage drop over the diode is only 0.45 V, corresponding to a power dissipation of 1.35 W as illustrated in **Figure 3**.

But if you want to use diodes at higher currents, such as 100 A or more (which is certainly realistic with lithium-ion batteries), the power dissipation rises to an unacceptable level of 50 W or more, even if you use Schottky diodes.

The Ideal Diode

To reduce this power dissipation, Linear Technology has developed ideal diode controller devices such as the LTC4357. This controller has an input pin (anode), an output pin (cathode), and a ground pin. Combining the controller with an n-channel MOSFET, as shown in the circuit in **Figure 4**, produces an 'ideal' diode, and the LTC4357 has a rated maximum voltage of 80 V. Of course, the maximum rated drain-source voltage of the MOSFET must be at least equal to the voltage present between the input and output. The maximum diode current only depends on the maximum rated drain current of the MOSFET, and the power dissipation is solely dependent on the drain-source resistance of the MOSFET in the On state.

In the typical application circuit shown in Figure 4, the LTC4357 basically operates as a comparator. When the input voltage is higher than the output voltage, Q1 is switched on, and otherwise Q1 is cut off to prevent current flow from the cathode (drain) to the anode (source).

Looking at Figure 4, you may wonder how the circuit can work with the LTC4357 supply voltage pin (VDD) connected to the output (cathode). The answer is that when the LTC4357 is powered up, it draws its supply voltage through the body diode of the MOSFET if no voltage from another source is present at the cathode. As an additional feature, the MOSFET is switched off if there is a short-circuit between the cathode terminal and ground.

In the illustrated application circuit, a type IRF2805 MOSFET is used. According to its data sheet, the drain-source resistance

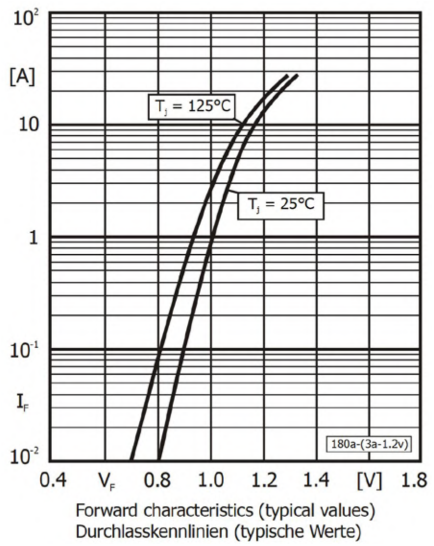


Figure 2: 1N5404 forward voltage versus current characteristic (source: Diotec Semiconductor data sheet).

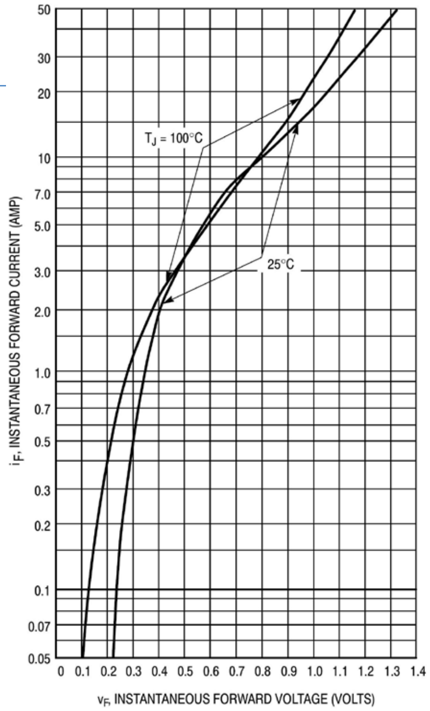


Figure 3: 1N5822 forward voltage versus current characteristic (source: Onsemi data sheet).

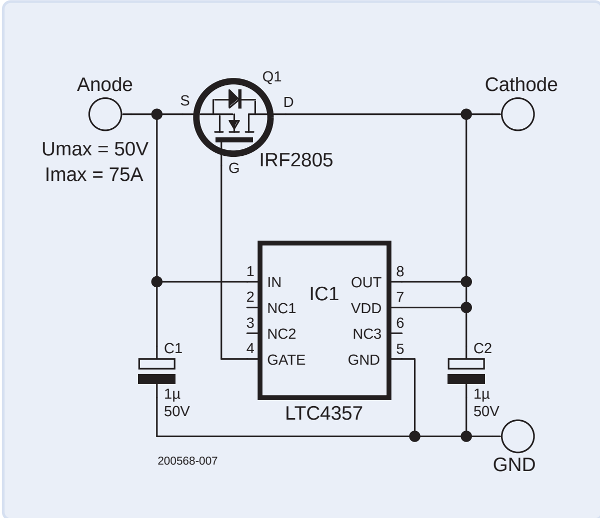


Figure 4: The standard application circuit consists of an ideal diode controller and a MOSFET.

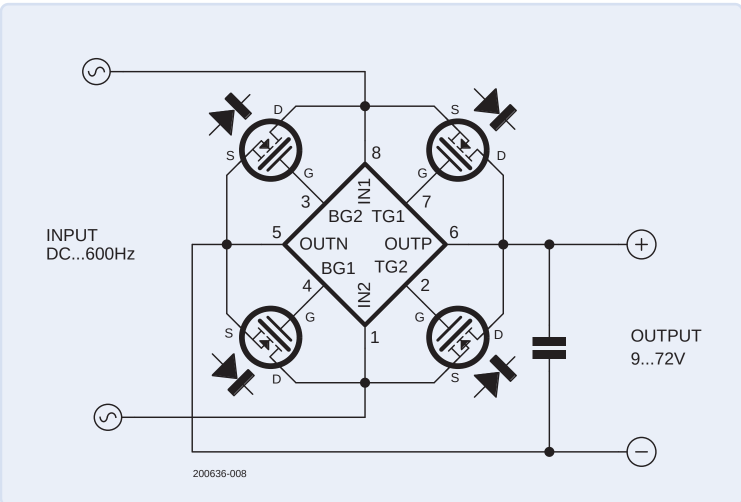


Figure 5: A rectifier using the LT4320.

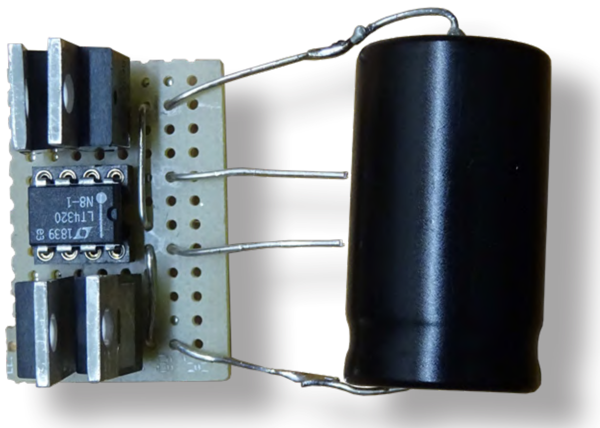


Figure 6: Prototype rectifier circuit on perfboard.

is only 4.7 mΩ. With a current of 3 A, the voltage drop over the MOSFET is therefore only 14.1 mV, so the power dissipation is a modest 42 mW. The following table shows comparative figures for the MOSFET and a diode (in this case an IXYS DSEI 120) at a current of 75 A.

The Eagle files for the schematic diagram and layout of the previously illustrated application circuit are available at [1].

Component	Voltage drop	Power dissipation
IRF2805	350 mV	26 W
DSEI 120	1.5 V	112.5 W

What About AC?

There's a limitation with the LTC4357: it's not suitable for rectification of AC voltages. To deal with this, Linear Technology also offers the LT4320, which can be used to build a bridge rectifier. The typical application circuit shown in **Figure 5** is taken from the Linear Technologies data sheet.

Bridge rectifiers for voltages from 9 to 70 V can be implemented in this way. The frequency range extends from DC to 60 Hz with the LT4320, or DC to 600 Hz with the LT4320-1. Here as well, the maximum current and power dissipation of the rectifier depend on the MOSFETs used. The Eagle files for the schematic diagram and layout (for SMD and THT versions) of this rectifiers circuit are also available at [1]. The layout is designed so that the assembled circuit can replace conventional type BxxCyyyy bridge rectifiers. **Figure 6** shows a rectifier circuit built on a piece of perfboard.

Summary

The Linear Technology ideal diode controllers allow the power dissipation of diodes and rectifiers to be drastically reduced. The increased circuit complexity (and additional cost) is entirely acceptable in circuits operating at high current levels.

Of course, the Linear Technology ideal diode controllers are not perfectly ideal, as can be seen from the voltage waveform of the 'ideal diode' rectifier (**Figure 7**), since the parasitic parameters of real components cannot simply be wished away. Nevertheless, the combination of controller and MOSFET is the best way to reduce the power dissipation of a diode.

Schematic diagrams for simulation with LTSpice are available for the LT4357 and LT4320 at [1]. A video on this topic can be viewed at [2].

200568-01

Questions or Comments?

Do you have any technical questions or comments about the ideal diode controller? Contact the Elektor editorial team at editor@elektor.com.

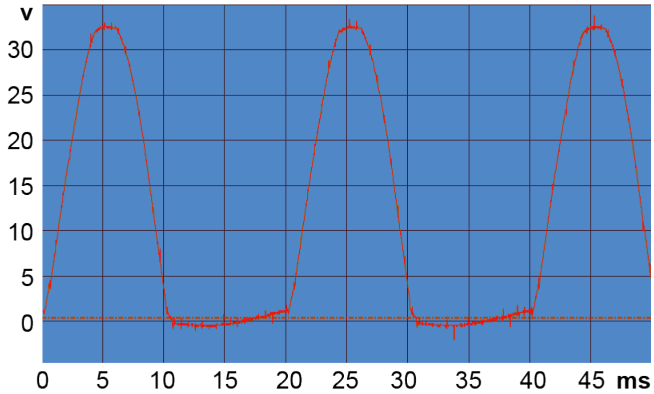


Figure 7: Rectifier output voltage waveform.

RELATED PRODUCTS

- **M. A. Shustov and A.M. Shustov, *Electronic Circuits For All* (SKU 18333)**
  www.elektor.de/18333

WEB LINKS

[1] Elektor Labs page for this project: https://bit.ly/3PDZVz5
[2] R. Schuster, "Ideal Diode Controller," YouTube, November 2020: https://www.youtube.com/watch?v=nd1zTrDmi0w

LED Garlands with ESP32 and FreeRTOS

Flashing and Variable Brightness

By Serge Sussel (France)

For holidays and parties, 24 V DC LED strings that flash and vary in brightness can be eye candy. You need only an ESP32 to drive an entire system with 13 different parameters. With FreeRTOS, multiple program tasks can run at the same time.

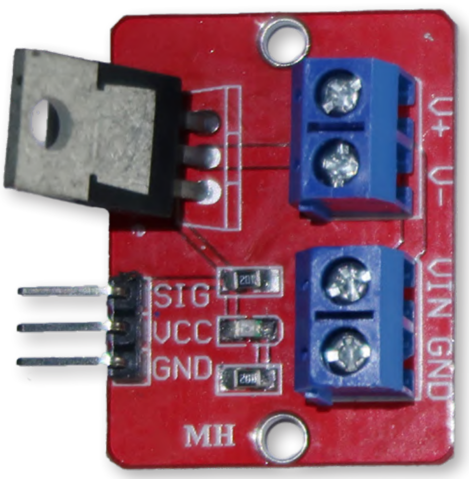


Figure 1: FET module.

For the end-of-year celebrations, I wanted to decorate and illuminate the Christmas tree. I had very old string lights with incandescent bulbs in series, each encapsulated in small colored plastic lanterns. And, to bring this string of lights to life, a primitive thermal switch was connected between the power grid and the lights. In addition, the string was quite short, so the animation capabilities were quite limited for the tree.

So, I looked for a commercial site on the web for garlands using LED technology, which consumes less power and doesn't get as hot. I found one (Lumitronix) and opted to purchase two much longer colored LED string lights with the correct transformers. It's a 24 V system with a rectifier that can power several LED strings. Alone, the colored string lights remain on all the time without animation — a little sad for Christmas tree lights.

I also updated my old garland by removing the filament bulbs and replacing them with colored LEDs of the same color as each plastic incandescent lamp, and lengthened the wires between each lamp, conformed for 24 V, with the LEDs having a series-connected current-limiting resistor in the connector. This produced three strings of lights for me.

Finally, to animate everything, I thought of programming and using a microcontroller, and, with a MOSFET interface, driving the strings to flash or vary the LEDs' brightness. I also educated myself by reading books on C/C++ and on the Arduino to train myself and to learn new things.

To begin with this project, I wondered how to use several PWM outputs simultaneously, but in an asynchronous manner, in order to have a different animation for each string. I was thinking of developing a finite-state automation for this, but I found that a bit complicated.

So, I started the project with an Arduino Nano and some simple programming that drove a single PWM output with the MOSFET interface. Then, I duplicated all of this, so that I could control two garlands.

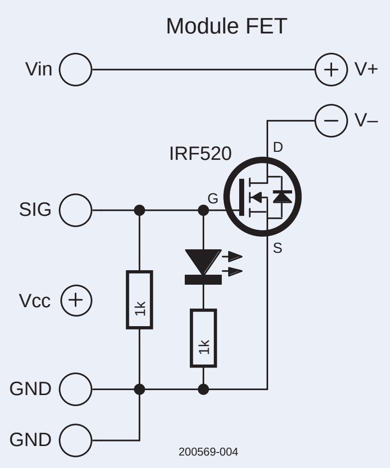


Figure 2: FET module schematic.

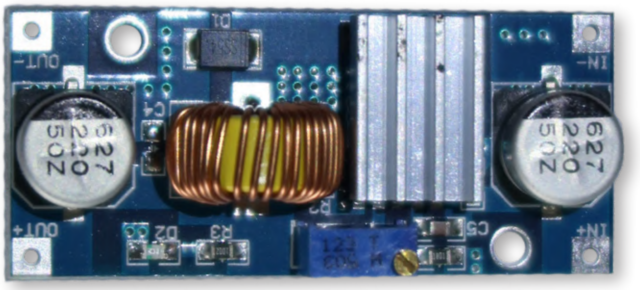


Figure 3: DC/DC Converter to get 5 V output.

As I had three strings, the third one had the same animation as one of the other two. While testing the project, I also improved the program's animation settings several times to improve the visual aesthetics.

The ESP32 Project

While discovering and reading Elektor's articles by Warren Gay about FreeRTOS [2], and also after the acquisition of his book on this subject (see Related Products), I tried to adapt FreeRTOS to the Arduino Nano, but I quickly found its limits. After several tries, I couldn't run more than one RTOS task at a time on the Nano. Surely, there were optimizations to do.

So, I turned to the ESP32 platform in order to port my project to this platform and implement FreeRTOS and independent asynchronous tasks. I started by writing one task into it, and discovered the differences between this microcontroller (ESP32) and the Arduino Nano in C/C++ programming.

After several programming and testing iterations, I no longer had any compilation errors, and the task was working. With my oscilloscope on the PWM output pin, I was getting the signals I wanted. And, with FreeRTOS, each task is independent of the others, if we don't use a wait-and-synchronize mechanism. That's exactly what I wanted to do.

Thus, each string is able to have its animation drawn randomly, however, two identical animations at the same time are rare and, even if they are, they won't begin at the same time due to time lags in previous animations.

I was able to measure the ESP32's power and, after several trials and tests, managed to create two, then three, then four tasks that ran simultaneously. So, I used FreeRTOS on the ESP32 to drive four outputs via four tasks. However, the ESP32 is able to drive more outputs with its additional available PWM pins.

I use the PWM outputs so that I can gradually vary the brightness of the LED strings, and also switch them on and off, among other animation settings. I mounted my project on a hole-matrix board and put everything in a plastic box. I also posted this project on elektormagazine.com/labs.

Necessary Components

To source components for my project, I consulted the Far East Internet and found small modules all with mounted MOSFET, resistors, and LEDs. However, delivery times were more in weeks than in days. So, I reverse-engineered the module (see **Figure 1** and the schematic in **Figure 2**).

Likewise, I found a fully-assembled and adjustable power supply module accepting 24 V DC input, and, after adjusting the multi-turn potentiometer, it delivered the appropriate output voltage (5 V) for the microcontroller (**Figure 3**).

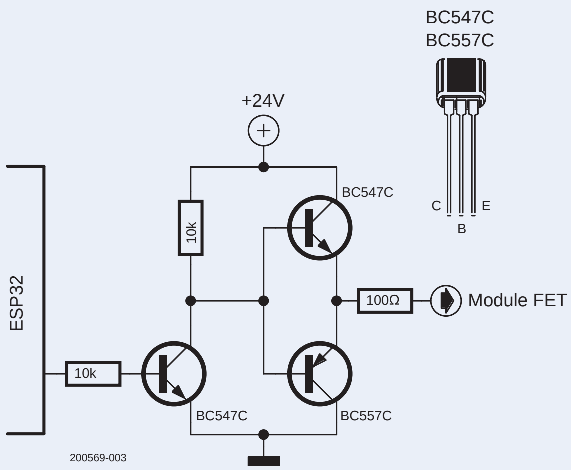


Figure 4: Driver for MOSFET.

Listing 1: 13 sets of parameters for the animations.

```
#define MAXPROGR 13   // Max value of LED
                     // programs (0 to MAXPROGR -1)

// struct for LED programs
 struct  pled_t    /* structure def */
 {
     int ledvar;    /* 0: flashing ; 1: light
                                          varying */
     int ledon;     /* time ON */
     int ledoff;    /* time OFF */
     int ledvaloff; /* value for OFF status */
     int ledxtime;  /* repeat this program x times */
 };
pled_t pled [MAXPROGR];  /* reserve memory for the
                  parameters for the LED programs */


...


// init for the LED programs' parameters

     pled[0].ledvar = 0;
     pled[0].ledon = 750;
     pled[0].ledoff = 900;
     pled[0].ledvaloff = 18;
     pled[0].ledxtime = 7;

     pled[1].ledvar = 0;
     pled[1].ledon = 1100;
     pled[1].ledoff = 800;
     pled[1].ledvaloff = 18;
     pled[1].ledxtime = 8;

...

     pled[5].ledvar = 1;
     pled[5].ledon = 1024;
     pled[5].ledoff = 1024;
     pled[5].ledvaloff = 0;
     pled[5].ledxtime = 6;

     pled[6].ledvar = 1;
     pled[6].ledon = 1280;
     pled[6].ledoff = 1280;
     pled[6].ledvaloff = 0;
     pled[6].ledxtime = 5;

...
     pled[12].ledvar = 1;
     pled[12].ledon = 1024;
     pled[12].ledoff = 512;
     pled[12].ledvaloff = 0;
     pled[12].ledxtime = 8;
```

Listing 2: Variable mode for fading on and off.

```
// values for each step in variable program for
// LED,
// 32 steps for OFF to ON and same for ON to OFF,
// half sine values
 const int varval[] = { 0, 10, 25, 35, 45, 60,
75, 90, 100, 112, 122, 134, 145, 155, 165, 175,
184, 192, 200, 208, 215, 220, 226, 232, 236, 239,
241, 244, 247, 250, 253, 255 };
```

Listing 3: Defines for the hardware.

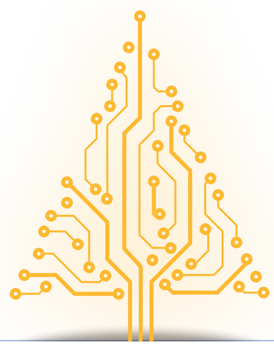
```
// Defining User Types
 // 4 garlands for this project
 #define GUIRL_A  16         // GPIO for garland A
                        // digital  PWM - Task1Led
 #define GUIRL_B  17         // GPIO for garland B
                        // digital  PWM - Task2Led
 #define GUIRL_C  18         // GPIO for garland C
                        // digital  PWM - Task3Led
 #define GUIRL_D  19         // GPIO for garland D
                       // digital  PWM - Task4Led


 ...


// Setting PWM ESP32 properties
 const int freqpwm = 5000;     // Freq Hz
 const int resolution = 8;     // 8 bits
 const int ledChannelA = 0;    // Channels for
                              // each garland
 const int ledChannelB = 1;    //
 const int ledChannelC = 2;    //
 const int ledChannelD = 3;    //
```

Listing 4: Task deleting itself.

```
void loop()
{
 // Delete self, unused
  vTaskDelete(nullptr);
} // end loop
```



Also, in an Elektor article, I found an interesting assembly to drive the MOSFET module, based on three transistors—a couple of BC547s and a BC557—and their respective resistors (see **Figure 4**) to improve transitions on the MOSFET gate. However, this inverts the signal, so that must be borne in mind when programming. Yet again another order to be placed and its arrival patiently awaited.

With all the components finally in hand, I was able to assemble and carry out final testing. Fortunately, the MOSFET modules were delivered as a set of 5 because I ended up with just the body of one MOSFET transistor in my fingers. It must have been bent several times, weakening its pins. A bit of tinkering by me put and end to the start of some pin fractures.

So, at the ESP32's output for each string garland, I have an interface module with its BC547 and BC557 transistors, and this drives each MOSFET module, which can drive one or more LED string lights (see **Figure 5**). I enclosed everything in a plastic case and mounted connectors for the DC voltage input and the outputs for the string lights.

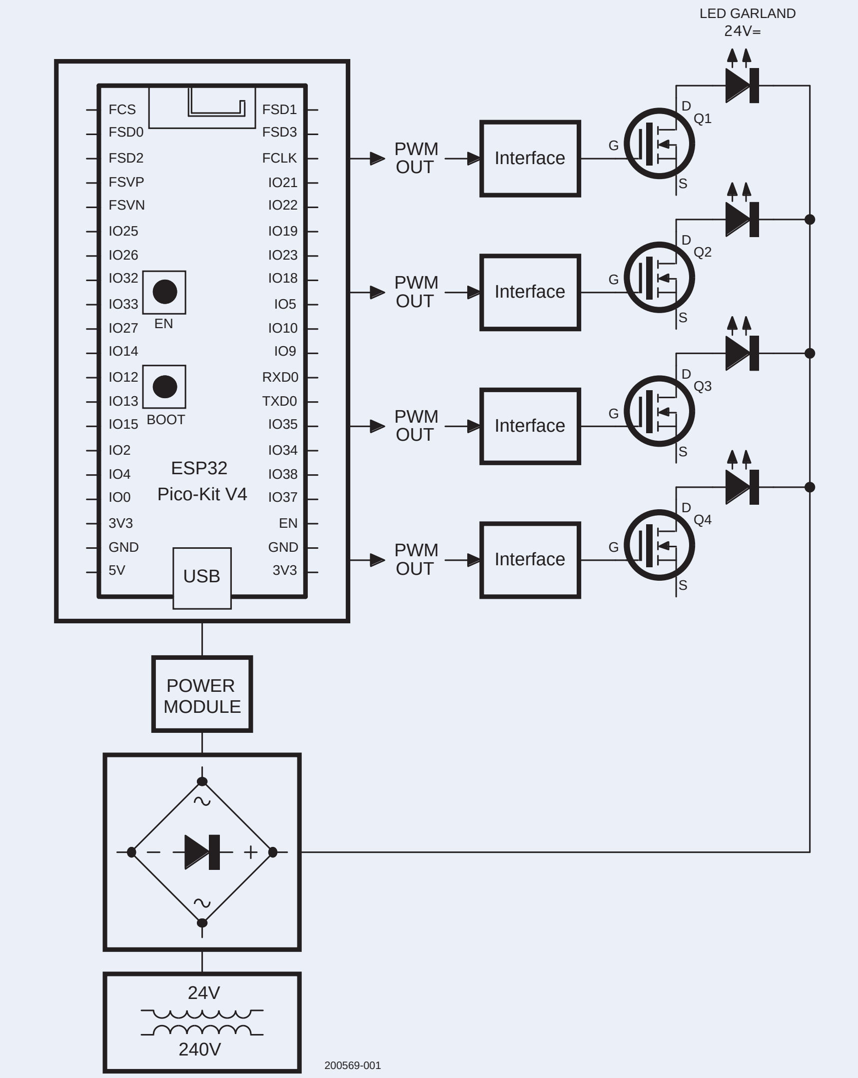


Figure 5: Schematic with ESP32 and MOSFETs.

The ESP32 Animation Code

I used the Arduino IDE to develop, compile, and upload the program [1] to the microcontroller. Now, to get to the heart of the project, namely, the LED animation. I used the option of defining a table with a set of parameters in a `struct` describing the animations. There are 13 entries in this table (see **Listing 1** for the `struct` used and the values to initalize it). However, this table can be extended with more entries.

I have defined two types of animations. One type is an ON/OFF animation with an additional option for residual light in the OFF mode. Each output has an ON time, an OFF time, and the number of iterations to perform for each power-on and -off cycle. The second type of animation is the variable mode. For this, I created a table with 32 elements in it. These are sine-like values to gradually fade the LEDs on and off (see **Listing 2**). The cycle duration is controlled by the ON and OFF times within the parameter table.

At the end of these iterations, the program will load another parameter-set from the table, drawn with a random number used for the parameter array. If the number drawn is the same as the previous one, the program redoes the draw, so as not to have the same animation twice in a row for the same garland. This improves the tree's aesthetics.

Code Sections in Brief

At the beginning of the program, I define the PWM outputs used and the constants for the ESP32 (**Listing 3**). Then comes the function used to have a pseudo-random number (lines 61-67 in the code [1]), and then the code for the RTOS task (lines 72-145), which will be executed indefinitely. This task is reusable, as it is defined with a parameter (PWM pin number) passed to it.

Next comes the `setup()` function, which first assigns all the values to the aforementioned animation parameters table. The section after that handles the PWM output parameters (lines 231-245), and the creation of the FreeRTOS tasks, with their parameters, to make them active (lines 251-315). In the ESP32, the scheduler is started by itself, and begins tasks as soon as they are declared.

Finally, in the `loop()` function, which is itself a task, we let it delete itself, as it is not executing any code — a task can delete itself and free up resources. These lines are shown in **Listing 4**. And, the fairy lights come alive (**Figure 6**)!

To Go Further

With its multiple PWM outputs, the ESP32 can control other garlands. We can imagine using all of the PWM outputs to control garlands to enliven a garden or a house facade. Another possibility would be to use the Wi-Fi available on the platform to control the ESP32 from a mobile phone via a small interface that can be developed. Suggestions are open.

All materials for this Project can be found on the Elektor Labs page [1] for this project.

200569-01

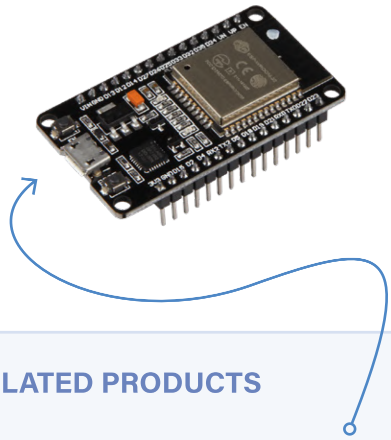
About the Author

Serge Sussel discovered electronics in the mid-1960s by purchasing electronics magazines such as Elektor, Radio Plans, Haut-Parleur, and Audiophile. Then his graduate studies allowed him to develop his IT expertise, among other things. He worked within the French National Central Bank (NCB) on large systems at the level of the OS (Operating System) and database subsystem, also by developing a preprocessor to compile the transactions security elements. On a personal level, he has been interested in analog electronics from the beginning when he fell into the cauldron. He built measuring devices, among other things, with Heathkit kits, HIFI preamps and amplifiers, and a three-keyboard organ supplied as a kit in the early 1980s. Now retired, he still deals with analog but also with microcontroller platforms, and he restores badly damaged devices and those discarded by people not knowing that with a few components to change, it's OK for several years more.

Questions or Comments?

Do you have technical questions or comments about this article? Contact Elektor at editor@elektor.com.

Figure 6: The fairy lights working in the tree.



RELATED PRODUCTS

- **Joy-IT NodeMCU ESP32 Development Board (SKU 19973)**
  www.elektor.com/19973
- **Warren Gay, *FreeRTOS for ESP32-Arduino* (Elektor 2020, SKU 19341)**
  www.elektor.com/19341

WEB LINKS

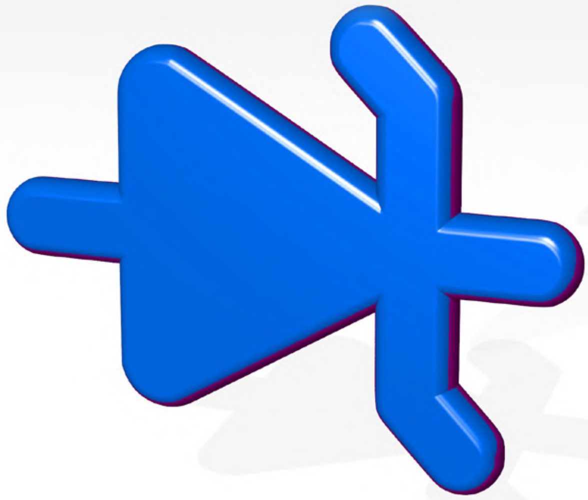
[1] Project Sources and Materials for this Project on Elektor Labs: www.elektormagazine.com/freertos-led
[2] Elektor Articles by Warren Gay: www.elektormagazine.com/warrengay

Starting Out in **Electronics**

...Cheerfully Continues Zenering

By Eric Bogers (Elektor)

We concluded the previous installment with a quick look at the Zener diode, a very common component that we will now deal with in more detail.



Just to refresh your memory a little: a Zener diode is used in the reverse-biased direction and — in contrast to an ordinary diode — it does not fail when it starts to conduct in the reverse direction. This makes the Zener diode an ideal component for regulating voltages. Apart from very special applications, a Zener diode **must** be used with a resistor in series to limit the current through the component to a safe value. This is illustrated in **Figure 1**. The schematic symbol for a Zener diode differs from that for an ordinary diode by the additional 'stroke' on the cathode bar.

Figure 2 shows the typical current/voltage characteristic of a Zener diode, in this case, a type ZDP12. As you may have guessed already from the '12' in the part number, this is a diode with a breakover voltage ('Zener voltage') of 12 V. The graph shows that this device starts to conduct at a voltage slightly under 12 V (11.87 V, to be exact). That voltage then increases minimally as the current is increased further. The significant characteristic here is that the voltage across this diode remains at a reasonably constant value of 12 V which makes this component perfectly suitable for regulating voltages.

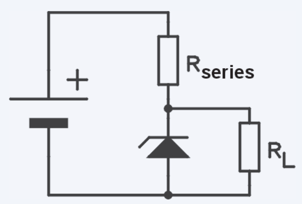


Figure 1: Basic circuit with a Zener diode.

The maximum allowable power dissipation for Zener diodes from the ZPD series amounts to 500 mW. Because the voltage increases a little with the current flowing through the diode, you really should be using a second-order equation to calculate the maximum allowable current. However, as a rule of thumb, you can confidently start with 90% or so of the nominal power rating:

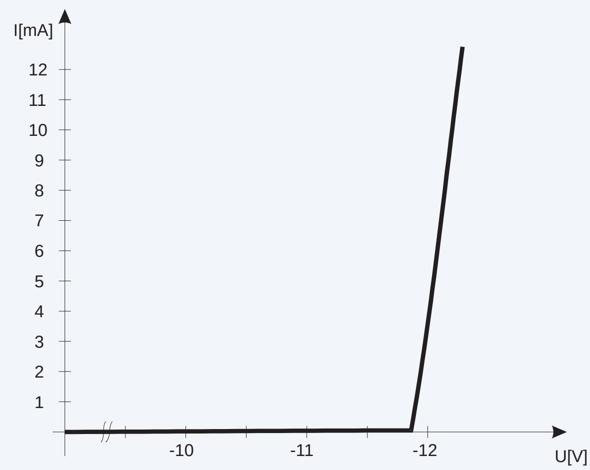


Figure 2: Zener diode characteristic curve.

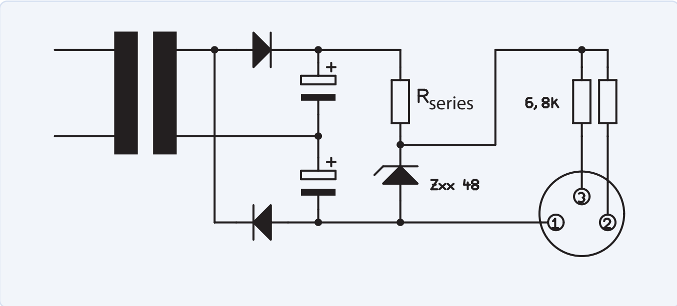


Figure 3: Regulated microphone phantom power supply.

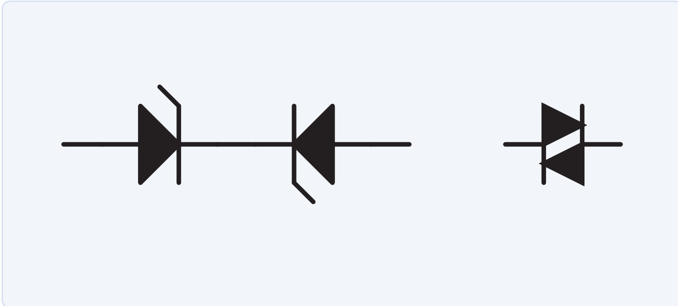


Figure 4: Diac.

$$I_{max} = \frac{0.9 \cdot P_{loss}}{U} = \frac{0.9 \cdot 0.5\ \text{W}}{12\ \text{V}} = 37.5\ \text{mA}$$

The circuit shown in Figure 1 is only suitable for relatively small currents. Larger currents would require a series resistor with a correspondingly smaller value which would increase the current through the diode too much. This would result in excessive power dissipation in the diode. That's why Zener diodes are nearly always used in combination with transistors or op-amps.

To help with your understanding of this device, let's work through all the calculations for a circuit similar to that in Figure 1. Hence, we choose a circuit designed for regulating the voltage of a microphone phantom power supply [1].

A phantom supply is called so because the microphone's bias voltage arrives via... the microphone cable! A condenser microphone, in particular, cannot function without phantom power for its built-in amplifier. However, the principle of "phantom-powering" also has applications elsewhere.

As shown in **Figure 3**, the phantom power supply delivers 48 V which is connected to the two microphone cable signal conductors (XLR connector: pins 2 and 3) through two resistors of 6.8 kΩ each. The Ground return is obviously connected to the screening (braid) of the microphone cable (XLR connector: pin 1).

We would like to dimension this power supply circuit so that it is stable in any imaginable scenario. The lowest possible load resistance is zero ohms because the circuit is then only loaded by the parallel circuit of the two 6.8 kΩ resistors – that load, therefore, makes a total of 3.4 kΩ.

The maximum load current works out at:

$$I_L = \frac{U}{R_L} = \frac{48\ \text{V}}{3.4\ \text{k}\Omega} = 14.1\ \text{mA}$$

Assuming the use of a 24-V rated transformer, the maximum voltage across the electrolytic capacitor then amounts to:

$$U_{top} = 48\ \text{V} \cdot \sqrt{2} - 1.4\ \text{V} = 66.5\ \text{V}$$

During a half-period, the voltage is allowed to sag to about half the difference between the unloaded voltage and the nominal voltage of the phantom supply:

$$\Delta U = \frac{66.5\ \text{V} - 48\ \text{V}}{2} = 9.3\ \text{V}$$

Consequently, the filter capacitor's minimum value is:

$$C = \frac{I}{f \cdot \Delta U} = \frac{14.1\ \text{mA}}{50\ \text{Hz} \cdot 9.3\ \text{V}} = 30.3\ \mu\text{F}$$

Because 33 µF is difficult to obtain value these days, consider selecting a 47-µF capacitor instead. Let's use this value to calculate the actual voltage difference:

$$\Delta U = \frac{I}{f \cdot C} = \frac{14.1\ \text{mA}}{50\ \text{Hz} \cdot 47\ \mu\text{F}} = 6\ \text{V}$$

The lowest voltage across the capacitor, therefore, amounts to 60.5 V. The voltage drop across the series resistor (R_{series}) is then 12.5 V. The current through the series resistor is at least equal to the current through the load (the Zener diode then carries no current). The series resistor then becomes:

$$R_{series} = \frac{12.5\ \text{V}}{14.1\ \text{mA}} = 886.5\ \Omega$$

Naturally, we picked the standard value of 820 Ω. The greatest current through the diode flows when the circuit is not loaded. The voltage across the filter capacitor is in the range of 60.5 V to 66.5 V and therefore amounts to 63.5 V on average. In the unloaded state, the average current through the resistor as well as the Zener diode amounts to:

$$I = \frac{63.5\ \text{V} - 48\ \text{V}}{820\ \Omega} = 18.9\ \text{mA}$$

And from this follows the power dissipation:

$$P = U \cdot I = 48\ \text{V} \cdot 18.9\ \text{mA} = 907.2\ \text{mW}$$

Meet the Diac

The more or less constant Zener voltage only appears across a Zener diode when reverse-biased. When a Zener diode is used in the forward-biased direction, its voltage drop is the same as that of a normal diode. Consequently, a Zener diode is less suitable for AC applications.

In this scenario, you can "make do" by connecting two Zener diodes in anti-series, that is, two devices in series but facing in opposite directions as illustrated in **Figure 4**.

From your favorite electronics-by-mail store (sadly the "electronics shop around the corner" has vanished) you can buy a component with the simple yet exotic name of 'diac' which contains two Zener diodes connected in this way. The nominal voltage of diacs is typically around 33 V and their use is limited to conventional dimmers mostly (to be covered next time).

220384-01

Editor's Note: The 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.

Questions or Comments?

Do you have any questions or comments prompted by this article? Send an email to the editor of Elektor via editor@elektor.com.

WEB LINK

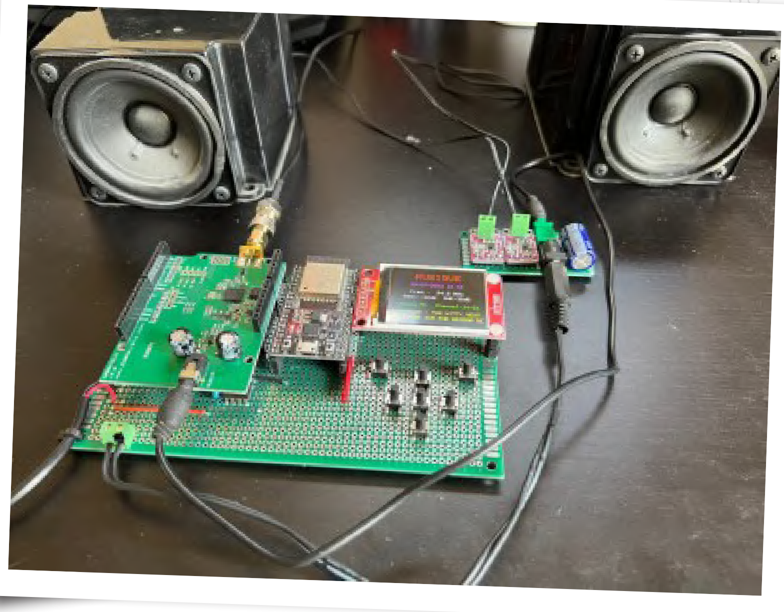
[1] Phantom power: https://en.wikipedia.org/wiki/Phantom_power

RELATED PRODUCTS

- **B. Kainka, *Basic Electronics for Beginners*, Elektor 2020. (SKU 19212)** www.elektor.com/13950
- **B. Kainka, *Basic Electronics for Beginners* (E-Book), Elektor 2020. (SKU 19213)** www.elektor.com/18232

FM/DAB+ Receiver

The Best of Both Worlds



By Yves Bourdon (France)

In the 1960s and 1970s, if you were into electronics, there were, in my opinion, two devices that you absolutely wanted to build yourself: a radio receiver and a digital clock. Today, this is still true for many electronics enthusiasts — except that now the radio must be digital too. In this article, we explain how to build a digital radio with an ESP32 module and an Arduino shield based on the Si4684 digital receiver chip from Skyworks.

I was less than 10 years old when I built my first radio. In our doctor's waiting room, I came across a magazine called *Le Haut-Parleur* (which means "The Loudspeaker", Elektor didn't exist yet) which was mainly focused on tube hi-fi. However, one article that talked about diodes, transistors, and long wave receivers had caught my attention. I took the magazine home without asking permission first. (Dear doctor, please accept my sincere apologies.)

It took me almost a year to build my first radio, until one morning I finally heard for the first time 'Nights in White Satin' by the Moody Blues. My radio consisted of a detector diode, a huge antenna (certainly not tuned at all), an LF amplifier (OC71 transistor) and a small, scrounged speaker. The tuning was done with a variable capacitor. It was the first of a long series of more and more complex radios, the ultimate being an FM receiver with an all-transistor stereo decoder.

In 2010 Elektor published an article about building a fully digital FM radio receiver based on a Skyworks Si4735 processor from Silicon Labs [1]. Of course, I built this radio, I even built more than five different versions of it. When DAB+ reception became finally available in my region (Aix-en-Provence, France) I started looking for a successor to the Si4735 and settled upon the Si4684 (in the meantime Silicon Labs has become Skyworks). With it I could build myself an FM/DAB+ receiver.

Regarding the DAB+ Standard

The DAB+ standard for Digital Audio Broadcasting concerns digital terrestrial radio. It is the equivalent of DTTV for radio. It turns good old analog radio in the FM band into a digital signal.

DAB+ occupies VHF band III, located between 174 MHz and 240 MHz, formerly used by analog television. The main advantages of DAB+ are:

- Free public service (no subscriptions required)
- No background noise ('hiss') due to bad reception or interference. The DAB+ standard uses the AAC+ codec (MPEG-4 Part 3).
- The audio quality, which has a higher bandwidth than FM, is excellent (I receive most stations with a bit rate of 88 kHz).
- Automatic preselection of stations, like DTTV. Each city has six to seven multiplexes of about fifteen stations. In Aix-en-Provence I receive 83 DAB+ stations!
- Display of information related to the show on air (show's title, scrolling text, album cover, weather map, etc. depending on the capabilities of the receiver).

On the other hand, the reception is weak inside buildings and a good antenna is needed. I use a vertically polarized ¼-wave antenna (34.5 cm/13.6") that I installed near a window.

The Si4684

Initially, I planned to design a printed circuit board (PCB) for the Si4684 chip. However, when studying the datasheet closely, I realized that there was an issue with the Intellectual Property (IP) rights concerning the firmware of the component which is generally stored in an external serial EEPROM. This firmware can only be used after signing an agreement with Skyworks — the manufacturer of the chip — and paying a fee.

Therefore, for an individual like me, obtaining the firmware in a legal way is mission impossible. And even though pirate copies can be found online, I did not want to go there (probably due to my past as a design engineer who has always defended the notion of Intellectual Property). I therefore looked for a commercially available solution from a manufacturer approved by Skyworks.

This is how I found the DAB Shield sold by the English company AVIT Research. The company's CEO, Adrian, authorized me to use his excellent *DABShield* library in my project. I hereby want to thank him for his support in this project!

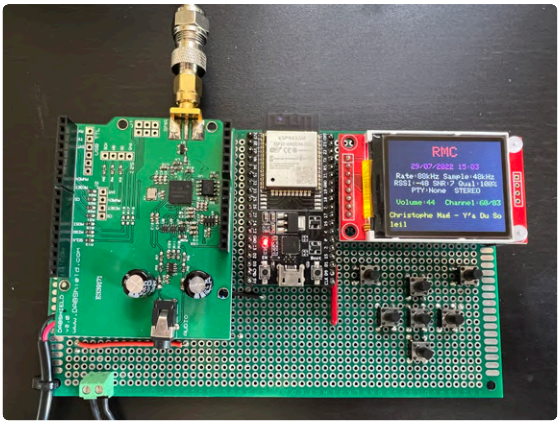


Figure 1: My prototype. Based on an ESP32-DevKitC module, this assembly fits inside a transparent case (Hammond 1591C).

The FM/DAB+ Receiver Circuit

For my prototype I used an Espressif ESP32-DevKitC (**Figure 1**). If you look at the schematic (**Figure 2**), you will see that I used almost all the available I/O pins. The ESP32 module was also chosen for its computing power and especially for its available memory (512-KB RAM and 4-MB flash memory).

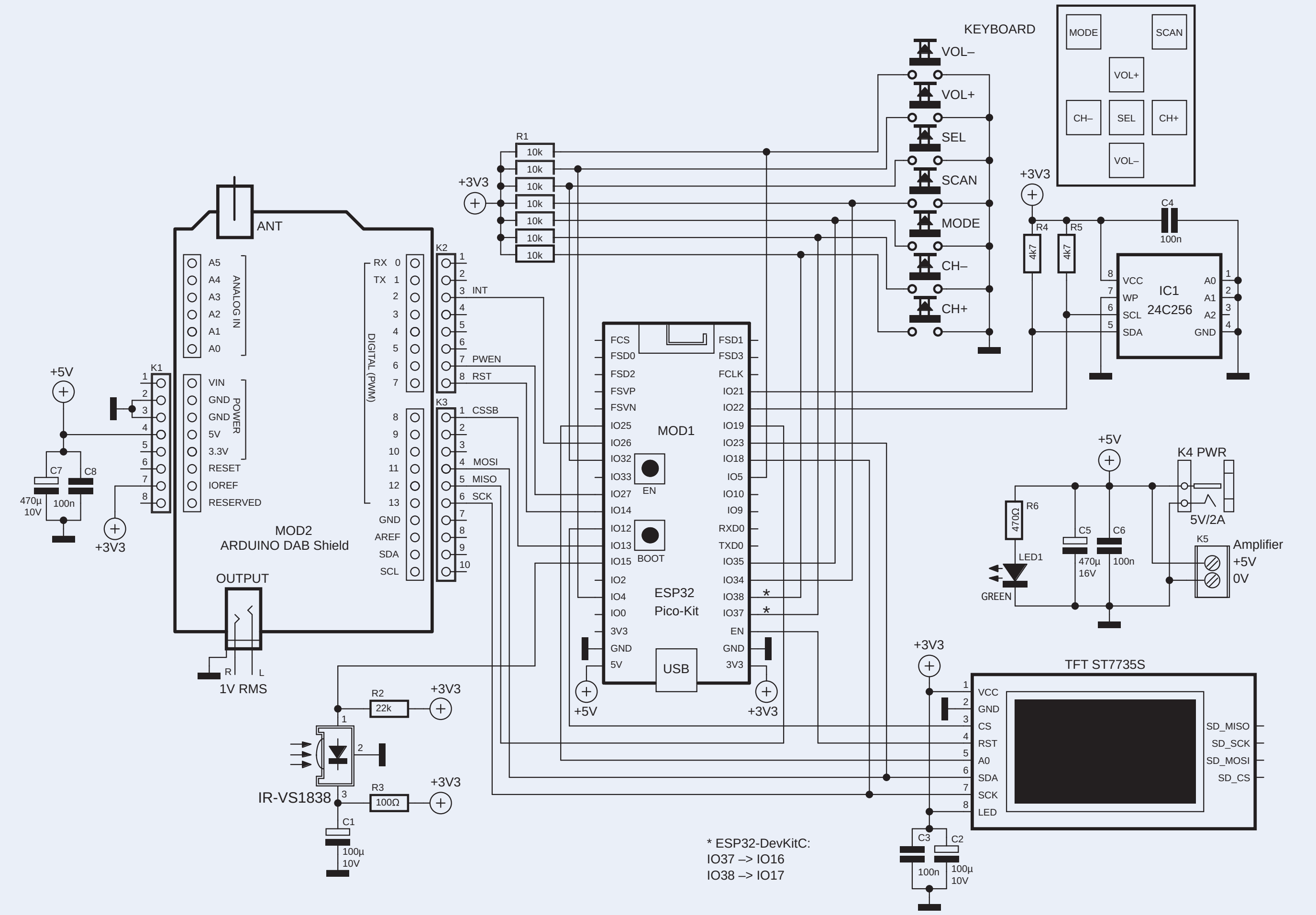


Figure 2: Schematic of the FM/DAB+ receiver.

EEPROM Trouble

Despite all this memory, I also added an external EEPROM. The reason for this is the ESP32's *EEPROM* library that I used at the beginning of the project to store FM and DAB+ stations. As the ESP32 does not have a real EEPROM, this library uses a part of the flash memory to emulate an EEPROM. Unfortunately, the library is being phased out and only works correctly if the memory size does not exceed 512 bytes. (I did try a maximum size of 4 KB as is suggested in certain forums, but this inevitably results in a program crash as the data stored in EEPROM is altered in a rather random way.) It is better to use the library *Preference* instead.

However, when I discovered the problems of the *EEPROM* library, most of my program was already written and I didn't want to start all over again with the library *Preference*. And so, I decided to add an external 32-KB EEPROM (24C256) managed by the library *SparkFun_External_EEPROM*. This chip (which costs about 50 cents) uses the I^{2}C bus of the ESP32 (SDA on IO21 and SCL on IO22). Connecting its pins A0 and A1 to 0 V fixes the I^{2}C address of the device to 0xC0. Pin A2 can be left unconnected.

I had planned to store a maximum of 250 FM and 250 DAB+ stations. The name of the station (eight characters max for FM and 16 for DAB+) as well as the FM frequency, DAB+ multiplex and station number are stored for each station. Furthermore, 10 bytes are necessary to store the last station listened to: volume, mode (FM or DAB+), FM frequency, DAB+ multiplex and channel. A minimum memory capacity of $10 + 13 \times 250$ (FM) $+ 20 \times 250$ (DAB+) is therefore required, (i.e., 8260 bytes, or 66,080 bits). A 16 KB EEPROM of type 24C128 would have been sufficient too.

Display & Keyboard

As a display for the receiver, I used a small 160 × 128 ST7735S-based TFT color display with a SPI bus. The excellent *Adafruit_ST7735* and *Adafruit_GFX* libraries allow to easily manage this screen. This display uses four pins of the ESP32: MOSI (IO23) and SCK (IO18) of the SPI port, CS (IO12) and A0 (IO25). The Adafruit driver can also drive the RST signal, but to save a port, I set `TFT_RST` to -1 (in the *Screen Connections* declaration of the software) and I connected it directly to the ESP32's reset pin (EN).

Note that the SDA and SCL marking on the display (and reproduced in Figure 2) is rather confusing as it is indeed the SPI bus (without MISO) which drives the screen.

The display's power supply is decoupled by C2 and C3, and the backlight is always on (LED pin connected to +3.3 V).

Seven keys control my radio: Volume up/down (VOL+/VOL–), Channel up/down (CH+/CH–), Select (SEL), Mode and Scan. They are connected to the +3.3 V supply rail with 10-kΩ pull-up resistors.

DevKitC or Pico-Kit?

The schematic shows an ESP32-Pico-Kit module because of its small size, but an ESP32-DevKitC can be used too, like I did on my prototype. However, the ESP32-DevKitC does not expose IO37 and IO38. IO16 and IO17 must be used instead, which are in turn not available on the ESP32-Pico-Kit. It is therefore necessary to select the right module in the software before compiling it (lines 76 and 77 at the time of writing). For the DevKitC use:

```
//#define ESP32_PICO
#define ESP32_DEVKIT
```

For the Pico-Kit use this:

```
#define ESP32_PICO
//#define ESP32_DEVKIT
```

Remote Control

The circuit has support for an infrared remote control thanks to the VS1838 IR receiver. The power supply for the device is filtered by the network R3/C1 to avoid corrupted frames on its output (connected to IO15 with a 22-kΩ pull-up resistor). Software support for the remote control was not ready at the time of writing this article, but with a bit of luck, it will be when you read this.

The DAB Shield

The Arduino M0 used to be the ideal companion for the DAB Shield, but it has been discontinued. Therefore, in this project an ESP32 module is used instead. The DAB Shield can be controlled easily by the ESP32 as only seven signals are required.

Even though the DAB Shield needs a 5 V power supply, its I/O lines expect 3.3 V levels. As this is also the case for the ESP32 module, the two can be connected without level shifters. The shield's IOREF pin must be connected to 3.3 V to ensure this compatibility.

The DAB Shield communicates with the ESP32 using the SPI bus (MOSI, MISO and SCK). The *DABShield* library only allows changing the pin number of the CSSB signal (I used IO13). The signals INT, PWEN, RST must be connected to ports IO26, IO27 and IO14 respectively.

Power Supply

The +5 V power supply for the FM/DAB+ receiver enters at connector K4. There is no reverse-polarity protection, so be careful (of course, you can add one). C5 and C6 provide some noise filtering and LED1 (green) serves as a power-present indicator.

A two-way screw terminal block (K5) is intended for powering an optional amplifier board (see below). If no external amplifier is connected, a 5 V/500 mA power supply is sufficient as we do not use the power-hungry Wi-Fi of the ESP32. However, if you connect the optional amplifier, you need at least a 5 V/2 A power supply.

Optional Amplifier Board

Positively surprised by the sound quality of the Nintendo Wii game console, I investigated a bit and learned that it uses a PAM8302 3 W_{RMS} class D amplifier. This amplifier is easily found online mounted on a small PCB, and so I connected two of these modules to the FM/DAB+ receiver (see **Figures 3** and **4**). The sound quality is amazing (with good speakers, of course).

The audio output of the DABShield connects to the amplifier with a short cable with a 3.5 mm stereo jack on each end. The VOL+ and VOL– keys control the volume.

The Software Development Environment

To develop the software of the FM/DAB+ receiver, I used the Arduino IDE. After setting it up for use with ESP32 modules, make sure to select the following parameters:

- ESP32 Dev Module
- 240-MHz CPU frequency
- Partition Scheme: default 4 MB with SPIFFS

You must install a few external libraries; I have indicated in the source code where to get them:

- *DABShield*
- *Adafruit_GFX*
- *Adafruit_ST7735*
- *SparkFun_External_EEPROM*

Finally, after selecting the right serial port, compilation and uploading to the ESP32 module should work without a hitch.

The Software

Before going in any deeper, let me start by saying that writing software is not my best skill. (I am what you call a hardware engineer.) So, in advance, I thank all of you interested in my project and willing and able to extend my work or redo what I could have done better. Having that said, my program (v1.63 at the time of writing these lines [2]) is very reliable without any malfunctionings that I know of.

The software is quite extensively documented, and after reading what follows below, it should be quite easy to understand. It is instructive to monitor the output of the serial port of the ESP32, because a lot of debug information is sent. At power-up, the screen displays the connection status of the Si4684 components and the serial EEPROM (**Figure 5**). If there is a problem, an error message is shown, and the program will hang.

Format the EEPROM

When the program is launched for the very first time, the EEPROM must be formatted. To do this, press the SEL button while switching on the receiver. When the display shows "*Init EEPROM …*", you can release the SEL key. The initialization takes about fifteen seconds.

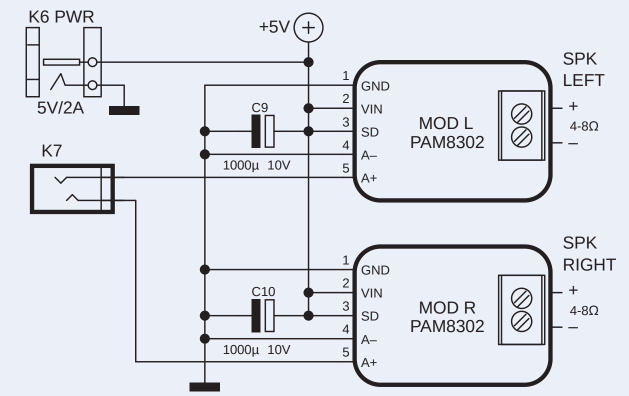


Figure 3: Schematic of the optional amplifier board.

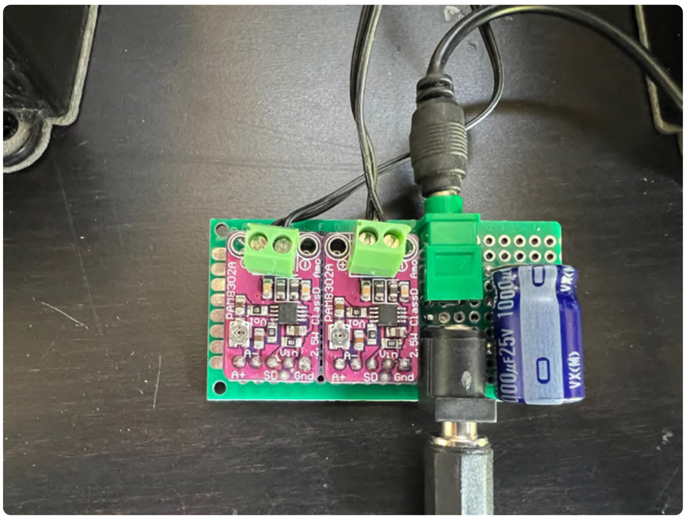


Figure 4: The optional amplifier board assembled on prototyping board.

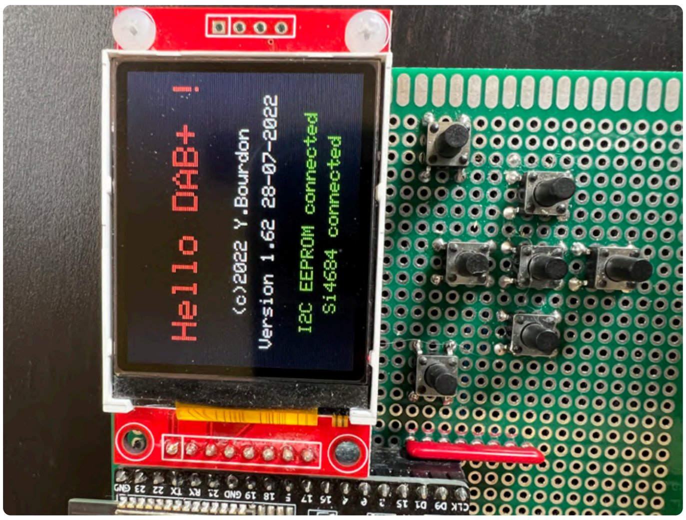


Figure 5: The software version and the connection status of the hardware are indicated.

Figure 6: Here we see that the multiplex MARSEILLE 8A is found and that it contains 13 stations.

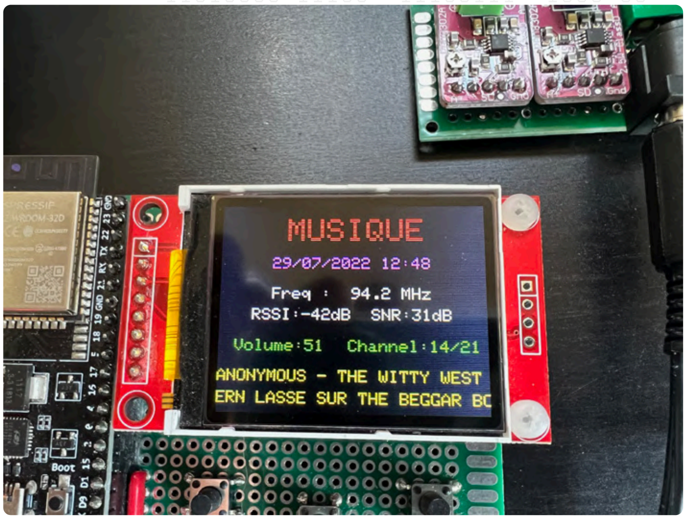


Figure 7: Quite a lot of information is shown on the small color display.

The User Interface

I wanted a reactive and pleasant-to-use user interface. The keys are scanned every 200 ms. This allows for repetitive keystrokes while keeping the button pressed and avoids contact bounce (variable `debounceDelay`).

The Mode key toggles between FM and DAB+ (`dabMode` in the software). If no station is stored in the selected mode, you will be asked to press the Scan key (**Figure 6**).

Station Sorting

In DAB+ mode (`DAB_scan` in the program), all the multiplexes are scanned, and if stations are found (with an RSSI higher than -30 dB), they are stored.

Even though each multiplex sends the stations in alphabetical order, as there are several multiplexes, all the stations found must still be sorted in alphabetical order (`sortStations` in the program). Sometimes two identical stations are found on two different multiplexes, but as the reception characteristics are not the same, I decided not to filter anything out (with 83 stations I have seen this only once). If a station's name is not found, because the field was left empty for some reason, the program replaces it by 'Unknown?'.

For performance reasons, the stations are first stored and sorted in RAM before being copied to EEPROM (`saveDABchannelToEEPROM`).

FM Scanning

In FM mode things are a bit more complex. Indeed, scanning is very fast (`FMscan`) and all frequencies between 87.5 MHz and 108 MHz showing a signal with an RSSI higher than -30 dB are stored. However, no station names are found at this point. Therefore, at the end of the scan, the stored frequencies are selected one by one, and the RDS data returned by the station (time and station name among others) is inspected. If a name is found, it is stored in RAM with the corresponding frequency. If after 30 seconds no name has been found, it is set to 'Unknown?'.

As this process can be long (I receive 27 FM stations here in Aix-en-Provence, up to 30 s per station), you can interrupt it at any time by pressing the Scan key.

When the name search terminates (normally or because you ended it prematurely), an alphabetical sort is launched in RAM and the station number, frequency and name are stored in EEPROM (`addStation`).

When a station is selected, its RDS status is read again (`Dab.task`), and if the name found does not correspond to the name in memory, then the new name is stored in the EEPROM. This happens when, for example, 'Unknown?' is being displayed because the name was not found during the scan or because the RDS name has changed. (It's quite annoying that some stations use the name to display information such as the title of the song, when RDS provides a data field just for that.)

Then, whether in FM or DAB+ mode, you can scroll through the station names (just hold your finger on CH+ or CH–) and select the one you have chosen with the SEL key (`FMsetChannel` or `DAB_SetChannel`). The display shows the details of the received station, including the time and additional information (refreshed every 30 seconds, **Figure 7**).

At each power-on, the EEPROM is read (`lastEEPROM`) which allows finding the last station that was listened to (DAB+ or FM) with its corresponding volume.

I have deliberately chosen not to implement an *Add Station* menu. This will have to wait until I write the remote-control part where I plan to add, among other things, this feature.

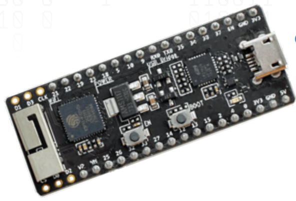
Radio Complete

I finally managed to build the radio I wanted. It is very practical to use and proudly stands on my desk. Without having been instructed on how to operate it, my family uses the radio too, which is a good sign. And it made us quickly realize that we listen almost always to the same station (a good thing I allocated memory for 500 stations).

I would like to thank Adrian from AVIT Research, my friend Stephan Calderoni who helped me with the station name sorting function and Elektor for the publication of this article and for redrawing my hand-drawn schematics. Thanks also to Adafruit for publishing all their sources and schematics.

I hope that this article has allowed me to share with some readers the passion that drives me since I was young and that continues doing so today, even at the age of 64. ◂

220249-01



DAB+ in France

In France (trailing behind its neighboring countries), DAB+ broadcasting is authorized since July 15, 2021, and 40% of the French population should be able to receive DAB+ in 2023. Currently, DAB+ coverage in France is rather poor, especially when you know that the radios of new cars are required to be DAB+ compatible since July 2020, a requirement that is also valid since December 2019 for all other radios sold in France. This will certainly accelerate the deployment. It is likely that FM will gradually disappear in France as is already the case in Switzerland, England, and Norway.

To see the availability of DAB+ in your area, you can use the site: www.csa.fr/Ma-radio-DAB-Plus.

Questions or Comments?

Do you have technical questions or comments about this article? Email the author directly at yb.electronique@orange.fr or contact Elektor at editor@elektor.com.

RELATED PRODUCTS

- **ESP32-Pico-Kit (SKU 18423)**
  www.elektor.com/18423
- **Elektor Raspberry Pi RTL-SDR Kit (SKU 19518)**
  www.elektor.com/19518

WEB LINKS

[1] B. Kainka, "The Elektor DSP radio," Elektor 7/2010: https://www.elektormagazine.com/100126

[2] Downloads and updates: https://www.elektormagazine.com/labs/radio-dab


Photo: breakermaximus/Shutterstock

From Life's Experience

Electronica Obscura

By Ilse Joostens (Belgium)

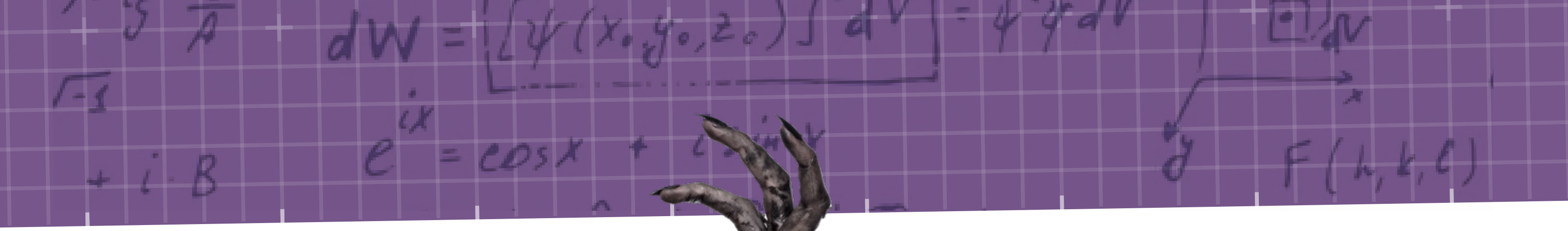
Time flies. This is already column number 13 in front of you. Now that the darker season is again upon us, it appears to me to be the ideal occasion to shed a little light on the somewhat more shady side of electronics. My apologies if the title has misdirected you, but, in this instance, we are not exploring the topic of electronic music.

My parents (my father in particular) were incorrigible hypochondriacs. Not only did they present various scary diseases regularly, with or without a medical encyclopedia in hand, but the manner in which less-fortunate fellow villagers and acquaintances had kicked the bucket was a favorite subject. The woman next door would frequently chitchat cheerfully along, where the ghastliest details were never taboo. It will therefore not surprise you that, in my youth, I had to put up with quite a bit of anxiety and I have always had an unhealthy fascination for ghosts and the paranormal.

Instrumental Transcommunication

In my quest for the hereafter, many years ago, I was a member of a paranormal society for a brief period. I occasionally even ventured into 'ghost hunting,' armed with a digital compact camera and a dictaphone with microcassettes. Digital technology hadn't advanced much back then, but, nevertheless, there were already various circuit diagrams and build instructions for simple designs such as a Raudive diode to more complete 'spirit boxes.' The latter is effectively a combination of a white-noise generator and a defective radio receiver. These contrivances were supposed to enable you to pick up the voices of the deceased and other entities, and even two-way communication was a distinct possibility for the more advanced user [1]. The paranormal society warned in their member publications and elsewhere that attempting to contact entities could be quite dangerous without the necessary experience, and hence I was never brave enough to build any of those designs. Heaven forbid, as in the better classic horror movies, you inadvertently invite an evil spirit into your house with all the consequences that entails.

The results of my personal quests were more of a disappointment: I did take a couple of strange photos, but nothing that ultimately could not be explained in a more down-to-



earth manner. The paranormal had been off my mind for a long time, and I had not been involved in it at all until I received a question from the Elektor Lab to design something with a geophone [2]. These are special microphones that pick up vibrations and sound waves from the earth and are used for seismological research as well as for the search for minerals such as oil and gas. These instruments not only come with a considerable price tag, but are also not that easy to find. In my search for a supplier, I discovered that these things are also merrily used by paranormal researchers to detect vibrations while hunting ghosts. Apparently, paranormal research is *hot* these days, and the Internet overflows with shops that offer the necessary equipment such as EVP recorders, EMF detectors, spirit boxes, spirit pods, UV lamps, infrasound generators, infrared lamps, vibration detectors, special 'full-spectrum' cameras and even thermal cameras. Nothing is too crazy. There are even complete courses on offer for the genuine diehards that lead to a qualification of 'Paranormal Researcher Level 1.'

Even Elektor had their own ghost when the lab was still in the castle in Limbricht and the *League of Paranormal Investigators* investigated it in 2013. Strange noises were supposedly detected, and a researcher even received scratches on her back [3][4]. I have been to the castle in Limbricht multiple times, also during the late hours, and I have never noticed anything strange and certainly nothing threatening. Now that I mentioned Elektor, I am reminded of the chaos machine [5][6][7] from the end of 2011. Whoever wants to experience the shivers responsibly — read: without risk — from poltergeist sounds must certainly build these!

Quackery and Pseudoscience

I am somewhat of a history fanatic and I occasionally delight over the gym equipment of Dr. Gustav Zander [8] from the end of the 19th century. These 'instruments of torture' are not only amusing but also grisly. This was also the time of the Victorian postmortem photography and the emergence of numerous strange electric devices for electrotherapy or for calming down hysterical women. The 'violet wand' from the beginning of the 20th century is an illustrious example. Further details of this strange apparatus are not really suitable for publication in this magazine, but there is nothing that prevents you from researching it in more detail yourself.

In my youth, earth rays were all the rage. For sale were not only special, expensive earth ray devices—containing a coil and a capacitor — which would neutralize this harmful radiation [9], but even women's magazines would devote entire articles to it. Meanwhile, while we ought to know better, nothing is further from the truth, regrettably... A few years ago, I ordered surplus electronic parts from the United States, and, in the packaging, I also found some advertisements with links to websites. One of these links went to a website with a whole range of amateurishly built electronic circuits on breadboards with cigar boxes for their enclosures. These 'contraptions' would not only help with scores of the buyer's illnesses and symptoms, but the seller would be better off because the typical sale prices were more than a thousand dollars for such a cigar box. Closer to home, I was quite shocked to discover that even one of my former suppliers now mainly sells Schumann resonance generators. These not only supposedly calm you down, but they make music sound much better. Great fodder for audiophiles therefore...

220383-01

WEB LINKS

[1] Electronic voice phenomenon: https://en.wikipedia.org/wiki/Electronic_voice_phenomenon
[2] Geophone: https://en.wikipedia.org/wiki/Geophone
[3] Report confirms suspicions: Limbricht Castle is haunted (DUTCH): https://www.dichtbij.nl/2987065/fotos-geluidsopnamen-rapport-bevestigt-vermoedens-het-spookt-op-kasteel-limbricht
[4] L1 Nieuws Limburg - LPI-International at Limbricht Castle (DUTCH): https://www.youtube.com/watch?v=SO41c5FYXao
[5] M. Ambaum, "The Chaos Machine: Analogue Computing Rediscovered (1)," Elektor 9/2011: https://www.elektormagazine.com/magazine/elektor-201109/19731
[6] M. Ambaum, "The Chaos Machine: Analogue Computing Rediscovered (2)," Elektor 10/2011: https://www.elektormagazine.com/magazine/elektor-201110/19749
[7] Angel of Lorenz: https://www.youtube.com/watch?v=fXQRKR-KZrw
[8] The world's first gym machines designed by Dr. Gustav Zander, 1892: https://rarehistoricalphotos.com/first-gym-machines-zander
[9] A Radiant Future: The Return of Earth Rays (DUTCH): https://skepsis.nl/stralen/

Tracing **the Cause of Software Bugs** Wirelessly

Circular Buffer and Webserver on the ESP32

By Laurent Labbe (Hong Kong)

Logging debug data from a microcontroller to a laptop is not always convenient. Either there is no spare laptop, or the development board is in a difficult-to-reach location. This Elektor Labs project not only solves this issue with a gigantic buffer memory for debug messages and Wi-Fi link, it also has a 3D-printable case and is highly extendable.

Software development for microcontrollers is often challenging. With few exceptions, microcontrollers offer some sort of debugging solution that can start and stop the processor and allows variable and register contents to be examined. This helps in determining the cause of an issue. However, many maker boards, such as Arduino Uno or BBC micro:bit, have no such support natively, leaving the developer to edit and download code repeatedly until the source of the issue is found.

But debuggers are not always the panacea they seem to be. When developing real-time code for Ethernet, Wi-Fi, or USB, or in applications such as motor control, you cannot simply halt the microcontroller mid-flow. This results in a break in communication and can even cause damage to power devices, should a MOSFET be caught in its on-state.

Thanks to the ease with which a serial output can be initiated on maker boards, most developers add some text-based debug output to their code by sending messages to a terminal on a PC via USB. When analyzing the output after a test run, the developer can trace the path taken by the code – hence the name 'software trace' for this method of debugging. This also allows debugging of applications that cannot be stopped during operation.

The Project

Elektor Labs regular Laurent Labbe often uses the serial interface for tracing embedded code execution but doesn't always have a spare laptop to log the messages. This got him thinking about whether there was an alternative approach. Armed with an ESP32, an OLED display, and a 3D printer, he came up with the "Wireless trace for debug" project [1].

The approach uses an ESP32 as a buffer for debug messages, connected to the target controller by a serial interface; the buffer is made accessible by Wi-Fi and a web server (**Figure 1**).

The massive amount of SRAM on the ESP32 allows you to implement a giant circular buffer. Laurent's projects typically use a low baud rate of 9600, but this can be modified. Every time a character

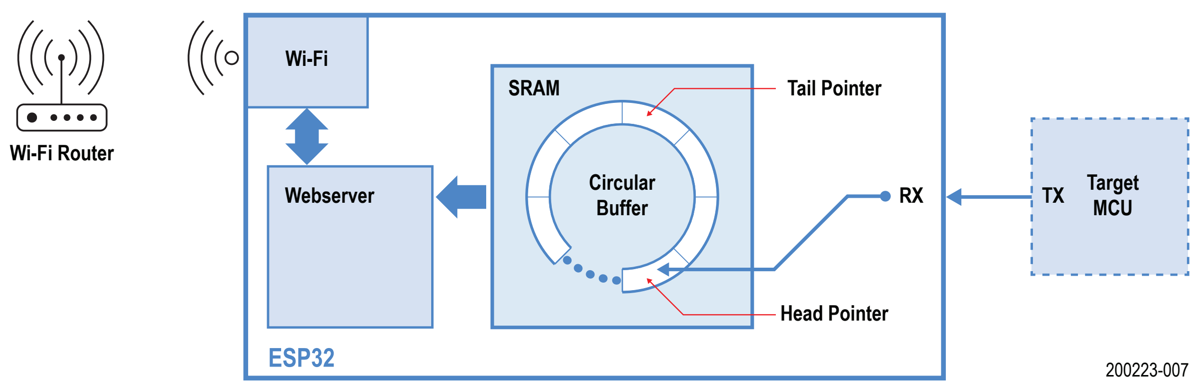


Figure 1: This simplified block diagram shows how incoming serial data is stored in the circular buffer. Upon request, the data is retrieved over the Wi-Fi interface as a webpage.

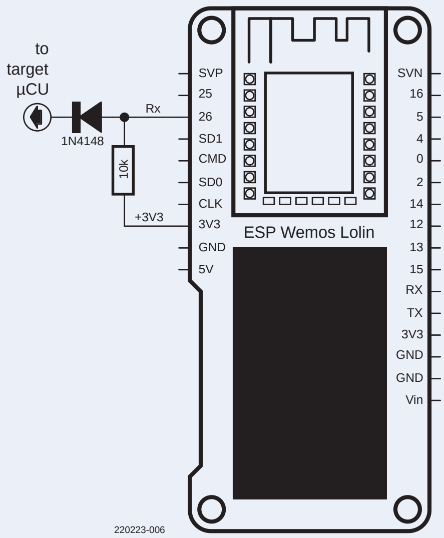


Figure 2: As the ESP32 has 3.3 V pins, this circuit allows a 5 V microcontroller to be attached.

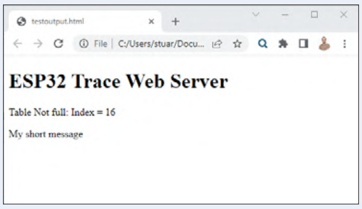


Figure 3: An example web page output.

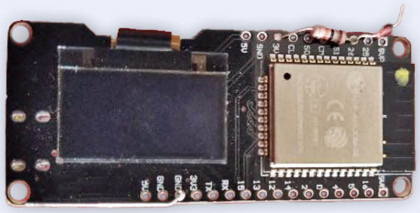


Figure 4: The ESP32 complete with circuitry to support 5 V interfacing.

Figure 5: A wireless serial debug unit complete with 3D-printed case.

is received, it is pushed into the head of the circular buffer. The buffer is 65,530 bytes (unsigned char) in size, so there is plenty of space for gathering trace messages. *Serial1* is initialized for data collection using pins 25 and 26 (TX and RX, respectively), although only the RX pin is required. Because the ESP32 is a 3.3 V device, Laurent included a resistor/diode circuit to allow 5.0 V microcontrollers to be connected to the serial interface (**Figure 2**).

As said, the project uses the ESP32's Wi-Fi capability, which is where this design shows its uniqueness. After registering with the network as defined in the code, any local laptop or mobile device can access a webpage offered by the ESP32. The ESP32 then serves a simple page that includes the current contents of the circular buffer (**Figure 3**).

Second Network, Serial Interface, and Display

There are a few other cool features built into the code too. For example, a second SSID and password for an alternate Wi-Fi router are supported. Should the first link fail for any reason, the ESP32 automatically attempts to connect to the backup. With potentially hours or days of data stored on the device, this offers more robustness for retrieving the trace messages. The web server uses port 80 by default, but an alternative port can be defined at initialization.

The circular buffer also implements wrap-around. Thus, should the buffer be filled completely, new incoming messages overwrite the oldest data. For clarity, the webpage includes an appropriate message before displaying the circular buffer's content from oldest to newest.

The ESP32 also outputs messages via the *Serial* interface (over USB), enabling this project's code to be debugged. Debug messages received via *Serial1* are output to *Serial* for immediate visibility. Any data received on the *Serial* interface is also inserted into the circular buffer.

Information on the IP address and other relevant details are output to an I²C-based OLED display connected to pins 4 and 5. The display used is the SSD1306 from Adafruit together with their driver and GFX graphics libraries.

Laurent used a WeMos Lolin32 OLED (**Figure 4**, the board is based on the ESP32-WROOM-32 module with added circuitry) to implement the USB-to-UART interface and support for connecting and charging a Li-Ion/LiPo battery. Together with his 3D-printed case, for which a CAD file is provided, this wireless debug trace tool can be deployed almost anywhere to collect data from your target autonomously (**Figure 5**).

Options

The beauty of this project is the combination of its simplicity and extensibility. The code's functionality is clear, making it easy for experienced developers to extend and modify this project. For example, extending the available SRAM using external devices wouldn't be difficult, and you could even store the trace messages on an SD card. The serial interface speeds for logging data can also be adapted, or data from an I²C or SPI interface could be collected instead. Finally, should your messages require a little color or formatting, you could insert appropriate HTML or CSS during web page generation.

200223-01

Questions or Comments?

Do you have technical questions or comments about this article? Email Elektor at editor@elektor.com.

WEB LINK

[1] Elektor Labs Project Page: www.elektormagazine.com/labs/wireless-trace-for-debug

Did COVID **Cause a Boost** in Engineering Innovation?

Innovative Components and Solutions from 2022

The COVID-19 pandemic has created countless challenges for the engineers and executives in the electronics industy. But despite all the staffing-, logistics-, and supply-related difficulties, innovation has continued in the face of unprecedented adversity. Let's take a look at some of the new components and solutions that stand out.

By Stuart Cording (Elektor)

The past two years may have been a struggle for those looking to purchase components, but this year's trade shows have shown that design teams around the world were anything but sluggish during that time. While excitement at the new products on offer could be attributed to the euphoria of meeting in person again at exhibitions, closer analysis shows that true advancements have taken place. And these appear across the board, from small analog power devices to processing behemoths that will change the face of the automotive industry.

Performance and Safety for Automotive

It has been clear for some time that the future of the automotive industry lies in selling software wrapped in a mechanical shell. The software-defined car will make this happen, providing us with vehicles that can have their software upgraded and new features deployed over their lifetime. BMW has already announced features-as-a-service, with seat heating available for a monthly fee [1] in the UK. This means a massive change in how vehicle electronics, especially software, are developed.

Rather than creating an electronic control unit (ECU) for each function, such as a window lifter, multiple functions will be integrated into a handful of powerful domain controllers. Interlinked using automotive Ethernet, a new single-pair implementation of the well-known networking protocol, they will sit around a high-performance computer (HPC). However, this approach cannot be to the detriment of fulfilling ASIL [2] safety requirements.

This brings us to the launch of the truly impressive S32Z and S32E real-time processors from NXP (**Figure 1**). To start with, they feature a smorgasbord of processors targeted to fulfill the critical deterministic behavior of the car at clock speeds of up to 1 GHz, a figure unheard of for an ASIL D-capable device. Eight Arm Cortex-R52s do the heavy lifting that can operate independently or in lockstep. One lockstep Arm Cortex-M33 is dedicated to system management, while two more provide acceleration for CAN FD automotive communication. A final Arm Cortex-M7 directs the function of the hardware security engine (HSE), a block critical for ensuring a secure system.

Core-to-Pin Virtualization

In order to support multiple functions on a single system-on-chip (SoC), such devices use a hypervisor. This enables multiple operating systems (OS) to execute on the SoC, unaware of each other's presence (typically POSIX and AUTOSAR [3]). The processors of servers running hypervisors use a memory management unit (MMU) to separate the OSes along with some clever software to assign, for example, the correct USB device to the correct OS or to share the Ethernet port amongst them. However, for the S32Z and S32E, things are different.

Virtualization is supported from core to pin, meaning that the allocation of peripherals to a specific OS happens in hardware. This simplifies assignment, reduces software overhead, and ensures that a failure won't impact a safety application of one OS on another. The capability also supports the general-purpose IOs (GPIO) with the groups of bits in registers appearing as a dedicated virtual register containing only the pins required by the virtualized OS.

The current portfolio of devices is built using 16 nm technology, but Brian Carlson, Director, Global Product and Solutions Marketing, explained that the roadmap is to move to 5 nm. The industry has also recognized the importance of these devices, with Axel Aue, VP of Engineering at Bosch, stating that "[these devices] offer a performance increase of a factor of 2 compared to embedded NVM MCUs." Furthermore, the devices received the Embedded World 2022 Award in the hardware category, making them a technology to watch as vehicles go increasingly electric and electronic.

Single-Pair Ethernet for Industrial Networking

Looking at the collections of cables and connectors in factories, there is clearly some significant room for optimization. Currently, a plethora of Field buses are chosen according to price, safety requirements, and suitability to the specific application. Most of these don't support multidrop, resulting in many cables routed to a single PLC. However, some order may be restored thanks to multidrop Single-Pair Ethernet (SPE) as defined in a series of extensions to existing Ethernet standards.

Until now, the necessary hardware has only been available in microcontrollers as an integrated peripheral. However, with the launch of OnSemi's NCN26010, a standalone SPE 10BASE-T1S Ethernet controller with

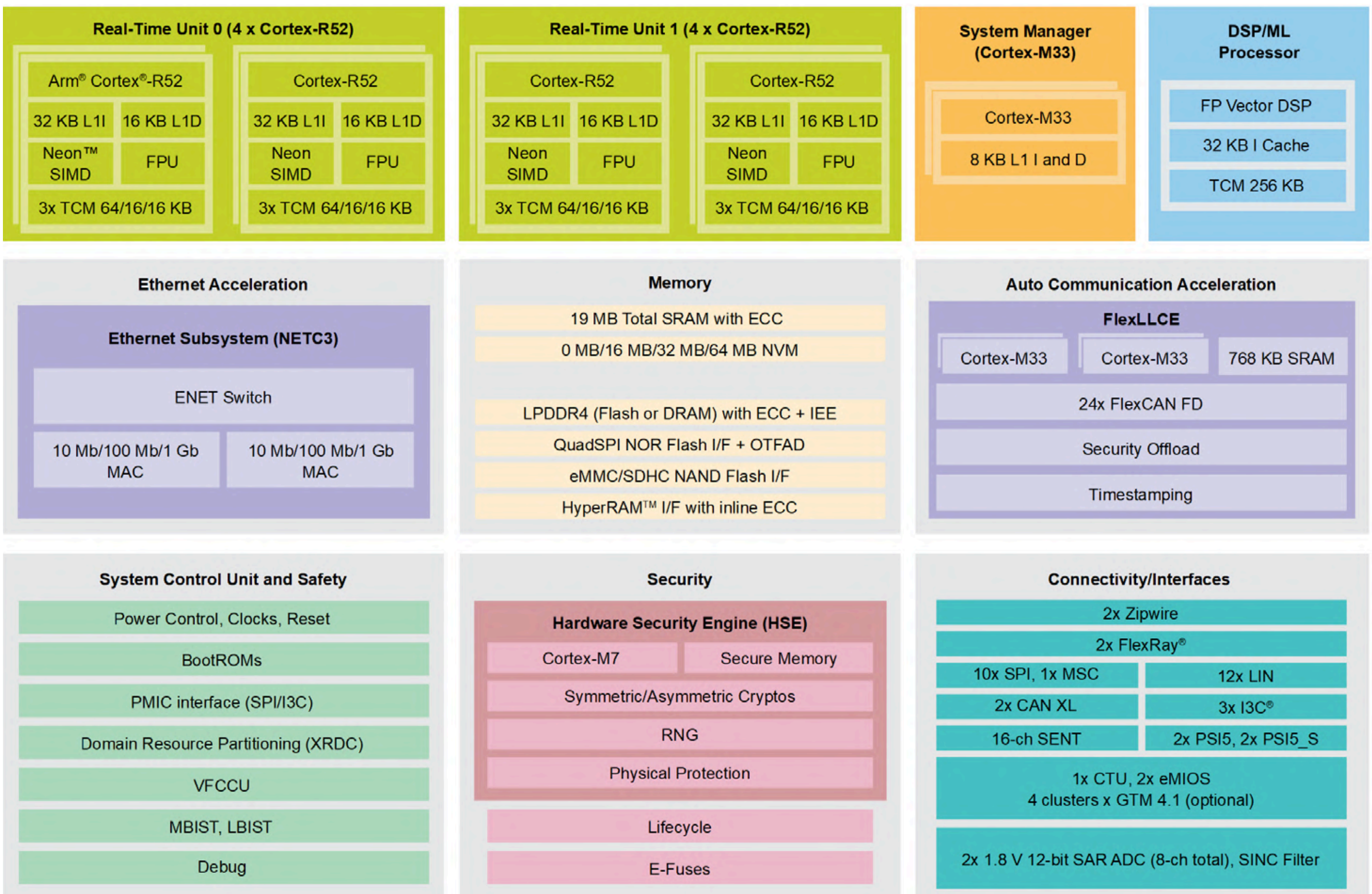


Figure 1: The S32 series of real-time processors from NXP target the new software-defined vehicle architecture and support core-to-pin virtualization. (Source: NXP)

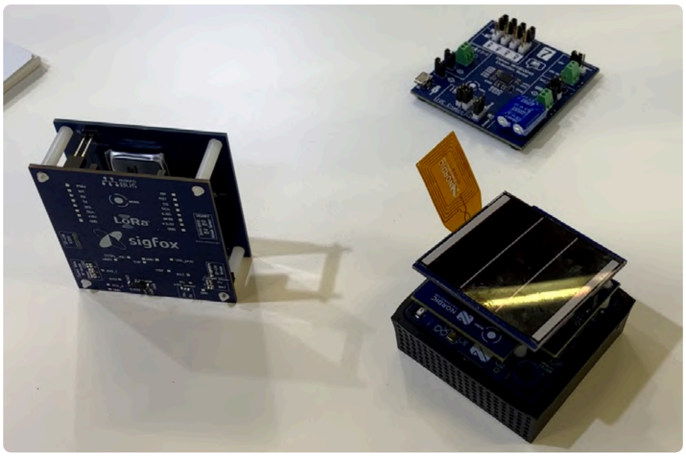


Figure 2: The Diatom PMIC (NH16D3045) from fabless startup Nowi offers highly-efficient energy harvesting from a range of sources.

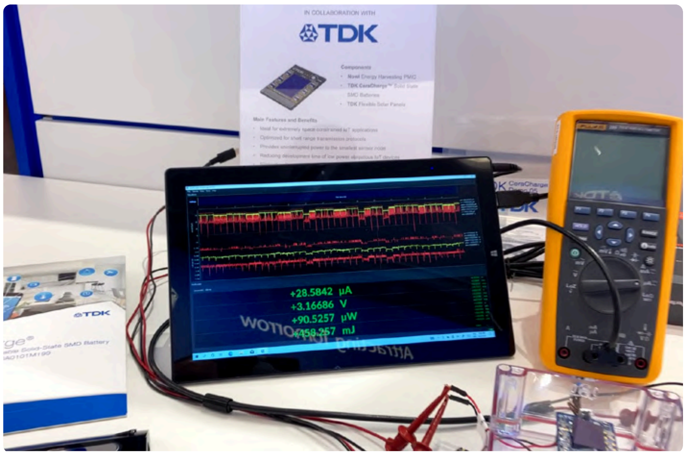


Figure 3: TDK's rechargeable solid-state, surface mount battery, CeraCharge, uses a multilayer lithium-based oxide structure.

integrated MAC and PHY is available. The device can connect using SPI to a standard microcontroller or a board, such as a Raspberry Pi, for which software drivers are available (Linux, FreeRTOS). The controller supports the standard's minimum of eight multidrop nodes over > 25 m, but can support up to 40 nodes and longer distances if needed.

To maintain reliability under the electrically noisy conditions of a factory, the device uses a range of innovative noise-immunity features. Additional communication reliability is provided by an optional IEEE capability built into the MAC, known as Physical Layer Collision Avoidance (PLCA). This provides a round-robin arbitration method that avoids collisions and increases networking utilization to almost 100%.

Powering IoT

With the growth in Internet of Things (IoT) devices, it is only fitting that we question whether batteries are the best method to power devices that have no alternative power source. Nowi, a small fabless semiconductor start-up based in Delft, The Netherlands, has examined this issue. Their most recent power management IC 'Diatom' (NH16D3045) is a high-efficiency energy-harvesting solution for low-power applications (**Figure 2**). Targeting smart wearables and wireless sensors, it can deliver power in the micro- to milliwatt range from sources as diverse as solar panels, thermoelectric generators, or vibration from piezo devices. Various demonstrations have already been built, including electronic shelf labels and television remote controls.

Figure 4: Laurens Slats explains how the IoT Stars networking event brings people together to explore issues common across the IoT industry.

▼

Of course, the energy harvested needs to be stored until the application needs to use it. TDK has launched a new storage technology, CeraCharge, for this purpose (**Figure 3**). This solid-state solution merges the best from lithium-ion batteries and multilayer capacitors to create a lithium-based oxide multilayer battery. Its chemistry makes it safe for use even in a vacuum because it cannot leak or explode. The same size as 1812 MLCC capacitors, it is 10 times smaller than comparable super caps, and it can be handled using pick-and-place and soldered using a typical reflow profile. After 1,000 recharge cycles, the battery still provides 80% of its original capacity. The CeraCharge 1812 offers a nominal voltage of 1.5 V, a nominal capacity of 100 µAh, and operates over -20°C to 80°C. Thanks to discharge rates of up to 10C it can also support Bluetooth Low Energy (BLE) beacons.

The Stars of IoT

Another challenge of IoT is the islands that build up around differing technologies, such as the various wireless networks or IoT platforms. This holds back the development of what are, at their core, 10 similar applications tackling common challenges. Addressing this is IoT Stars, a networking organization that is providing meet-ups alongside the industry's trade fairs (**Figure 4**). Laurens Slats, Developer Relations, explained how their events enable developers and suppliers involved in all aspects of IoT to share their experiences, whether in low-power design, platform integration, or wireless technology. Their next event is planned for Barcelona's Mobile World Congress (MWC).

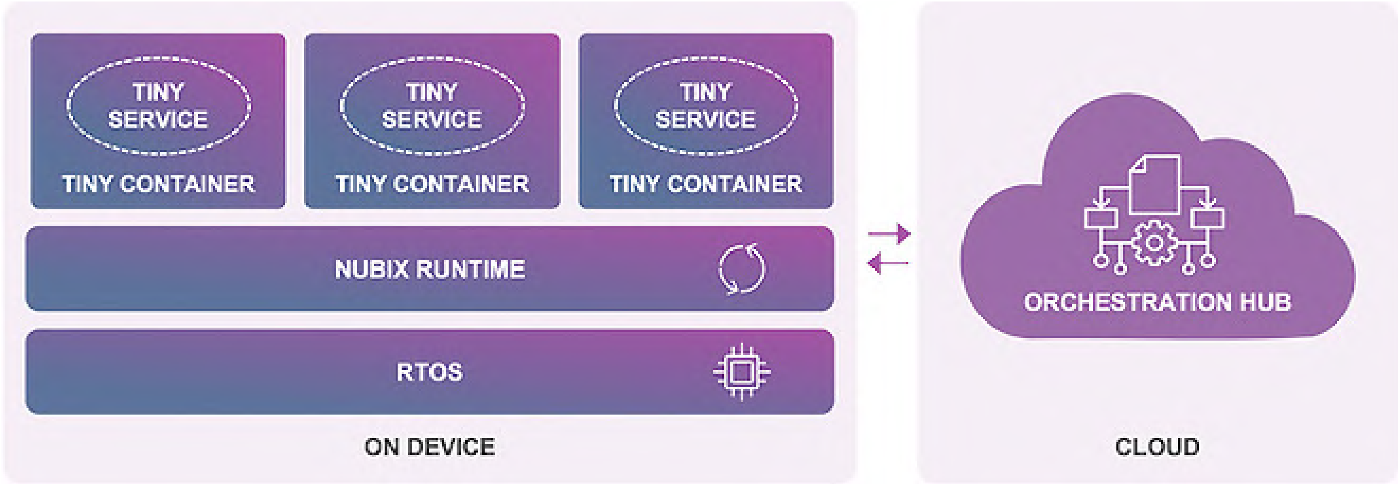


Figure 5: Nubix aims to simplify IoT feature deployment to standard microcontrollers with their Orchestration Hub and container approach. (Source: Nubix)

Another member of the IoT Stars community is Rachel Taylor, who launched her new venture, Nubix, at IoT Stars during Embedded World. Rachel's concern is that IoT devices rely too heavily on traditional development processes and haven't fully leveraged the capabilities of existing cloud services. As a result, over-the-air (OTA) updates or even deploying new applications remains a struggle. Nubix is building an edge-native application platform that is suited to the Arm Cortex-M microcontrollers currently used in this space. Starting with a real-time operating system and a runtime layer, applications are deployed as services in 'tiny containers.' When connectivity is available, data can be collected and services updated through their Orchestration Hub (**Figure 5**).

New Flash Drive Format

Mini and client PCs are space-saving while providing enough performance for surfing the Internet and writing the occasional letter. But their integrated flash drives, soldered to the motherboard, essentially define their shelf life as, once the OS and data grow suitably large, there is no way to upgrade. In the future, this could also impact cars and other applications. However, this could become a thing of the past thanks to XFMEXPRESS (**Figure 6**), a new flash drive format from Kioxia. Looking similar to an SD card, the device supports PCIe and NVMe, making it compatible at its interface with today's M.2 SSDs. However, it is designed to be a serviceable rather than a portable data device. At just 1.4 mm thick, it is installed into a clamshell socket that provides a tight and secure mounting. Offered in densities of up to 1024 GB, this technology is defined as a JEDEC standard to garner broader adoption.

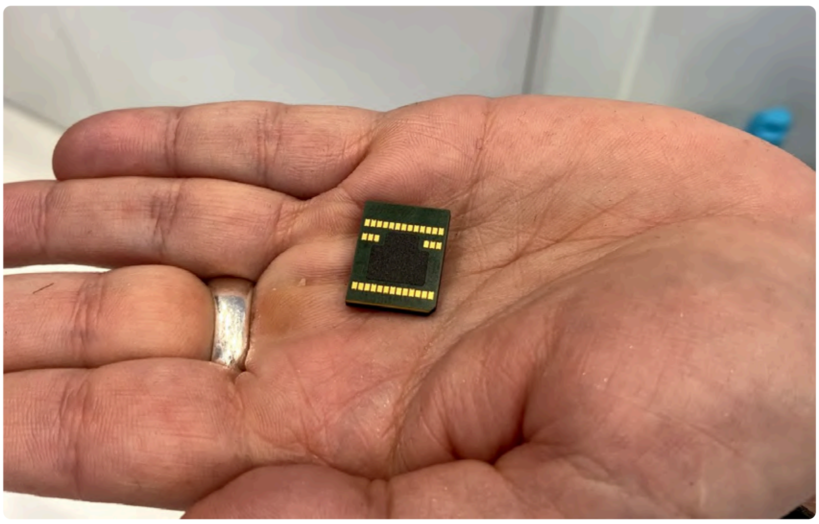
Processor Design Made Even Simpler

One of the benefits for developers of RISC-V cores is the ability to add custom instructions to speed up specific algorithms. Today, a range of standard cores is available from suppliers that can support the customization process. However, the use of new instructions requires the programmer to implement them using inline assembler [4] that, of course, requires changes to the source code. Codasip, formed in 2014 and headquartered in Germany, demonstrated that this doesn't need to be the case using their L31 embedded RISC-V core. While using Tensor Flow Lite to perform recognition of the MNIST handwritten digit database, Rupert Baines, CMO, explained that processing hotspots could be determined. From here, two new custom instructions are defined to accelerate digit recognition and integrated into the core. The same code, without any modifications, then uses the customized L31 core to achieve an 80% improvement in inference time (**Figure 7**).

Another big part of machine learning is the need for access to powerful graphics processing units (GPU) and neural network accelerators (NNA). Startups developing new silicon often find it challenging to finance the license fees for core IP. They are often forced to divert funds away from hiring the employees who can deliver the innovations. Imagination, a supplier of RISC-V and GPU IP, is making this easier with their new program, Open Access. By scrapping licensing costs for scale-up companies, teams can access four

Figure 6: XFMEXPRESS from Kioxia provides a serviceable alternative to soldered-on flash drives for thin clients and mini PCs.

▼



▲

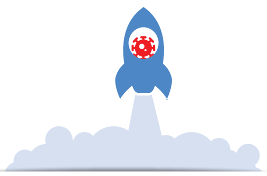
Figure 7: Adding and using new instructions with RISC-V cores can be very simple, explains Rupert Baines from Codasip.

PowerVR Series8XE GPUs and three Series3NX NNAs. The program includes access to support and tools as they make their first steps to innovate in silicon, only taking royalties once products ship.

Tackling the Scourge of Counterfeit Components

Perhaps the biggest kick in the teeth during COVID has been the shortage of components coupled with the surge in counterfeit devices. And while some counterfeits are more obviously spotted, many are easily overlooked. For Electronics Manufacturing Services (EMS) that service thousands of customers, it is difficult to keep on top of the supply of the millions of components that are picked and placed every week. The startup Cybord has taken on this challenge with its electronic component analytics and traceability platform. Integrated into the manufacturing line, the system captures images of every single component, storing it with its charge number and other delivery note data in a database. Artificial intelligence (AI) is then used to pinpoint anomalies in everything from silicon chips to passives.

Oshri Cohen, Chief Strategy Officer, explains that the system can also assess other issues, such as poor-quality solder pads and different date codes for products in a single reel. These are then highlighted by the system, allowing operators to decide whether or not to go ahead and use the parts. As well as analyzing the components, the system also maintains a database of the components soldered into each product built. If a product fails and is returned due to a poorly-soldered capacitor, the manufacturer can go back and review the state of the capacitors used for other boards in that batch. If other capacitors are identified as having had poor quality solder pads, a handful of affected boards can be recalled rather than hundreds or thousands. This provides a surgical traceability capability that could help to reduce electronic waste.



During COVID, We Remained Busy

Perhaps, having been forced apart for so long due to COVID restrictions, the progress seen this year is more mirage than reality. But the facts don't lie — there are loads of new players, new products, and new platforms solving challenging problems in innovative ways. Maybe working from home was the efficiency improvement development engineers have secretly been waiting for all these years!

220395-01

Questions or Comments?

Do you have technical questions or comments about this article? Email the author at stuart.cording@elektor.com or contact Elektor at editor@elektor.com.

Elektor
Engineering Insights

Elektor Industry Insights: Watch Live

Elektor Industry Insights is a go-to resource for busy engineers and maker pros who want to stay informed about the world of electronics. During each live episode of the show, Stuart Cording (Editor, Elektor) discusses real engineering challenges and solutions with electronics industry experts.
Visit www.elektormagazine.com/eei for details about upcoming and past shows.

WEB LINKS

[1] P. Valdes-Dapena, "Why BMW is offering heated seats on a monthly subscription," CNN Business, July 2022: https://cnn.it/3dqmIAT
[2] "Automotive Safety Integrity Level (Automotive) (ASIL)," IT Wissen.info, July 2019: https://elektor.link/ASIL
[3] AUTOSAR Website: www.autosar.org
[4] S. Cording, "What Is RISC-V?," Elektormagazine.com, April 2021: www.elektormagazine.com/articles/what-is-risc-v

Ersa i-CON TRACE
The IoT Soldering Station for Makers

Contributed by Kurtz Ersa

Which factors are decisive for successful hand-soldering? The skills of the user and the right tool! Even when Ernst Sachs patented the electric soldering iron back in 1921, his focus was absolutely on developing a functional soldering tool. And so it has remained: With the Ersa i-CON TRACE, the No.1 system supplier for electronics manufacturing from Wertheim presents a modern soldering station that has a lot to offer, from a new soldering tip technology to network integration!

Ersa's i-CON TRACE focuses on what matter most – the soldering process itself. The station convinces with an extremely ergonomic and powerful soldering tool, the i-TOOL TRACE. The lightweight and ergonomic soldering iron is equipped with a 150 W heating element, making it the perfect tool for all soldering tasks. The new Soldering Tip Series 142 has been thermodynamically revised. Based on extremely precise temperature control, Ersa ensures the correct working temperature at all times. This is one of the most important factors for the quality of soldering work. A wide variety of soldering tip types can be used

> *"First of all, the performance of the i-TOOL TRACE soldering iron, i.e. its heat transfer as well as the handling and the very easy tip change, were important for me."*
>
> *(Feedback from a pilot customer on the i-CON TRACE)*

- from fine 0.1 mm pencil tips for extremely delicate soldering tasks on the smallest SMT chip components, to a 12 mm-wide chisel tip for high-thermal-mass applications, to the 20 mm-wide wick tip for desoldering or picking up residual solder on an assembly. All tips are printed with a unique QR code and can thus be identified. This function is important during process documentation.

The tip-change is indeed an innovation: identical change times to a cartridge system, but also the ecologically-sound and economically-sensible separation of soldering tips and

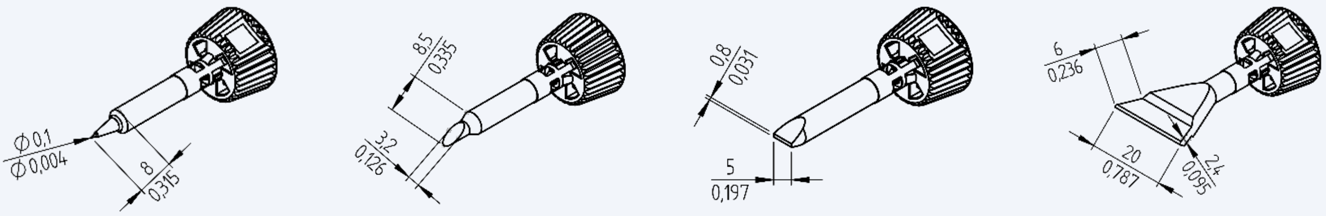


Figure 1: Selection from the new Soldering Tip Series 142 with bayonet lock and optimized heat conductivity.

Figure 2: The patented Tip'n'Turn concept of the Ersa i-CON TRACE allows for a tip change in record time.

Figure 3: The connectivity of the i-CON TRACE allows every single soldering process to be documented: assemblies, tip used, temperature, and soldering time. The TRACE COCKPIT application for computers or the TRACE APP for mobile devices are available for this purpose.

exchangeable heating element! The new, patented bayonet lock allows the soldering tip to be changed within a few seconds, even when hot (**Figure 1**). The multifunctional storage stand can be used directly in seconds with the help of the Tip'n'Turn technology - or the tip can be changed by hand as normal (**Figure 2**).

Intuitive LED-Based User Interface

The operating concept of the i-CON TRACE is also completely new: Instead of a display and control elements on the station, the user interface has been shifted almost entirely to the TRACE APP for iOS or Android smartphones and tablets or the browser-based TRACE COCKPIT (**Figure 3**). Once all parameters are set, the user receives the essential information via three LEDs on the station. All indicators light up green, meaning a clear path

Figure 4: GREEN MEANS GO! When all conditions for the assigned soldering task are met, i-CON TRACE's LED interface gives the green light to start the soldering process.

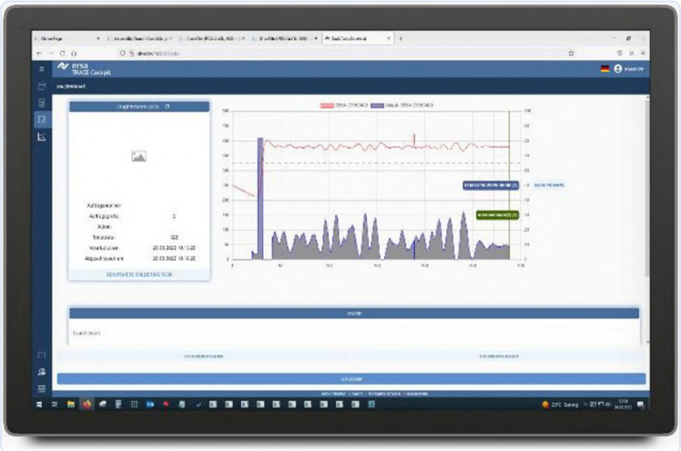


Figure 5: Documentation of a soldering job in TRACE COCKPIT.

for soldering — or "green means go!" as the Ersa engineers say. This keeps the user's concentration on the soldering task itself (**Figure 4**).

This simple and intuitive operation is made possible by the unique connectivity of the i-CON TRACE. It is the first soldering station ever to be equipped with integrated Bluetooth and Wi-Fi module as standard. It can thus be added to any network in just a few simple steps. An optional plug-in LAN module is available for wired communication. The operation of one or more stations via the free TRACE APP (iOS and Android) is completely intuitive. From temperature setting to behavior control to standby and sleep mode, all values can be set in no time and are updated in real time.

For professional customers, the i-CON TRACE offers even more via the server-based browser application, TRACE COCKPIT: The i-CON TRACE is the "missing link" and closes the previously open gap in the hand soldering process in terms of documentation with maximum traceability (**Figure 5**). Thus, TRACE COCKPIT can provide the recording of an entire soldering task in a desired file format (PDF, CVS, XML). Specific soldering tasks (jobs) can be assigned centrally to each soldering station via TRACE COCKPIT.

This IoT soldering station can even be integrated into production processes controlled via Manufacturing Execution Systems (MES), making the entire manual soldering process traceable and documentable. Here, important key data such as the assembly, the QR code of the soldering tip in use, the solder wire and the flux applied are recorded using a hand scanner. In this way, the system "knows" that all preconditions for the assigned soldering task have been met. The operator concentrates entirely on soldering, reducing the possibility of errors to an absolute minimum. All soldering work process data performed is stored centrally and can be evaluated at any time – for example in the event of complaints. As the first IoT soldering station, the i-CON TRACE opens up completely new dimensions for all users in soldering technology.

220553-01

i-CON PICO & i-CON NANO – Compact Soldering Performance

For those who desire professional soldering performance, but have little space on the workbench as well as a limited budget, Ersa offers two more compact soldering stations.

The i-CON PICO (footprint 145 × 80 mm) offers three fixed, presettable temperatures or stepless temperature adjustment from 150 to 450 °C. It also has standby and sleep modes and can be parameterized with a microSD card. If an ESD-safe environment is given, the i-CON NANO with the same functionality can be considered. All surfaces are made of antistatic material. Both stations also feature separately replaceable soldering tips (Series 102) and heating elements (max. 150 W) as well as excellent soldering performance on small-to-medium-sized solder joints. Handy and smart!

i-CON PICO (left) and i-CON NANO - compact soldering performance for regular work areas and those with ESD requirements.

WEB LINKS

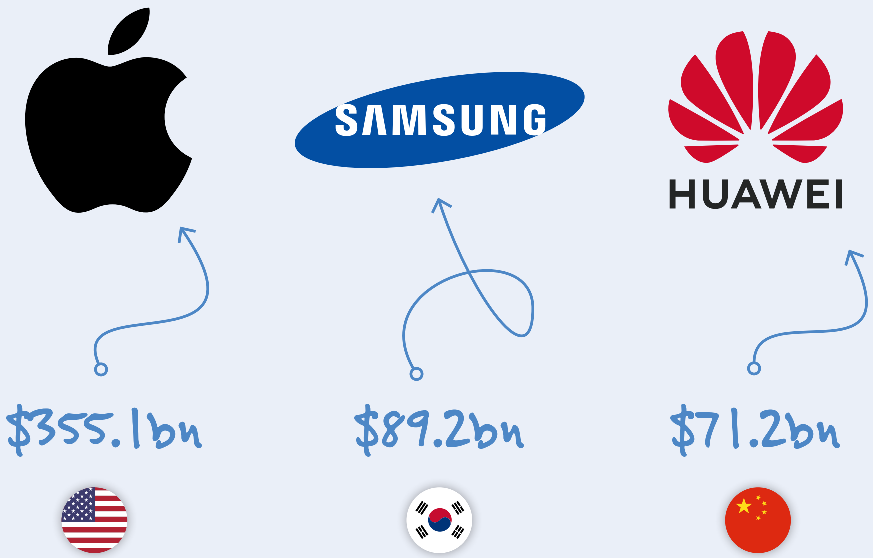
[1] Learn more: https://www.i-con-trace.com
[2] Ersa i-CON PICO and i-CON NANO product video: https://youtu.be/eUE0a_2C6XI

By Robert van der Zwan

Apple **Is the Big Winner** of 2022

How strong can an electronics brand be? As strong as the special methodology of Brand Finance allows it to. Every year, Brand Finance publishes a ranking with the world's top 50 most valuable and strongest electronics brands. Its methodology takes all kinds of things into account: emotional connection to the brand, current and future revenues, potential license agreements, post tax income, and so on. Apple is on top with a staggering brand value of USD $355 billion, a year-on-year increase of 35% and a 2.5 times increase since the start of the pandemic. Branding Finance contributes the unprecedented success of Apple to a very convincing combination of innovative devices and high-quality services.

(Source: Brand Finance)

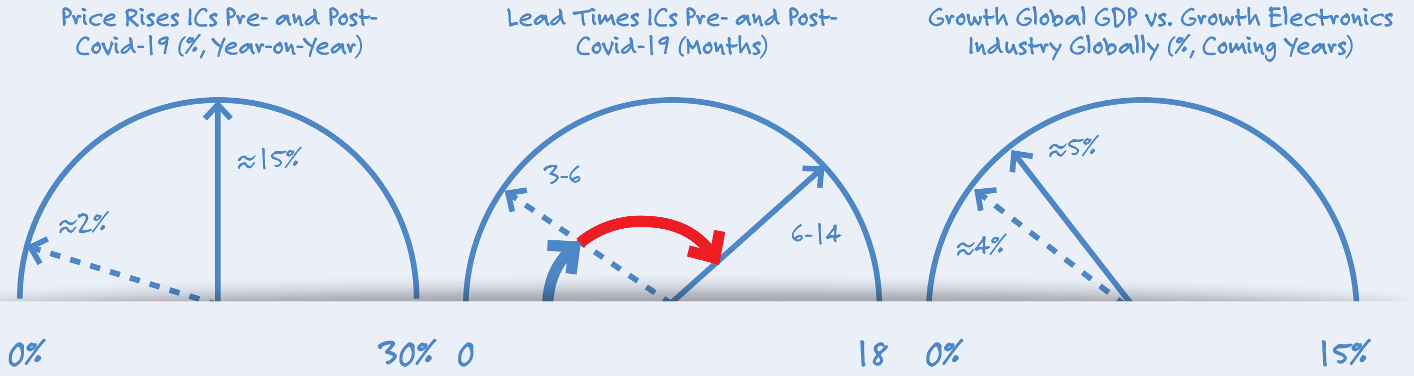


Everything Is Uncertain, Apart From … Demand

At the end of last year, the mood in the semiconductor industry was upbeat. A workable equilibrium between supply and demand was not only on the horizon, but within reach in 2022. Some analysts believed that lead times would soon go back to pre-pandemic levels. However, the war in Ukraine and new outbreaks of Covid-19 in China have smashed such optimism. Since the pandemic started, the price of an IC has roughly gone up 15%. Lead times could now even surpass the delivery times in mid-2021, when shortages were on its highest. Does this affect demand in the electronics industry? No. Autonomous and electric driving, 5G, gaming, edge processing: they all lead to more growth than the global GDP itself.

(Sources: Nikkei Asia, Qualitel, The Business Research Company)

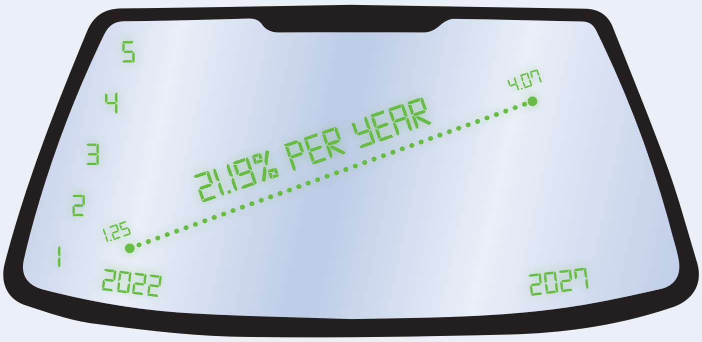
Before Covid-19 and After the Start of the War

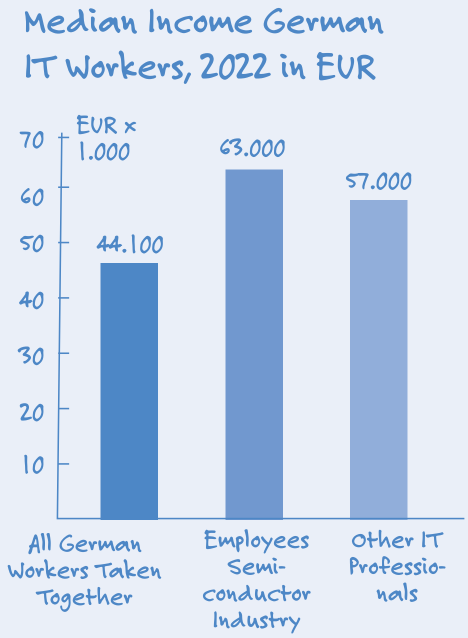


Transparent Electronics: A Different Outlook Indeed

It may not be a huge market yet, but transparent electronics certainly has a lot going for it. For example, transparent electronics makes it possible to integrate solar cells in ordinary windows, making any window a potential power generator that works much more efficient than current solar cells do. And then there is this other great outlook for transparent electronics. A driver or pilot can keep track of speed while at the same time keeping his or her eyes on the road or on the clouds. Transparent electronics is as promising as wireless charging or 5G. Like both technologies, the growth of this new kid on the block is in double digits: 21.19%, going from USD $1.25 billion in 2022 to $4.07 billion in 2027.

(Source: Research and Markets)





Salaries Through the Roof? **Not So Much**

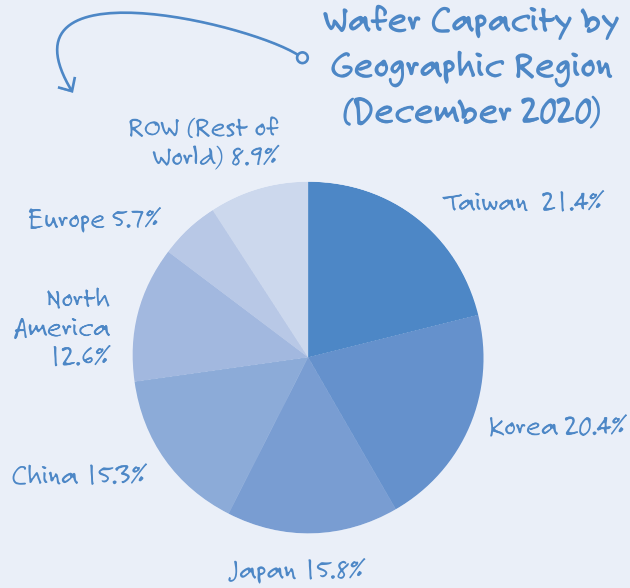
Given the capacity problems within the semiconductor industry, it stands to reason that salaries within the IC industry are bound to go upwards. And this is indeed the trend. But the median incomes for employees in the semiconductor industry haven't doubled — whereas many lead times have. The reason for this moderacy has to do with the uncertain times we are in, given the supply chain disruptions from the last two years. Better weather the storm than make the ship too heavy. This seems to be the attitude of German IT workers, based on research from StepStone and Interconsult. According to StepStone, salaries could increase 3-4% this year, slightly more than the 10-year average of 2-3%.

(Sources: Interconsult, StepStone)

Russia: Semiconductors **Are Not a Commodity** Here

Russia may threat the West with cutting supplies for gas and oil, but this same strategy won't work when it comes to semiconductors. The reason is simple: the production capacity for ICs in the Russian Federation is negligible. Have a look at the rather small slice 'ROW' ('Rest of World') in the pie diagram. In this slice, you will find the total wafer capacity for countries like Singapore, Israel, Malaysia, Australia, Belarus and ... Russia. Why, then, is Russia still a force to be reckoned with? It is a major supplier of neon, argon and helium, inert gases needed to produce ICs. Although Western companies already have secured supplies from elsewhere, a fivefold price increase for new contracts is not unheard of.

(Sources: Aroged, Financial Times, IC Insights)



EDGE IMPULSE

What Are We Going to Do with All This Compute?

By Zach Shelby (Co-Founder and CEO of Edge Impulse)

Edge Impulse co-founder Zach Shelby sits down with former Arm CEO Simon Segars to talk about how Acorn computers helped bring us to a world of machine learning on the edge.

We're finding that data and edge computing are driving new innovations for real industries, thanks to brand-new innovations in the space of edge computing. I recently met with Simon Segars to discuss all the amazing things happening in this industry (**Figure 1**). Simon is a technology visionary; he was the long-term executive at Arm, a board member of global corporations such as Vodafone, and recently joined the board at my company, Edge Impulse. He helped create a lot of the technology on display in the Computer History Museum, making it a fitting site for our conversation.

This is an excerpt from a longer discussion; you can listen to it in its entirety at youtube.com/edgeimpulse.

Zach: Right here behind us we have the BBC Micro, among many other amazing pieces of computing equipment. Tell us a little bit about the journey from the BBC Micro and Acorn computers to Arm.

Simon: These computers were a lot of fun and certainly played a role in my life in getting interested in computing and technology and everything. The BBC was a huge component of that. It was introduced into the UK market as an educational tool; the BBC wanted to help teach the UK public about computers, so they commissioned its creation. The team at Acorn got together and built it. It's a fascinating story of getting a bunch of really smart people together and having them build something. And it all came together at the last minute, but it turned out to be an incredible computer.

The team at Acorn then wanted a more advanced microprocessor to power their next generation of computers. They couldn't find one, so they thought, "How hard can it be? Let's build a microprocessor." And that led to the Arm1 (**Figure 2**). Groundbreaking design, very small, very power efficient, and very efficient in its use of memory as well. That was then the CPU that went into the Acorn Archimedes series of computers. I got to play around with those when I was at university and it was like, "Wow, this thing is unbelievably fast."

Little did I know, in parallel, lots of stuff was going on in Acorn. It got to the point where the company couldn't really afford to have this R&D team building microprocessors, so they looked for a partner. Apple came along, looking for a microprocessor for the Apple Newton. They got together and decided to form a joint venture: Arm. The company was spun out of Acorn.

I joined a couple of months after that as the 16th employee. It's been a fantastic journey since; we've made these things more and more energy efficient with higher and higher performance. There are now billions of them out in the world.

Zach: How has the microcontroller journey come together to enable a new wave of machine learning on edge computing?

Simon: When people started using the term the Internet of Things, what they were talking about was, "Let's take a sensor and connect it to the network and take that data and process it somewhere else." And pretty quickly, it's like, "Okay, well, security matters." You know, billions of devices, you need to worry about making sure they're secure. We need more performance for that. Should there be a cryptography accelerator in the chip? Well, how much silicon can you afford? Fortunately, silicon manufacturing is getting better and better all the time. And then you get to this tipping point where you've got enough performance in this tiny device. If you start doing some of the processing work there, on the very far endpoint of the network, you can start thinking about how much data you actually have to transmit. Get that to a minimum and, well, now the energy efficiency goes up.

We've seen this kind of advancement in underlying technology capability, leveraging advances that were made somewhere else in the cloud. People can experiment all day long. It's very, very inexpensive to do so. Suddenly it all kind of comes together and you say "OK, I can now do so much more on the edge. Let me do that."

Zach: I remember my Edge Impulse co-founder Jan Jongbloom and me sitting down over a beer, saying, "What are we going to do with all this compute?" It's like having a party. What are we going to do with all this beer? There's just so much computing. The traditional stuff that we're doing cryptography for IoT, some data processing and DSP aren't even hitting the tip of the iceberg of what's possible. This is what got us starting to think about, "Well, why don't we bring these machine learning toolkits from the cloud and apply those to microcontrollers and microprocessors?" And that kicked off a lot of really interesting work around machine learning.

Figure 1: Zach Shelby (left) and Simon Segars. (Photo: Mike Senese [1])

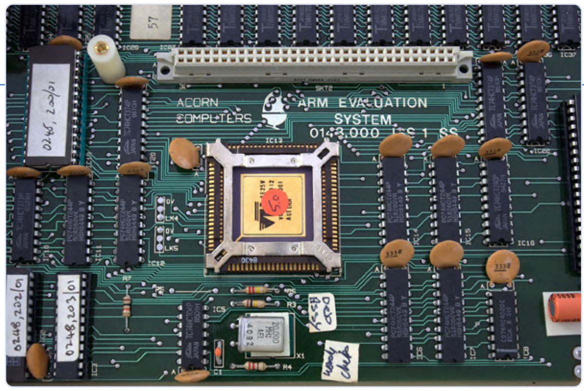


Figure 2: Arm1. (Credits: Peter Howkins, CC BY-SA 3.0 [2][3])

Simon: I think one kind of moment along that journey was a sort of realization that with these technologies, with machine learning and sensing and everything, you can do more things. Suddenly you've got this sensor and you've got this high-performance processor anywhere you can start asking, "How warm is the room? Should we cool it down? Is there anybody in it? Why don't we turn the heating off?" And people just start thinking of these new use cases, leading to them thinking, "How do I program that on this tiny microcontroller that cost next to nothing? I need a better programming environment for that."

And that's the problem that Edge Impulse is really solving. How do you enhance the productivity if somebody wants to build an application on the edge, taking advantage of all of this computing performance, all of this learning that's gone on in the cloud, how do I now take it down to the tiniest device? Because the underlying math is pretty horrendous. But if all I want to do is bring some application to life, I don't have to worry about all of that. I want my productivity to be enhanced so I can leverage all of this great technology.

Zach: Where do you see some of the interesting opportunities for machine learning in the enterprise?

Simon: Fundamentally what you're looking for is insight. Sampling data and doing some analysis on it. But you want some actionable insight from that, whether it's in the case of a medical device or really cool, you know, "How well did I sleep last night?" "What is my overall state of health?" Lots of innovation going on in that. What can I tell by sampling the surface of my skin? Am I about to have a seizure? I've seen the application on that. And I think that's going to be an area where we get some really interesting research done.

It's about turning that data and using that technology for something that is actionable, something that really delivers value and across pretty much every industry. Is my machine going to break down? Can I detect where in it and order a spare so that when it gets serviced, the person turns up with the right equipment, the right tools, and the things taken out of action for a short period of time? There's so much money that could be saved and so much greater efficiency that can be created in the world. I see endless possibilities for driving real driving insight, driving real value, creating greater efficiency, and then just learning more, getting more insight about what is going on in the world that will create new business opportunities and make the place just much more efficient.

Zach: What kind of advice should we give industry executives to make use of tech for good in their business cultures?

Simon: At Arm what we saw was was huge impact from what we did. When I joined the company I think the CEO was the only person that had a mobile phone and now billions of people have them. It has enabled connectivity. It's enabled people to get access to information that they couldn't have before. And it has helped increase the quality and quantity of life the world over. And that is an amazing impact from sitting in a converted barn. Knocking out code to impact like that is really quite phenomenal. And then that kind of sense of what we're doing creates impact. So we wanted to encourage that, to encourage our people to get involved in some of these great projects that you see where people are taking these sensors and working out where endangered species are. I've seen examples where rhinoceroses are getting tagged, and the areas are geo fenced, and they're using it to track the habits of these creatures. We're seeing technology being used to listen for the sounds of illegal logging in the rainforests to help preserve that. So these people get all these great ideas. And again, if we can enable them and let them invent and let them create, then that's really, really impactful.

Businesses are being looked at increasingly to play a positive role in the world. Business isn't just about making money on behalf of your shareholders. You'd better be doing something good for the world. There is a role for technology to play in addressing all of the world's biggest issues.

220544-01

To learn more about Edge Impulse visit edgeimpulse.com.

WEB LINKS

[1] Source of the Photo: https://photos.app.goo.gl/3D34o4itFwnUT4vQ8
[2] License: https://creativecommons.org/licenses/by-sa/3.0/
[3] Wikipedia Source: https://en.wikipedia.org/wiki/ARM_architecture_family#/media/File:Acorn-ARM-Evaluation-System.jpg

How to Drive Ynvisible's E-Paper Display

Contributed by Ynvisible

This article will provide instructions on display driving and the electrical integration of Ynvisible's e-paper technology. It will introduce both the hardware and firmware needed to operate the displays successfully.

Ynvisible's printed e-paper displays are ultra-low power (**Figure 1**) [1]. The recommended driving voltage is ±1.5 V and one square centimeter active display area requires approximately 1 mJ to activate. This translates to roughly 1 - 2 µW/cm² for an always-on display.

The displays are manufactured using roll-to-roll screen-printing and lamination processes. They are non-toxic, ITO-free, and mainly comprised of PET plastic. The plastic substrate and roll-to-roll production means thin, flexible, scalable, and highly cost-effective displays. Get started using Ynvisible's e-paper display kit [2].

Background

Ynvisible's technology is very simple to drive. This is one of the key differentiators to other e-paper technologies. The GPIOs in most MCUs can drive the displays with a minimal requirement of additional components. Apply a positive voltage across the display segment to turn on and short circuit, or apply a negative voltage to turn off. The voltage should only be applied when the display switches or is being refreshed. There are some different options depending on the use case and system prerequisites that we will cover below.

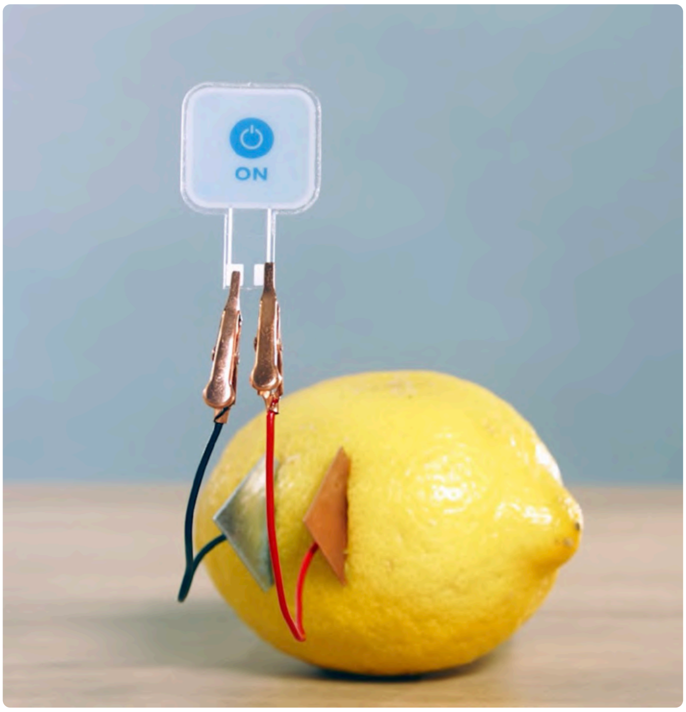


Figure 1: Ynvisible's printed e-paper displays are ultra-low power.

Quick Facts

- Display driving will need to be adapted to the final display design and use case, but the fundamental principles are the same for all Ynvisible displays.
- The displays are direct-driven, one electrode per segment plus one common electrode.
- A positive voltage, in reference to the common electrode, turns ON the display segment.
- A negative voltage (or shortening the work and common electrode) turns OFF the segment.
- A higher voltage level enables a faster switching speed, while a lower voltage enables a longer lifetime.
- The typical recommendation is ±1.5 V across the segment for a good trade-off between switch speed and long lifetime.
- Keeping the voltage to a minimum is recommended if switching speed is not an issue. Only 1.2 V is sufficient to reach full contrast, and it is possible to shorten (≈0 V) the common electrode and the work electrode to turn the segment OFF.

Ynvisible's Display Driver & Resources

Ynvisible has developed a Display Driver [3] together with instructions and a library [4] for rapid prototyping and demonstrators. Please check the datasheet [5] for more information, including electrical and timing characteristics. They also offer a 16-pin adapter [6] for convenient flex-to-pin integration.

Circuit Suggestions

There are many ways to add the Ynvisible E-Paper Display to a circuit. It typically requires zero or very few additional components. All suggestions are based around an MCU with IOs that can be set to High-Z mode (almost all MCUs have this feature).

Circuit 1 (Voltage Regulator Circuit)

A low pass filter and an operational amplifier are used to create a variable virtual ground on the common electrode (see **Figure 2** and **Table 1**). By adjusting the frequency of the PWM signal, the voltage can be adjusted to the desired driving voltage. In this way, the correct voltage can be applied to the segments, independent of the MCU operating voltage. The IOs require a High-Z state to maintain the image between the updates.

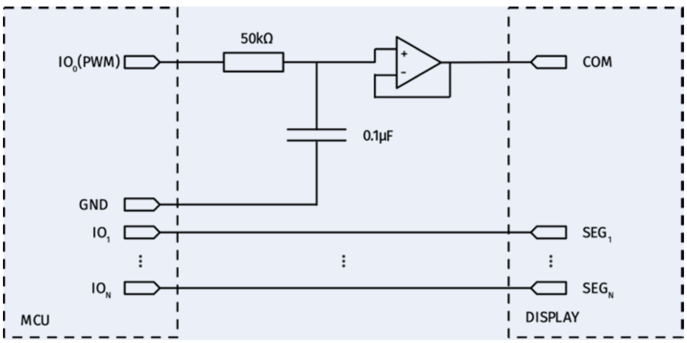


Figure 2: A low-pass filter and an operational amplifier are used to create a variable virtual ground on the common electrode.

Table 1: Specifications of the components for Circuit 1.

Component	Example	Value Unit	Comment
Resistor		**50 kΩ**	Different resistor values may be used depending on PWM frequency and required response time.
Capacitor		**0.1 µF**	Different capacitors may be used depending on PWM frequency and required response time.
Operational Amplifier	Texas Instruments TLV9001SIDBVR		Used to maintain a stable COM potential at different loads.

Circuit 2 (DAC Output On Common Electrode)

If the MCU has a built-in DAC, it can be used as a virtual ground for the common electrode (**Figure 3**). The DAC replaces the external components in circuit 1. The IOs require a High-Z state to maintain the image between the updates.

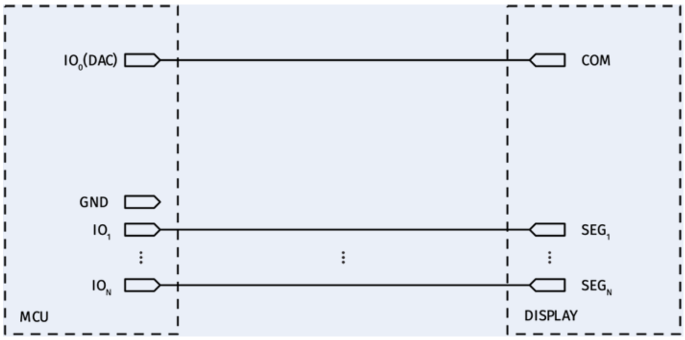


Figure 3: The DAC replaces the external components in circuit 1.

Circuit 3 (2-Level Variable Common Electrode)

A voltage divider is created with R1 and R2 (see **Figure 4** and **Table 2**). Setting IO0 to HIGH and IO1 to LOW, a first voltage level is achieved on the common electrode. A second voltage is achieved by setting IO0 to LOW and IO1 to HIGH. The IOs require a High-Z state to maintain the image between the updates.

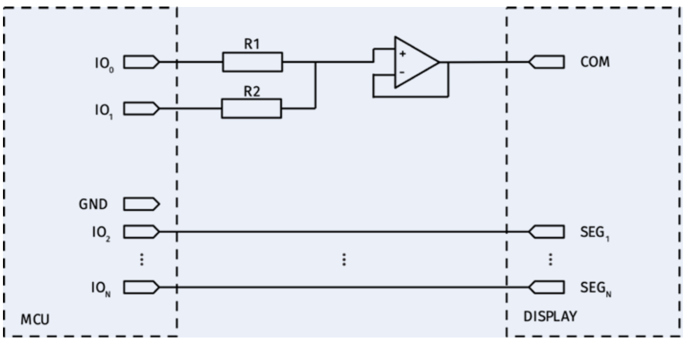


Figure 4: A voltage divider is created with R1 and R2.

Table 2: Resistor suggestions for different supply voltages to achieve ±1.5V driving on different voltage levels.

Supply Voltage	R1	R2	Comment
1.8 V	30 kΩ	6 kΩ	The resistors should be selected to create a voltage divider with an offset voltage of 1.5 V. Other resistor pairs are possible. However, a smaller resistance value leads to more leakage.
3 V	30 kΩ	30 kΩ	
3.3 V	30 kΩ	36 kΩ	
5 V	30 kΩ	70 kΩ	

Circuit 4 (Digital Outputs)

This approach does not require any external components (**Figure 5**). The voltage will be limited to the supply voltage of the MCU in use. The ideal driving voltage for the display is ±1.5 V. Operating voltages of 1.8 V and higher can be considered if the lifetime requirements are limited. Adding a resistor between IO0 and COM can also increase lifetime.

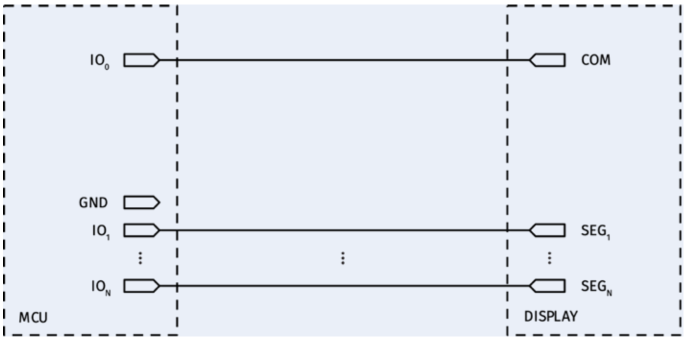


Figure 5: This approach does not require any external components. The voltage will be limited to the supply voltage of the MCU in use.

Ynvisible E-Paper Driving Schemes

Below are a few different driving schemes suggestions (see **Figure 6** and **Table 3**). We also indicate which circuit suggestions described above are compatible with the driving schemes.

Table 3: Definition of the conventions used in the following driving schemes.

Convention	Segment no. in figure	Definition
COM	-	Common electrode
SEG (OFF – OFF)	1	**Segments that should be kept in OFF state**
SEG (OFF – ON)	2	Segments that should turn ON
SEG (ON – OFF)	3	Segments that should turn OFF
SEG (ON – ON)	4	Segments that should be kept in ON state

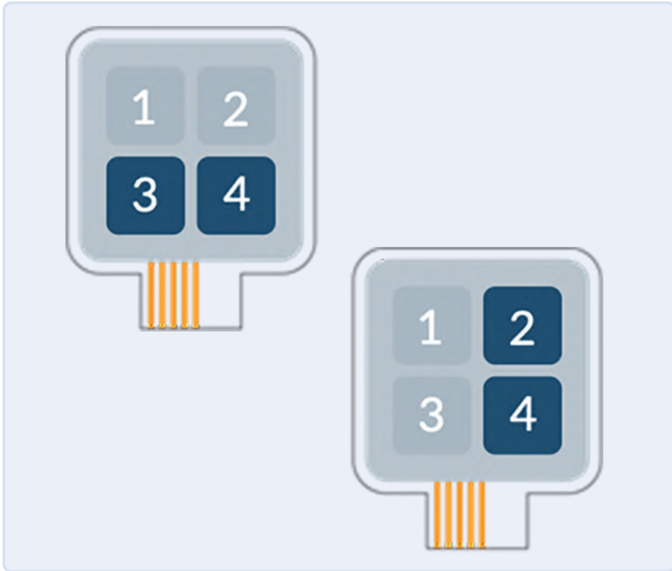


Figure 6: Left: before update. Right: after update.

Driving Scheme A (Compatible With Circuits 1, 2 and 3)

This driving scheme updates the display in two steps (**Figure 7**). First, some segments are turned OFF by setting the common electrode to 1.5 V and the relevant segment electrodes to LOW/0V (resulting in -1.5 V across the segments). Secondly, some segments are turned ON by setting the common voltage to VSUPPLY - 1.5 and the relevant segment electrodes to HIGH/VSUPPLY (resulting in +1.5 V across the segments). A shorter refresh pulse is required on the segments that should be kept in ON state. The sequence ends with setting all signals to High-Z to maintain the state.

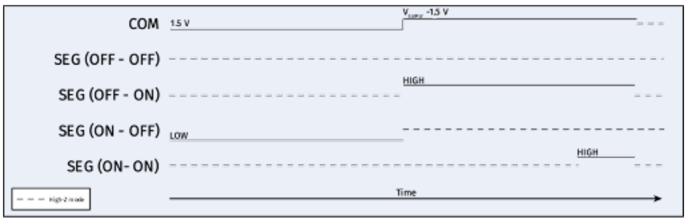


Figure 7: This driving scheme updates the display in two steps.

Driving Scheme B (Compatible With Circuits 1, 2, 3 and 4)

This driving scheme updates the display in two steps, like driving scheme A, but without a variable common electrode voltage (**Figure 8**). First, some segments are turned OFF by setting the common electrode to HIGH and the relevant segment electrodes to LOW/0V (resulting in -VSUPPLY across the segments). Secondly, some segments are turned ON by setting the common voltage to LOW and the relevant segment electrodes to HIGH (resulting in +VSUPPLY across the segments). A shorter refresh pulse is required on the segments that should be kept in ON state. The sequence ends with setting all signals to High-Z to maintain the state. If the system operates at a low voltage or if lifetime requirements are limited, this could be a good option.

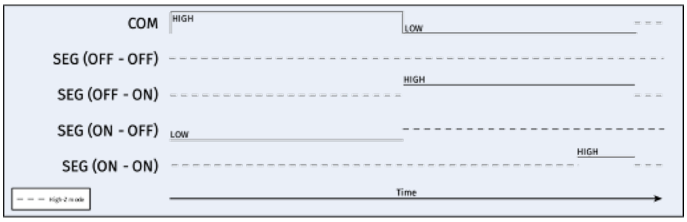


Figure 8: This driving scheme updates the display in two steps, like driving scheme A, but without a variable common electrode voltage.

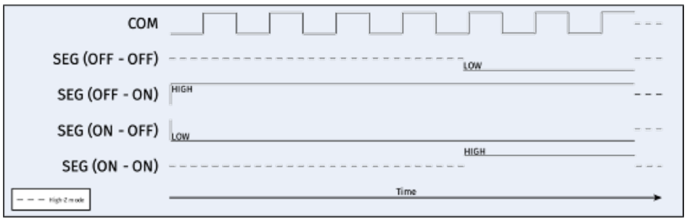


Figure 10: This driving scheme updates the display in one step. The display is enabled by applying a PWM signal to the common electrode.

Driving Scheme C (Compatible With Circuits 1, 2 & 3, if |VON| + |VOFF| = VSUPPLY)

This driving scheme updates the display in one single step (**Figure 9**). The segments are turned ON and OFF at the same time. This is enabled by setting the common electrode to a voltage in between LOW and HIGH, typically ±1.5 V for a 3 V system, but could also be, for example, ±1 V for a 2 V system. In this way, a positive and a negative voltage can be applied to the respective segments simultaneously. A shorter refresh pulse is required on the segments that should be kept in ON state. The sequence ends with setting all signals to High-Z to maintain the state.

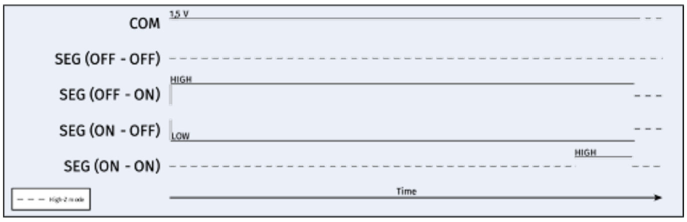


Figure 9: This driving scheme updates the display in one single step.

Driving Scheme D (Compatible With Circuit 4)

This driving scheme updates the display in one step (**Figure 10**), like driving scheme C. The display is enabled by applying a PWM signal to the common electrode to simulate a virtual ground between LOW and HIGH. On many MCUs, this driving approach causes significant leakage leading to significantly higher energy consumption than driving scheme C. The sequence ends with setting all signals to High-Z to maintain the state.

Driving Scheme E (Compatible With Circuit 4)

This driving scheme updates the display in one single step like driving scheme C, but with the difference that the turn-off voltage is 0 V (**Figure 11**). Turning off the segments with 0 V is significantly slower than applying a negative voltage (for example -1.5 V). For this reason, it takes a longer time for the segment that should be turned OFF to switch, compared with the segments that should be turned ON. A shorter refresh pulse is required on the segments that should be kept in ON state. The sequence ends with setting all signals to High-Z to maintain the state. This driving method can connect the common electrode directly to the ground.

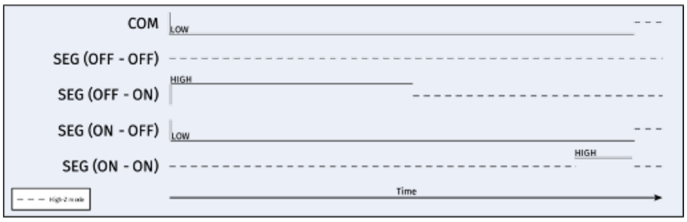


Figure 11: This driving scheme updates the display in one single step, but with the difference that the turn-off voltage is 0 V.

Conclusions

Integrating and driving Ynvisible's e-paper displays are relatively straightforward compared to other display technologies. To get started right away, visit the Ynvisible Store [7] to see our available hardware. Do not hesitate to contact *sales@ynvisible.com* if there are any questions.

220411-01

WEB LINKS

[1] Examples for Energy Consumption: https://www.ynvisible.com/segment-displays#Energy
[2] E-paper Display Kit: https://www.ynvisible.com/product/e-paper-display-kit
[3] Display Driver: https://www.ynvisible.com/product/e-paper-display-driver
[4] The instructions and the library: https://www.ynvisible.com/getting-started#driver
[5] Datasheet: https://www.ynvisible.com/datasheet
[6] The offered 16-pin adapter : https://www.ynvisible.com/product/adapter
[7] The Ynvisible Store: https://www.ynvisible.com/shop

All-Time Innovation **with InnoFaith**

Q&A with Walter Arkesteijn

By Alina Neacsu (Elektor)

Walter Arkesteijn (InnoFaith Beauty Sciences)

InnoFaith is not only a great example of a successful company but also substantiates that "innovation" isn't exclusive to startups. The company makes a deliberate effort to preserve startup traits and even stresses the importance of innovation by including it in the company name. As outlined in earlier articles, teamwork and creativity are key components of their business, and these abilities are used extensively and regularly at all levels. How did this come about, considering that InnoFaith was a startup not too long ago?

As an example of teamwork and creativity right across the work floor, the "look and feel" of the app that accompanies InnoFaith's main product, the Observ 520x skin analyzer [1], has active contributions from practically all the company's employees. In the end, as Walter Arkesteijn highlights, anyone should be able to use their product without much of a hassle!

Alina Neacsu: In the previous interview [2], it was mentioned you "started InnoFaith Beauty Sciences [3] out of entrepreneurial ambition." At which point in your journey did engineering first intersect with entrepreneurship? Did you face any challenges?

Walter Arkesteijn: I used to do vacation work for many years which didn't give me satisfaction because I dreamt of creating things. So, engineering and entrepreneurship first crossed paths when my brother came to me asking if I could solve a problem he had run into at his side job. The pizzeria he worked at had the idea of putting an oven in the delivery truck to keep the pizzas warm during delivery but they did not know how to bring this idea to reality. During this project, I encountered a number of challenges. Here I think it is important to always remember that being naive is the best time to start with something you feel like doing. However, you can underestimate it a lot. You think you can do that without knowing exactly what you are getting into. The desire to create something beautiful does not always match with planning and budgeting as a result. You learn to review things because setbacks are part of the process. This first project sparked my interest in entrepreneurship. I had a challenge here that I didn't know exactly what I was getting into, but when you finally work out the idea and you've been able to create something you could only dream of before, you feel a lot of satisfaction.

Alina: Suppose you were faced with the choice to start InnoFaith again. What do you think would change right now? Is the recipe to success the same as 25 years ago?

InnoFaith's "Observ 520x" product and the associated app running on a tablet.

A look at the customer/patient side of the Observ 520x. The subjects of optics and electronics blend nicely here.

Walter: I do believe that the recipe for success has remained the same since 25 years ago and would not want to change much. If I were faced with the choice of restarting InnoFaith Beauty Sciences, with today's knowledge I would choose to have the operational management part picked up earlier. For me personally, a project feels finished when I have fulfilled it and I prefer to focus on new innovations. Because of this, you miss commercial opportunities. My biggest motivation is not commercial, but organic growth occurred as we tackled bigger and bigger challenges within InnoFaith Beauty Sciences. Space has now been created within the company to further exploit already developing projects while I can focus on innovating.

Alina: Your work brings together electronics, skin beauty, and entrepreneurial skills. I anticipate that your "process of fantasy becoming reality with the help of technology" can inspire some innovators in Elektor's community to begin exploring how to use various disciplines, including electronics. Is electronica fast forward, the start-up platform powered by Elektor [4] a unique opportunity to showcase their ideas and technology?

Walter: I definitely think it is a unique opportunity for startups to be presented to the market through the 'electronica Fast Forward' platform. It is very important for new initiatives to understand the technical developments. Through the startup platform, the opportunity is offered to get exposure. A tech company knows exactly how its product works but it is very important to clarify what the meaning is for the user of that innovation. The bridge is essential to make the value of technical development clear. No matter how beautiful the technology is, if it is not understood, it will not be appreciated.

Alina: What do you think of the mindset of the newer generations? Do you have any advice for newcomers?

Walter: One major change compared to 25 years ago is that access to the world out there has become very easy. This gives the advantage of being able to start initiatives at a small scale. On the other hand, the disadvantage is that the amount of information is enormous and it is more difficult to differentiate yourself. So, the question is, how do you stand out and be heard in a crowded and easy, accessible market? My advice is to look for partners who have access to that market. If you start from the technology, there is still a lot of knowledge that you have to gain yourself, this gives a slow trajectory. Therefore, find strong partners to be aware of other aspects such as distribution, marketing and sales. I would also like to add that setbacks are precisely the way to find a path to get back on top, and they provide good motivation to get going.

Alina: Thank you for the interview and we will be reading and hearing more from you and your company soon.

In May 2022, Elektor met for the first time with Walter Arkesteijn and paid a video visit to InnoFaith in Eindhoven, the Netherlands to discover how their high-end equipment for skin analysis is created. For more information, you can read the previous articles, *Inspiration, That's What It's All About: Q&A with Walter Arkesteijn of InnoFaith*, and *Minimizing Hardware with Smart Software: Zooming in on the Technology at InnoFaith* [5]. Moreover, you can watch the video visit on The Elektor YouTube channel [6].

220257-C-01

Working at InnoFaith

Technology at the heart of the aesthetic medicine and professional beauty industry, delivered by a small but strong team of 31 who have worked at InnoFaith for years. That shows that InnoFaith is in it to stay. InnoFaith Beauty Sciences shares the mindset towards innovative design and the manufacturing of state-of-the-art high-tech scanning and imaging diagnostic devices. Take a look at their vacancies at www.innofaith.com.

WEB LINKS

[1] Observ 520x: https://sylton.com/products/observ-520x/
[2] Q&A with Walter Arkesteijn: www.elektormagazine.com/news/inspiration-that-is-what-it-is-all-about-innofaith
[3] Innofaith Beauty Sciences: https://innofaith.com/
[4] electronica fast forward: www.elektormagazine.com/effwd-2022
[5] The Visit to InnoFaith lab: www.elektormagazine.com/news/minimizing-hardware-with-smart-software-zooming-in-on-the-technology-at-innofaith
[6] Video Visit on YouTube: https://youtu.be/cAL17Zl_UvQ

Industrial Automation

Easy and Scalable IoT Retrofitting

Source: pressmaster

Contributed by Würth Elektronik

Industrial manufacturing facilities with machinery that has evolved over the years are often finely-tuned and highly-optimized. Through IoT retrofitting, production can be upgraded and digitized, as demonstrated by a collaboration between WE, FEGA & Schmitt, and IAV.

The latest and most advanced technology is always believed to be superior. Sometimes, however, it is better to use tried-and-tested, decades-old, current, or even legacy technologies. There are, of course, several other challenges associated with older equipment, including efficiency, inconsistent quality, expensive maintenance, and manual labor.

Replacing older manufacturing equipment involves a different set of considerations for business owners. It is not uncommon for legacy equipment to represent capital investments of millions of dollars and years of planning. Consequently, the retrofitting approach is more cost-effective.

Production environments can be greatly improved by introducing intelligent automation. Existing systems can create additional value through increased automation. Because older machines are often already written off, the economic impact of higher productivity, without the need for major new investment, is particularly advantageous for survival in an international market. Automated machines must accurately record and analyze operating data in order for modernization to succeed. Furthermore, it is essential that any conclusions drawn from these evaluations can be extended to other manufacturing sites.

The difficulty with legacy machines is that we lack the knowledge to ask the right questions. How can this be resolved? Retrofitting machines is the best strategy.

Retrofitting is the process of updating or adding new features to existing equipment using an IoT solution in a non-invasive way. As a result of transforming a machine into its digital twin, production can be examined and optimized in greater detail and better efficacy.

Proof-of-Concept in Partnership

Würth Elektronik is an avid supporter of the open-source concept and, together with FEGA & Schmitt and IAV, has realized this proof-of-concept for industrial cutter monitoring **(Figure 1)**. FEGA & Schmitt conceptualized this project, Würth Elektronik supplied connectivity and sensing components and, together with IAV, provided cloud infrastructure solutions **(Figure 2)**. IAV also offered data analysis and full system integration services.

The goal was to develop an easy-to-install product for FEGA customers, to monitor industrial cutting machines and detect utilization based on current measurements, as well as to detect possible problems with the cutting tools before they occur.

Sometimes, a particular combination of tool movements can cause tools to break. By identifying this set of movements, a failure prediction can be made. Consequently, there will be significantly less production downtime. A current measurement, on the other hand, provides the ability to determine machine utilization and simplifies the planning process.

During the proof-of-concept, a strict requirement for the installation was not to interfere with the customer's infrastructure or to cause any process downtime.

Customers receive comprehensive system availability information from the finished product. Predictive maintenance is a key characteristic and differentiator for FEGA & Schmitt products through the use of sensors and AI-supported data evaluation.

Prototyping with FeatherWing Boards

FeatherWings are a set of stackable prototyping boards with different functionalities. Würth Elektronik created a range of FeatherWing development boards that are open-source and fully compatible with the Feather form factor. This includes sensor wings, WE Pro-Ware wireless connectivity, Wi-Fi, and various power supplies. There is a GitHub repository [1] for all open-source boards, including their schematics, BoMs, software and cloud connectivity descriptions for Azure and AWS.

Sensing Using Acceleration

Sensor FeatherWings **(Figure 3)** are used to create the initial data points. As the acceleration is closely connected to the movement of the cutter hand, the use of an acceleration sensor is a good starting point for monitoring movements.

The WE Sensor FeatherWing is a development board with four sensors. In addition to the Adafruit Feather form-factor, it is also compatible with Sparkfun's QWIIC-connect, which provides a standard I²C interface that is also compatible with STEMMA QT and Grove/Gravity. This offers endless possibilities for prototyping.

All the above makes it easy to plug-and-play various sensors and devices from different manufacturers without a lot of wiring and makes it extremely useful for prototyping.

Connectivity by LTE-M/NB-IoT

Node and gateway connectivity is resolved in different ways. Gateway/cloud connectivity can be established via two distinct channels. Using an industrial Raspberry Pi with LTE connectivity, vast amounts of data is sent to the cloud for spectral analysis throughout the model generation phase. After the model is created, connectivity is switched to Würth Elektronik's Adrastea-I LTE-M/NB-IoT module [2]. This greatly reduces network traffic and,

Figure 1: Industrial cutter from FEGA & Schmitt with monitoring. (Source: Würth Elektronik eiSos)

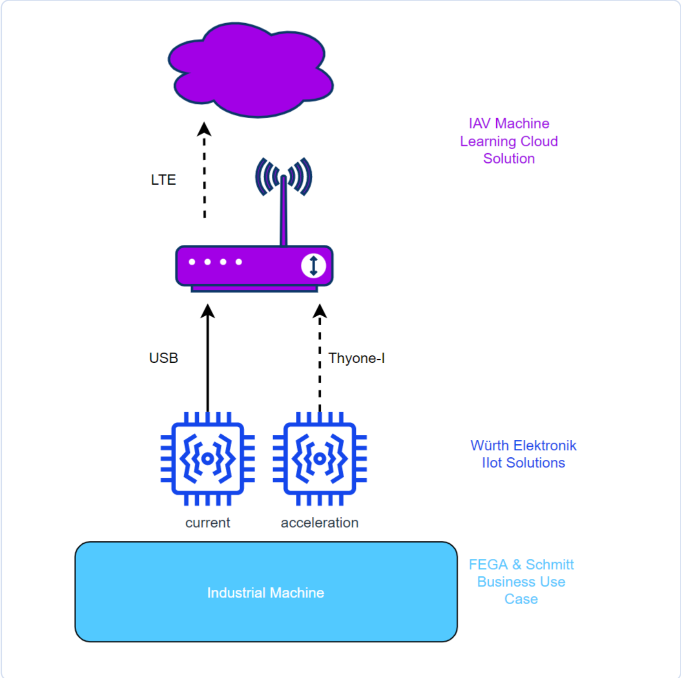


Figure 2: The concept of IoT retrofitting and roles of the partner companies. (Source: IAV)

Figure 3: WE Sensor FeatherWing. (Source: Würth Elektronik eiSos)

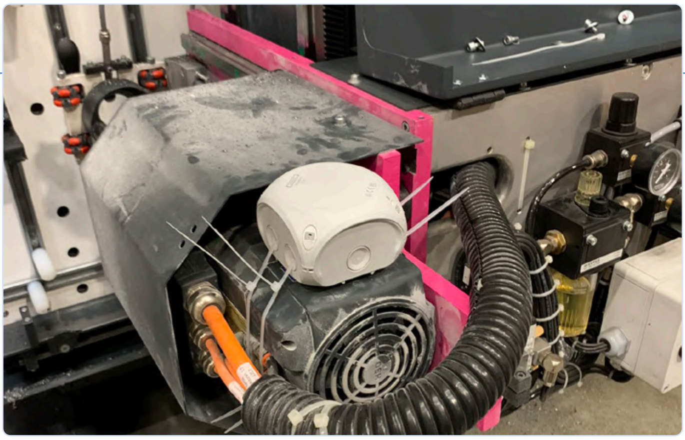


Figure 4: Vibration measurement using an accelerometer. (Source: Würth Elektronik eiSos)

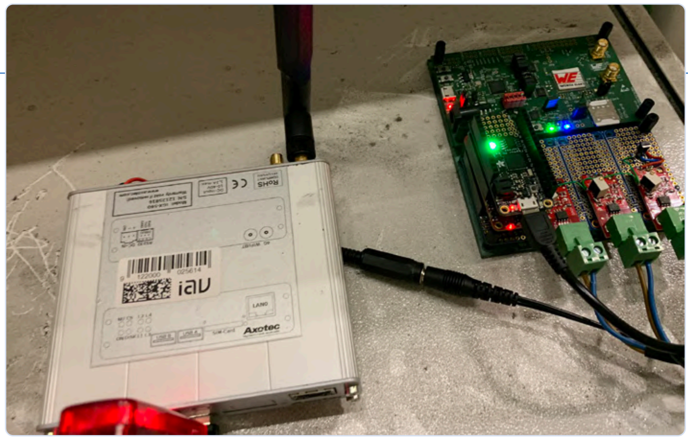


Figure 5: Current measurement using a Hall-effect sensor. (Source: Würth Elektronik eiSos)

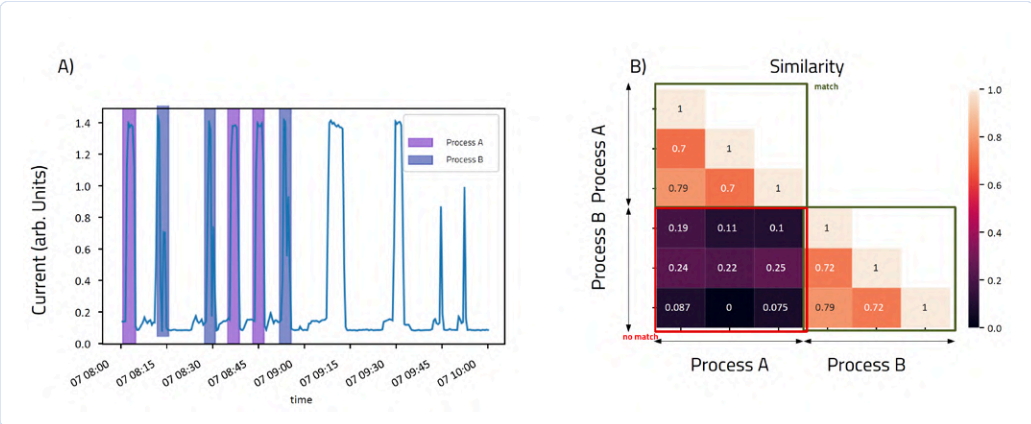


Figure 6: Data analysis to identify patterns with machine learning. Similar process patterns are recognized and labeled automatically. (Source: IAV)

consequently, costs. Both methods have been tested in cloud-connected production environments.

The node is connected to the cloud via a gateway using the Thyone-I Wireless 2.4 GHz proprietary radio module [3]. Security should not be underestimated, therefore the gateway to cloud connectivity uses the TLS protocol, and the node employs a similar approach with the secure element (ATECC608A-TNGTLS from Microchip Technologies) on one side and the cloud key vault on the other. The whole connection is protected and encrypted between all the communication participants, nodes, gateways, and the cloud.

Implementation in Detail

Vibration Measurement

To select the appropriate accelerometer, a clear understanding of the application and its measurement tasks is essential. In this case, a 3-axis acceleration MEMS sensor was used to detect cutter arm movements. Developers have long hoped to take advantage of the MEMS sensors offer in terms of size, cost, and reliability, and this was fully exploited using a WSEN-ITDS - 3-axis acceleration sensor **(Figure 4)**.

Current Measurement

Current measurements must be non-invasive, since the devices being monitored cannot be interfered with. The solution should be easy applicable to any similar machine. For this purpose, the WAGO split-core current transformer 855-4101/400-001 and the SparkFun ACS723 Hall-effect sensor breakout were used **(Figure 5)**. The advantage of using a Hall-effect sensor is that the circuit being sensed and the circuit reading the sensor are electrically isolated; hence, the circuit being sensed can operate at higher DC or AC voltages than the main board.

Connectivity Solutions

For proof-of-concept, two versions of the connectivity solutions were used. Version one, used in the initial data collecting stage, was an Industrial IoT Raspberry Pi-compatible gateway. A Linux-based system was used to generate C code and optimize the data collection and transfer, as a vast amount of data is necessary to validate machine behavior. For the cloud, a dashboard was created for real-time monitoring of the data using Node-RED and Grafana. In addition, the time stream data was analyzed to identify trends and patterns with machine learning. Similar process patterns are automatically recognized and labeled **(Figure 6)**. The remaining

WEB LINKS

[1] GitHub repository: https://github.com/WurthElektronik/FeatherWings
[2] Würth Elektronik's Adrastea-I LTE-M/NB-IoT module: https://www.we-online.com/catalog/en/ADRASTEA-I
[3] Thyone-I Wireless 2.4GHz proprietary radio module: https://www.we-online.com/catalog/en/THYONE-I_FEATHERWING_2
[4] Adafruit's Awesome Feather GitHub : https://github.com/adafruit/awesome-feather

patterns are marked as unknown. This data serves as the basis for process statistics that can be used for various business use cases, such as process monitoring, quality assurance, and predictive maintenance.

Testing in a Real-World Environment

Many challenges were encountered during the real-life testing: loss of data as a result of the distance and sources of radio signals in the manufacturing hall, constant movement of the stackable boards and power supply, or lack thereof.

Acceleration sensors were mounted on the cutter arm without any nearby power sources. This obstacle was overcome with the help of a LiPo battery. Despite the low standby current consumption, constant data transmission during the initial stage drained the battery. Vast amounts of information were transmitted daily, resulting in an empty battery every two to three days. The solution was to use a solar panel to recharge the battery. For that purpose, an open-source solution from Adafruit was used.

The second problem was the location of the sensors and radio modules. The sensor has to be situated on the tool handle, which is a moving part. On the machine, all moving parts are protected by metal housings, which act as a Faraday cage. Despite being small and efficient, the integrated antenna was of no use. This was resolved by attaching an external antenna to the outside of the housing.

The current sensing part is a composition of split-core current transformers and Hall-effect sensors for each phase. Combining two sensors required calibration, which was performed by Würth Elektronik.

Speeding up Prototyping

Making a proof-of-concept with open-source components can dramatically reduce prototyping time. Combining pre-existing boards with standard pinning and sensors with standard connectors makes it easy to test and experiment with the setup.

Using two stages in the proof-of-concept prototyping allowed for the creation of an effective model in the first stage, which could then be implemented in the second. The second stage will deploy local models on the microcontroller and only send out the bare minimum amount of data. The necessary data will be sent to the cloud using the Adrastea-I cellular module.

Würth Elektronik offers free Arduino-style SDKs for different processors and sells the boards. These boards can be easily adapted using data (PCB and BoM) from Würth Elektronik or Adafruit's Awesome Feather repository on GitHub [4].

This use-case demonstrated that using open-source standards for prototyping offers flexibility, resulting in enormous implementation speeds.

220531-01

About the Authors

Miroslav Adamov studied Physics and Informatics at the University of Belgrade, Serbia. After that, he continued scientific work at TU-Berlin, WIAS Berlin, FAU Erlangen/Nürnberg and Center of private equity research in Munich. After a couple of years in quantitative finance, in 2015 he joined Würth Elektronik as Senior Business Analyst. In 2017 he took over the position of Senior IoT Solution Architect with primary focus on conceptualization and implementation of Industrial IoT solutions.

Adithya Madanahalli graduated from the Technical University Munich with an MSc. in Communications Engineering. He then worked for several years as a software engineer in the field of wireless connectivity and sensors. Since 2022, Adithya has been an IoT Engineer at Würth Elektronik eiSos in the business unit for Wireless Connectivity and Sensors. There he specializes in the design and development of IoT solutions focusing on hardware, embedded software, and end-to-end security.

Dr. Jan Gieseler received a Dipl.-Phys. from the University of Karlsruhe, Germany and an MPhys. in Optoelectronics and Lasers from Heriot-Watt University, Scotland, followed by a PhD. in Photonics from ICFO in Barcelona, Spain. After that, he continued to work as a postdoctoral scientist in fundamental research at ETH Zurich, Harvard University and ICFO. In 2020, Jan joined the DigitalLab at IAV in Berlin, Germany. There, he works as a Data Scientist with primary focus on data engineering, time series analysis and IIoT & smart sensor solutions.

Bernd Grimm is a Business Economics and Information Technology graduate. Since starting his job in the electrical wholesale industry in 2008, he and his teams worked on numerous projects with a strong focus on customer service. He has been the industry and facility leader for project management at FEGA & Schmitt since 2019. In this capacity, he collaborates with his team on the project "Be.Linked," which aims to establish the topic of "service distribution paired with digitalization & AI" for FEGA & Schmitt.

Eduard Richter completed his education as a certified electrical technician and Bachelor of Business Administration. Since 2017, he has been working in electrical wholesale as a technical key account manager. His task is to position FEGA & Schmitt services with existing and new customers. With his sales expertise, he is involved in the development and improvement of the services.

Visit Rohde & Schwarz at electronica 2022 in hall A3.307!

Next Generation Oscilloscopes for Accelerated Insight

Rohde & Schwarz introduces the R&S MXO 4 series

Contributed by Rohde & Schwarz

Rohde & Schwarz is adding a completely new series to its oscilloscope portfolio that delivers a number of industry firsts. The new R&S MXO 4 series oscilloscopes feature the world's fastest real-time update rate of over 4.5 million acquisitions per second. Development engineers can now see more signal detail and infrequent events than with any other oscilloscope. The 12-bit ADC in the R&S MXO 4 series has 16 times the resolution of traditional 8-bit oscilloscopes at all sample rates without any tradeoffs for more precise measurements. A standard acquisition memory of 400 Mpts on all four channels gives the instrument up to 100 times the standard memory of comparable instruments.

Rohde & Schwarz presents the new R&S MXO 4 series, the first in the next generation of oscilloscopes (**Figure 1**). The R&S MXO 4 oscilloscopes come in four-channel models with bandwidths of 200 MHz, 350 MHz, 500 MHz, 1 GHz, and 1.5 GHz. They have a starting price of 7,600 euro, many unparalleled functions and excel in both performance and value. Rohde & Schwarz will demonstrate the new R&S MXO 4 series oscilloscopes at electronica 2022 in Munich in hall A3.307 from November 15 to 18, 2022.

Instant View of Signal Details

R&S MXO 4 series oscilloscopes boast the world's fastest update rate of 4.5 M acquisitions per second, revealing more signal activity than any other available oscilloscope (**Figure 2**). Development teams can quickly see and isolate infrequent events, get a better understanding of physical layer signals and test faster. This is unparalleled in the industry.

A unique 200 Gbps processing ASIC makes this feature possible. It is one of several new technology blocks Rohde & Schwarz engineers developed and implemented for the first time in the R&S MXO 4 series (**Figure 3**). Dr. Andreas Werner, Vice President: Oscilloscopes at Rohde & Schwarz, explains: "The new hardware and software technology blocks and architecture allowed our development team to achieve a once-in-a-decade engineering breakthrough. Our customers will experience a whole new level of performance, and all at a price more affordable than has ever been seen on the market."

Lower Measurement Noise and the Highest Available Vertical Resolution

The R&S MXO 4 series incorporates a 12-bit ADC that operates across all the instrument sample rates with an 18-bit vertical resolution architecture for greater resolution precision than any other oscilloscope. The R&S MXO 4 series also has the lowest noise and largest offset range (±5 V with a 500 µV/div scaling) in its class. Users can see DC and other signals with more precision than with any other oscilloscope on the market.

Deepest Standard Memory

In addition to bandwidth and sample rate, memory depth is an important factor and determines whether an oscilloscope can handle a large range of troubleshooting tasks. More acquisition memory enables oscilloscopes to capture more time and retain rated bandwidth information for shorter time base settings. With a simultaneous standard acquisition memory of 400 Mpts on all four channels, the R&S MXO 4 series has up to 100 times the standard memory of its primary competition. The additional memory also provides extra measurement capability when needed.

Figure 1: The R&S MXO 4 is the next generation oscilloscope from Rohde & Schwarz.

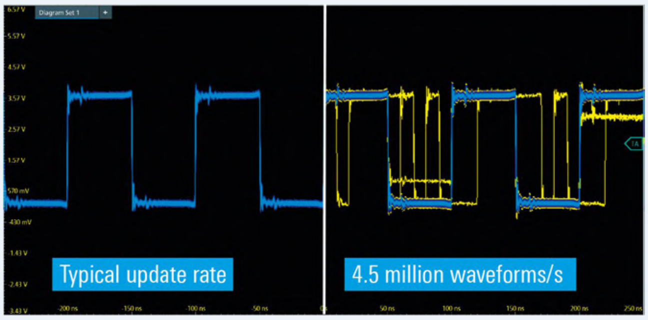


Figure 2: R&S MXO 4 oscilloscope feature an update rate exceeding 4.5 million waveforms/s to discover even infrequent events.

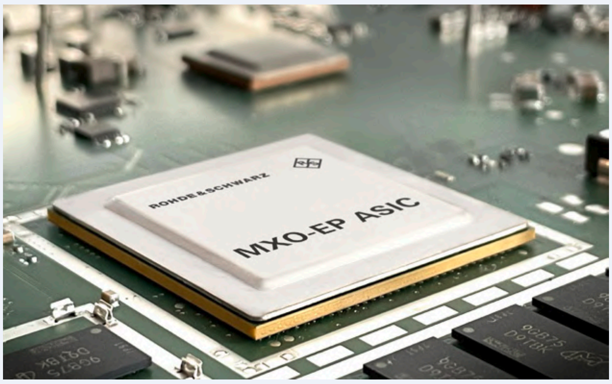


Figure 3: Rohde & Schwarz incorporated its own 200 Gbps processing ASIC into the new R&S MXO 4.

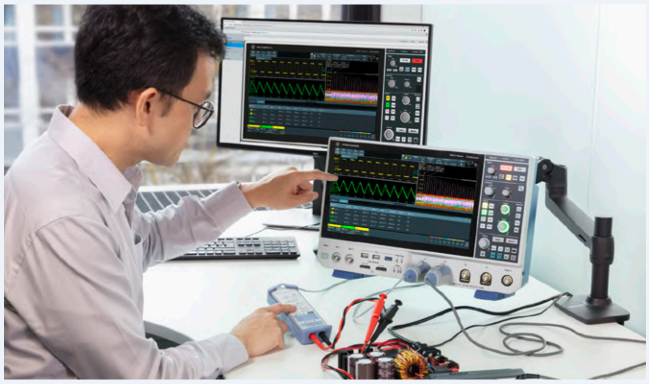


Figure 4: VESA mounting make the R&S MXO 4 oscilloscopes ideal for any engineering workspace.

High-Precision Digital Trigger

Once only available in higher performance oscilloscopes with higher price points, the digital trigger comes standard with all R&S MXO 4 series oscilloscopes. The trigger sensitivity of 1/10,000 division can isolate difficult-to-find small physical layer anomalies in the presence of large signals. No competitive oscilloscope has this degree of trigger sensitivity for isolating small signals. The digital trigger complements the 18-bit vertical architecture, allowing users to fully utilize the precision of the R&S MXO 4 series.

Superior RF Measurement Capability

Many development engineers need to debug products and test in both the time and frequency domains. In addition to time domain measurements, R&S MXO 4 series oscilloscopes have superior RF spectrum measurement capabilities. They are the first oscilloscopes to perform 45,000 FFTs (Fast Fourier Transforms) per second, while comparable oscilloscopes deliver fewer than 10 FFTs per second. This base feature lets engineers view more RF signals than with any other oscilloscope in its class.

Enhanced User Experience

Using an oscilloscope is a visual experience, where a lot of time is spent viewing a display. The R&S MXO 4 series incorporates a 13.3" full-HD capacitive touchscreen and an intuitive user interface. The instrument's small footprint, audible noise of less than a whisper, VESA mounting and a rackmount kit for installation in integrated environments make R&S MXO 4 oscilloscopes ideal for any engineering workspace (**Figure 4**).

When users have more demands, a number of upgrade options are available, including 16 integrated digital channels with a mixed signal oscilloscope (MSO) option, an integrated dual channel 100 MHz arbitrary generator, protocol decode and triggering options for a variety of industry standard buses and other options that expand the oscilloscope's capabilities.

The new R&S MXO 4 series oscilloscopes are available from Rohde & Schwarz and selected distribution channel partners [1].

220516-01

WEB LINK

[1] More information: www.rohde-schwarz.com/product/MXO4

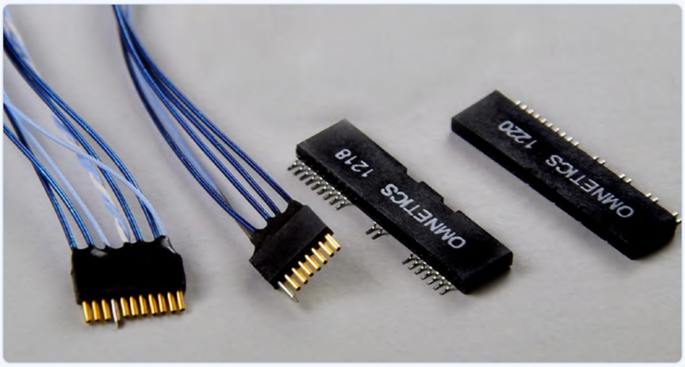
Low-Profile Linear Connectors Solve Multi-Signal Data Management

Contributed by Omnetics

Today's high-density electronic devices require routing more signals to and from the data source to displays and other processing instruments. These cables often carry multiple signals and require high pin-count connectors in long, linear formats to align with a display or overall design. Simultaneously, these same instruments are used within rugged and portable equipment employed on vehicles, robots or worn by dismounted soldiers on the ground. High density, portable, robotic, space, and body-mounted electronics all share in similar requirements for rugged, low-weight solutions capable of increasing bandwidth requirements while decreasing the overall footprint. New sensors, detectors, injectors, and small motors for rugged mobility are designed to operate at micro-currents and voltages in an effort to support the new digitization of the highly compacted electronic modules. Optical and analog position data is processed through an A/D converter on the soldier or device. This dramatically increases signal speed and signal count. Beam-forming antenna and communication systems are employed to focus specifically on targeted areas. These systems require a high quantity of signal sections, similar to those on phased-array antennas. Single-board computers are carried for handling the new data loads at higher speeds, but fortunately, these new high speed digital signals are run on Gallium Arsenide and other chip technologies that operate on very low voltages and minimal current. The new wiring design system includes differential digital signal wiring sets of a positive and a negative for each signal as well as a return, (drain wire), to accomplish the data transfer. Finally, each differential wiring set requires shielding to avoid noise coupling from wire set to wire set. A complete cable set can begin at 30 to 40 wires and go up exponentially based on the functions they serve. Micro- and nano-sized wires and connectors are solving the space and weight problem, while performing exceptionally well in relation to higher-speed digital electronics in the field.

These advanced systems are small and rugged, but will be more exposed to higher levels of environmental abuse as we are employing them where the action is. In fact, the signals do not require the massive size and weight of older generation electronics. Designers are instead focusing on these miniaturized connectors and cables because they work well with digital electronics and are resilient in the field. Working directly with cable and connector designers early in the system development process can help significantly improve the overall design and performance of your cable to connector solution.

As we develop higher density, the signal content, data speed, impedance, potential crosstalk, noise, and EMI sensitivity within the system will need to be considered early on. An interconnect specialist can help review key wire type, gauge, shielding, and drain systems. Digital signals are dependent upon square-wave rise-time and matching the wiring impedance from the driver circuit to the cable. This has been proven in RF technology and is now becoming critical as digital speeds increase. Some multiple digital signals are stacked upon one circuit with NRZ (non-return to zero) voltage



Miniature strip connectors.

Sample board includes strip connectors.

levels (such as in PAM-4), and can be more susceptible to SNR (signal-to-noise ratio) issues. This is controlled with careful wire design, spacing, and connector pin-out planning. Standard cable can easily handle gigabit signal transmissions using differential pair wiring and a dedicated drain wire. As mentioned earlier, wires are shielded separately from other wire groups inside the cable. As speed increases, ground or return lines must operate as fast as the transmitted signals. This is changing both ground line layout and the capacitance of the circuit boards being used.

A micro- or nano-strip connector must often match the routing and spacing needs of the board. (Note: Having an extra connector pin or two for additional side-bar ground or return lines often saves a redesign phase in developing a system.) Many connector suppliers offer designs that include IPC standard pads and through-hole layout patterns, but those standards are quite mature and some newer boards may require tailored connector lead patterns and center-to-center pin spacing. High-reliability connector design companies can offer both standard sizes as well as offer interconnection systems specifically designed to meet new design layouts.

Designers are advised to begin with Military Specification levels established for Micro-D (MIL-DTL-83513), and or Nano-D (MIL-DTL 32139), as a good baseline. These two specifications were designed by a team of connector specialists from military supply companies. The focus was to define a range of applications in rugged and extreme environmental conditions in the defense industry. The reliability portion of the specifications is centered around mates and de-mates, and physical conditions such as shock, vibration, corrosion, and immersion. Those specifications can be used as a reliability checklist for newer connectors being developed that are smaller and lighter in weight, and for those going into deep space or other harsh conditions that these connectors are subjected to.

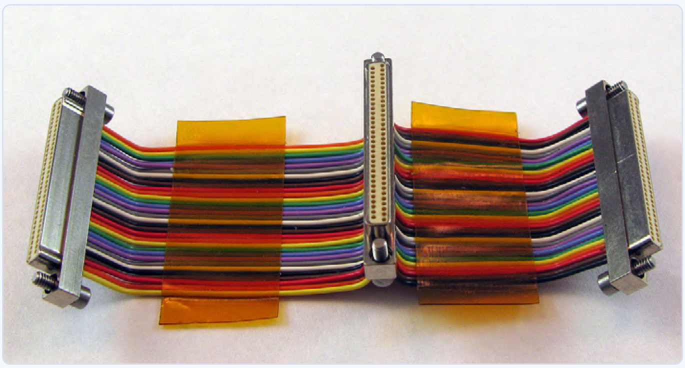
Miniature strip connectors are rapidly evolving in this next level of need and seem to fall into two categories. Older styles include strips designed for the commercial market with limited testing and certification, but are quite useful for many applications. Newer applications require the use of proven materials and designs using key elements tested to military standards. Companies, such as Omnetics Connector Corp., use their Military Specification solid BeCu (beryllium copper) spring pin and sockets that are plated with Mil. Spec. Nickel and Gold to assure the highest reliability in the industry. Pin-to-socket mating and de-mating tests show constant signal integrity beyond 2000 connections. These strip connectors offer rugged shock and vibration performance and have passed testing beyond the needs used in electronics on the battlefield and on the Mars rover. System designers can request sample strip connectors for a first test on their design. Micro-strip connectors at .050", (1.27 mm) pitch and Nano-strip connectors at .025", (.635 mm) pitch are established standards and readily available.

Edge card Nano-connector with latch.

System engineers can begin developing an adapted military-quality strip-connector with a connector designer using online solid modeling to tailor the connector to their exact application. When satisfied with the new design, a prototype sample can be requested to assure form, fit, and function before proceeding. 3D-printed models can be quickly built and sent to the system team. The final step in ensuring your interconnect system meets the need for today's new circuitry is to review test and any unique quality standards required by your application. Discuss the environmental, or any electrical specifications that may be of concern with the connector designer.

220507-01

Mix of strip connector options.



Strip connector harness.

Smart – Innovative – Cost-Efficient

GateMate FPGAs Developed and Manufactured in Germany

Contributed by Cologne Chip

Cologne Chip AG from Cologne has been a well-known name in the market as a manufacturer of telecommunications chips for over 25 years. As a German chip manufacturer, the company has succeeded, throughout its history, in outstripping industry giants such as Siemens, Infineon, and Intel in the field of ISDN chips. Two years ago, Cologne Chip presented its latest product family to its customers at Embedded World in Nuremberg: the GateMate FPGAs.

New Architecture and a Production Site in Germany for Supply and Planning Security

The core of the GateMate FPGAs contains a novel architecture, which was developed in Germany and has already led to patents being granted for essential points. Since the company is on the market as a fabless semiconductor manufacturer, attention was paid to short distances when selecting the production site. Thus, the chips are manufactured in cooperation with Globalfoundries in Fab 1 in Dresden.

The company thus ensures short supply chains — especially for customers in Europe — for maximum security of supply and planning. Especially in current times, many FPGA users are affected by delivery delays and partly exorbitant price increases. Not so for customers of Cologne Chip. Due to excellent advance planning and stock-keeping, the supply for customers can be guaranteed at any time. Also, the risk of trade restrictions or high customs duties is reduced to a minimum with GateMate.

Technically, the new architecture is based on so-called "Cologne Programmable Elements" (CPEs) - logic elements with eight combinatorial inputs each in a so-called "LUT tree." Each of these CPEs can be configured with 2×4 or 1×8 inputs, thus having up to two outputs.

Through additional linking possibilities, typical gate circuits can be implemented without cascading, for example. An intelligent routing engine makes it possible to efficiently set up multipliers of any size at any point in the chip. This results in a very high combinatorial density. Thus, the GateMate FPGAs are also suitable for the realization of AI functions, for example.

Target Markets and Applications

Cologne Chip names low-end and low-power applications as general target markets. Wherever smaller FPGAs of around 20,000 logic elements tend to be used, the GateMate A1 FPGA offers a good and cost-effective alternative to previously used FPGAs.

In addition to the patented manufacturing process, the GateMate FPGAs also have a widely-scalable performance potential. For example, the core voltage and clock frequency can be varied to

Main Features of GateMate FPGAs

New CPE Architecture

- 20,480 programmable logic elements (CPEs) for combinatorial and sequential logic
- 40,960 latches / flip-flops within programmable elements
- CPE consists of LUT-tree with 8 inputs
- Each CPE configurable as a 2-bit full-adder or 2x2 multiplier

Low Power Consumption

- Globalfoundries™ 28 nm SLP process
- 3 operation modes: Low-power, Economy, Speed
- No excessive start-up currents
- Only two supply voltages needed, can be applied in any order

Features

- 4 programmable PLLs
- Fast configuration with quad SPI interface up to 100 MHz
- Multi-Chip configuration
- 1280 Kbit dual-ported Block RAM
- All 162 GPIOs configurable as single-ended or LVDS differential pairs
- DDR support in all GPIO cells
- 2.5 GB/s SERDES controller

Package

- 324-ball BGA package (15 × 15 mm)

scale the processing speed by a factor of 2.5. This is also possible dynamically during the operation of the FPGA. The three operating modes — Low-Power, Economy, and Speed — can be set simply by changing the core voltage to 0.9 V, 1.0 V, or 1.1 V. The higher the voltage, the higher the performance. This allows the chip to be used for a very wide range of applications.

Lowest "Total Cost of Ownership" and Open-Source Software Support

When it comes to cost efficiency, Cologne Chip places great emphasis on the lowest specific costs. As a user of FPGAs, it is important to keep an eye on the total costs of using a specific FPGA. A low-cost chip alone is not of much use as long as the costs for various peripherals are exorbitantly high. For example, GateMate FPGAs only need two supply voltages. One core voltage and one I/O voltage, which saves on additional voltage regulators.

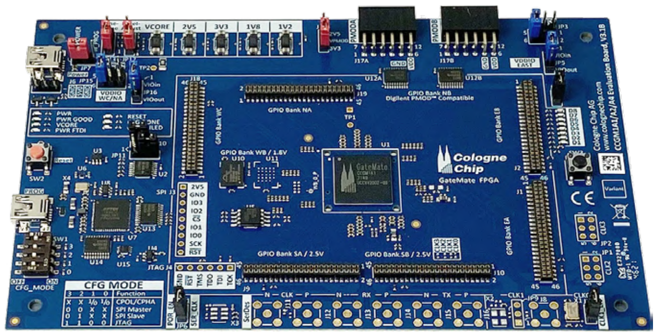
When selecting a suitable PCB, the developer has it just as easy: a PCB with only two signal layers, i.e. four layers, is sufficient to route all signals and thus save costs on additional PCB layers. Stock keeping is also simplified, especially when using GateMate for different end products. There are no "speed grades" or similar derivatives.

Cologne Chip also focuses on cost efficiency and flexibility in the software environment. But, this is not the only reason for choosing an open-source toolchain: the synthesis tool "Yosys".

If Verilog or VHDL code is already available, it can be easily synthesized into the architecture with Yosys. The currently still-proprietary "GateMate Place & Route" is available free of charge and can be downloaded from the Cologne Chip website after one-time registration as a user. With automatic clock skew optimization, the tool takes over the porting of a circuit into the FPGA.

FPGAs and Evaluation Kits Available from Stock

In current times, it is not self-evident that Cologne Chip has both their FPGAs and the GateMate Starter Kits available from stock. Thus, even in the year 2022, Cologne Chip is able to supply its customers with production quantities of FPGAs within a few days.

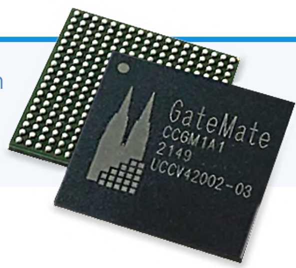


The Starter Kit itself contains an evaluation board with the GateMate A1 FPGA, a cable set, and an additional programmer – allowing the customer an easy start in the evaluation of GateMate FPGAs.

220515-01

WEB LINK

[1] Website: www.colognechip.com



Tools to Support
Low-Cost Sensor Development

By Stuart Cording,
for Mouser Electronics

Figure 1: Long-term data collection is supported by the Extech 250 W environmental meters when coupled with a Bluetooth-enabled smartphone or tablet and the ExView app.

When it comes to monitoring the world around us, engineers rely on sensors to measure physical quantities such as humidity and convert them into signals for computers to process. The team specifying the sensors will need to consider the measurement accuracy and range as well as other aspects, such as robustness and protection against the intrusion of dust and liquids. As sensor performance increases and its robustness for the target environment climbs, the cost for the sensor inevitably grows too. This causes problems when rolling out sensors for use since high purchase costs can hold back their wider deployment.

One such example is in the field of particulate matter measurement, where sensors collect data to quantify air pollution. Gravimetric sensors suited for delivering high-accuracy measurements of airborne particles are costly. However, they can be trusted to provide the necessary data to support the selection of optimal countermeasures, such as changes to traffic rules in cities. But this issue is growing in importance, so more sensing is needed at a price point that enables broader deployment for a more granular understanding of the issue. As a result, much effort is being made to develop cheaper alternative sensors with similar performance.[1]

This is the compromise many design engineers face. Something needs to be measured, but total cost, system size, robustness, power consumption, and other factors must be weighed against sensor accuracy, linearity, and hysteresis. Test equipment has to be sourced to resolve these issues so that the sensor under development can be evaluated, compared, and possibly calibrated against something more accurate.

Figure 2: The MachineryMate 800 (MAC800) provides handheld measurement to monitor the vibration of pumps, motors, fans, and bearings.

Compare Your Sensor with Environment Measurements

Handheld meters are ideal for simple sensing designs, enabling them to be located or mounted in a test setup alongside the application under development. Battery-powered devices avoid the need for a power cable and wall wart, while the display must be large and clear to ease the readout of the measurements made. An excellent choice for a wide range of data collection tasks are the Extech 250 W Bluetooth Connected Environmental meters.[2] Five devices cover everything from air velocity and sound level to humidity, air temperature, rotation speed, and light intensity (**Figure 1**).

Measuring just 150 × 53 × 28 mm (5.9 × 2.1 × 1.1 in) and weighing 80.5 g (2.8 oz), the RH250W measures relative humidity from 0 to 100 % with an accuracy of ±5 % and ambient air temperature from -10 to 60 °C (14 to 140 °F) to an accuracy of ±1 °C. Like all the units in the series, power is supplied by three AAA (1.5 V) batteries that are included. An auto power-off feature also protects the battery. Top and center is a large LCD with a backlight displaying that can display maximum and minimum readings in addition to the current measurement. Aiding correct positioning of the meter for long-term data collection is a standard tripod mounting screw (1/4").

For light intensity measurements, Extech offers the LT250W. Data is collected at two samples per second and covers light intensity up to 100,000 Lux (10,000 Fc). Below 9999 Lux, the maximum resolution is 1 Lux at an accuracy of ±4 % rdg. Above this, resolution changes to 10 Lux for ≥10,000 Lux and 100 Lux for ≥100,000 Lux, both at an accuracy of ±5 % rdg.

This entire range of Extech environmental meters is fitted with a Bluetooth interface that supports data transmission over a range of 90 m within line-of-sight. Measurements can be collected on a smartphone or tablet using the ExView app, available for iOS [3] and Android [4] devices. In total, eight meters can be connected to a single device. Audible alarms can also be set for minimum and maximum values. Data is easy to import into analysis tools thanks to the use of the common CSV format (comma-separated values), and photos of the test setup taken by your mobile device can be integrated into PDF reports.

Vibration and Predictive Maintenance

Many of us have met an engineer with the uncanny ability to 'know' when a piece of equipment is nearing the end of its life. Years of listening to the sounds and feeling the vibrations of motors and conveyors deliver them an almost divine sense of pending failure. However, today's highly-automated industrial systems require something a little more digital. To determine the difference between good and bad vibrations during the development of predictive maintenance solutions, developers can turn to the Amphenol Wilcoxon MachineryMate, a range of handheld vibration meter kits.

Figure 3: The EMpro II energy meters from Phoenix Contact offer remote monitoring in units both with and without a display.

The MachineryMate 200 [5] (MAC200) is a handheld vibration monitoring and analysis tool suited to diagnosing faults with motors, pumps, fans, and bearings. Operating from two AA batteries (1.5 V) for 50 hours of operation, this IP67 rated tool delivers its measurements using color-coded readings. The first is the ISO value as specified by the ISO 10816-1 velocity level chart. Displayed in mm/s or inch/s, vibration velocity is given for the frequency band 10 Hz to 1 kHz (600 – 60,000 RPM) or 2 Hz to 1 kHz (120 – 60,000 RPM). Noise associated with worn bearings is the second measurement offered, displayed in Bearing Damage Units (BDU), with green highlighting values below 50 from a maximum of 100 BDM.

Finally, the meter also offers vibration analysis, enabling the user to determine if the machine is out of balance, misaligned, or if mounting bolts or foundations are loose.

By opting for the MachineryMate 800 (MAC800), results from various machines and their test points can be logged and uploaded to a PC through the USB docking cradle (**Figure 2**). Using the included DataMate PC software [6], comparisons can be made between machine readings and even historical readings to detect issues and trends. Other optional extras include a strobe light attachment and Bluetooth headphones that enable the user to listen to the accelerometer signals.

Keeping Track of Energy Consumption

We all need to contribute to reducing energy use, regardless of whether that energy is green or not. So, when building complex machines, it helps to have an energy meter for monitoring and further analysis. Units such as the Phoenix Contact EMpro II are user-friendly and offer a range of connectivity to access energy consumption in real-time (**Figure 3**).

Figure 4: Complete with a handy carry case, the Klein Tools IR1 infrared digital thermometer offers temperature measurement at a safe distance.

Available both in panel-mount format with display or ready-to-mount on a DIN rail without, the unit is suited to single-, dual-, and three-phase installations. The EMpro II [7] features a Modbus TCP interface but is also available with support for Modbus RTU, PROFINET, and Ethernet I/P. Current measurements are undertaken using current transformers or Rogowski coils, while the voltage of the phases is monitored via direct connections.

The multilanguage integrated web server provides a clean and modern interface, guiding the user through the setup steps. It also offers real-time access to measurements along with the definition of alarms and integrated logging. A REST API is also provided, aiding integration into self-developed industrial web applications.

Temperature Measurement at a Distance

During system development, components often get hot, especially in power converters and motor inverters. Due to the often high voltages used, a contactless method for monitoring temperature is advisable. Handheld infrared digital thermometers, such as the Klein Tools IR1 [8], are the perfect measurement solution (**Figure 4**).

The unit is powered by the supplied block 9 V battery, providing five hours of use with the backlight enabled. Battery life is extended thanks to an auto power-off feature. Measurement results are displayed in Celsius and Fahrenheit, and the temperature range supported reaches from -20 °C to 400 °C (-4 °F to 752 °F). An integrated laser ensures that the sensor is correctly aimed at the desired component. With a distance-to-spot ratio of 10:1, an area 13 mm in diameter can be targeted at a range of 127 mm, or 25 mm in diameter at 254 mm range. For ease of carrying, a case is also supplied.

Ever Improving Sensors

In order to make better decisions, detect machine failures earlier, or better protect our environment, developers are building sensing solutions that are as close to the best measurement devices available today while bringing the cost down to levels that enable broader deployment. The test and measurement equipment reviewed here helps support them in these efforts. By delivering data on the relevant physical quantities to compare against the results provided by the low-cost sensor they've developed, teams can improve their own designs' accuracy, linearity, and hysteresis.

220524-01

WEB LINKS

[1] A Review of Low-Cost Particulate Matter Sensors from the Developers' Perspectives: www.ncbi.nlm.nih.gov/pmc/articles/PMC7730878/
[2] Extech 250W Bluetooth Connected Environmental Meters : https://bit.ly/extech-250W
[3] ExView on Apple Store: https://apps.apple.com/us/app/exview/id1547400277
[4] ExView on Google Play Store: https://play.google.com/store/apps/details?id=com.extech.exview2&hl=en&gl=US
[5] Amphenol Wilcoxon MachineryMate™ Vibration Meter Kits : https://bit.ly/MachineryMate
[6] DataMate user guide: https://buy.wilcoxon.com/amfile/file/download/file_id/611/product_id/387/
[7] Phoenix Contact EMpro II Energy Meters : https://bit.ly/phoenix-contact-empro-ii
[8] Klein Tools IR1 10:1 Infrared Thermometer with Laser: https://bit.ly/klein-tools-ir1

Polyfuses

Peculiar Parts, the Series

By David Ashton (Australia)

Do you have fuses everywhere, but not one to replace that which has just blown? Join the club! However, there is an alternative — the polyfuse. Discover how its clever chemical construction enables it to reset automatically.

How many times have you blown a fuse? The sacrificial fuse is a great component, preventing damage to the valuable circuit you've just built. But then, right after, you have the hassle of hunting down the correct replacement. And, if you've failed to fix the problem that blew the fuse in the first place, well, the new fuse blows too, compounding the hassle! Wouldn't it be nice if we could have a self-resetting fuse? Well, there are circuit breakers. However, these are electro-mechanical devices that you have to reset yourself, and you can't really get them in lower ratings than 1 A. Additionally, they are best suited to high voltage applications (well, high for us electronics types, anyway) like mains switchboards.

But there is a device that does what we want, capable of protecting low-voltage circuits with a current consumption down to around 100 mA or so. It's called a Polyfuse. Polyfuses are, in some ways, similar to Positive Temperature Coefficient (PTC) resistors in that they initially have low resistance. However, unlike PTCs, it is the self-heating effect caused by the flow of large currents that causes them to go high resistance, thus limiting the current to a safe value. They were discovered and patented by Gerald Pearson at Bell Laboratories in 1939 and are still widely used in professional electronic equipment.

These devices contain an organic polymer substance into which carbon particles have been impregnated. The polymer is usually in a crystalline state with its carbon particles in close contact providing good conduction at low currents. When a larger current flows, the carbon heats up, causing the polymer to expand into an amorphous state. This results in the carbon particles separating, leading to an increase in resistance and a subsequent reduction of the current. The residual current that flows under fault conditions will usually keep the device hot enough to limit the current until the cause of the overload is removed. At this point, it cools again, allowing current related to correct operation to flow again.

Polyfuses have a short but appreciable time delay in their operation. Because of this, they don't protect against large surges and spikes. Their main benefit is their self-resetting nature, making them very useful for protection against short-term overloads and short-circuits in, for example, Power-over-Ethernet (PoE) circuits.

Available in a wide variety of form factors, both as through-hole and SMD types as shown in **Figure 1**, they come in ratings from 100 mA up to about 5 A and are mostly intended for low voltage circuits up to about 30 V. Their specifications include a *Hold Current*, the current at which they will never trip, and a *Trip Current*, the minimum current at which they are guaranteed to trip. The trip current is usually about twice the hold current. Because they rely on temperature rise for their operation, their specifications change in higher ambient temperatures. After a trip condition, their resistance reduces to a lower value fairly quickly, but they may take a long time, sometimes days, to get back to their initial low resistance. This is something to keep in mind when designing with them.

As a cheap and compact component, polyfuses are great for set-and-forget protection in circuits that may be subject to occasional overload conditions.

220302-01

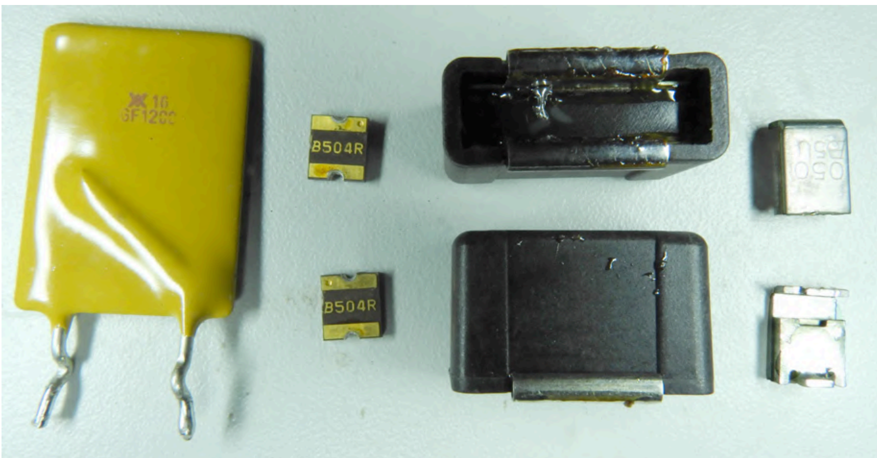


Figure 1: A selection of polyfuses including a yellow through-hole type (left) and various surface-mount components.

Isolated Analog Output for Arduino Uno

By Giovanni Carrera (Italy)

This project uses the Arduino Uno PWM output to realize a fully isolated analog output with a range of 0..5 V or more. The use of an averaged PWM signal is not comparable with a real DAC, but it has advantages of simplicity since it is sufficient to use an opto-coupler for isolating the digital PWM signal.

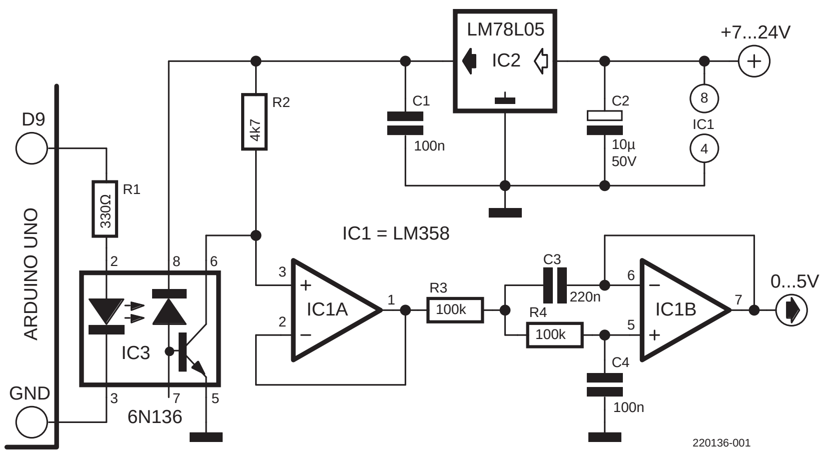


Figure 1: The simple circuit diagram.

In control systems of industrial plants, it is always advisable to isolate both the inputs and the outputs coming from the field. This prevents disturbances caused by power surges, lightning strikes, or other EMI sources and also by ground potential differences.

Arduino Uno or any other ATmega328-based systems do not feature a true analog output, but this may be realized using a PWM output, averaged with a low-pass filter. The use of an averaged PWM signal with 8-bit setting is not comparable with a real DAC. However, in the insulation case it presents undoubted advantages of simplicity since it is sufficient to use an opto-coupler for isolating the PWM digital signal.

The Arduino PWM

An Arduino Uno has several pins (D3, D5, D6, D9, D10 and D11) that can be configured for PWM output. For this project, I used pin D9 because the others were used by various devices (LCD, SD and RTC).

The PWM signal on pins D9 and D10 is generated by the ATmega328's Timer1. It has a prescaler which divides by 1, 8, 64, 256, 1024, controlled by the three least significant bits of the register TCCR1B. The default value of the prescaler set by the Arduino IDE is equal to Np = 64 (TCCR1B, bits 2..0 = 110), which provides an output frequency:

$$\text{PWM frequency} = \text{CPUClock} / (2 \times Np \times TOP) = 16000000/(2\times64\times255) = 490.196\ \text{Hz}$$

where TOP is the maximum timer/counter value.

Using a common opto-coupler with a phototransistor, as 4N25, the frequency is limited because of the high transition times, so I used a faster opto-coupler with photodiode and with an open collector output, such as the 6N136. To eliminate output noise, I utilized a second order active low-pass filter, Sallen-key type, with a cut-off frequency of about 11.2 Hz.

Circuit

The circuit diagram, shown in **Figure 1**, is quite simple. The isolation is achieved with an opto-coupler; of course, you must use for this circuit a power supply different from the one used for Arduino. If the insulation is not required, things become even simpler. Connect the filter to the PWM output. In this case, not even the reference source IC2 is needed.

I recommend using for IC1 a dual operational amplifier suitable for single-rail power supply, such as LM358. The LM358 chip must be powered with a voltage higher than 7 V (and lower than 32 V) to have an output voltage range of 5 V. And please keep in mind: the regulator also has a 2 V dropout.

The advantage of the open collector of the optocoupler is that you can easily obtain a different output range. For example, using a 10 V reference voltage and R2 = 10 kΩ the output range becomes 0..10 V. In this case, the LM78L05 must be replaced with a LM317 with an appropriate circuitry.

The capacitors used for the filter must be measured with a capacitance meter. For my prototype, I selected for C3 some 220 nF capacitors to search for a value that approached 200 nF.
And for C4, I selected a value half of C3.

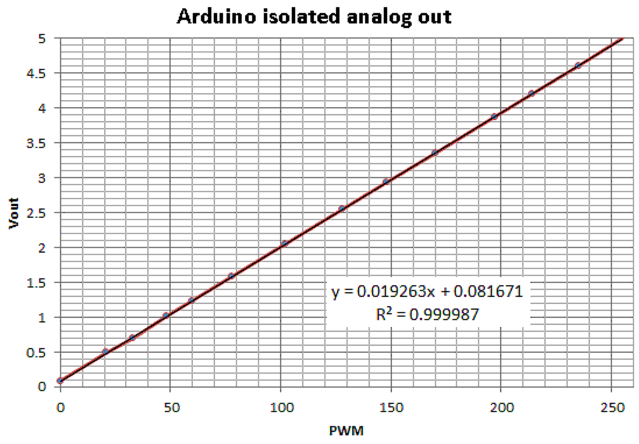


Figure 2: The calibration curve.

Testing

Figure 2 shows the results of the linear regression on the 14 measurements points made on my prototype. The test conditions are:

- PWM frequency = 490.196 Hz
- Vin = 12 V
- Vref = 5.00 V

The standard error is about 6.1 mV, so the results are very good at the default PWM frequency.

I also tested the system with a frequency of 3921.569 Hz, but with a standard error of 39 mV. The largest errors are found for high duty cycle values. In this area the pulses are narrow and the rise time is high; this phenomenon creates non-linearity. The period is: T = 1/3921.569 = 255 µs. The more narrow pulse has a duration of about 1 µs, approximately the same value as the rise time of the pulses. The cause of non-linearity is just due to this phenomenon. Using the default frequency of 490.196 Hz, the minimum pulse has a duration eight times larger, so it greatly improves the linearity.

The Arduino Program

To test the system, I used an Arduino Uno with an LCD and the analog input

Listing 1: Source code [1]

```
// program to test Arduino Uno PWM at 3.9 kHz
// G. Carrera 30 sept 2016

#include <LiquidCrystal.h>

int PWMpin = 9;      // PWM out on digital pin 9
int analogPin = 0;   // potentiometer connected to A0
int val = 0;         // variable to store the read value
char spacestring[17] ="                ";

// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(7, 6, 5, 4, 3, 2);

void setup() {
  pinMode(PWMpin, OUTPUT);  // sets the pin as output
  lcd.begin(16, 2);         // set up number of columns and rows
  lcd.setCursor(0, 0);      // set the cursor to column 0, line 0
  lcd.print("Stalker PWM"); // Print a message to the LCD
}

void loop() {
  val = analogRead(analogPin) >> 2;  // read the potentiometer as 8 bit
  analogWrite(PWMpin, val);
  val = 255-val;                     // complement
  lcd.setCursor(0, 1);
  lcd.print(spacestring);
  lcd.setCursor(0, 1);
  lcd.print(val);
  delay(500);
}
```

COMPONENT LIST

Resistors
R1 = 330 Ω, ±5%
R2 = 5.1 kΩ, ±5%
R3 = 100 kΩ, ±5%
R4 = 100 kΩ, ±1% metal film

Capacitors
C1 = 100 nF, ceramic
C2 = 10 µF, 50 V Electrolytic
C3 = 200 nF, Mylar ±2%
C4 = 100 nF, Mylar ±2%

Semiconductors
IC1 = LM358 dual opamp
IC2 = LM78L05 regulator
IC3 = 6N136

Others
Arduino Uno board

A0 connected to a potentiometer to vary the duty cycle of the PWM. The source code of the Arduino sketch can be seen in **Listing 1**.

220136-01

Questions or Comments?

If you have any questions or comments regarding this article, you can contact the author at g.carrera@elettronicaemaker.it or the team at Elektor at editor@elektor.com.

RELATED PRODUCTS

- **Arduino Uno Rev3 (SKU 15877)**
  www.elektor.com/15877
- **W. A. Smith, Ultimate Arduino Uno Hardware Manual (Elektor 2021, SKU 19678)**
  www.elektor.com/19678

WEB LINK

[1] Source Code: https://www.elektormagazine.com/summer-circuits-2022

HomeLab Tours ... Discovers the Theremin

By Gottfried Karenovics (Germany) and Eric Bogers (Elektor)

Ask people if they know what a Theremin is and, in most cases, you will not get an answer. A few people think they know that the Beach Boys used a Theremin in the song "Good Vibrations" — but that is not quite right. That was later developed and actually completely different, because it is not a touchless instrument, a so-called Electro-Theremin [1]...

Even in his youth, Gottfried Karenovics (born 1943, retired chemistry teacher) had read that it was possible to make music "in the field between two aerials" — without touching strings or keys. The idea never left him.

"In 2008, I happened to discover Lydia Kavina [2][3][4], the best Theremin player in the world, and the great-niece of Lev Termen (later Léon Theremin), who invented the instrument with the same name in 1920 and patented it in 1928 [5]. I really wanted to own such an instrument. The Theremins for sale (most of them by Moog) were too expensive, so I decided to develop my own. And not just a regular instrument — I wanted to build the 'Steinway among the Theremins'."

*Mr. Karenovics is self-taught in electronics. He has developed numerous transistor circuits, including one for detecting very small heat flows, as part of his doctoral research at the University of Dortmund. The development and construction of the Theremin took quite some time; in 2013 his (first) instrument — in concert quality — was all done (**Figures 1** and **2**).*

"My Theremin has three oscillators: two for the pitch (one local and one variable) and another one for the volume control. I designed the oscillator circuits with the assistance of LTSpice and improved and optimized them step by step - to the point where they functioned not just satisfactorily but perfectly. The LC oscillators of my prototype operate at 530 kHz. The antenna circuit is a series circuit

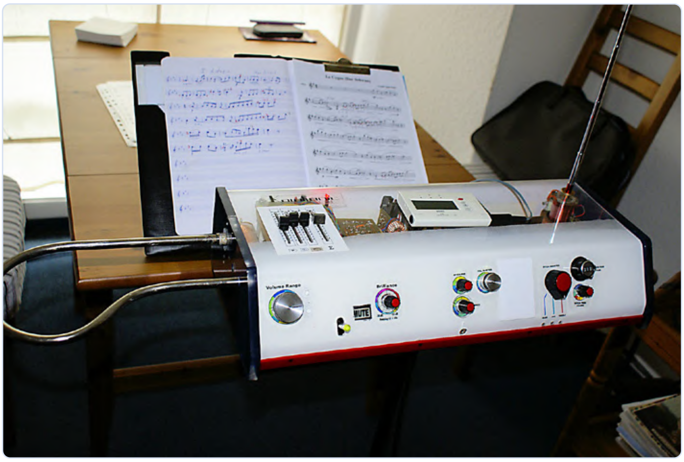


Figure 1: Gottfried Karenovics' Theremin in full glory.

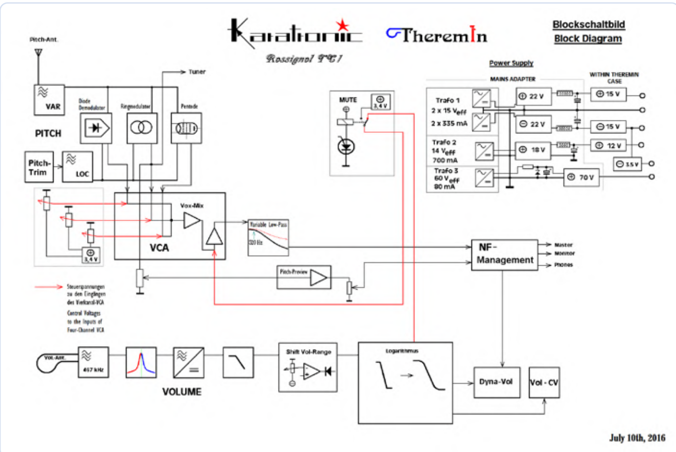


Figure 2: Block diagram of the self-built Theremin.

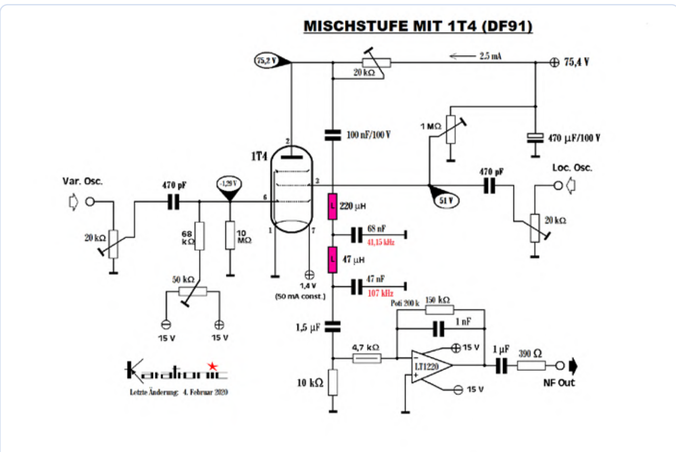


Figure 3: The mixing stage is built around a 1T4.

consisting of two coils with a small trim capacitor in between. When the resonant frequency is precisely met, the 'pitch field' becomes nicely cylindrical and linear."

"The volume oscillator operates at 467 kHz. The steep filter circuitry (a series circuit in the first stage and a parallel circuit in the feedback loop) provides a wide control range - holding your left hand in or directly above the loop antenna completely suppresses noise. Moving your left hand up increases the volume by 100 dB."

"The pitch control consists of three demodulator circuits: a ring modulator, a diode demodulator, and a circuit around a miniature pentode (a 1T4 with an anode voltage of 70 V and an anode current of 50 mA). These three signals can be merged with a 'mixer' and make a beautiful sound (**Figure 3**)."

"In contrast to the instruments of market leader Moog, my Theremin offers unique frequency stability. The instrument retains its settings for years - because I have used high-quality components, such as mica capacitors and ferrite-pot core inductors in the frequency-determining circuits. The Moog Etherwave gets out of tune within a few weeks to a few months and then needs to be recalibrated, which is not that easy."

During a visit to Colmar (Alsace), Lydia Kavina played the instrument of Mr. Karenovics; she particularly liked the sound of the home-built Theremin.

A problem with a Theremin, of course, is that the player cannot quickly turn over the sheet music; that would have catastrophic consequences for pitch and volume. Mr. Karenovics is therefore working on a sheet music rolling machine, with which the sheet music is glued together to a roll that can be rolled forward and back with the help of pedals. For this purpose, he has constructed a flat casing with aluminum rollers on the sides, which are driven by servomotors and toothed belts. Unfortunately, so far this has only worked well with thin rolls. With thicker rolls (i.e. longer pieces of music), the paper starts to undulate and then gets stuck. So there is still some work to be done, for example, with carrier and slipping clutches.

"I chose plexiglass for the housing of my Theremin because it has little or no influence on the electromagnetic fields. I designed the PCBs for the electronics myself - drew them in Microsoft Paint, and then exposed and etched them myself (**Figures 4** and **5**). Paint is a very simple program, but it helps to draw straight print tracks and to keep the boards neatly arranged."

In his workshop (**Figure 6**) *Mr. Karenovics has not only been building his Theremin. Around 1997, he developed and built an electrosmog detector for low-frequency electric and magnetic interference fields; it has become a handy little device of which he sold 20 pieces to a small independent contractor in the neighborhood. And recently, he built a timer based on a 7555, which turns on the air pump of an organ and switches it off again after a fixed time of 3 hours — because the organ player himself regularly forgot to switch off the motor of the pump.*

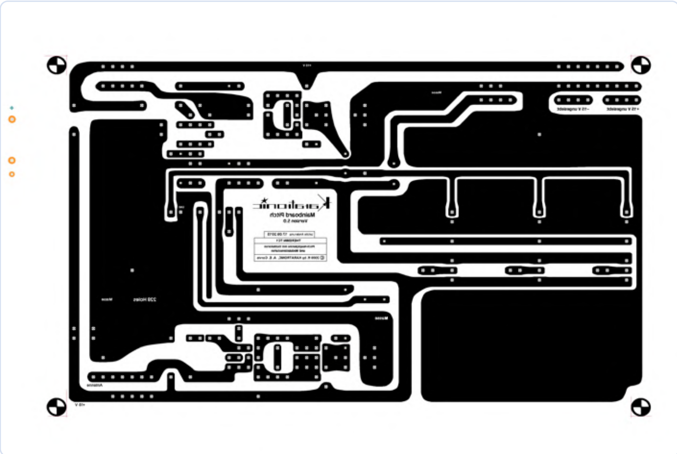


Figure 4: Microsoft Paint can also be used to design neat circuit boards.

Figure 5: Is beer the secret of a good etched print?

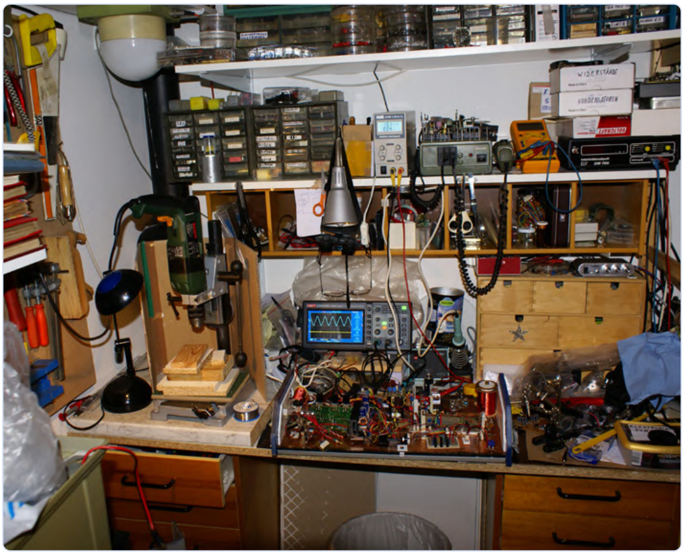


Figure 6: Still a lot of work to be done here.

Figure 7: Mr. Karenovics at a performance, of course playing his own instrument.

"In order to play the Theremin, it is essential to have a musical ear and it is an advantage if you can already play some other instrument. Regular practice is absolutely necessary to train a kind of muscle memory, so that after a while your arm will 'automatically' know which tone is where. And secretly I still hope that a company will be interested enough in my instrument to build it in series..."

200717-01

Questions or Comments?

Do you have questions or remarks regarding this article? Please send an e-mail to the author or to the editorial staff of Elektor at editor@elektor.com.

WEB LINKS

[1] The Electro-Theremin, known from Good Vibrations: https://en.wikipedia.org/wiki/Electro-Theremin

[2] Lydia Kavina's website: www.lydiakavina.com/

[3] Lydia Kavina's biography: https://en.wikipedia.org/wiki/Lydia_Kavina

[4] This is how good a Theremin sounds: www.youtube.com/watch?v=tXgkXTSTXgQ

[5] Lev Termen's biography: https://en.wikipedia.org/wiki/Leon_Theremin

E-FFWD

electronica fast forward 2022 powered by Elektor

November 15 - 18, 2022, electronica, Munich

Lineup and Timetable

By Udo Bormann (Elektor)

It's been an exciting evaluation time as our jury — consisting of our editors, engineers and experts — has been looking at different start-ups, scale-ups, and companies that have been demonstrating new technologies. But, now it's time for the results and we're very excited to announce the final lineup for this year's electronica fast forward 2022 – powered by Elektor. We've selected 9 participants – each with a technology that impressed our jury. From the thinnest inductive charger to an autonomous driving wheel, we will present outstanding technologies and the teams making them possible. Join us at electronica 2022 at our booth in Hall B4.440. Meet the participants and have a look at their technology. This might be the best opportunity to get in early-stage with outstanding technology that might change the future of electronics!

During a ceremony on Friday at 11:00, we will present three startup awards and hand over prizes. The winners will receive a share of an Elektor marketing budget totaling €150,000.

fast·forward
startup platform
by electronica & Elektor

Here's the overview of this year's **electronica fast forward 2022 – powered by Elektor** participants, in alphabetical order.

AirHood (France)

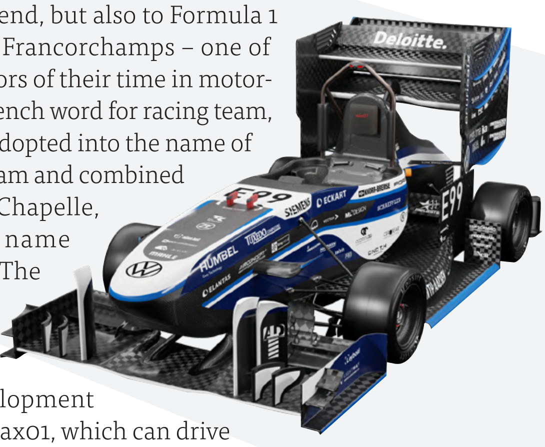
AirHood is a portable range/cooker hood that reduces grease, smoke, and cooking odors as they occur, and stops oil films from forming on surfaces. It keeps the air and kitchen countertops clean while adding a friendly but non-intrusive touch to any kitchen.
https://theairhood.com

AMSEL GmbH (Germany)

AMSEL stands for Advanced Materials and Surfaces for Environment and Life. AMSEL GmbH aims at providing innovative and ecological chemical-free surface engineering solutions through the use of compact, safe, user- and eco-friendly eBlaze technology. Objectives such as bubble-free and residue-free soldering of high-power electronics, adhesion of bubble-free conformal coating, and creation of a sealed bond line in electronic housings can be solved with inline eBlaze treatment.

Ecurie Aix – RWTH Aachen University Project (Germany)

The name of this team is a reference to the motorsport history of the Aachen region. Less than an hour away is Spa-Francorchamps, the famous racetrack, which not only is home to the world-famous Eau Rouge bend, but also to Formula 1 team Ecurie Francorchamps – one of the dominators of their time in motorsport. The French word for racing team, Ecurie, was adopted into the name of the RWTH team and combined with Aix-la-Chapelle, the French name for Aachen. The Ecurie team will present their newest development project, the eax01, which can drive autonomously.
https://ecurie-aix.de



QUADRUPED Robotics (Germany)

QUADRUPED Robotics is specialized in the development and distribution of research and development components. With QUADRUPED Robotics, the focus is more on application development for multi-legged robots, especially based on Unitree products.
https://quadruped.de

Opulo (United States)

Opulo's goal is to create machines that allow people to create products at a larger scale than they could otherwise have. With their LumenPnP product, a desktop pick-and-place machine that automates your board assembly, you will never hand-assemble your boards again. With this open-source machine, no outsourcing is required.
https://opulo.io

Treesense (Germany)

Treesense enables people to better understand the world of trees. They do their utmost to ensure that people can use the ecosystem's finite resources sustainably. These are primarily clean water and air, soil fertility, a healthy climate and biotope, and species protection — especially forests' recreational possibilities. They research and develop technologies based on the latest scientific findings to consider trees as a central part of our ecosystem.
https://treesense.net

V-Juice (Germany)

V-Juice will be the smartest and best charging device a customer can buy. It is the thinnest and most discreet charging station that can be installed and reinstalled anywhere where there's an available surface.
https://v-juice.xyz

Voltera (Canada)

Voltera makes additive electronics platforms that enable product developers to design today's innovative solutions – whether rigid, soft, flexible, or stretchable. They help you cross the bridge between what you can do and what you wish you could do with electronics.
https://www.voltera.io

wheel.me (Sweden)

wheel.me is the world's first autonomous wheel that comprises a robotic component, indoor navigation technology and data analytics, enabling you to make everything and anything move effortlessly.
https://wheel.me

Planning to visit the electronica trade fair? Don't miss out on the electronica fast forward area, where, this year, we have our own 'playground', where the participants will showcase their technology in action. If you want to see a specific participant presenting their technology, check out the timetable below and mark it on your agenda. All presentations will take place in Hall B4, Booth 440.

During a ceremony on Friday at 11:00, we will present three startup awards and hand over prizes. The winners will receive a share of an Elektor marketing budget totaling €150,000.

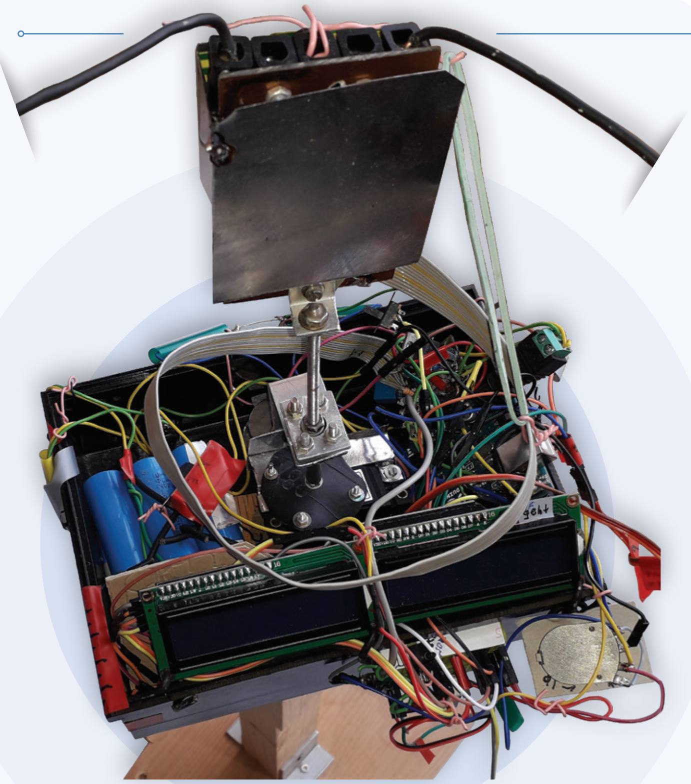
Of course, Elektor will have its own spot within this area, and we're looking forward to seeing you there.

220422-01

Here is the official timetable

Timetable

Day	Start Time	End Time	Who
Tuesday, Nov 15th	10:00	18:00	Expert Meetup
	11:00	11:30	Treesense
	11:45	12:15	QUADRUPED Robotics
	12:30	13:00	AMSEL
	13:15	13:45	Ecurie Aix
	14:00	14:30	Voltera
	14:45	15:15	wheel.me
	15:30	16:00	Opulo
	16:15	16:45	Airhood
Wednesday, Nov 16th	10:45	11:15	V-Juice
	11:30	12:00	Voltera
	12:15	12:30	wheel.me
	12:45	13:15	Ecurie Aix
	13:30	14:00	Treesense
	14:15	14:45	AMSEL
	15:00	15:30	Opulo
	16:00	16:15	QUADRUPED Robotics
	16:30	17:00	Airhood
Thursday, Nov 17th	10:30	12:00	Official Pitch at Cyber Forum Hall B4
	13:00	13:30	Voltera
	14:00	14:30	QUADRUPED Robotics
	15:00	15:30	Ecurie Aix
Friday, Nov 18th	11:00	11:30	Ceremony



Radio direction-finder prototype.

Radio Direction Finding

Tracking Down Lost Wireless Weather Sensors

By Rolf Hase (Germany)

If you have several wireless weather sensors distributed around a weather station, sometimes you may not be able to locate one or more of these sensors. Maybe they have been overgrown by shrubbery, or you might have simply forgotten where you put them. This project can help. You can use radio direction finding to locate wireless weather sensors.

A good weather station can not only measure air temperature, air pressure and humidity, but also provide more or less reliable information about future weather conditions. For this, however, you also need to measure wind direction, wind speed, the amount and duration of precipitation, solar illumination levels and other parameters, all evaluated by sophisticated microcontroller software in the weather station. This involves a large number of suitable sensors, which are usually connected wirelessly to the weather station ('connect and forget'). Here, we're mainly interested in 433 MHz modules.

In order to use radio direction finding (RDF) to locate a lost weather sensor, you first need to know how a weather station works. This doesn't mean learning about the specific pulse scheme of a particular brand, but instead gaining insight into the data traffic. Aside from Manchester or Ethernet codes, there aren't that many different ways of transmitting a serial bit pattern, and, with the rtl_433 software [1], you can easily decode any sensor's data traffic, even if the software is designed for a whole range of frequencies. There is even a compiled version available online, but only for 433 MHz.

Basics

Without divulging any secrets, it can be assumed that the transmit frequency of a weather station is in the industrial, scientific and medical (ISM) band at 433.92 MHz or 868 MHz, stabilized by a resonator. This is where the problem lies: all transmitters in the vicinity — your own and those of your neighbors — operate at one or both of these frequencies. The devices, usually powered by two AA batteries, transmit with radiated power in the milliwatt range and operate with very low duty cycles to make them very energy-efficient. One to three data packets are sent, separated by very long time intervals, such as 44 s in our case (**Figure 1**). This is done with highly precise timing, since even the simplest weather station has the same accuracy as a crystal-controlled clock.

This precision allows a clever hobbyist or maker to prioritise their own sensor by inserting a small DIL switch within the receiver's positive supply line. When the right button is pressed and held for two to three seconds, the weather station goes into search mode, in which the receiver is persistently powered for two to three minutes (more about this later). The receiver icon blinks in search mode. As soon as your sensor is detected, you press the DIL switch. This way your own sensor is the only one marked in the time register. After the search mode has ended, you switch on power again, and everything works as usual for an extended time.

Low-power operation is also important with receivers in weather stations, most of which are battery powered. They take advantage of the high timing accuracy of the recurring data packet transmissions to switch on the receiver at the right time, under control of a switching signal. If you hold a wideband receiver (such as my good old ICOM PCR1000 [2]) near the receiver, you can hear the noise of the super-regenerative receiver (also called a reflex receiver or reflex audion) starting up just before the data packet arrives. Nowadays, super-regenerative operation is possible even in the UHF range, thanks to modern semiconductor technology. The noise on the PCR1000 comes from the high gain achieved by alternating between oscillating and not oscillating. Of course, superheterodyne (superhet) receivers are also used in this area. The difference is that a superhet receiver has a sensitivity of -112 dBm, while a simple receiver is about 6 dBm worse. That's enough said about weather stations, RF and electronics, in preparation for the question of radio direction finding.

From the Idea...

We have the following initial situation: The sensor and the weather station are working properly, but we need to determine the sensor's location. An oscilloscope— such as my PicoScope, purchased from the Elektor Store, with its excellent digital triggering characteristics — is a big help in this. In my direction-finding receiver, I used a compact Aural RX 4MM5 superhet receiver [3]. For the initial tests to record the relevant data packets, all that's required is a short antenna (approximately 16 cm long) connected to the superhet receiver mounted high above the rest of the hardware. The construction instructions in the datasheet must be observed in so far as that either a small piece of circuit board, or at least relatively thick wires, must be used as a soldering star point for the ground. Many other types of superhet receivers tested by the author exhibited uncontrollable persistent oscillations.

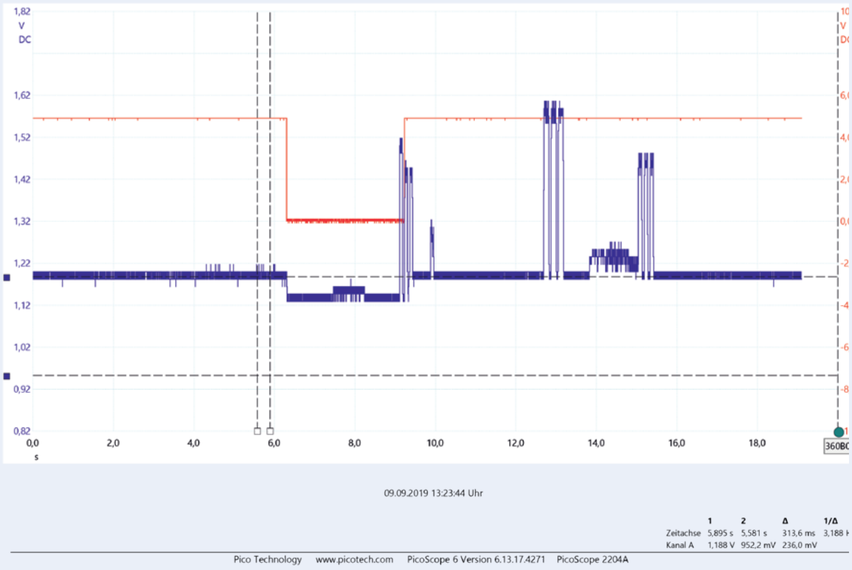


Figure 1: The 433 MHz band is very busy. Signals from different transmitter modules are shown here. The pulse sequence in the middle is the one we want.

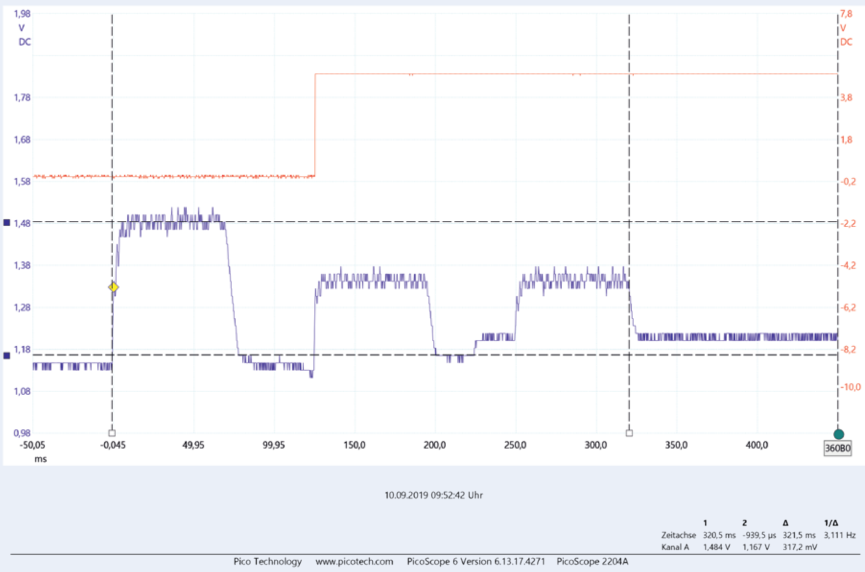


Figure 2: Timing is critical for selecting the middle pulse.

For initial orientation, I connected an earpiece output, consisting of a 470-Ω resistor and a small electrolytic capacitor, to the pulse output (pin 14 of the RX 4MM5). In parallel with this, I monitored everything on the PCR1000, also using a short wire antenna about 16 cm long. The oscilloscope must be set to single-shot trigger mode, since this is the only way to trigger on the desired event (the relevant pulse sequence).

In order to filter out the correct data packet, I performed a battery reset on the receiving weather station (by literally removing and reinserting the battery), as this automatically starts the sensor search. Then, the weather station immediately shows a valid value as soon as it comes from the sensor, and its timing should also match the signal on the oscilloscope if there's no interference from another signal.

The packet's pulse and break durations can be read from the oscilloscope display (**Figure 2**, which was taken from the already-completed device). The length of the relevant packet is 321 ms, while a different packet had a length of 340 ms. This procedure is thus relatively time-critical, but doable, and it saves searching for an ID number within the pulses.

The times determined in this way will not change, and they were entered in the software of the radio direction-finder. The waveform also shows the drop in signal level due to antenna switching by the PIN diodes (more about this later), resulting in a lower signal level. The large dynamic range of this measurement avoids various errors that inevitably occur with manual direction-finding. The digital L/H transition in the upper red waveform in Figure 1 indicates that the Arduino has recognised the correct (middle) pulse as well as the pulse break, and shortly after this has measured the level of the second pulse, which is shown in the bottom line of the display. Evaluation of the signal level also holds risks, since the low-pass filter produces a signal edge that, through the signal strength (proximity to the transmitter) and the threshold value, influences the time that the Arduino uses as the evaluation criterion. However, this method has proven reliable. An alternative approach is to measure the length of the data signal (the triggered pulses) using a sample-and-hold circuit, but this would involve dealing with time constants.

As I did not want to work myself to the bone like the participants in a fox hunt (see **box**), it's better to have the direction-finder rotated by a servo motor instead of by the user. It's only a small step from this insight to automated operation with a servo.

However, it turned out that developing a usable device was not so easy. That's because I first built a 70 cm Yagi antenna with six wire elements, on account of its narrow bandwidth, and used it for tests in the garden. The tests were very time-consuming due to the long signal intervals, and, in the end, they did not yield useful results. A construction similar to that of a fox hunt receiver [4] [5] is actually better: a separate, hand-held device with an RF-tight enclosure and its own power supply, without an irritating cable that could alter the RF field when moving. In addition, for actual use at a weather station, the oscilloscope has a difficult task: it must capture the right (and very short) signal every 44 seconds from amongst numerous other signals and keep the signal level relatively constant, despite large fluctuations. That is simply hopeless, so using a servo to rotate the antenna(s) automatically is the only alternative.

...to the Circuit

Books such as Alois Krischke's *Rothammel's Antenna Book* are full of nice antenna patterns. To record such patterns, you need ideal free field conditions and precise test equipment. In this case, however, what matters is not exact values for every angle, but only the direction of the minimum. In addition, you don't want to annoy the neighborhood with a CW transmitter. To roughly measure the expected directional characteristic, I placed a small, low-cost transmitter module with a resonator (a remote control for a wireless power outlet operating at 433.92 MHz with the button clamped down can also be used briefly for this purpose) as far away from my house as possible (7 to 8 m).

On the receiver end, I used a potentiometer to control the servo angle proportionally (which was required for dynamic testing of the mechanical construction in any case), along with a protractor to record the antenna pattern at 30-degree intervals. For this, I loaded suitable control programs.

Using what I learned from these tests, I put together a direction-finding receiver consisting of the following elements shown in the circuit diagram in **Figure 3**.

The two **λ/4 antennas** are at right angles to each other. The PIN diodes ensure that the two antennas are never switched on at the same time, and they should influence each other as little as possible.

If **filtering** is necessary, a low-pass T filter consisting of two air-core coils made of silver-plated copper wire (three turns on a 3 mm form) and a 2.2-pF capacitor can be connected directly to each antenna (not shown in the circuit diagram). A PCB is a good idea here because it allows low-profile, compact construction with antenna terminals and PIN diodes. The capacitors serve as solder posts.

The RX 4MM5 superhet receiver module receives the signals from the antennas and outputs the signal strength (RSSI), among other things. This analog signal, with a range from around 1.2 V (at -120 dBm) to 2.2 V (at -30 dBm), is the only signal that is used. It is smoothed by a low-pass filter (3.3 kΩ / 1 µF) and fed to the Arduino's A0 analog input.

The **Arduino** performs three tasks: It evaluates the filtered RSSI signal from the receiver and shows the result on a couple of 16×2 display modules; it switches on the two antennas individually; and it drives the servo to the correct positions for making the measurements.

The servo covers a range of approximately 180 degrees in six steps of 30 degrees each, starting from all the way to the left, for a total of seven measurement points. When a valid data packet is detected, the measured value of the first pulse, corresponding to the left-hand antenna, is output on the top line of the left-hand **display**. Before the second pulse of the same packet of three pulses, the right-hand antenna is switched on by the PIN diodes, and then the value of the second pulse is measured after a settling time of a few milliseconds and output on the bottom line of the display. Then, the servo turns further and waits for the next data packet.

The minimum of the measured values indicates the direction to the transmitter, as discussed in more detail below. The right-hand display, along with the potentiometer on the right and the breadboard, is for diagnosis and more detailed investigation (such as controlling the servo with the potentiometer in the early stages of development).

As is to be expected, the minimum is approximately perpendicular to the apparent directional orientation of the two antennas, which are arranged at 90 degrees to each other, as can be seen from the prototype. Although the antennas are electrically separated by the BA479 diodes, the left antenna acts as a director for the right antenna at a certain angle (in

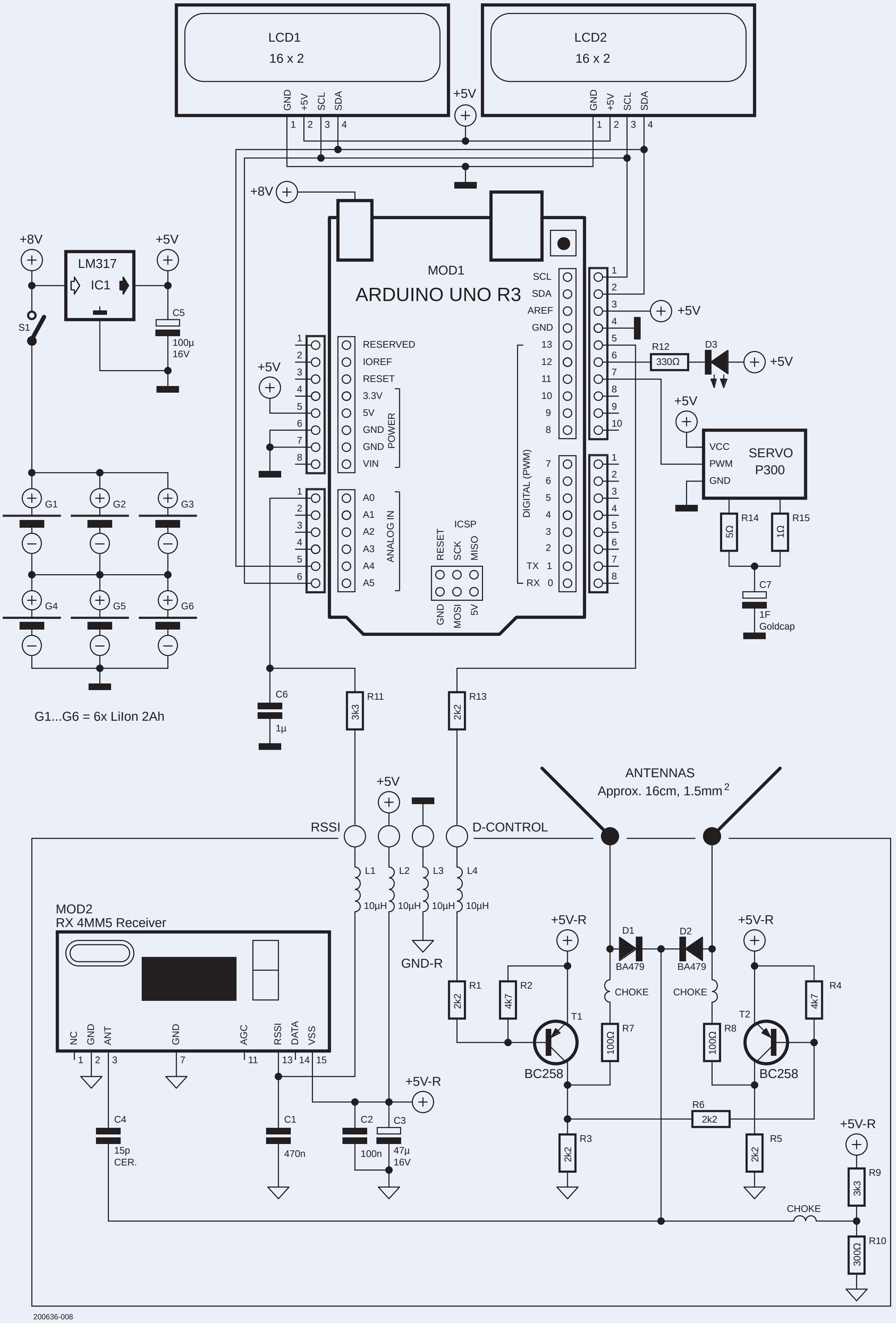


Figure 3: Circuit diagram of the direction-finding receiver. -R: receiver side; λ/4 choke: 16 cm 0.2 mm copper wire on 3 mm form. Connection to rotating antenna module: 14-way flexible ribbon cable, 50 cm (3 × λ/4). BA479: PIN diode.

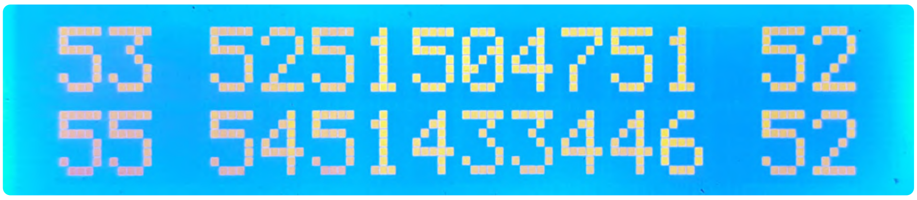


Figure 4: Readouts on the display.

line with the theory of Yagi antennas with one or more directors, a dipole and a reflector), but because it is too long for this, it acts more like a reflector and attenuates the signal in that direction. This can easily be seen on the display (**Figure 4**), where the antenna's visual directional orientation points to the already-known position of a weather sensor approximately 5 m away. From left to right, the pairs of values show 4: 50/43, 5: 47/34 and 6: 51/46. In particular, the value 34 for the right antenna (at the bottom on the display), which is covered by the left antenna in this position, shows exactly this effect. The directional orientation is thus clearly defined. Another criterion is the magnitude of the values, since the field strength decreases as the square of the distance due to the expanding surface area.

To allow the direction-finding receiver to work autonomously, it is powered by six lithium-ion batteries (two sets of three connected in series). The battery output voltage is reduced by a fixed voltage regulator (LM317) to 5 V for operation of the electronics. Note that the supply voltage of the antenna circuit must be taken directly from pin 15 of the receiver module.

Software Tasks

Anyone who (like me) has done a lot of programming in assembly language, where the software is very close to the computer hardware and real-time considerations are usually not much of an issue, has doubts about whether a higher-level language such as the Arduino's C variant can actually work in real time when it comes to time-critical applications. Everything seems very simple, but high-level languages have their internal conventions that you have to know or learn by trial and error.

The initialisation part of the sketch [6] does not need further explanation. The threshold value is defined there and may need to be modified. One noteworthy parameter is a settling time of a few seconds to let the Arduino warm up. Unlike the ESP32, which only provides estimates of analog values, the Atmel ATmega328 has an accurate A/D converter, which is used here. The analog value is read at the start of the main `loop()`. For this, there are the two routines `MessWert` and `TestWert`, which differ only in the number of measurements depending on the available time. The length of the High pulse is measured after a debouncing operation. This is done by measuring the time difference using the `millis()` function, so the initial value must be saved. As with measurements using the oscilloscope, the High pulse should have a duration of 63 to 76 ms. If this condition is fulfilled, the flag `Block1` is set to 1. Then the break time is also measured. If the total time is in the range of 117 to 127 ms, the relevant sensor has been found and `Block1` is set to 2. After a waiting time for the rising edge of the second pulse (`delay(20)`), `Wert2` is determined for the same horizontal rotation and later written to the display below `Wert1`. The rest is straightforward. The seven positions of the LCD can be addressed with the parameter `k`, up to at most the 37th second, or with enough distance up to the 44th second, where the next measurement of the sensor data packet takes place.

The question of whether the Arduino can handle real-time tasks can be resolved in software with precisely this arrangement of `while` and `for` loops. However, I had to number the loops sequentially, as otherwise I lost track after ten loops or so. When the software is waiting for the pulse, it shouldn't do anything other than wait. In particular, driving the display needs nearly 20 ms, which of course isn't possible during a pulse length of 75 ms or a break of 50 ms. However, we know that after a data packet is detected, the channel will be quiet for 44 seconds. That's more than enough time.

The relevant pulse and break times are polled with a certain tolerance. The trigger threshold for the pulse is also important. This is handled by averaging over a reasonable time interval. As previously mentioned, it all works exactly as it is programmed here. You should therefore be careful when making changes other than the numerical parameters for the pulses, unless you retain the loop structure. Some of the ancillary programs I found online and modified, for example for servo control, are included in the download for this article [6] and can be used for your own experiments.

Compartments

Good shielding is important for radio direction-finders, and the receiver is additionally enclosed in tinned sheet metal to shield it against strong mobile base stations. My past experience with building a lot of RF devices (amplifiers and converters) using PCBs in partitioned compartments came in handy here. I cut the circuit board sections to size to match the existing antenna connection box and soldered them in place, with intermediate compartments for the amplifier stages arranged as close to the antenna as possible. The data sheet for the superhet receiver recommends a large ground plane, so I mounted it on a piece of circuit board. If you don't have experience with striplines, etched PCB tracks are difficult to work with in the UHF range.

The device is built as a compact unit, so no inner compartment screening is required and only the overall receiver assembly is enclosed in soldered sheet metal for shielding. Freestanding construction or operation of the module, for example in a weather station, is only possible if the ground connections at the pins are kept short and not too thin, with decoupling capacitors fitted where necessary.

For the previously stated reasons, the mechanical construction should be as self-contained as possible. Power is provided by six standard lithium-ion cells, which is more than we need electrically, but this ensures reliable operation and resilience. I screwed a square post to a board acting as a base and mounted a Bakelite box on top of the post to hold the batteries, Arduino board and servo, with the servo positioned in the middle. Above the servo, I fitted a piece of sheet metal to hold a small ball bearing for an M4 threaded rod. The receiver is fitted at the top end of this rod, attached using a small bracket. The electrical connection to the receiver is provided by a thin, elastically-suspended 14-way ribbon cable with a length of approximately 50 cm. This corresponds to 3 × λ/4 and assists the 10 µH chokes fitted in all supply lines in the receiver.

As many connecting wires as shown in the lead picture are actually not required, since all signal and supply lines have ground lines on both sides. This provides good shielding and is only slightly worse than a coaxial cable.

I initially installed a miniature servo because the antenna assembly was very easy to rotate. That turned out to be a mistake, since inertia also has to be taken into account. The servo, with its motor driven by a bridge circuit, is dumb and outputs full power as soon as it is switched on, so the small gearbox wore out very quickly. Fortunately, I had a type PS300 servo with a higher torque rating in my parts box. You live and learn. To be on the safe side, I right away fitted an RC T network in the motor lead, consisting of two resistors (1 Ω and 5 Ω) and two goldcaps for a total of 1 F, which delays start-up by about 1 second. In addition, I cut a rubber washer from a bicycle inner tube and screwed it onto the carrier. The threaded rod is driven by this washer, which attenuates jerky motion. These measures tamed the dynamic drive problem.

When it comes to radio direction-finding in the radio amateur world, the so-called Spandau direction-finder should certainly be mentioned; it is still available from Funkamateur.de [7]. In the VHF range, it is used with more antennas linked together than would be suitable here. During the Cold War era, the Spandau direction-finder was used in West Berlin to hunt for Stasi spies. Of course, the extremely low duty cycle of weather sensors (400 ms in 44 s) was not a factor then. On the technical scale, which has no upper limit, coupling the two methods using BA479 switching diodes would certainly be conceivable.

200636-01

The Common Radio Amateur

Who's out fox-hunting over field, wood and meadow?
The sportive radio amateur, such a hale fellow!

(photo by K. Theurich from Funkamateur 9/88, with the kind permission of the Funkamateur editorial team)

It can't be claimed that the common radio amateur (imperitus scintillae vulgaris) leads a lonely, bleak existence in its radio shack, wearing earphones while listening to distorted, noisy chirping sounds and feeding on lukewarm pizza and sweet, sticky drinks. Indeed, an alert outdoor observer may sometimes see colorfully-clad figures with strange tubular metal constructions scurrying over the fields and crawling through the underbrush.

Why do radio amateurs do such things? Is it a communal food gathering exercise, or perhaps an unusual sort of mating ritual?

No, none of that. These radio amateurs are engaged in fox hunting, which doesn't mean they're shooting at innocent creatures. Instead, they're participating in a peaceful radio sport, or more formally, amateur radio direction-finding in the terminology of the DARC. This involves using a lightweight portable receiver, together with a map and compass, to track down transmitters hidden in the terrain, usually operating in the 80 m band (3.579 MHz) or — more difficult — in the 2 m band (144.5 MHz). This may be a friendly recreational activity for people of all ages, but (especially in Eastern Europe) there are also serious and strenuous competitions ranging all the way up to world championships. For descriptions and more information, see [5].

Questions or Comments?

Do you have technical questions or comments about this article?
If so, please contact the author at rolf.hase@arcor.de or the Elektor editorial team at editor@elektor.com.

WEB LINKS

[1] rtl_433 on GitHub: https://github.com/merbanan/rtl_433
[2] IC-PCR1000: www.funkamateur.de/typenblaetter-1.html?file=tl_files/downloads/typenblaetter/frei/IC-PCR1000_typ.pdf
[3] RX 4MM5: www.velleman.eu/downloads/7/rx4mm5_usersmanual.pdf
[4] About "fox hunting": https://en.wikipedia.org/wiki/Amateur_radio_direction_finding
[5] What is ARDF? (German): https://ardf.darc.de/pubrel/wasist.htm
[6] Downloads for this article: www.elektormagazine.com/200636-01
[7] Spandau direction-finder in *Funkamateur* 9-11/2011 (German): www.box73.de/product_info.php?products_id=2503

Estimate an IC's Internal Noise

A Simple Method

By Mario Rotigni (Italy)

You can use a simple probe to assess the internal noise of integrated circuits. Building and using the probe can provide useful information, and it can enable you to check the effectiveness of a modification done to reduce the noise emitted on the power supply or signal lines. This can help in EMC debugging.

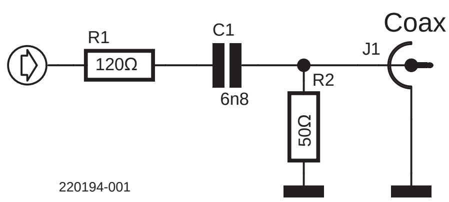
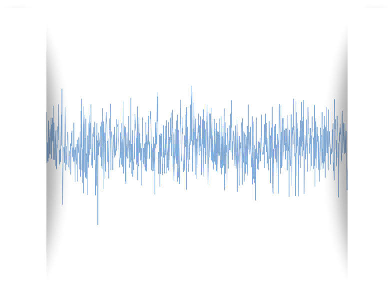


Figure 1: The 150 Ω network.



The source of electromagnetic emission on modern electronic equipment is often traceable to an integrated circuit. The industry developed international normative to specify dedicated test methods at the integrated circuit level that do not require expensive infrastructures. One popular in the semiconductor industry is proposed by IEC61967-4. It is called the "150 Ω direct coupling" method. This method allows for the measuring of the electromagnetic noise present on one specific pin of an integrated circuit. It requires the simple interface circuit presented in **Figure 1** (the 150-Ω network). The input, on the left, is connected to the targeted measurement point. The connector output J1 is typically connected to a spectrum analyzer that presents the amplitude of the noise in the frequency domain. The 150-Ω network is basically a high-pass filter, and it has two main functions. First, it loads the measurement point with a known impedance (about 150 Ω, as the reader could guess), allowing a comparison of different measurements, since it's being done in consistent conditions. Second, the network presents to the instrumentation the required 50-Ω impedance. The capacitor also prevents the application of excessive DC voltage levels to the very sensitive inputs of spectrum analyzers. From a technical point of view, what is measured is the conducted emission of the node under analysis — the unintentional radio frequency voltage that propagates through the physical connections.

Measurements

The measurement of the radiated emissions usually complements the investigation of the integrated circuits, but those are not part of this work. It is possible to measure on the power supply pins, typically with a coupling capacitor of 6.8 nF, but also on input or output pins. Since output pins can be active, for example transmitting a clock signal to an external peripheral, it is important to adapt the value of the coupling capacitor according to the maximum capacitive load specified in the datasheet of the integrated circuit under test. The cut-off frequency of the network is 174 kHz with 6.8 nF, 24 MHz for 50 pF. Over the cut-off frequency, in the band useful for the measurements, the attenuation is ideally a constant 15 dB.

The formal application of the method requires the integration of the 150 Ω network in a test PCB, according to precise layout rules. The same method could be applied at home in a less formal way, implementing the network on interesting nets of our PCB or as a probe. The repeatability and stability of the measurements are in this way compromised, introducing uncertainty in the load impedance and frequency response. However, the results allow understanding of the trends, helping in the noise reduction debug. For instance, it would be possible to assess different decoupling capacitors on one supply or the effect of the different driving strengths offered by many modern microcontrollers' general- purpose output pins.

Pre-Compliance Tests

Interestingly, when the probe is applied to a static digital output pin, we get an idea of the noise on the internal power rails. In fact (see **Figure 2**), when the output pin is at a high logic level, the PMOS transistor is conducting, presenting a low resistance and giving access to the internal power net. When it is at a low level, the NMOS is giving us access to the internal VSS. It could be interesting to enable and disable different peripherals of a microcontroller and see the effect on the generated noise. These trials can be part of pre-compliance electromagnetic tests. In principle, a calibration could make a probe more reliable, but it is always difficult to solve the indeterminacy given by the connection with the device under test.

220194-01

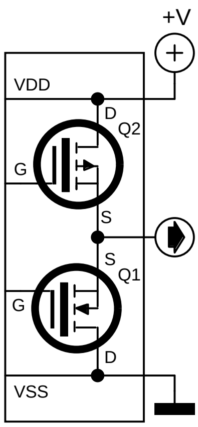
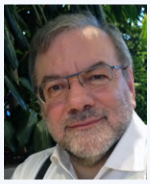


Figure 2: Standard digital output circuit.

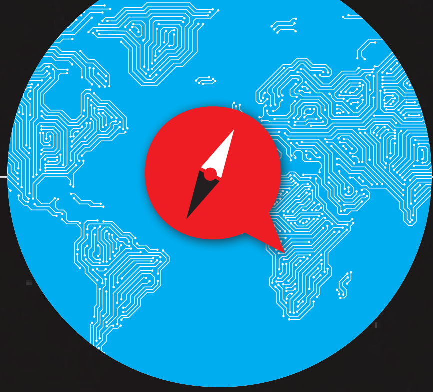
About the Author



Mario Rotigni was born in Bergamo, Italy, in 1958 and received a diploma in electrical engineering in 1977. He discovered electronics as a hobby when he was 14. In 1978 electronics become his profession, where he work in R&D on the design of process instrumentation operating in very hostile electromagnetic environments. After designing an Automatic Test Equipment for microcontrollers, he joined a major semiconductor manufacturer, where he has held various positions in engineering, design, and now in R&D in the Automotive Product Group.

Questions or Comments?

Do you have technical questions or comments about his article? Email the author at m.rotigni@elettronicaemaker.it or contact Elektor at editor@elektor.com.



ETHICS IN ACTION

Powered by WEEF

By Don Akkermans (Chair, WEEF) and Shenja Panik (Project Manager, WEEF)

The World Ethical Electronics Forumn inspires global innovators with open discussions and publications about ethics and sustainable development goals. Join us for WEEF 2022 on November 15, 2022 — either in person at electronica 2022 or live online — to share your ideas about eco-friendly design practices, SDGs, ethical HR practices, sustainable resources, e-waste management, diversity in STEM, and much more.

Finally, the electronic industry has its own platform to discuss ethics and the economy — the World Ethical Electronics Forum (WEEF). For far too long, only lobbyists, activists, NGOs, and politicians dominated the discussion, and they merely emphasized the bad influences that electronics companies have had on people and the planet. Consumers were typically portrayed as the willing victims of the electronics industry's marketing campaigns which allegedly had them stuck in a product buying bonanza that never ends. The picture was bleak: consumers were depicted racing to purchase products to satisfy needs that they never knew they had in the first place.

A member of the Swedish parliament once suggested, with a smiley face: let's make laws that stop the buying process for 12 months and the world will turn into a happy green place in a year! The smiley face was appropriate: even during the recent lockdowns and almost total stand still of cars and planes CO_2 was reduced by only 4%. So, stopping the buyers' economy might not be the perfect solution. But what is?

Fun fact: In Amsterdam, you can find poster cartoons in stores where a staff member says, "We have nothing to sell," and a client answers, "That is exactly what I'm looking for."

Yes, there is truth in the slogan "less is more." Why pollute the world with air conditioning systems when eco buildings create a cool climate thanks to clever use of (often traditional) materials and intelligent design?

No worries about revenue declines if innovators and startups would find non-electronic solutions. Electronic applications soon will be embedded in almost everything anyhow. Even in towels. "Ping!" says the IoT towel app on your mobile: "Please change me because I have been used seven times."

More electronics in more products and more robots and AI-driven applications instead of old-fashioned human power — it is an unstoppable development. That's good news for the industry. There will be plenty of capital to also invest in developing sustainable electronics, fair trade, sustainable distribution, and social human resource management — in short, doing ethical business. If entrepreneurs and CEOs put people and the planet on the same level as profit, companies will be better long-term changemakers than short-term politicians and their short-sighted voters.

This was not always the case though.

The first WEEF forum in 2021 made clear: engineers are idealist but are also realistic thinkers. The industry has no need for aggressive 100% inclusive thinking activists.

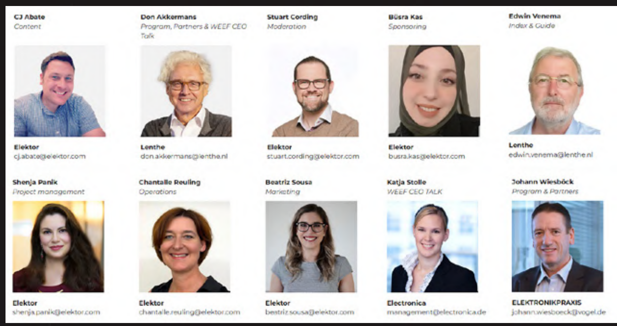
In 2014, when Elektor launched the first opinions, comments, and articles about ethics and electronics, a lot of CEOs and other industry leaders couldn't suppress their laughs. They thought it was plain naïve. Elektor needed to convince them first about the *why* of making their company also "a force for good."

In 2022, the question — and the questions of all employees, clients, and shareholders — is not anymore about the *why*. The world is flooded with consultants, associations, politicians, and NGOs telling companies to aim for value instead of profit. So, nowadays, there is more emphasis on the *how* and *what* and *when* to change — to start closing the gaps between industry and nature, between rich and poor, between NGOs and companies.

How can this movement be accelerated without killing profitable business? Would launching green/ethical/social trademarks be one of the accelerators? Food for thought.

The program committee of WEEF is not convinced that more "green labels" will help. Take B Corp: answer 200 questions and when you get a green flag on 40% of them, bingo, the PR managers can proudly inform the press and public that "all is good (with us); sleep well!"

The iconic quote from Michael Douglas in the movie Wallstreet in 1987. Would it be better to say "Green greed is good"?



Contact the WEEF Committee if you want to be interviewed, give a speech, or launch a triggering statement. Visit worldethicalelectronicsforum.com.

It has all the appearances of a slick marketing tool more than anything else. It's no coincidence that the CEO of B Corp is under the attack of its own members since it allowed Nestlé in. "How can you approve Nestlé when their CEO states that access to water is not a human right?" That is a credible question.

Join us for WEEF 2022 on November 15, 2022 — either in person at electronica 2022 or live online — to share your ideas.

Others embrace the birth of all these labels. "The more the merrier," they argue, and debates about their validity creates rumor. Hey, why is your company (still) not labeled? Clients and buyers have a choice to move towards products and services from companies that are tested and labeled.

What do *you* think about labels? What is *your* opinion and comment in this YES/NO debate? Maybe you'd like to escape from the black and white options and aim at a more balanced position.

And now to the heart of the matter on a personal level: Do *you* have the personal courage to commit yourself openly to an individual e-PLEDGE that we are going to introduce in the next couple of months? A pledge that contains the basics of ethical business behavior on a personal level? Can you honestly talk about your dreams and doubts?

If you do, then maybe you want to inspire others? That is why we invite you to be part of our new WEEF community — people who are prepared to walk the walk and talk the ethical talk.

How about we interview you? Can we publish your statement? Can we show a cartoon you love? Can we stream a video of you talking about ethical electronics? Do you already have a video you want to share? Can our editors produce an "ethical passport" for you and for the company you work for? In short, let's talk!

Send Shenja an email at shenja.panik@elektor.com, and we will get back to you within 24 hours. We hope to meet you on our forum (online or live) and in our printed ethical guide.

220394-01

Get Involved with WEEF
Interested in ethics and electronics? The Program Committee invites ethical engineers and leaders who are seriously involved in the ethical policies of their companies, universities, action groups, NGOs, and associations to step forward. Let us also know if you want to give a speech, contribute a video, or join a debate about ethical electronics. Visit WorldEthicalElectronicsForum.com for additional information and to register for the WEEF newsletter.

No Ethics, No Sustainable Business

An Interview with Professor Stefan Heinemann

By Edwin Venema (Lenthe Foundation)

Can an electronics company be sustainable and profitable without business ethics? Professor Stefan Heinemann dives into the details.

Very often, ethics and business are seen as each other's natural enemies. Ethics would be a barrier to true profitability. A politically correct dictate of the woke culture. A "tick the box" and then get on with "real" business. According to Stefan Heinemann — philosopher, theologian, and professor of business ethics — that framing is completely outdated: ethics and doing business are two sides of the same coin. Without business ethics, sustainable, and therefore profitable, business is simply no longer possible. As a solution partner to many other industries, the electronics industry has an almost moral obligation to play a pioneering role in the major paradigm shifts of this century: digitalization and sustainability. And, yes, Heinemann is positive about binding the forces of good: "There is always hope. We can still shape the future. But remember: business ethics in electronics starts with ... you!"

Edwin Venema: Doing ethical business sounds like a no-brainer. Who could be against it?

Stefan Heinemann: Ethics might be a no-brainer in a way, but it is hard to do. Ethics is the theory of morality. It concerns our actions and statements about what's right and wrong. Sometimes the difference between the two seems rather obvious. No one doubts that killing your children is wrong. But that red ethical line can become a lot thinner in practice, especially when it comes to doing business. You could say that the economy as a whole has some unethical foundations — call it the dark side in Luke Skywalker terms. But luckily, there is also a — in my opinion a much larger — light side. I am convinced that the electronics industry could, or even should, consider itself as a central element for digital solutions. Keep in mind, however, that digitalization is not an end in itself (apart from the fact that analog solutions will still play a role in this context): it ultimately serves sustainable companies, customers, and our society as a whole. Investing in ethics is the best thing you can do, very close to the company's own value creation.

This also requires moral leadership and role models. That is a challenge in a very diverse sector in the entire range from sole proprietorships, small family businesses to large corporates. You will have to put yourself in a leadership position to engage with ethics in a more systematic way. Not from herd behavior (everyone does it), but from self-awareness: we have a pioneering role. We see the importance, for our customers and customers of our customers. Benjamin Parker, or Uncle Ben, the paternal uncle of Spider-Man said it right: "With great power comes great responsibility!"

I'm deeply convinced we have only two options. Either we see ethics as a part of business success, or as a form of "moral washing," or we passively wait for top down regulations to change our way of doing business.

Venema: Top-down regulations are often conceived as inevitable "compliance" ...

Heinemann: Compliance is the more formal, legal kind of rules forced upon you "from above." Ethics is about the freedom to do something "from within." It's about internal motivation. Look at the Volkswagen emission scandal: it could have spared them billions of dollars if the internal structure and culture had been more supportive of morally acceptable behavior.

Compliance is enforced morality and less effective than personal integrity. That's why the tone and behavior of business leaders is so important. We need role models.

Venema: Can you name some specific role models?

Heinemann: That is very difficult, because what do you actually say when a person or a company is "ethical"? Are the people, the numbers, and the products "ethical"? No person or company on this earth is 100% so. You can give examples of small or large companies that reduce their CO_2 footprint more than is required by law. That does not mean that these companies act 100% ethically. But good examples from the supply chain that try to make a difference without going bankrupt are and will remain important. A nice task for the WEEF index, I would say. However, always remember: we are only human; we sin and we make mistakes.

Uncle Ben, the paternal uncle of Spider-Man, said it right: "with great power comes great responsibility!"

Venema: When ethics starts with personal integrity, it becomes more complex in companies, especially at even higher levels: your personal responsibility dilutes in the dynamics of organizations, and of political reality.

Heinemann: Responsibility can be diffused in companies, sectors, and societies, that's right. Who is responsible for what precisely? What can I do as an individual? I cannot actively place my responsibility directly on the shoulders of others. "Let George do it," the Americans say. Let someone else do that eco-friendly stuff! See no evil, hear no evil. For the development of personal responsibility, you need an environment and a society that stimulates and monitors this. In this context, WEEF can play a facilitating role. Invite (young) people to have a say in this; give them a voice. But don't think that's sufficient, because in the end, it's about a systemic change. Everyone alive today, whether you're five or 50, belongs to the last generation to be able to affect this systemic twist.

Venema: That sounds rather doomy and gloomy.

Heinemann: There is hope! The world is what it is. In this world, we can do what we're supposed to do. As a Christian, I call that "creation," but whatever you want to call it, it is possible for us to turn this planet for the better. I'm not a fatalist that says "game over."

Venema: Even with the widespread fear of artificial intelligence applications that eventually will end the human race?

Heinemann: In an earlier interview with Elektor, I said: "The optimist thinks the world is the best of all possible worlds; the pessimist fears that the optimist may be right. I would describe myself as an AI realist. AI is shaping the world, for sure. But who will shape AI?"

Look, if we do not ethically secure the future and also of course already the present of the further development and the use of artificial intelligence, we might have an artificial general intelligence in our lifetime — which will possibly reproach us for having created it. Only humans can be moral actors, love, suffer, think, be creative, confused and dangerous, fascinating and boring. It would be wrong to fundamentally reject AI out of fear that the world could become a different, worse one, but to limit it with the will to make the world a different but better one. For companies, AI is a great opportunity to combine digitalization and sustainability to succeed with legitimate business models. This also includes taking a critical look at data security and data protection, doing more than what you absolutely have to legally, but taking social responsibility.

Venema: What is, apart from our role as individuals, the role of other stakeholders?

Heinemann: Ethics concerns everyone. On a micro level, there are the individual employees and employers we just mentioned. On a mezzo level, we have the companies. And on a macro level, sector platforms and governments. On these higher levels, it's more about ethical framework conditions. We are heading for a much more diversified and dynamic new world order, where system competition is always centrally a competition about ethical convictions, on how the societies should develop. Autocracies are ethically always more problematic than democracies. But it's more complex than you might think. A sensible environmental policy by a "wrong" regime is not in itself wrong policy; conversely, free choice does not automatically generate wise decisions or leaders: the 2016 elections in the US made that painfully clear.

Venema: Consumers seem to play a crucial role when it comes to ethical business.

Heinemann: Consumers are able to bring about significant change — for example, towards a less materialistic world. The EU with its guidelines has already accelerated this process towards more personal responsibility and dematerialization. At the same time, the democratic and digital literacy seem to be going backward, probably accelerated by the pandemic. You might have a lot of freedom in western societies, but you can't do anything with it if you're illiterate. Many people do nothing — voting for instance — with their legitimate freedoms. That's a real problem, because we obviously don't want a digitized autocracy, like in China.

Consumption has many structural similarities with democracy. You vote by buying something. Not everyone buys products that they really need, but that are presented to them as such by "smart" marketing. The electronic industry has to accept though that a world of eternal growth is a completely outdated concept. That's yesterday's business. Growth is sustainable development, growth is growth in innovation, growth in earnings, but no longer necessarily growth in revenue numbers. Therefore companies need different people, different competences, and different leadership.

It has to become clear to an electronics company that ethics is not a contribution to global philanthropy, but essential to successful and good business.

Venema: Might a Code of Ethics, or even better, a Code of Conduct, be of help for electronics-focused businesses?

Heinemann: Codes may or may not work. As within all voluntary commitments, it depends on the seriousness of the companies. And the way these codes are introduced, preferably not with a raised finger, and intelligently integrated and communicated internally and anchored in day-to-day business. In the end, it has to become clear to an electronics company that ethics is not a contribution to global philanthropy, but essential to successful and good business. As I said, it's important not only to talk, but to do. Making it applicable. We all talk a lot about a free and peaceful world, but how do we get there?

Venema: Some SDGs (especially SDG 5, 9 and 12) are primary candidates to be explicitly and expressly included in codes of ethics. This matches up with the often-repeated proposition that codes of ethics should reflect the sustainability with SDGs and be the foundation for a future world which will fairly and sustainably balance economic, environmental, and social factors in the context of a highly competitive knowledge economy. Your thoughts?

Heinemann: The SDGs are useful to take a closer look at it when we talk about ethics. To see where there are connection points for the electronic business, apart from the existing rules and regulations from the government. It remains to be seen though whether it is of any use to you as an electronics company. Arguably, these SDGs inspire governments more than they do individual businesses and their embracement and measurement at the business level faces a myriad of

About Prof. Dr. Stefan Heinemann

Prof. Dr. Stefan Heinemann is Professor of Business Ethics at the FOM University of Applied Sciences and spokesperson of the Ethics Ellipse Smart Hospital at the Universitymedicine Essen. He focuses on the economic and ethical perspective on digital medicine and the healthcare industry. For the second consecutive time he will contribute to the WEEF Panel at electronica Messe München. Heinemann is the Scientific Director of the HAUPTSTADTKONGRESS Lab (Springer Medicine, Wiso). He is head of the research group "Ethics of the Digital Health Economy & Medicine" at the ifgs Institute for Health & Social Affairs of the FOM University of Applied Sciences, member of the "Working Group AI in Internal Medicine" within the commission "Digital transformation of internal medicine," as well as an expert advisor in various research and educational institutions. In addition, the philosopher and theologian is a member of the scientific advisory board "Digital Transformation" of the AOK Nordost, a member of the advisory board of the Institute for Patient Experience of the Universitymedicine Essen and a member of the social and health policy advisory board of the BARMER regional representation North Rhine-Westphalia. He is also on the board of the Cologne Science Round, chairman of the board of "Science City Essen," and member of the board of trustees of sneep e. V., a student network for business and corporate ethics. Heinemann is co-initiator of www.dataprotection-landscape.com as a platform for the multidimensionality of data protection.

November 15, 2022
worldethicalelectronicsforum.com

shortcomings. The projection of SDGs in codes of ethics, and ultimately in the strategy and daily operations of involved businesses, seems challenging to me, but not undoable. WEEF could start by looking at existing frameworks like the SGDs, but also at other millennium goals from EU sustainability groups for instance. And read them, as nobody seems to read those things ... to translate them into practical steps for implementation. It can make the industry more visible on ethics as a connecting theme, while most think that electronics is too fragmented to actually do anything.

Venema: And in what way could WEEF be helpful?

Heinemann: We obviously won't succeed with just a code or manifesto. It is much better to start with a kind of manual or handout for companies that tell you what you can do in terms of sales, earnings, customers, and products. Using practical examples. And so to help managing ethics to become a sustainable effect on your business and society. And being part of that society as a business.

Given the enormous diversity in the industry, it is advisable not to follow a "one size fits all" philosophy. It is better to assume a kind of green-orange-red traffic light system: what are you already doing? Where are you now as a company? Here WEEF could be helpful with neutrally formulated guidelines and advice covering the vast majority of businesses in the electronics industry.

It is also important to pick the low-hanging fruit first. Smaller companies cannot afford large investments. If such an ethical operation costs a FTE or fifty grant, it is "game over." The large companies often have those resources and so the financial pressure is placed on the small ones. And you lose the competition, especially if government regulations are also laid down. So you have to be smart. Use that intern in your company, who is intelligent enough to understand the concept, to get started with such a manual or guidelines. That is already a first step.

WEEF could help with materials to facilitate those first steps. As a result, you also have a greater chance of a level playing field in the field of ethics. Handouts or checklists cannot of course replace lawyers and compliance or CSR officers, but they can ensure that small companies also come on board.

Venema: What are success factors for an initiative like WEEF?

Heinemann: In short, I would focus on three basic conditions:

1. Transparency and clarity of the whole process: Who are the initiators and what are their basic intentions? Sometimes these initiatives smell like "green washing" or a marketing campaign in disguise. Think "movement" more than "organization." Be humble and ready to end the project when the industry or other platforms are ready to act on their own behalf.

2. Involvement in all sizes of companies: bring in their people, CSR manager/founder; bring them around a table and give them a voice. Think grassroots. Think co-creation and develop ideas together. Don't forget: 80% of the industry consists of smaller companies that are often the suppliers of the big ones, so mind the ratio between the sizes of the companies. Every soul is important. You could even cluster these small companies accordingly. In the end, sustainable end products will have to have a sustainable chain of suppliers/building parts. There is a common interest.

3. Utility and applicability: not just a document, pledge, or code, but a practical toolkit and maybe some templates to give the process a good start. Don't reinvent the wheel: sometimes the chambers of commerce have those tools, but not specifically targeted at the electronics industry. So, tweak them to make them applicable.

Venema: Finally, what attention should be given in the education and training of electronic engineers when it comes to "ethics"?

Heinemann: Ethics should be an integrated part of economics. You can't just fly in a professor of ethics into an economics curriculum and tick a box. It must be linked to all disciplines and therefore also be discussed everywhere as a completely organic part of education. I have worked intensively with colleagues to make "ethics" in the broadest sense a fixed component of management education in higher education. This includes initiatives in teaching, research, practice transfer for companies and the management of the university itself. Overall, I think that we are seeing progress today, but still not in the broad sense. There is obviously room for further progress.

220433-01

About the Author

Edwin Venema has more than 30 years of experience in both journalism and content marketing. He has worked with Lenthe since 2003. As a copywriter (www.dekopijmeester.nl), Venema helps people and organizations with editorial communication and creative content that convinces.

Prof. Heinemann's 2021 Keynote

Watch Prof. Dr. Stefan Heinemann's keynote speech from WEEF 2021, where he covered a range of topics including sustainability and corporate ethics.
youtu.be/ELpxR6SuLb8&t=1621s

The 2023 WEEF Index

By Edwin Venema (Lenthe Foundation)

In the coming months, we will publish The 2023 WEEF Index, which will distributed to hundreds of thousands engineers and executives. The index will feature profiles of ethical innovators who are inspiring others to consider the importance of ethical electronics.

Apples and pears. Randomly. Surprising. Questionable. Inspiring. Favoritism. Offhand. Scandalous. Crooked. Daring. Unbalanced. Stimulating. Unreasonable. Arbitrary. Impossible. Mind boggling. Laughable. Stupid. Encouraging. Attention seeking. Nepotism. Admirable. Populism. Haphazardly. Ticking the right boxes. Provoking. A trick. Vanity. Wrong signal. Right signal. Triggering. Narrow minded. Groundbreaking. Unjust. Eye opener. Power politics. Finally!

These are all qualifications that pass when organizations or publishers introduce ranking lists, especially when it is about individuals in their industry. We have no doubts that the new *2023 WEEF Ethics Index* will raise some eyebrows and provoke reactions of all sorts. And that is exactly why we're introducing our pioneer index.

No Pressure, No Diamonds

The devil's advocate has many questions: How on earth do you determine an individual's influence when it comes to ethics in the electronics industry? And if you rather miraculously would succeed in establishing such a list of persons, what then is the overall objective? The answer to the last question is clear: mapping who exercises the most influence in the electronics ethics-wise is, in itself, a statement and as far as we are concerned definitely more than a publicity stunt. (That wouldn't be very ethical, right?) Besides pleasing the vanity of the elected and annoying the undoubtedly severely bruised egos of the unelected, indexes also express a general sense of appreciation and recognition. Always in the knowledge that the votes often represent the best that an industry or profession has to offer, they then act as role models — or as a crowbar to open the boundary doors of a sector. What? How are they, of all people, part of this index? Oh, well, they've gone mad at WEEF!

You see, there are no diamonds when there's no pressure. Look at the Oscars or Emmys every year.

The Fruit Approach

The "apples and pears" argument is a classic. Different people, different companies, different responsibilities. Sure, but apples and pears are still fruit, right? It's of course about the common denominator. The index is not rocket science; it's predominantly common sense. Individuals undersign a pledge and represent a vision, or a groundbreaking method or sheer courage to move in opposite directions or outside the box. They stimulate our thinking and our discussions about ethics — a topic that still must cover some considerable ground in the electronics industry. There are some legitimate questions to be answered, such as:

- Do electronics engineers, on a personal level, have an ethical responsibility to use their skills for more than making a profit?
- Should ethics play a role in how the leaders of electronics-focused companies conduct business?
- To what extent should they concern themselves with topics like sustainable development, green manufacturing, and social responsibility?
- How do their decisions affect local communities and the environment?
- Should their associations offer help in geopolitical disputes?

It's Not a Ranking ... Yet

An index is one thing; a ranking is another. If you really aim for heated discussions or controversy, go straight to such an index and soon that brownish stinky stuff will hit the fan. We have gone for a compromise in our pioneering edition, gathering a list of influential people that reflect the ideas behind WEEF. This can be seen as a build for future editions that may well offer a ranking. But, for now, we follow the route of progressive insight.

The 2023 WEEF Index will therefore contain an alphabetical list of one hundred influentials, plus a "number one." Rather than being a "winner," the latter will be more of a flag bearer, someone inspirational - the first among equals, so to say. A wise and just jury will make a selection from nominations submitted by the public to determine the list of the remaining 99 individuals in the index.

The Jury Is Out

The jury will judge the online nominations, nominate candidates themselves and coordinate all communications.

- Don Akkermans (managing director, Lenthe Foundation; chair, WEEF)
- Johann Wiesbock (editor in chief, Elektronik Praxis)
- Tessel Renzenbrink (independent journalist, specialized in ethics)
- Priscilla Haring-Kuipers (journalist, Elektor)
- Shenja Panik (project manager, Elektor/WEEF)

The Jury's Criteria

The jury will consider the following criteria:

- Level of influence (in media, forums, socials and with peers)
- Level of innovation (including, for example, integration of SDGs)
- Willingness to share ideas/concepts with peers

The candidates on the index will have a few things in common: they dare to go off the beaten track and are effective and visible in what they do.

The Rules

- The online polls will be announced and opened (TBD).
- Online voting rules: provide a (brief) motivation statement when nominating your favorite candidates. Nominations will not be accepted without a motivation statement; you may nominate an unlimited number of candidates, but you cannot nominate a candidate more than once: duplicate or automated nominations will be detected and invalidated, and you're allowed to nominate yourself once.
- Ineligible to participate in the WEEF100 are: members of the jury and employees of Lenthe Foundation, the publisher of the index.
- The argument for those nominated will be recorded in a jury report. He or she will receive a tangible and especially ecofriendly designed WEEF AWARD.
- The complete WEEF100 will be published on the website of WEEF and on the websites of Lenthe Foundation and and its media partners Elektronik Praxis, electronica Munich, and Elektor.

Visit worldethicalelectronicsforum.com for udates and additional details.

220434-01

About the Author

Edwin Venema has more than 30 years of experience in both journalism and content marketing. He has worked with Lenthe since 2003. As a copywriter (www.dekopijmeester.nl), Venema helps people and organizations with editorial communication and creative content that convinces.

Contribute to the WEEF Compendium

Would you like to contribute to the 2023 WEEF Compendium? Contact WEEF project panager Shenja Panik at shenja.panik@elektor.com. For more information, visit WorldEthicalElectronicsForum.com.

WORLD ETHICAL ELECTRONICS FORUM

LENTHE Immer bloeyende

Filter Software

Design Tools for Analog Filters

By **Alfred Rosenkränzer** (Germany)

Anyone who knows (or at least knows where to find) the formulae for designing analog filters will always be able to do the necessary calculations by hand. These days, however, such an approach seems somewhat quaint if we want to look beyond the simplest types of RC-network filters. Now there exists software to do the job, and fortunately IC manufacturers even make suitable tools available for free. In this article we will mainly look at some software produced by Texas Instruments.

In the article "Analogue Filter Design (Part 2)" that appeared in the November/December 2020 edition of Elektor [1], we looked at active filter structures. We talked in that article about the existence of specialized software that significantly reduces the effort involved in designing such configurations. It is no longer so necessary to have a detailed understanding of the mathematical background to arrive at one's goal, but readers nevertheless interested in the formulae can readily find them in the literature, such as in "Tietze/Schenk" [2].

As a typical example of the filter design software that is available, we have selected the desktop program *FilterPro* and its online successor, *Filter Design Tool*.

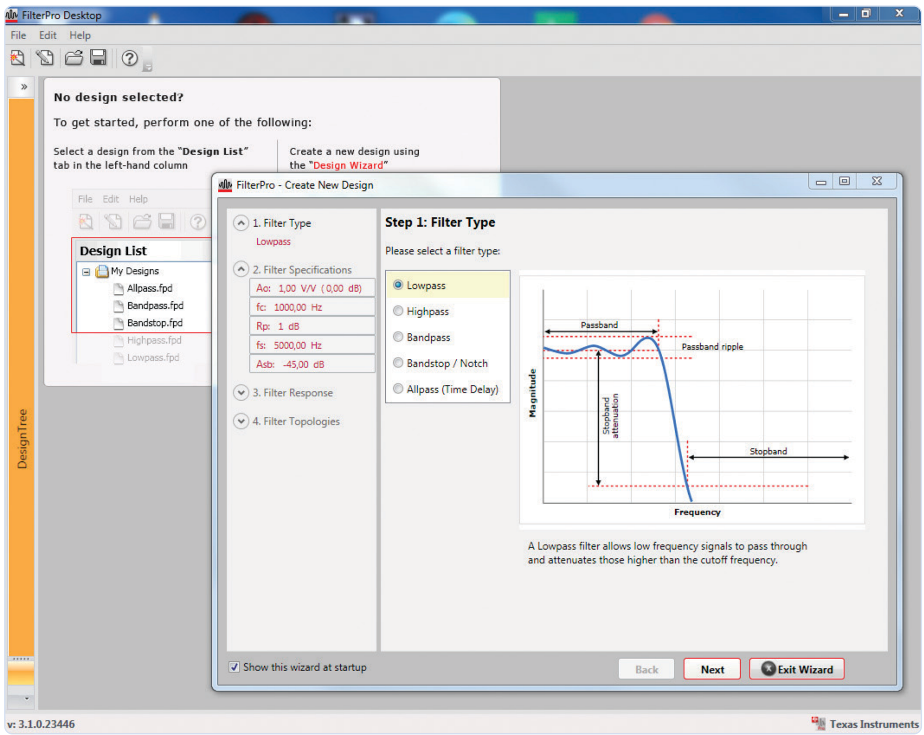


*Figure 1: The **FilterPro Desktop** start menu with the filter wizard.*

FilterPro

The desktop program *FilterPro* has not been under active development by Texas Instruments for quite a while, but it nevertheless remains a very useful tool. The most recent version, which runs under Windows, can be downloaded for free at [3]. After installing and running the program, the user is presented with the screen shown in **Figure 1**. In the window we can see the *Filter Wizard*.

If the wizard does not appear automatically, it can be launched using the *magic wand* button at the top left. The wizard will guide you through the design process step by step. In the first step you choose the filter type (low-pass, high-pass and so on). The right-hand part of the image shows the parameters that must be entered in the next step: passband, passband ripple, stop band and so on.

In the second step you enter the specification of the filter: see **Figure 2**. The first parameter is the gain of the filter. Although in many applications a gain of greater than one is desirable, it is recommended to start with a gain of exactly one ("unity gain").

When specifying the cutoff frequency of the filter, it is worth bearing in mind that approximating structures such as Bessel and Butterworth filters treat this as the frequency at which the amplitude of the response falls by 3 dB. For Chebyshev filters, on the other hand, it specifies the frequency at which the amplitude falls below the permitted ripple.

Next we enter the permitted passband ripple. For filters that do not exhibit ripple, such as the Bessel and Butterworth designs, this value can be left at its default.

There are two ways to specify the order of the filter. You can either check the *Set Fixed* box and then enter the desired order in the box immediately to its right (as shown in Figure 2) or, with the box unchecked, you can specify the attenuation required by the application at a particular frequency. The program will then choose a suitable order automatically. This is a good way to compare the complexity of solutions offering different types of approximation.

In the third step, you choose the *Response Type*, that is, the type of filter approximation (see **Figure 3**). The graph shows the behavior of amplitude, phase and group delay as a function of frequency. You can use the scroll wheel to zoom in on an area, and you can also click and drag to scroll the plot. A right click returns to the original full view. Note that the frequency axis is logarithmic.

In the fourth and last step you choose the topology (**Figure 4**). Here there is a choice between *Multiple Feedback* for single-ended amplifiers, *Sallen-Key* (also single-ended) and *Multiple Feedback (Fully differential)*. These terms are explained in detail in [1].

When you finally click on *Finish* the circuit will be displayed with all component values, a table showing the filter specification, and two plots showing the amplitude, phase and group delay behaviour of the design (**Figure 5**). These plots also allow zooming and scrolling.

An important result shown in the middle of the table is *Min GBW reqd*. This is the minimum gain-bandwidth product that the opamp must have if the filter circuit is to exhibit the desired behaviour; the lower the gain-bandwidth product of the device used, the less well the circuit will perform.

The parameter *QualityFactor (Q)* is also explained in [1].

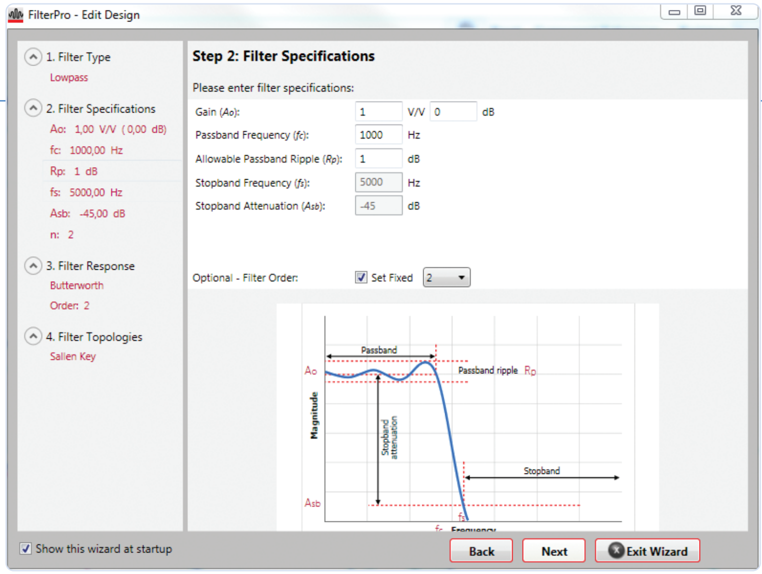


Figure 2: Entering the filter specifications.

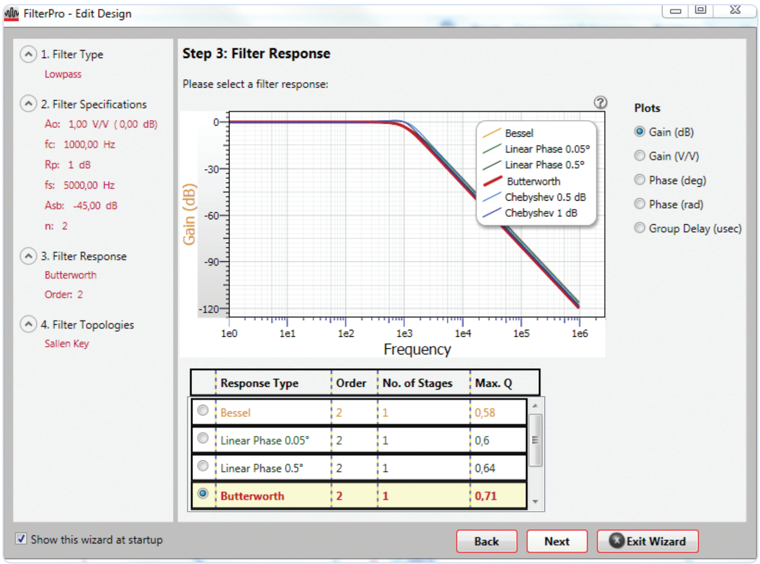


Figure 3: Filter response and approximations thereto.

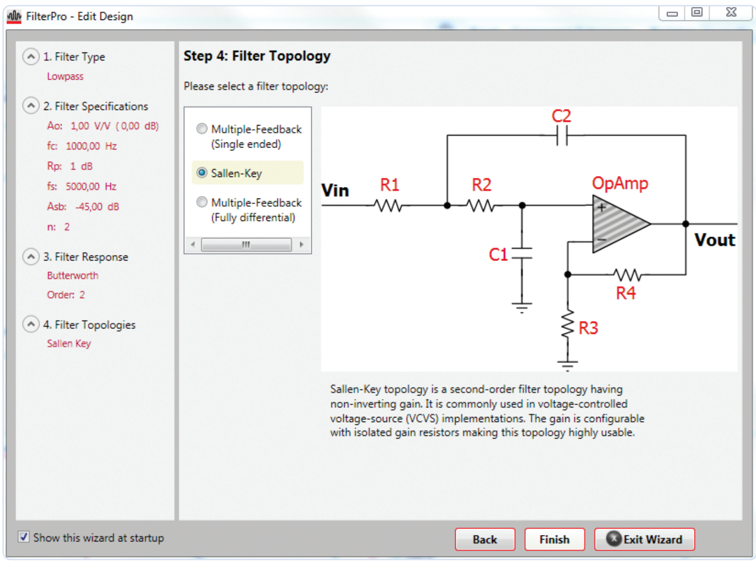


Figure 4: Choosing a filter topology.

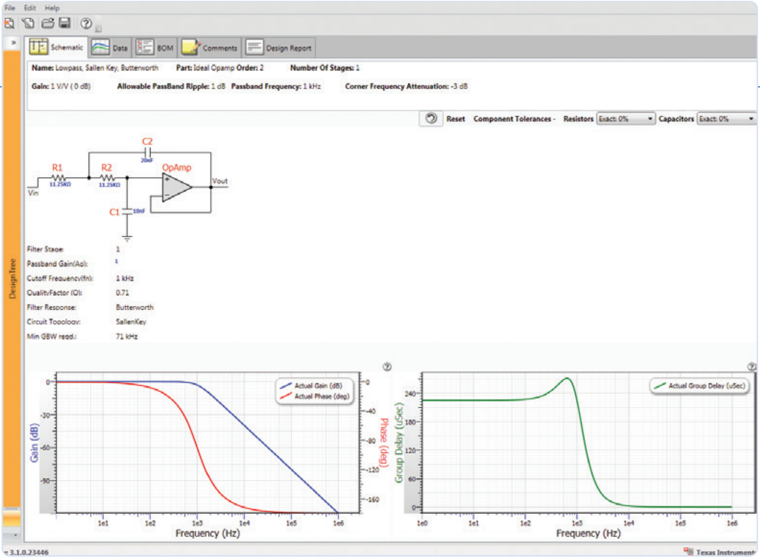


Figure 5: The result: a finished circuit and plots of the filter's behaviour.

RELATED PRODUCTS

- **OWON SDS1104 Four-Channel Oscilloscope (100 MHz) (SKU 19514)**
  www.elektor.com/19514
- **OWON XDM1041 Digital Multimeter (55000 count) (SKU 19715)**
  www.elektor.com/19715
- **OWON AG051 Arbitrary Waveform Generator (5 MHz) (SKU 18874)**
  www.elektor.com/18874

A Practical Application

In contrast to their passive brethren, active filters have two degrees of freedom in choosing their component values. Click, for example, on the value of C1 and change it from 10 nF to 1 nF (a reduction by a factor of ten), and C2 will change in proportion. The two resistor values also increase by a factor of 10. Both sets of component values give the same filter response, although other properties such as noise and distortion figures can be different.

In audio applications it is typical to choose resistor values in the 1 kΩ to 10 kΩ range: this gives a good compromise between noise (which reduces with smaller resistor values) and distortion (which increases with smaller resistor values because of the larger currents involved). In order to come up with practical component values, it is a good idea to experiment first with the capacitors: typically, these are only available in a relatively limited range of values (E3 to E12 series) compared to resistors (E12 to E96 series).

If we wish to understand the second degree of freedom then, like it or not, we are going to have to get our hands dirty with some formulae. The value of C1 can be chosen freely, but there is a minimum ratio between C2 and C1, which depends on the selected approximation type, order and gain. At this minimum value, and at unity gain, the two resistors will be equal. The *FilterPro Desktop* program displays this minimum ratio, assuming exact capacitor values.

If the capacitors must be chosen from a particular E series, then the program will choose the values nearest to optimal, and the ratio between C2 and C1 will increase. That in turn leads to a change in the resistor values: they will no longer be equal.

In the example above, the values selected for C1 and C2 are exactly 10 nF and 20 nF, respectively: a ratio of 1:2. The two resistors have the same value, namely 11.25 kΩ. If we need to use capacitors from the E12 series then we can leave C1 at 10 nF but C2 must be increased to 22 nF; in consequence, R1 now has a value of 7.68 kΩ and R2 a value of 14.65 kΩ.

The currently available online tool (on which more below) behaves in the same way. Unfortunately, it is not possible to specify the ratio directly; but instead, in the upper right of the window shown in Figure 5, you can specify separately for the resistors and capacitors whether you prefer exact values or whether values from a particular E series should be used. When the choice is restricted to an E-series value, the plots will show the response curves both for the specified E-series values and for the ideal values. This allows you to make an informed decision about what deviation from ideal performance is acceptable.

In the example above there is, however, a trick to simplify things. If the two resistors have equal value, then C2 must be exactly twice the value of C1: incidentally, this specific variant is described in Tietze/Schenk. To obtain good accuracy, choose a readily available part with a suitable package and tolerance specification for C1, and for C2, use two copies of the identical device wired in parallel. If the three capacitors come from the same batch, their values should be in good agreement. Any deviation from the nominal values can be corrected for by adjusting the resistor values: enter the measured capacitance of C1 in the window shown in Figure 5 and you will see the adjusted resistor values (or the nearest available values in the specified E-series).

When building a precise crossover circuit, it is also a good idea to use the same capacitors in the high-pass network as in the low-pass network. This will help ensure an optimal transition between the low-pass and high-pass characteristics. Again, of course, it is possible to synthesize more tightly specified capacitance and resistance values by combining two or more individual components.

Special Features

You can save the results of your optimization experiments before trying out a different filter configuration. If you click on the *Data* tab in the row at the top of the window, you will see the frequency response presented as a table; you can then use *Export to Excel* to process the data further — for example, to compare the results against a prototype or for documentation purposes. The *BOM* tab produces a bill of materials. *Comments* allows you to add your notes to the design and *Design Report* automatically creates documentation (but not including the frequency response table).

It is worth simulating the circuit you have designed before actually building it. A particularly useful technique for analyzing the effects of component tolerances is Monte Carlo simulation. You can simulate many variations on a particular filter and directly compare their performance against one another.

Multi-stage filters are built from individual first- and second-order stages. Note that cascading two identical second-order Butterworth filters does not produce a fourth-order Butterworth filter, but rather what is called a Linkwitz-Riley (or "Butterworth squared") fourth-order filter.

It is possible to experiment to determine what *Quality Factor* (*Q*) can be expected from the design, and the required gain-bandwidth product of the op-amp.

If the filter is to have greater than unity gain, that can be included in the specifications. In the case of a multi-stage filter the gain is distributed equally over the stages. It is possible to watch how the component values change as the desired gain is increased, and to avoid too great a divergence of component values. If it proves necessary, it is always possible to implement extra gain in a separate stage; this has the advantage that other component values will remain the same if the gain later needs to be changed.

One further note: Texas Instruments is no longer maintaining the desktop version of the software, and indeed it is no longer available on the company's servers. However, a quick Internet search for "FilterPro desktop" quickly leads us to working downloads such as at [3]. The program works equally well under Windows 7 and Windows 10, and, astonishingly enough, it is even stable under Windows 11. At start-up the program occasionally appears to pause for a minute or so; but after that everything works without problems. The complete manual can be found at [4].

Online Tools

The more recent version of Texas Instruments's filter software is called *Filter Design Tool* and is available at [5]. After registering, you can begin to design a filter. There is no "Pro" version and therefore also no artificial restrictions on use. The user interface has a rather more modern feel than the desktop program, but the underlying functionality is broadly the same.

Changes compared to its predecessor include the ability to display the step response of the filter. And if instead of ideal values you select E-series values, then you also have the option to specify component tolerances, separately for resistors and capacitors.

Then, in the displays of frequency response in terms of amplitude, phase, and group delay, as well as in the step response plot, you will see a tolerance band around the ideal curve. This feature saves subsequent Monte Carlo simulation of the design (though I would recommend doing this anyway to be on the safe side).

The desktop version can calculate band-reject filters based on the Sallen-Key topology (not ideal: see the article at [1]) and multiple feedback topologies, whereas the online version only offers the Bainter topology [6]. More specialist design software can be found on the Internet to support the design of Fliege-topology filters [7] and state-variable band-reject filters.

The biggest disadvantage of the online tool is that it is more difficult to manipulate the component values than in the desktop version, and that is the reason I prefer the latter tool. *Filter Design Tool* does at least appear to support calculating the minimum feasible capacitor ratio.

Finally, a remark on Analog Devices's filter tool [8]: this online tool appears to insist on a fixed capacitor ratio of 1:1 or of 1:10. The larger of these ratios tends to lead to a wide spread in component values, which is not ideal in my opinion.

210041-01

Questions or Comments?

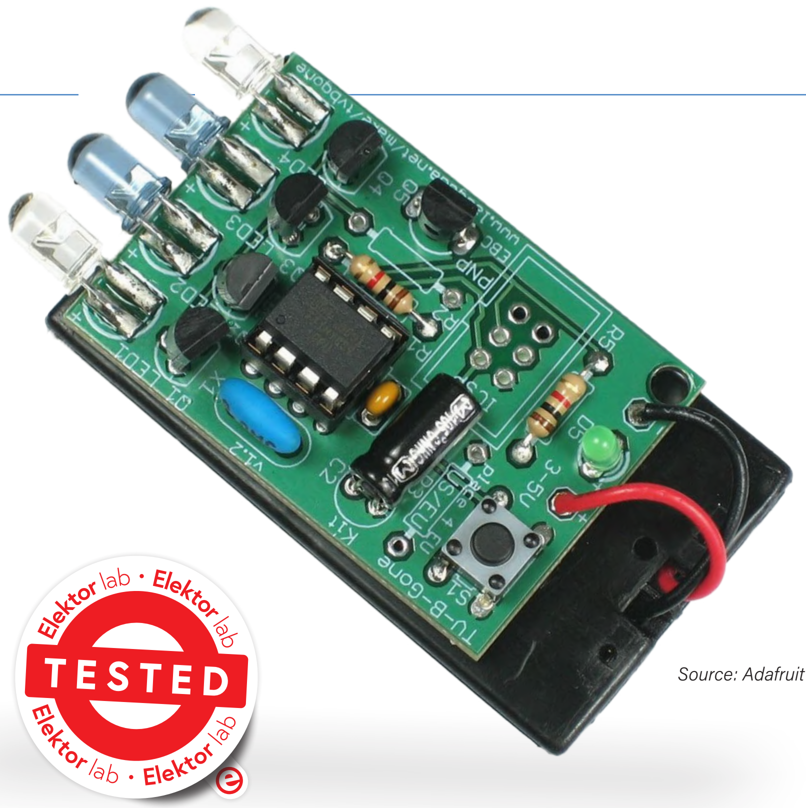
If you have technical questions or comments on this article, feel free to e-mail the author at alfred_rosenkraenzer@gmx.de or the Elektor editorial team at editor@elektor.com.

WEB LINKS

[1] A. Rosenkränzer, "Analogue Filter Design (Part 2)," Elektor November/December 2020: www.elektormagazine.com/magazine/elektor-159/59111
[2] U. Tietze, C. Schenk and E. Gamm, "Electronic Circuits: Handbook for Design and Application," Springer: http://tietze-schenk.com/tsbook.htm
[3] Download FilterPro Desktop V. 3.1.0.23446: www.softpedia.com/get/Science-CAD/FilterPro-Desktop.shtml
[4] FilterPro User's Guide: www.ti.com/lit/an/sbfa001c/sbfa001c.pdf
[5] Online filter design tool: webench.ti.com/filter-design-tool/topology
[6] B. C. Baker, "Bandstop Filters and the Bainter Topology," Analog Applications Journal: www.ti.com/lit/an/slyt613/slyt613.pdf
[7] Fliege-topology filter: http://earmark.net/gesr/opamp/notch.htm
[8] Analog Filter Wizard (online): https://tools.analog.com/en/filterwizard/

TV-B-Gone!

... Or At Least B-OFF



Source: Adafruit

By Luc Lemmens (Elektor)

Having dinner with friends in a restaurant with loud TVs? Do you want to fool unsuspecting TV viewers? Just point and click!

Long, long ago, wireless remote controls for some expensive television sets worked with ultrasound. The story goes that an owner of such a luxurious device returned it to the supplier for repairs repeatedly because either the TV or the remote control seemed to lead a life of its own: randomly changing channels, changing volume or spontaneously switching off... To the despair of the owner and repair technician, the cause of the malfunction could not be found; in the repair shop, it worked without problems. When the TV was installed in the owner's living room by the technician for the umpteenth time, the owner happened to notice that the beloved pet of the house — a parrot — opened its beak and the TV immediately switched off. Apparently, the animal imitated the sound (inaudible to human ears) of the remote control!

Whether the story is true or not we will leave to one side, but it is certainly amusing. Later, in the age of remote controls with infrared light, the stories of children (no: adults do not do this) controlling the neighbour's TV by secretly standing outside the living room window with a remote control came to light. The condition is, of course, that the device works with the same IR protocol as the TV in question. The kit we will be discussing here takes no risk: it transmits more than 230 different IR codes for switching off for more than 230 different types of TV sets and claims to be effective over a distance of 45 m! Most TVs use the same code for switching on and off, so in this case this remote can also switch a TV on (again).

The TV-B-Gone Kit

Adafruit produced a kit containing a PCB and all components needed to build this project, which was designed by Mitch Altman, and now it is also available in the Elektor Store [1]. As with many products nowadays, it comes with a web link printed on the package, there is no documentation on paper supplied with the kit. To make up for this, there is really a lot of very clear online information supplied on the website of Adafruit [2], GitHub [3], and the designer's website [4].

The first contains all the documentation you need on (building) and using the kit. The instructions are easy to follow and very clearly illustrated, so even for people who have never built a circuit before, it should be possible to complete this project successfully - if you can solder, or are being guided to learn how to solder. It is good practice material, even though the layout of the board is somewhat compact, tidy and accurate work is required. Don't forget to read the *Design Notes* section, which contains useful background information on the hardware and remote control codes.

If you want to change the hardware (the PCB) or firmware (for example, if you want to add IR codes for devices that are not supported), GitHub is the place to be. The source code and the Eagle schematic and PCB design files can be found there. Of course, this is stuff for the more advanced tinkerer.

On the Mitch Altman's website, you'll find more, similar projects for monitoring and influencing TV viewing behaviour. You may find more useful products there, or maybe they inspire you to develop your own applications in this field.

The Hardware

The schematic diagram of the TV-B-Gone is shown in **Figure 1**, nothing too complicated and most of the hard work is done in software.

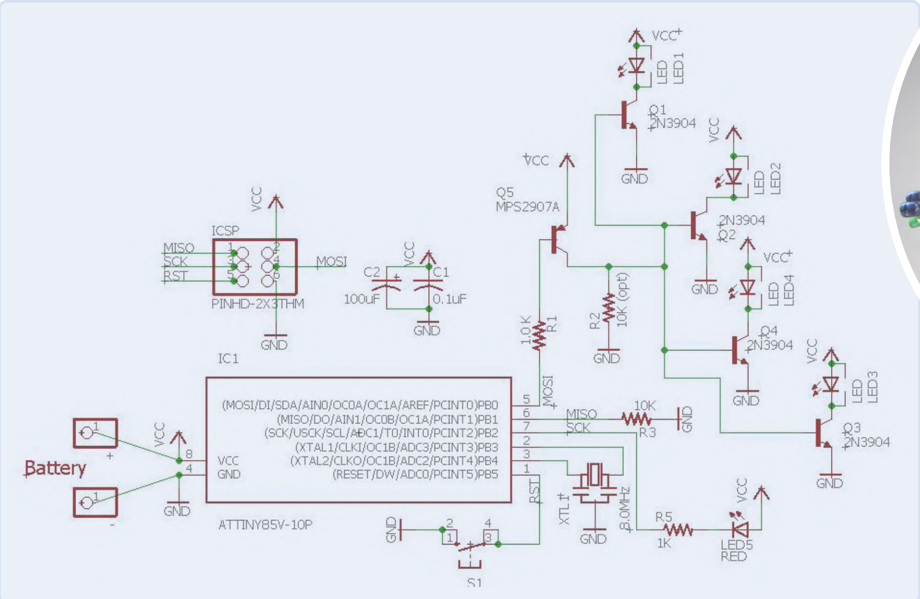


Figure 1: The schematic diagram.

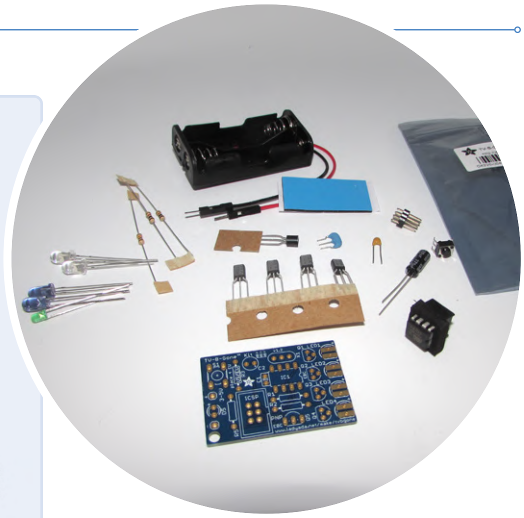


Figure 2: Contents of the kit.

Pressing and releasing push button S1 will start sequential transmission of all 'known' *Off*-codes via transistors Q1 to Q5 and IR LEDs LED1 to LED4. LED5 is used as an optical indication when the TV-B-Gone is active. The kit is shipped with a pre-programmed ATtiny85 microcontroller; the six-way header to connect an AVR-ISP programming adapter (and for that matter: the adapter itself) are not needed, unless you want to experiment with the firmware.

Building TV-B-Gone

Figure 2 shows the contents of the kit, always check if all components are in the bag, using the list on Adafruit's website. Note that there are different versions of the Bill of Materials, we tested version V1.2; the version number is printed on both sides of the PCB.

Following the instructions and photos in the *Solder It!* section on Adafruit's website, it will be easy to assemble the kit. Seasoned makers will probably skip these instructions and just start soldering. It's really not difficult to build. But for the less experienced builders among us: just follow the guide.

Using This Remote Control

There's really not much to it: just press and release the push button and the IR LEDs will start emitting *On/Off* codes. The green LED will blink to indicate that the circuit is active, it takes quite some time before all the different codes are transmitted, and it may take some time (up to more than a minute!) before the code that matches your TV set is sent.

I was impressed by the range specs of this remote. It is claimed that it still is effective at a distance of more than 40 m (150 feet). My living room is only a bit small to check the full range, but it was amazing to see that a TV set can be controlled from the next room and around the corner, with walls as reflectors for the IR beam. Not bad at all!

An extra remote control that is operated secretly can certainly provide comical effects for an unsuspecting TV viewer. The TV-B-Gone adds a boosted IR output for a much larger range than a standard remote control, and, of course, 230+ different codes to switch off (almost?) every TV with IR remote control you can buy. But before you start playing around with this, TV-B-Gone gadget: first, be sure that your victim(s) can appreciate this kind of humour. Some people can get very angry and even aggressive when you interrupt their favourite show, or when their favourite sports team is about to score in the last minute of the game and the TV suddenly switches off. Small chance they will find out it was you with this small remote control, but still... B-ware!

220236-01

Questions or Comments?

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

WEB LINKS

[1] Buying the kit: https://elektor.com/20140
[2] Building instructions: https://learn.adafruit.com/tv-b-gone-kit
[3] Software and design files: https://github.com/adafruit/TV-B-Gone-kit
[4] The designer's website: www.tvbgone.com/

RP2040-Based Air Quality Measurement

By Dr. Claus Kühnel (Germany)

At the beginning of 2021, the Raspberry Foundation announced the Raspberry Pi Pico. As the readers of Elektor magazine know, this is not just another model of the Raspberry Pi family but an independent microcontroller board with the RP2040 microcontroller. You can use the RP2040 to measure air quality. It acquires data from a CO_2 sensor and then transmits it via an ESP8266 to the popular ThingSpeak cloud platform.

Even after the announcement of the Raspberry Pi Pico, there were a lot of controversial discussions on the Internet. While one party euphorically welcomed the new controller, the other party immediately drew attention to the lack of functionality from their point of view. Elektor tried to give a more neutral overview in [1]. But at this time, the evaluation was often highly polarized, and there was hardly any space for differentiated opinions.

In the meantime, Arduino came to the market with the Arduino Nano RP2040 Connect. The RP2040 microcontroller enhanced by a ublox NINA-W102 radio module builds a complete IoT device with Wi-Fi and BLE connectivity. If you use the Arduino Nano RP2040 Connect in a project, you will probably also use the Arduino or the PlatformIO IDE. Both do not support some specialties of the RP2040 like dual-core and PIO support.

On the other side, if you use the Raspberry Pi Pico alone, you can choose between the Raspberry Pi Pico C/C++ SDK and the Raspberry Pi Pico Python SDK, both of which support all the features of this microcontroller. However, you will then miss the support of any wireless communication. But there are enough communication modules available today to add this functionality.

Due to the support of different microcontrollers and the many libraries available, I often use the Arduino IDE for my projects. The new major release of the Arduino IDE is faster and even more powerful. The Arduino IDE 2.0 is now moving to stable status with a series of Release Candidate (RC) builds. In April 2022, Arduino IDE 2.0 RC 2.0.0-rc6 was available, and you can download it at [2]. In addition to a more modern editor and a more responsive interface, it features autocompletion, code navigation, and even a live debugger.

Raspberry Pi Pico

The Raspberry Pi Pico microcontroller will be discussed only briefly since it has already been the subject of many reviews, and most readers will be familiar with it. I want to go into details from my point of view.

The Raspberry Pi Pico provides a minimal infrastructure to operate the RP2040 microcontroller (**Figure 1**). The board's castellated pins are recognizable, which enables the easy assembly (board-to-board soldering) of the Raspberry Pi Pico on a carrier board. Castellated pins have been used for a long time on various PCB modules (for example, Bluetooth or Wi-Fi modules) to mount them directly on another board.

The RP2040 microcontroller is a cost-effective and powerful microcontroller with flexible digital interfaces. A dual-core Cortex-M0+ processor clocked with up to 133 MHz provides enough performance for most IoT applications.

Table 1: Main Pins & Functions

Pin	I/O Direction	Function
GPIO29	in	ADC3 captures VSYS / 3
GPIO25	out	User LED
GPIO24	in	Detection VBUS – high if VBUS is present, otherwise low
GPIO23	out	Controls the onboard SMPS

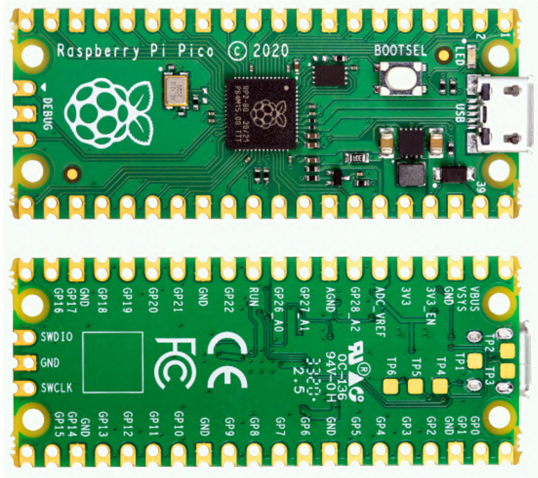


Figure 1: A top and bottom view of the Raspberry Pi Pico (Image: Raspberry Pi Pico data sheet).

Figure 2 shows the multiple assignments of the GPIOs of the Raspberry Pi Pico, which results in a high degree of flexibility in hardware design. You can see that the two UARTs, the two I²C buses, and the two SPI buses are available several times. Only the internal ADC connections are assigned to fixed pins. Some GPIOs serve internal functions. **Table 1** shows the relevant GPIOs and their functionality. In addition to these GPIOs, seven further connections are available to the outside. **Table 2** shows the designation of the connections and their function.

The switchable 3V3 (OUT) can disconnect sensors or actors from the supply voltage to save power. For battery-powered IoT applications, this can be very advantageous. If the accuracy of the ADC needs not to be high, the internally generated reference voltage is sufficient. You can improve the accuracy with an external reference voltage. That can be generated with an LM4040, for example, and applied to the ADC_VREF connection (**Figure 3**). Please note that the ADC of the current RP2040 still has some linearity problems. This affects all boards based on the RP2040.

Maker Pi Pico

Raspberry Pi Pico is not the only board based on the RP2040. Adafruit, Sparkfun, Pimoroni, and other well-known manufacturers are on the

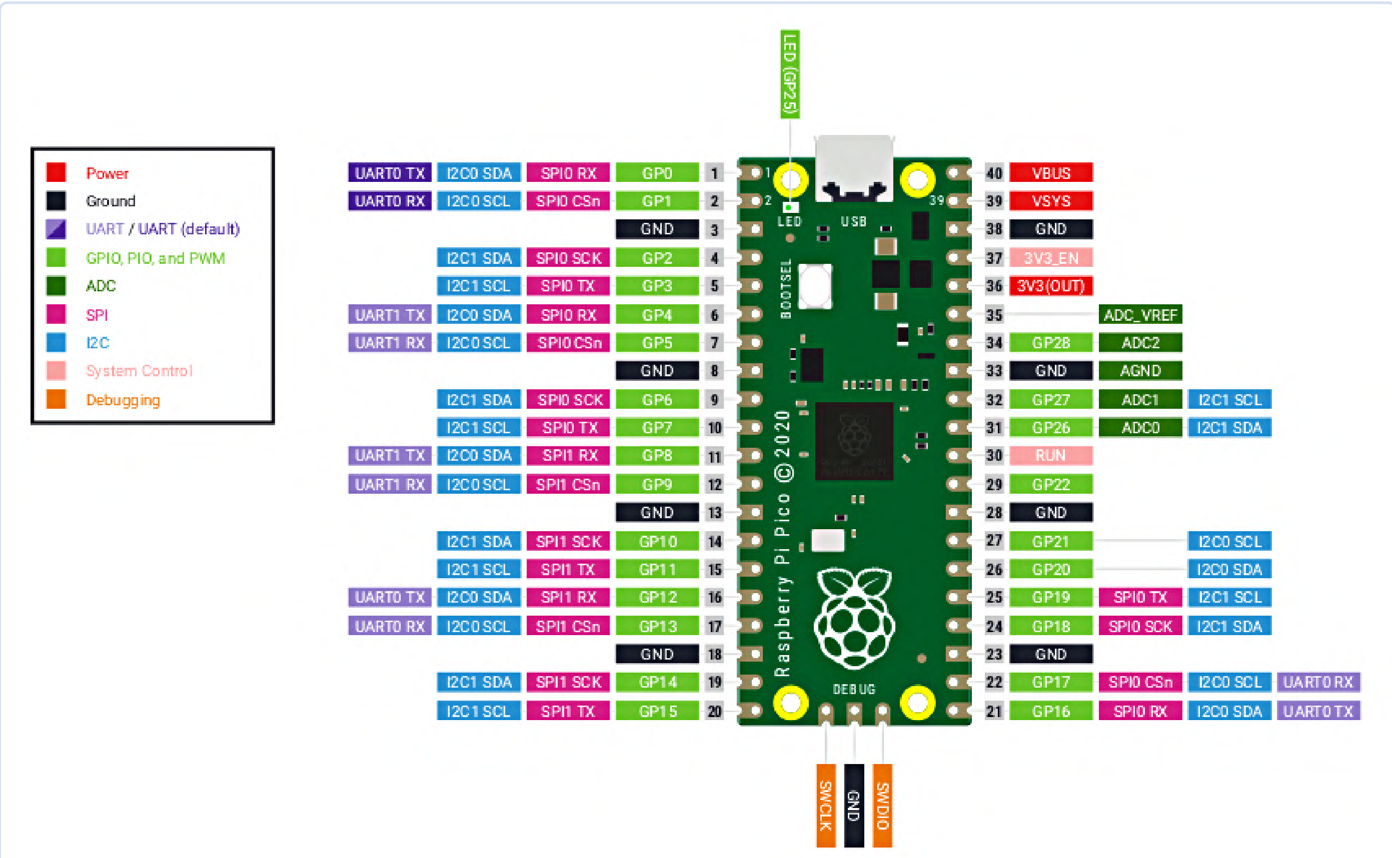


Figure 2: Raspberry Pi Pico pinout (Image: [9]).

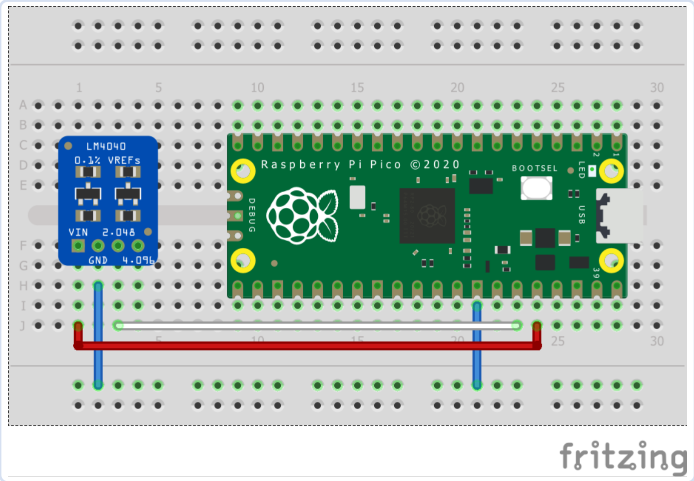


Figure 3: External ADC_VREF with LM4040.

Table 2: More Pins & Functions

Pin	Name	Function
40	VBUS	USB voltage (5 V). An external power supply via USB can be detected via GPIO24 (high: voltage available; low: no voltage available).
39	VSYS	System input voltage; range 1.8...5.5 VDC. The onboard SMPS generates the 3.3 V to power the RP2040 and its GPIOs.
37	3V3_EN	Set high via pull-up resistor. When connected to GND, the 3.3 V is switched off.
36	3V3 (OUT)	3V3 power supply for external components. Load should be ≤ 300 mA.
35	ADC_ VREF	Supply voltage and reference for the ADC. The use of an external voltage reference for better accuracy is possible.
33	AGND	Analog GND for GPIO26...29. If the ADC is not in use or ADC accuracy is not critical, this pin can be connected to digital ground (GND).
30	RUN	Set high via a pull-up resistor. A low resets the RP2040. There is no reset button.

market with their variants of RP2040-based microcontroller boards. You can measure air quality with any of these boards. I use the Maker Pi Pico for this purpose because of the excellent experimental basis provided by Cytron Technologies. In the Elektor Store, you will find more controller boards and add-ons for your projects [3].

The manufacturer Cytron Technologies uses the slogan "Simplifying Raspberry Pi Pico for Beginners" to advertise its Maker Pi Pico board (**Figure 4**). It is always important to play on well-known and stable ground when dealing with a new microcontroller. The new environment and new tools provide sufficient opportunities for erroneous action.

The Raspberry Pi Pico is already soldered, and you can see Grove connectors on the left and right sides of the board. There is an SD card slot for a microSD card. The connection for an ESP-01 module at the bottom right is essential to get Internet connection. In addition to numerous newer Wi-Fi modules, the ESP-01 based on Espressif's ESP8266 is a good old one for this purpose.

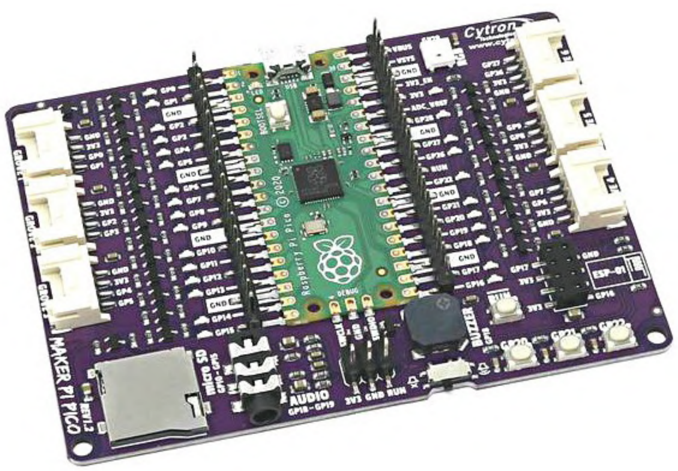


Figure 4: Maker Pi Pico top view (Image: Cytron).

Figure 5 shows the pinout of the Maker Pi Pico board. You will also find the corresponding pins of the Raspberry Pi Pico. The reset button on the board (missing on the Raspberry Pi Pico) is essential for practical work. One Neopixel RGB LED supports signalization of different states.

Figure 5 also shows the multiple assignments of the GPIOs of the Raspberry Pi Pico to the Grove connectors. You can see that the two UARTs, the two I^2C buses, and the two SPI buses are available several times. Only the two ADC channels are fix assigned to connector Grove6. Three GPIOs are connected to programmable buttons; and several outputs to the NeoPixel RGB LED, piezo buzzer, and audio. The ESP-01 Wi-Fi module has been mentioned already.

The addition of an ESP-01 Wi-Fi module eliminates the probably biggest shortcoming of a RP2040. The combination of a RP2040 board plus an ESP8266 Wi-Fi module usually costs less than €12. Compare this with the typical €30 you have to pay for the Arduino Nano RP2040 Connect board.

Measuring Air Quality

Air quality is an essential issue in the times of Corona. The risk of infection is lower during the summer, but there are various prognoses for the coming autumn and winter. Pollutants such as fine dust, asbestos fibers, formaldehyde, PCB, radon, cleaning agents, mold, dust, tobacco smoke, and volatile organic compounds (VOCs) affect indoor air quality, in addition to CO_2.

The proportion of carbon dioxide in the air we breathe today is approximately 415 ppm (≈ 0.04 %). The air breathed out by a person has a CO_2

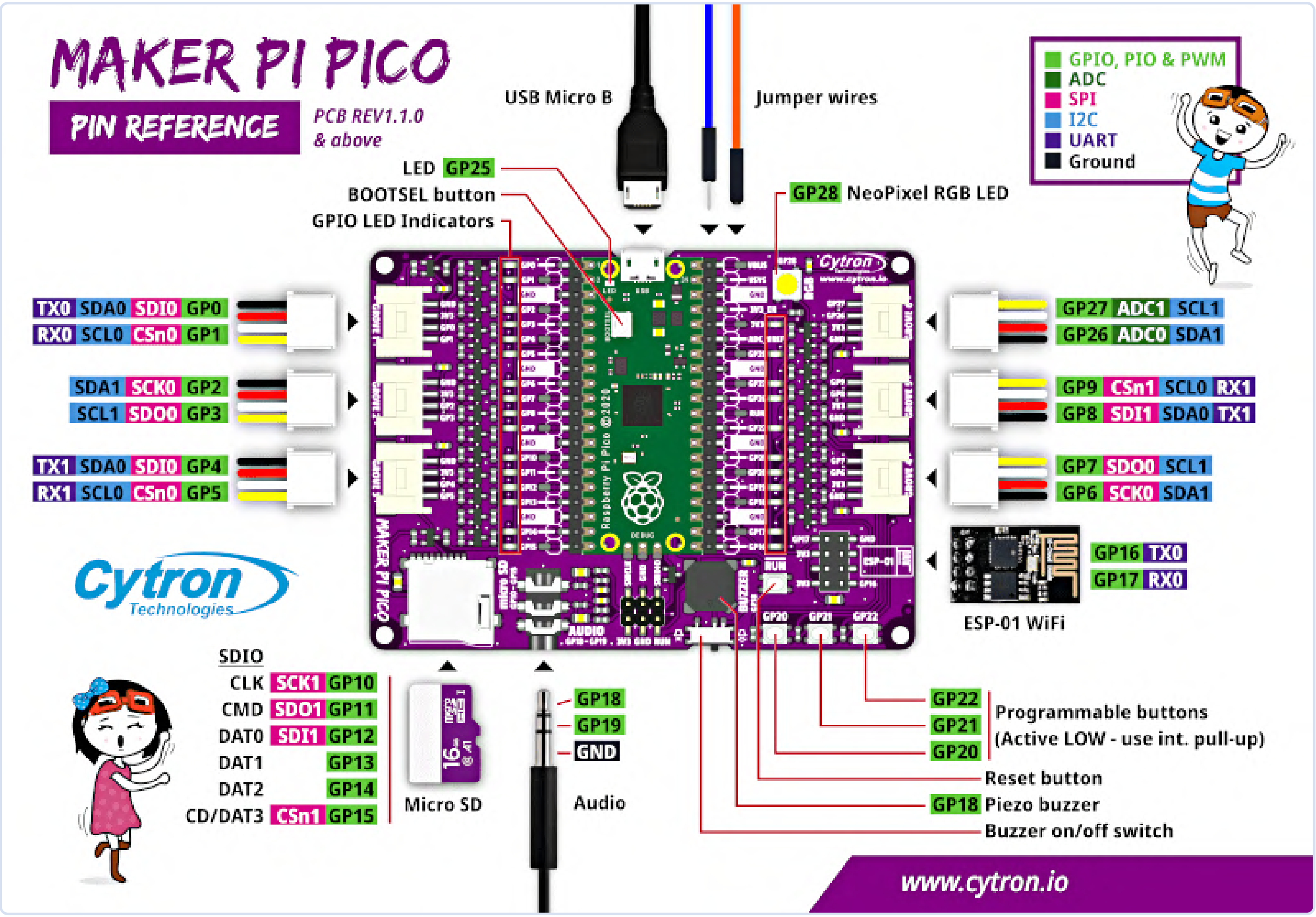


Figure 5: Maker Pi Pico board pinout (Image: Cytron).

content of around 40,000 ppm. Accordingly, in unventilated bedrooms, fully occupied classrooms, or meeting rooms, we can quickly measure up to 5,000 ppm. These high CO_2 concentrations are harmful to attention, performance, and health in general.

If you want to evaluate the air quality comprehensively, you have to provide a complex sensor system. In a professional measuring system for example, different sensors measure values for CO_2, fine dust (relevant size categories: PM1, PM2.5, and PM10), NO_2, CO, noise, temperature, humidity, and air pressure. This article concentrates on the measurement of two important values, CO_2 and VOC, which can be measured by two types of sensors:

- NDIR sensors (Non-Dispersive Infrared Sensors) use the concentration-dependent absorption of electromagnetic radiation in the infrared range. The maximum absorption of CO_2 occurs at a wavelength of 4.3 µm without much influence from other gases. The CO_2 concentration can therefore be measured very selectively and simply.
- With MOX sensors, the gas flowing causes a change in a gas-sensitive metal oxide layer. The change in resistance measures the concentration of VOC recorded in their entirety and cannot be dissolved into a particular substance. With the broadband VOC-measuring MOX sensors, sensors are available that detect a whole spectrum of substances that are hazardous to health in specific concentrations.

As said, this article concentrates on the measurement of CO_2 and VOC. Suppose we use the CO_2 concentration as a measure of the air quality. Then we have a good indication of the pollution of the air quality by the air breathed out by the people present and of the associated risk of infection from viruses transmitted via aerosols.

Suppose we use more broadband MOX sensors to measure the air quality. In that case, we have a good indication of air quality pollution by various pollutants, including human vapors and odors. In an extensive study, I examined the behavior of NDIR and MOX sensors when measuring air quality [4]. Sorry, the text is in German, but **Figure 6** shows an important result. In one of these experiments, I measured with two CO_2 sensors and one MOX sensor. The CO_2 sensors used were SCD30 (NDIR) and SCD41 (PASense), developed by the Swiss company Sensirion. The MOX sensor was an SGP30 also from Sensirion. Because there were no additional substances in addition to the human vapors, the measured values of the MOX sensor SGP30 also follow the two CO_2 sensors SCD30 and SCD41.

The air quality measurement of the more cost-effective MOX sensors shows results comparable to the pure CO_2 concentration wherever the breathing air and human vapors are dominant. Deviations occur in polluted environments (e.g., with Formaldehyde).

Air Quality via MOX Sensor

Because a MOX sensor is sufficient for measuring air quality, I used

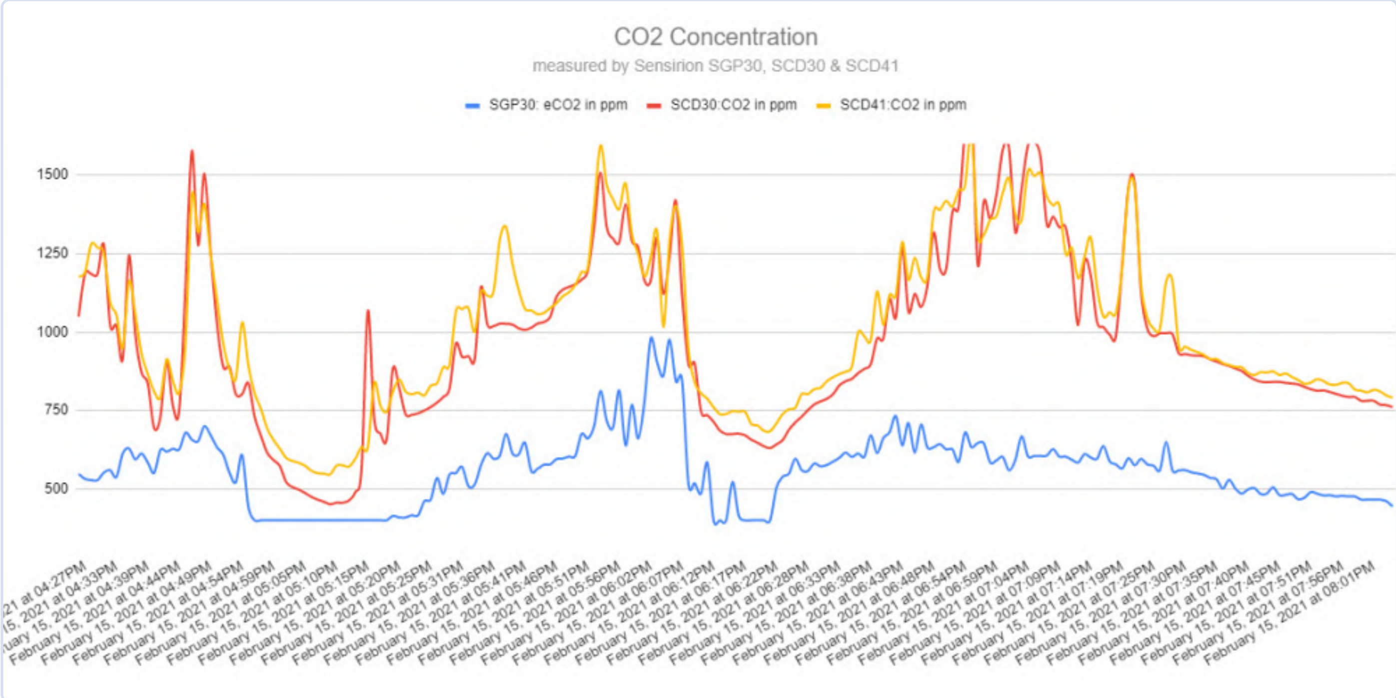


Figure 6: CO_2 concentration measured by NDIR and MOX sensor.

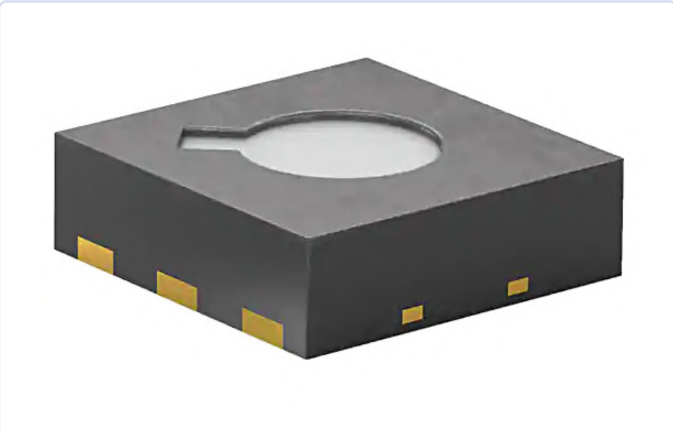


Figure 7: SGP30 (Image: Sensirion SGP30 Data Sheet).

the Sensirion SGP30 in my project. This sensor measures Total Volatile Organic Compound (TVOC) and equivalent calculated CO_2 (eCO_2) concentrations. eCO_2 is calculated based on the concentration of H_2 and therefore not as exact as measuring CO_2 directly, but good enough for my purpose.

I couldn't handle the chip (**Figure 7**) itself, so I used the M5Stack TVOC/eCO2 unit. This unit is a well-packed SGP30 connectable via a Grove I²C connector (**Figure 8**).

A 0.96" OLED display connected via I²C displays the measured values for TVOC and eCO_2. The ESP-01 is responsible for Internet access and connected via the UART interface Serial1 to the Raspberry Pi Pico. **Figure 9** shows all peripherals used connected to the Maker Pi Pico board. The NeoPixel serves as a traffic light display. Green

Figure 8: M5Stack TVOC/eCO_2 Sensor (Image: M5Stack).

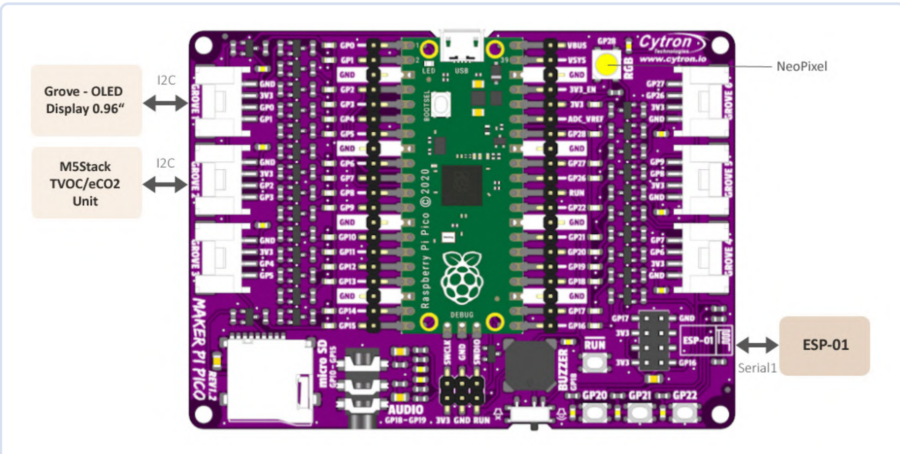


Figure 9: Peripherals used connected to Maker Pi Pico (Image: Cytron/Author).

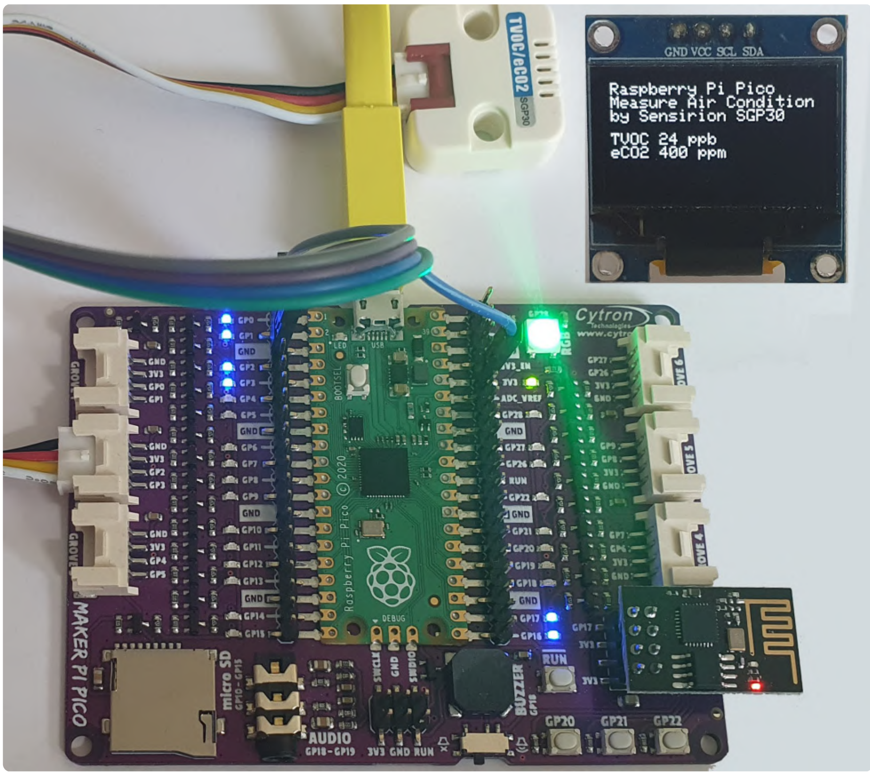


Figure 10: Air quality measurement with Sensirion SGP30 and Raspberry Pi Pico.

means good air quality, yellow means less good, and red indicates bad air quality (it is then essential to ventilate).

Figure 10 shows the complete circuit. The controller queries the SGP30 sensor every five seconds and transmits the last measured values to the ThingSpeak server once a minute. The color of the NeoPixel LED corresponds to the measured value of eCO_2 and can be easily adjusted (**Figure 11**).

For visualizing the measured values on ThingSpeak, the data is sent via HTTP GET access to the ThingSpeak API. **Figure 12** shows the visualization of the measured values in ThingSpeak [5].

Software

For this application, I used the Arduino IDE 2.0, as mentioned in the preface. Earle F. Philhower III

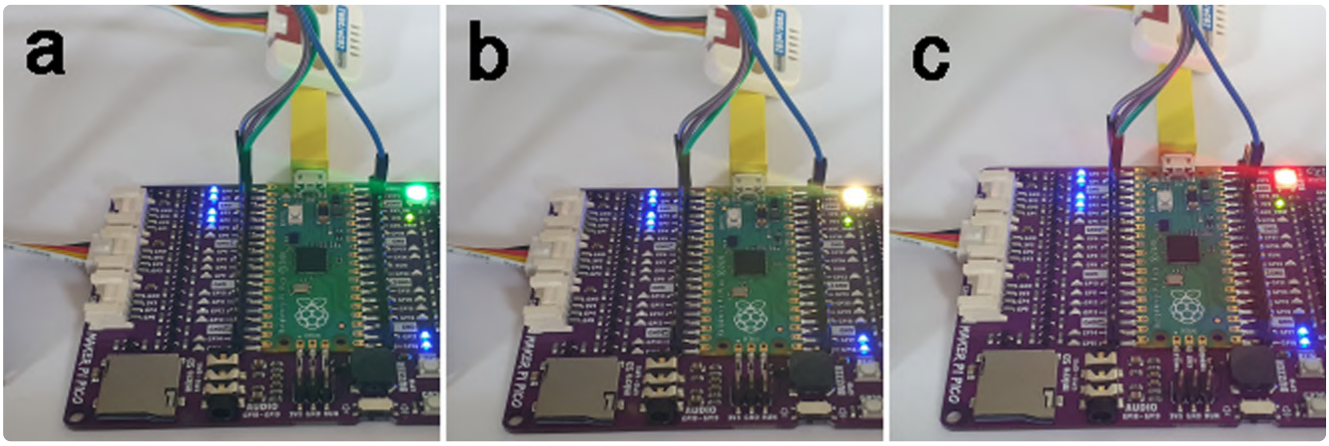


Figure 11: Signalizing measured eCO_2 value by the color of the NeoPixel RGB LED.

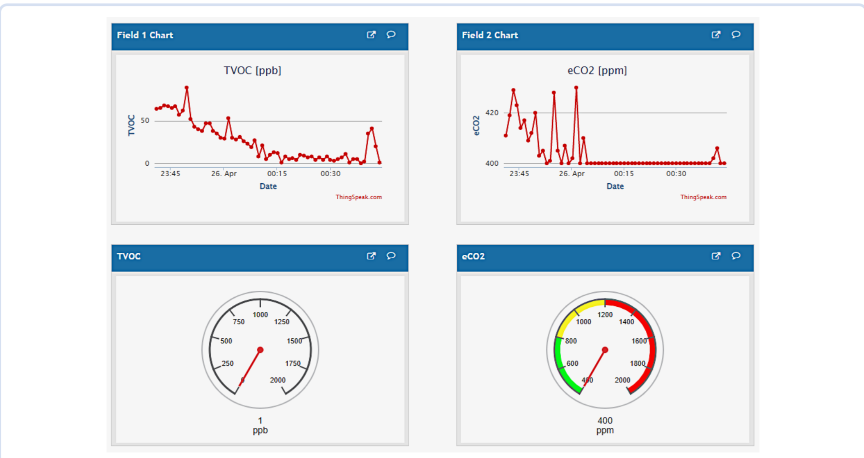


Figure 12: Thingspeak Visualization.

ported the Raspberry Pi Pico for programming in the Arduino IDE. Thanks to his work now we can program all different RP2040 boards with the Arduino IDE. This port of the RP2040 (Raspberry Pi Pico processor) to the Arduino ecosystem uses the bare Raspberry Pi Pico SDK and a custom GCC 10.3/Newlib 4.0 toolchain.

In bootloader mode, boards are automatically recognized to display them in the Arduino IDE. The upload command works with the Microsoft UF2 tool (included). You can find instructions for installation and use on GitHub [6].

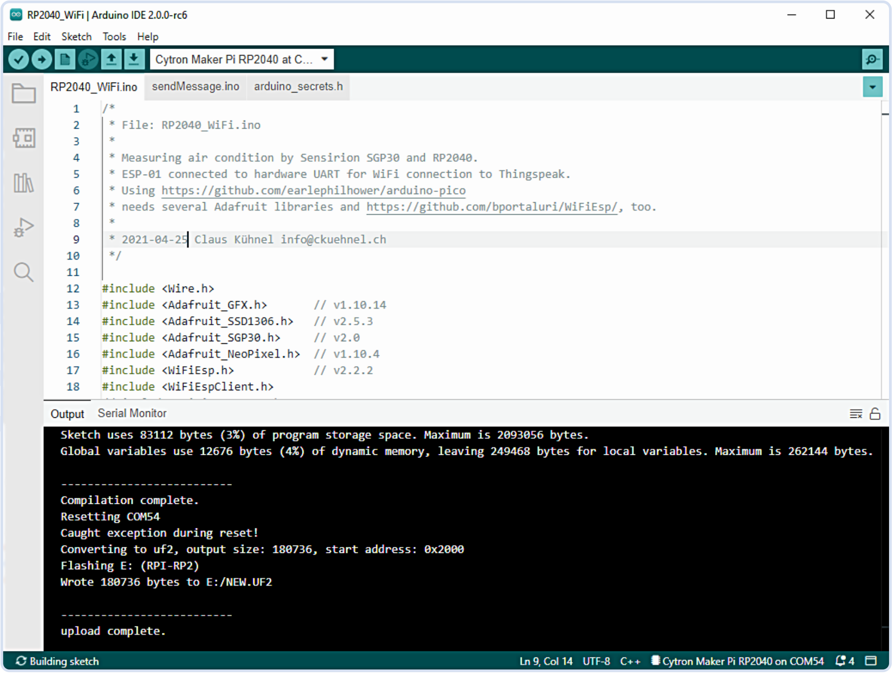


Figure 13: Program example RP2040_WiFi.ino in the Arduino IDE 2.0.

Figure 13 shows the program example *RP2040_WiFi.ino*. It is using two additional files, *sendMessage.ino* and *arduino_secrets.h*. They are available for download on GitHub [7]. During the first compilations of this software version, the compiler found two errors in the file *WiFiEspClient.cpp* of the WiFiEsp library v2.2.2. After adding the missing return statements, it worked.

```
size_t WiFiEspClient::print(const __FlashStringHelper
*ifsh)
{
    return printFSH(ifsh, false); // 2022-04-25 CK
}

// if we do override this, the standard println will
// call the print method twice
size_t WiFiEspClient::println(const __FlashString-
Helper *ifsh)
{
    return printFSH(ifsh, true); // 2022-04-25 CK
}
```

The program *RP2040_WiFi.ino* includes all required libraries. I wrote their used versions as a comment. Declarations and initializations follow before the function `setup()`. The initialization of the peripherals is interesting and underlines the flexibility of the RP2040. The following code is an excerpt from commented source code showing the assignment of functions to GPIO and their initialization.

```
//I2C0 for SSD1306 connection
Wire.setSDA(0);
Wire.setSCL(1);
Wire.begin();
…
// I2C1 for SGP30 connection
Wire1.setSDA(2);
Wire1.setSCL(3);
Wire1.begin();
…
// Serial1 for ESP-01 connection
Serial1.setRX(17);
Serial1.setTX(16);
Serial1.begin(115200);
WiFi.init(&Serial1);
```

eCO_2 values below 800 are indicated by a green LED. The LED lights up yellow between 800 and 1200. Over 1200 the LED becomes red (Figure 11c). Change these levels according to your needs.

The function `sendMessage()` is responsible for the HTTP GET access to the Thingspeak API. The line

```
client.println("GET /update?api_
key=" + api_key + "&field1=" + String(T-
VOC) + "&field2=" + String(eCO2) + " HTTP/1.1");
```

is responsible for sending API key, TVOC, and eCO_2 values to the Thingspeak API (**Figure 14**). Furthermore, you can see the serial output of the program after resetting in this screenshot.

For Wi-Fi access, you have to adjust your SSID and password and for Thingspeak, the write token in the *arduino_secrets.h* file. Registration with Thingspeak is required. The entries in the following code are non-working examples.

```
// Access data for services

// WiFi
const char* ssid   = "Sunrise_2.4GHz_8xxxx0";
const char* pass   = "u2uxxxxxDs";

// Thingspeak
// GET https://api.thingspeak.com/
```

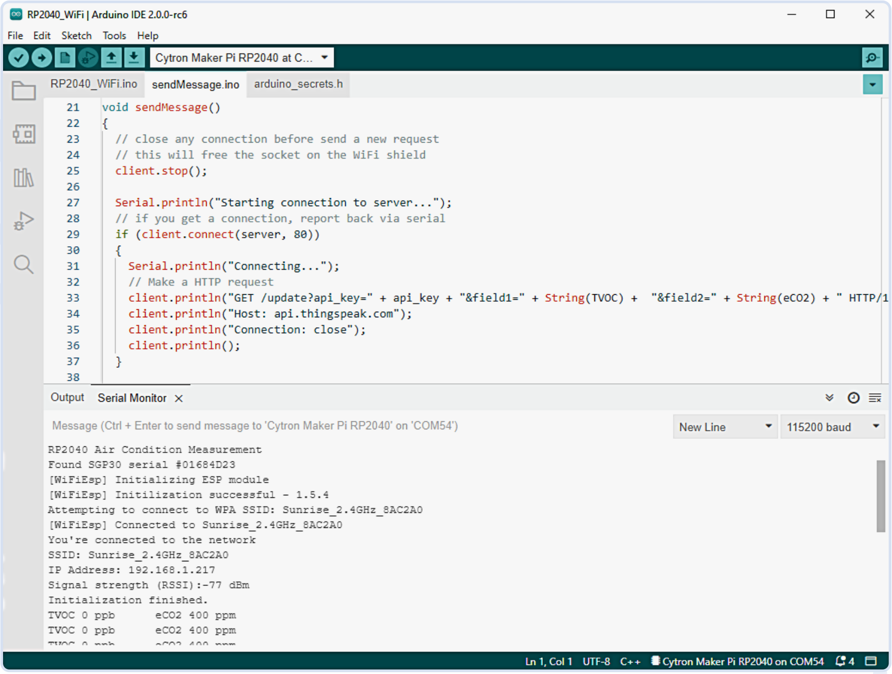


*Figure 14: Function `sendMessage()` in file **sendMessage.ino** and serial output.*

```
update?api_key=33xxxxxxSZE&field1=0&field2=0
const char* server = "api.thingspeak.com";
String api_key     = "33xxxxxxSZE";
```

You can expand this application into a closed-loop system based on the hardware used here. Use other Grove units to control the ventilation of a room based on the eCO_2 value, for example. Depending on temperature and humidity, regulating an air conditioning system is also possible. You now should be able to develop further ideas for implementing automation in your environment. Maybe another Elektor article [8] contains additional information on air measurement and some more inspiration for your projects.

210636-01

RELATED PRODUCTS

- **RP2040 controller boards and more @ Elektor**
  www.elektor.com/raspberry-pi/rp2040
- **Sensors @ Elektor**
  www.elektor.com/catalogsearch/result/?q=Sensors

About the Author

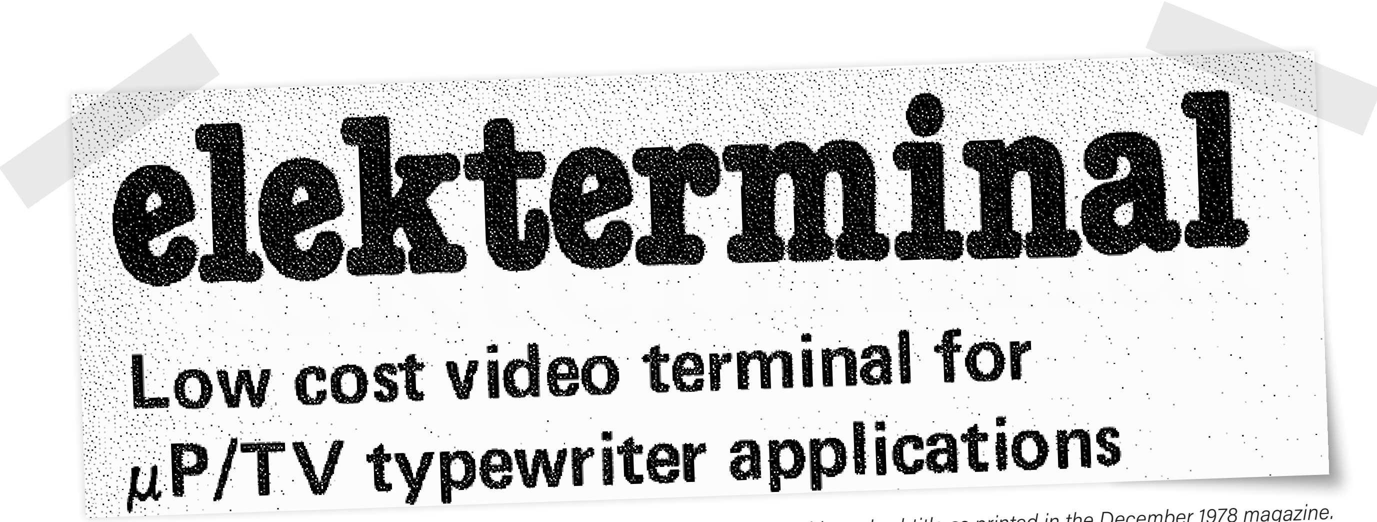
Dr. Claus Kühnel studied information technology at the Technical University of Dresden and has developed embedded systems for laboratory diagnostic devices, among others, for many years. In this interdisciplinary field, he came into contact with the maker scene. He has published numerous articles and books on microcontroller hardware and software in Germany and abroad. He is passionate about new technologies around microcontrollers.

Questions or Comments?

Do you have technical questions or comments about this article? Email Elektor at editor@elektor.com.

WEB LINKS

[1] L. Lemmens, M. Claussen, "Get to Know the Raspberry Pi Pico Board and RP2040," Elektor 5-6/2021: www.elektormagazine.com/magazine/elektor-175/59539
[2] Arduino IDE 2.0 Download (Windows 64 bit): https://downloads.arduino.cc/arduino-ide/arduino-ide_2.0.0-rc6_Windows_64bit.exe
[3] RP2040 controller boards and more @ Elektor: www.elektor.com/raspberry-pi/rp2040
[4] Measure air quality with NDIR and MOX sensors (German): https://tinyurl.com/yvj9z5sb
[5] Results via Thingspeak: https://thingspeak.com/channels/1392977
[6] Raspberry Pi Pico Arduino core for RP2040: https://github.com/earlephilhower/arduino-pico
[7] Example RP2040_WiFi.ino: https://github.com/ckuehnel/Arduino2020/tree/master/RP2040/RP2040_WiFi
[8] L. Lemmens, M. Claussen, "CO2 Guard," Elektor 5-6/2022: www.elektormagazine.com/magazine/elektor-256/60439
[9] Raspberry Pi Pico Pinout: https://datasheets.raspberrypi.com/pico/Pico-R3-A4-Pinout.pdf


elekterminal
Low cost video terminal for µP/TV typewriter applications

The project title and subtitle as printed in the December 1978 magazine.

By Jan Buiting (Elektor);
Photos by Antoni Gendrau (Spain)

Back in December 1978, Elektor published a computer terminal for home construction. "DIY" was the success factor then since terminals with CRTs and a keyboard were in the realms of professional, central computing, big offices, and big money. For the first time, hobbyists saw an affordable way to communicate with their kitchen-table microprocessor in writing — comments and all. ASCII, Cherry & The Flashing Cursor had arrived on the scene and lasted for at least two decades.


An elekterminal built by Antoni Gendrau [2].

The name "elekterminal" can be traced back to the progressive spelling used in Elektor's Dutch left-wing, post-hippy editorial department in the mid and late 1970s. Capital letters, spaces, and spelling based on Latin and Greek were abolished, and the Dutch habit of concatenating nouns and adjectives into a single (long) word was exerted to the extreme. Also, you cram as much of "Elektor" or "Elektuur" as you can into that project name! Hence, no "Elektor Terminal" or "ElekTerminal"; **elekterminal** it was [1]. In hindsight, "Elektuurminal" would have been funny as well as appropriate, but only for the Dutch audience.

_HELLO Through the AY-5-1013

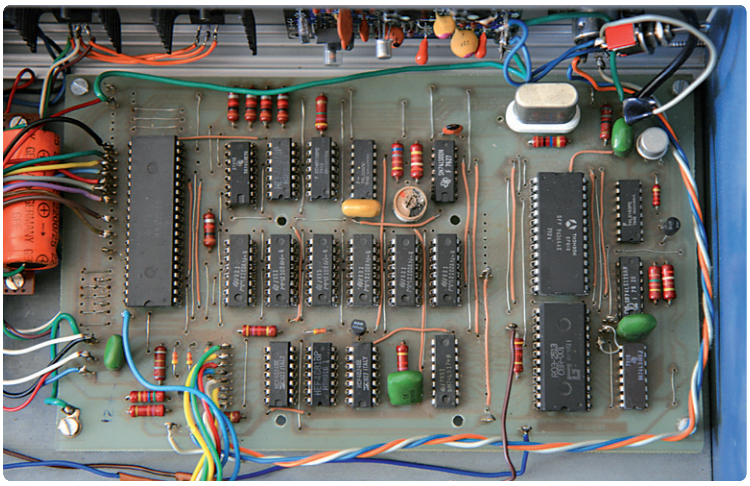
The main components of the elekterminal were an SF.F 96364 (*sic*) CRT controller chip from Thomson-CSF (Sescosem), a bunch of 2102A 1 K × 1 static RAMs for the page memory, and the legendary AY-5-1013 UART a.k.a. MM5303 for the serial comms. In the logic glue between these parts, we find a 1024-bit ROM type SFC71301E. This turned out an exotic part for many readers at the time but fortunately, the PROM contents were printed in the magazine and the device may have been available from Elektor's Software Service (ESS) at that time. Also, an equivalent was printed: the 74S387.

"Far Out Specs, Man"

The specifications of the elekterminal were summarized in the magazine as:

- 1024 characters per page, formatted as 16 lines × 64 characters.
- Plug-in option for expansion to 16 pages.
- Baud rates: 75, 110, 150, 300, 600, 1200.
- Serial interface options: 6- or 7-bit ASCII; even/odd/no parity; 1 or 2 stop bits.

Elektor's December 1978 magazine cover.



An elekterminal board, all home-etched and stuffed by Antoni Gendrau [2].

- TTL or RS-232C voltage levels.
- Normal (white on gray) or inverted (black on gray) video signal.
- Sophisticated, hardware-driven cursor control and screen scrolling.
- Full-duplex or half-duplex mode.
- Only 21 ICs on the board.

The elekterminal used 5×7 pixel characters rather than 7×9 because, the article says: "With 64 characters per line, the resulting bandwidth is several megahertz too large for conventional TV receivers, and results in poor definition. For this reason, the 7×9 matrix is generally reserved for use with video monitors." While the elekterminal did have a provision for driving a 'pro' video monitor, most users went "the TV way" by connecting a TV modulator tuned to VHF channel 2 or UHF 21. The modulator was either homemade (Elektor October 1978), off the shelf from Maplin's, or looped-in through a VTR or VCR. As to the ASCII keyboard, that too was described in *Elektor*, one month earlier. Jointly, the elekterminal and the ASCII keyboard soon united under the name "TV Typewriter".

All $$$, No _ERROR in 1978

Although not a pioneering device and essentially a "dumb VDU" (visual display unit), to hobbyists, the elekterminal opened the way to standardized, serial, communication with any computer system having a standard serial interface like RS-232 or even the 20 mA loop. Affordably.

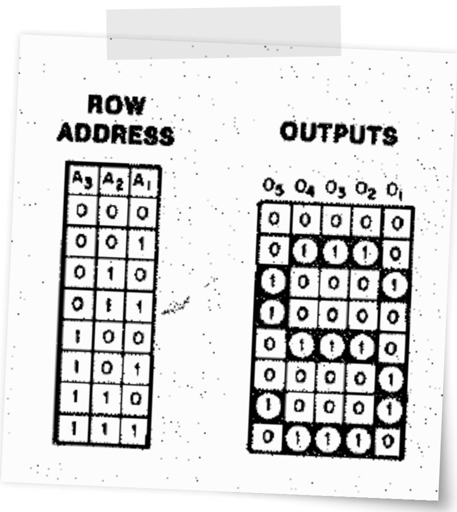
The elekterminal was hugely successful right from the start. Its capabilities, especially the screen format and the 1200-baud "data speed," may appear antediluvian in this day and age, but in fact, may have been at the root of any of that gigabit, 4K, 5G, or HyperTerminal stuff you're using today, or aspiring to use.

As far as prototypes of the elekterminal are concerned, nothing has survived at Elektor since the Augean clearing out of the lab in 2006. That's why the photos shown here are reproduced from Antoni Gendrou's hilarious article on the elekterminal printed in the June 2010 installment of *Elektor Retronics* [2]. I did see a perfectly built TV Typewriter though, on display in the Computer History Museum in Mountain View, California, back in 2014. Ah, the sound of those Hall-effect keys from the Cherry keyboard...

220213-01

Questions or Comments?

Do you have any questions or comments about this article? Email the author at jan.buiting@elektor.com.



5x7 character matrix used in the elekterminal.

WEB LINKS

[1] "elekterminal," Elektor 12/1978: https://www.elektormagazine.com/magazine/elektor-197812/58259
[2] Antoni Gendrau, "Elekterminal" (Retronics series), Elektor 06/2010: https://www.elektormagazine.com/magazine/elektor-201006/19337

Kickstart to Python 3

Sample Chapter: Digital Image Processing and Wand Library

By Ashwin Pajankar (Pakistan)

Here, Elektor book author Ashwin Pajankar examines an area where Python ranks high if not 'top' as a programming language: image processing. Join Ashwin in exploring an image processing library called Wand, which excels in the ease of programming special effects with minimum fuss, all in Python, of course, and at speed!

Editor's Note. *This article is an excerpt from the 210-page book* **Kickstart to Python 3** *(Elektor, 2022). The excerpt was formatted and lightly edited to match Elektor Mag's editorial standards and page layout. Being an extract from a larger publication, some terms in this article may refer to discussions elsewhere in the book. The Author and Editor have done their best to preclude such instances and are happy to help with queries. Contact details are in the* **Questions or Comments?** *box.*

Image Processing covers the use of algorithms to process image content. In the days of analog films and motion pictures, there were techniques to improve the quality of images and frames (in a motion picture) using manual techniques like the use of chemical compounds. This was a precursor to the modern idea of image processing. Nowadays, most images are digital. Of course, digital is yet to catch up with the vibrant colors and clarity of analog (chemical film-based imaging). However, since it is cheaper, a vast majority of people and organizations (film producing and processing organizations) use digital imaging in the production of images and videos. Modern computers are also fast enough to be used for processing digital images. We usually revert to modern programming languages like C, C++, Java, Python, MATLAB, and GNU Octave for processing images and videos. It is very easy to process images with Python as there are many third-party libraries for this.

ImageMagick is a software utility for the manipulation of images. It comes with APIs for various programming languages. We can use the library called **Wand** which provides a pythonic interface to ImageMagick. Let's set up the required software to get started. We first need to install ImageMagick for our OSes. We can install the ImageMagick on macOS with the following commands:

```
brew install ghostscript
brew install imagemagick
```

These two commands should install ImageMagick to your macOS. If not, then we must install it manually. This is easy — download the zip file found at [1] and then copy it to the *home* directory of your user on macOS. Extract it with the following command:

```
tar xvzf ImageMagick-x86_64-apple-darwin20.1.0.tar.gz
```

Now we need to add a few entries to the file *.bash_profile* located in the *home* directory of your user on macOS.

```
# Settings for ImageMagik
export MAGICK_HOME="$HOME/ImageMagick-7.0.10"
export PATH="$MAGICK_HOME/bin:$PATH"
export DYLD_LIBRARY_PATH="$MAGICK_HOME/lib/"
```

Exit and relaunch the command prompt and run the following commands one by one:

```
magick logo: logo.gif
identify logo.gif
display logo.gif
```

which will display the logo of the ImageMagick project.

Installation on Windows is easy. There are binary executable installable files for all flavors of desktop Windows (32/64 bit). Of all the options, we need to choose the one with the description *Win64/Win32 dynamic at 16 bits-per-pixel component with High-dynamic-range imaging enabled*. For 64-bit systems, use [2] and for 32-bit Windows, use [3].

Linux users should download the source with the following command,

```
wget https://www.imagemagick.org/download/ImageMagick.
tar.gz
```

Let's check where all the files were extracted:

```
ls ImageMagick*
```

It shows us the name of the directory:

```
ImageMagick-7.1.0-10
```

Go to the directory:

```
cd ImageMagick-7.1.0-10
```

Next, run the following commands one after another (if you are familiar with the Linux, you will recognize that this is a standard set of commands to install any new program on Linux distros):

```
./configure
make
sudo make install
sudo ldconfig /usr/local/lib
```

After we successfully install the ImageMagick program, we can install the Wand library on any platform with the following command:

```
pip3 install wand
```

That concludes the installation of ImageMagick and Wand on any operating system.

Getting Started

Please create a new Jupyter notebook for all demonstrations in this article. From here on, all the code should be saved and executed in the Notebook. Let's begin by importing the required libraries.

```
from __future__ import print_function
from wand.image import Image
```

These statements import the required modules. Let's read an image and print its dimensions as follows:

```
img = Image(filename='D:/Dataset/4.2.03.tiff')
print('width =', img.width)
print('height =', img.height)
```

The output is as follows:

```
width = 512
height = 512
```

We can also see the type of the image:

```
type(img)
```

Figure 1: Image displayed in the Jupyter Notebook.

This produces the following output:

```
wand.image.Image
```

Next, we can show the image in the Notebook as output just by typing in the name of the variable that stores the image:

```
img
```

This creates the output shown in **Figure 1**.

I am using the image dataset provided by ImageProcessingPlace [4]. All images are standard test images frequently used in image processing. I am not using the standard test image, Lena, as I believe the origin of the image is controversial and it is disrespectful and derogatory towards women in general.

We can also clone an image, change its file format, and save it to disk as follows:

```
img1 = img.clone()
img1.format = 'png'
img1.save(filename='D:/Dataset/output.png')
```

If you haven't already noticed, I am using a Windows computer for this demo. If you are using any Unix-like OS, you have to modify the location accordingly. For example, I am using the following code to save in a Raspberry Pi OS (Debian Linux variant) computer to save the output file:

```
img1.save(filename='/home/pi/Dataset/output.png')
```

We can also create a custom image with uniform color:

```
from wand.color import Color
bg = Color('black')
img = Image(width=256, height=256, background=bg)
img.save(filename='D:/Dataset/output.png')
```

Let's see how to resize an image. There are two ways, one:

```
img = Image(filename='D:/Dataset/4.2.03.tiff')
img1 = img.clone()
img1.resize(60, 60)
img1.size
```

and two:

```
img1 = img.clone()
img1.sample(60, 60)
img1.size
```


Figure 2: A blurred image.

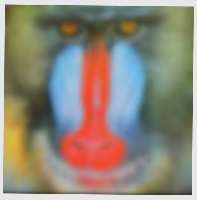


Figure 3: Adaptive blur.


Figure 4: Motion blur with a 30-degree angle.


Figure 5: Rotational blur.


Figure 6: Selective blur.

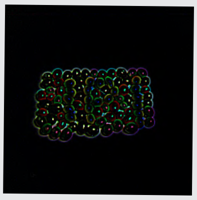


Figure 7: Edge detection.

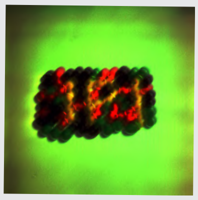


Figure 8: Emboss effect.

The routines `resize()` and `sample()` resize the image to specified dimensions. We can also crop a part of an image, like so:

```
img1 = img.clone()
img1.crop(10, 10, 60, 60)
img1.size
```

Image Effects

We can have a variety of image effects. Let's start by blurring an image.

```
img1 = img.clone()
img1.blur(radius=6, sigma=3)
img1
```

The output is as shown in **Figure 2**. Now let's apply adaptive blurring:

```
img1 = img.clone()
img1.adaptive_blur(radius=12, sigma=6)
img1
```

and then some Gaussian blurring:

```
img1 = img.clone()
img1.gaussian_blur(sigma=8)
img1
```

The output is shown in **Figure 3**. We can also apply a motion-blur effect:

```
img1 = img.clone()
img1.motion_blur(radius=20, sigma=10, angle=-30)
img1
```

Note that we are stating the angle of motion while calling the routine. The output should be as in **Figure 4**.

Then there's rotational blur (**Figure 5)**:

```
img1 = img.clone()
img1.rotational_blur(angle=25)
img1
```

and selective blur (**Figure 6**):

```
img1 = img.clone()
img1.selective_blur(radius=10, sigma=5,
threshold=0.50 * img.quantum_range)
img1
```

We can also despeckle an image i.e., reduce noise:

```
img1 = img.clone()
img1.despeckle()
img1
```

and detect edges (**Figure 7**):

```
img = Image(filename='D:/Dataset/4.1.07.tiff')
img1 = img.clone()
img1.edge(radius=1)
img1
```

We can generate a 3D emboss effect (**Figure 8**):

```
img1 = img.clone()
img1.emboss(radius=4.5, sigma=3)
img1
```

or change the image to greyscale and apply an image effect (**Figure 9**):

```
img1 = img.clone()
img1.transform_colorspace('gray')
img1.emboss(radius=4.5, sigma=3)
img1
```

For overall image sharpening, consider programming:

```
img1 = img.clone()
img1.sharpen(radius=12, sigma=4)
img1
```

or applying the adaptive sharpening algorithm:

```
img1 = img.clone()
img1.adaptive_sharpen(radius=12, sigma=6)
img1
```

or going the reverse way by using the unsharpening mask:

```
img1 = img.clone()
img1.unsharp_mask(radius=20, sigma=5,
amount=2, threshold=0)
img1
```

Lastly, try spreading the pixels randomly in the specified radius:

```
img1 = img.clone()
img1.spread(radius=15.0)
img1
```

and watch the result as in **Figure 10**.

Special Effects

Let's study how to apply special effects to an image. The first effect is *Noise*. There are various types of noise. Let's see how to introduce Gaussian noise.

```
img1 = img.clone()
img1.noise("gaussian", attenuate=1.0)
img1
```

The output is shown in **Figure 11**. The following is a list of all valid character strings that can be used as names of noise types:

```
'gaussian'
'impulse'
'laplacian'
'multiplicative_gaussian'
'poisson'
'random'
'uniform'
```

We can apply blue-shift to an image as follows (**Figure 12**):

```
img1 = img.clone()
img1.blue_shift(factor=0.5)
img1
```

or create the charcoal drawing effect (**Figure 13**):

```
img1 = img.clone()
img1.charcoal(radius=2, sigma=1)
img1
```

We can also apply a color matrix:

```
img1 = img.clone()
matrix = [[0, 0, 1],
[0, 1, 0],
[1, 0, 0]]
img1.color_matrix(matrix)
img1
```

A color matrix can have a maximum size of 6x6. In a color matrix, each column maps to a color channel to reference, and each row represents a color channel to effect. For RGB images, these are red, green, blue, n/a, alpha, and a constant (offset). For CMYK images, they are cyan, yellow, magenta, black, alpha, and a constant. In this example, we have created a 3x3 matrix with a result as shown in **Figure 14**.

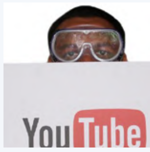
Other special effects supported by the program and described in the book include blending with constant color, imploding, Polaroid, sepia-tone, sketch, solarize, swirl, tinted, vignette, wave, wavelet de-noise, flip, flop, and rotated.

220314-01

Questions or Comments?

Do you have any technical questions or comments related to this article? Email the author at ashwin.pajankar@gmail.com or Elektor at editor@elektor.com.

About the Author



Ashwin Pajankar holds a Master of Technology degree from IIIT Hyderabad and has over 25 years of programming experience. He started his journey into programming and electronics with the BASIC programming language and is now proficient in assembly language programming, C, C++, Java, Shell Scripting, and Python. Further technical experience includes single-board computers such as the Raspberry Pi, Banana Pro, and Arduino.

RELATED PRODUCTS

- **A. Pajankar,** *Kickstart to Python 3*, **Elektor 2022 (Book, SKU 20106)**
  www.elektor.com/20106
- **A. Pajankar,** *Kickstart to Python 3*, **Elektor 2022 (E-Book, SKU 20107)**
  www.elektor.com/20107

Figure 9: Emboss on a greyscale image.

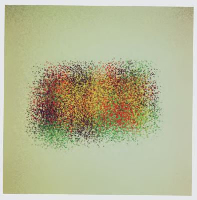


Figure 10: Spread effect.

Figure 11: Gaussian noise.

Figure 12: Blue-shifted image.

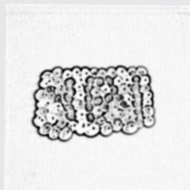


Figure 13: Charcoal effect.

Figure 14: Color-matrix effect.

WEB LINKS

[1] ImageMagick download:
https://download.imagemagick.org/ImageMagick/download/binaries/ImageMagick-x86_64-apple-darwin20.1.0.tar.gz
[2] ImageMagick for Win64 systems:
https://download.imagemagick.org/ImageMagick/download/binaries/ImageMagick-7.1.0-10-Q16-HDRI-x64-dll.exe
[3] ImageMagick for Win32 systems:
https://download.imagemagick.org/ImageMagick/download/binaries/ImageMagick-7.1.0-10-Q16-HDRI-x86-dll.exe
[4] Image Databases, ImageProcessingPlace.com: www.imageprocessingplace.com/root_files_V3/image_databases.htm

P. Haring-Kuipers generated this image with OpenAI DALL·E 2 [2].

SOLARPUNK

A Brighter Future Ahead

By Priscilla Haring-Kuipers (The Netherlands)

There is a socially fair and bright green future that embraces technology. A fantasy that you can aspire to with all of the making and none of the guilt.

Sometimes it might seem like all is bleak, especially in hardware design and manufacturing. Many of the fantastic solutions we engineer are made with unethical materials and used to uphold a system that is lacking in meaning and threatening our very lives. Changing these things seems beyond our control. In these trying times, it is important to imagine a future we actually want. We could really use an inspired future where your soldering iron can be a tool for good.

Fluffy Punk

Solarpunk [1] is a genre of science-fiction that does not take place in the aftermath of an apocalypse. Instead, it gives shape to how we might live after we have solved the eco-social crisis we live in, after have we created an equal society in which we can all thrive, after we have learned to comfortably live as part of nature, and after we have spread renewable energy around everywhere such that it is ubiquitous. It is a glorious fiction that is sometimes tantalizingly near-future. Filled with solar panels and a lot of biology. A technologically feasible utopia. At the moment Solarpunk is just a tiny sub-genre of sci-fi but interest, and content, is growing.

In this imagined future technology is not shunned nor is it dominating. Technology is supportive of a meaningful life as part of a bio-dynamic ecology. Both high- and low-tech solutions are applied wherever they facilitate an egalitarian and sustainable life.

P. Haring-Kuipers generated this image with OpenAI DALL·E 2.

Like all punk, solarpunk goes against the current ruling philosophy and requires a full system change. It lets care be the guide instead of greed. Solarpunk sees humans as part of the natural ecology, not apart from it as our current industrialized society does. There is great emphasis on getting your hands in the dirt following bio-dynamic permaculture and regenerative principles, to tend to your environment and grow your own food. Care of each other, care of ourselves and care of our environment are all intertwined. Solarpunk holds technology in its heart as a way to support this equal, care-driven, non-polluting meaningful life. It focuses on hyper-local, small, self-governing networks while also making the best of being connected global citizens. Without the capitalist push for the biggest economic benefit but with the eco-socialist spread of resources and benefit for all. Life would maybe have a slightly slower pace, but there would be much more to enjoy along the way.

Looks Like Sunshine

You may have already had a taste of a solarpunk society in *Star Trek* or seen solarpunk aesthetics in *Wakanda* or in Ghibli's *Nausicaä of the Valley of the Wind*. The quickest dive into what a solarpunk future might look like is Chobani's 30-second commercial *Eat today, feed tomorrow*.

The aesthetics of solarpunk are reminiscent of the decorative tendencies and swirling nature of art nouveau. Similar to this art movement of the 1900s, it applies art and craftsmanship everywhere in the environment to "uplift and inspire." Art is for the masses and craftsmanship is for everyone. Guided by natural forms and even bio-mimicry, often using dynamic lines to give a sense of movement and using every space and every object as an opportunity to express beauty. There are trees and plants growing everywhere. Fruit trees line the rivers and solar panels or various wind traps fill out the architecture. Bright natural colours with a lot of blue and green and plenty of light. It looks like a happy place.

There are already many things now that we could consider solarpunk (at least in part). Festo's amazing biomimicry robotics as well as electric vehicles charged with your own solar panels. A fully self-sufficient sailboat with solar panels and an electric engine is also pretty solarpunk, as are the passive-solar earthship homes in New Mexico. Sometimes things could do with a bit of aesthetic schwung and perhaps a luminescent algae tank here or a micro-growery there to really push the present into the future, but we are close. Very close.

Build It

Solarpunks' hyper-local and DIY tendencies would lead to growing cooperatives and shared maker spaces of all sorts. In the solarpunk toolkit, you might find a communal seedbank and a guide to mulching as well as a bioplastic 3D printer and a soldering iron. What technological support might a mini-grid of five houses sharing sustainable energy sources need? Or how would you build simple soil sensors? How would you improve on neighbourhood aquaponics? What might you build when renewable energy is ubiquitous and fossil fuels are out? Without large domineering hardware companies closing off their designs for economic purposes, all electronics would be more open to be played with. Imagine that most people can and will tailor hardware to their specific needs. What would you make, and can you start making this now? Spend a little time in this future imagining and figure out how you would use your capabilities to support it.

P. Haring-Kuipers generated this image with OpenAI DALL·E 2.

So how are we inspired by solarpunk? For our next big synthesizer project we are going to need a small factory floor. Probably in about two years. We plan to solarpunk this by trying to run it completely on renewable energy, avoiding unethical materials, providing a fair and supportive work environment and growing our own food. We might fall short on doing this 100%, but we will try. We want to treat our little factory as a tiny community and intend to share our space and resources with other synth makers. We aim to take the time to bring out the beauty in all our objects and spaces. With natural forms, dynamic lines and bright colours.

220396-01

WEB LINKS

[1] Solarpunk, Wikipedia: https://en.wikipedia.org/wiki/Solarpunk

[2] AI system that can create images from a description in natural language: https://openai.com/dall-e-2/

elektor store

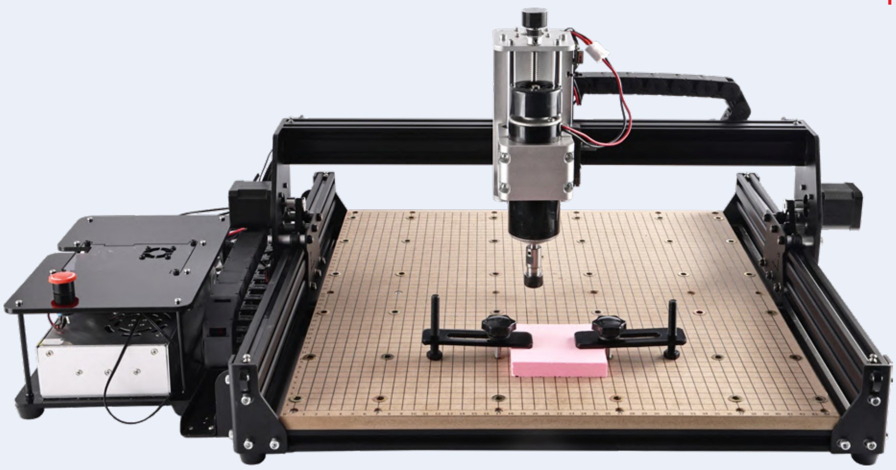
www.elektor.com

The Elektor Store

Never expensive, always surprising

The Elektor Store has developed from the community store for Elektor's own products like books, magazines, kits and modules, into a mature webshop that offers great value for surprising 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). Our main conditions: **never expensive, always surprising**!

Anet 4540 Desktop CNC Machine



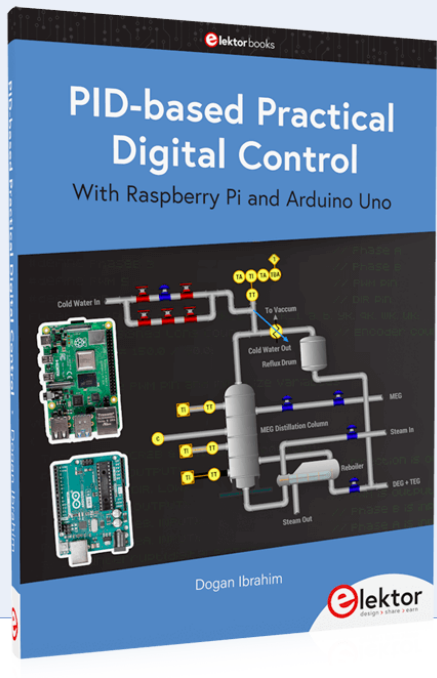
Price: €899.00

Member Price: €809.10

www.elektor.com/20260

PID-based Practical Digital Control with Raspberry Pi and Arduino Uno

Third print run! Claim your copy today!



Price: €34.95

Member Price: €31.46

www.elektor.com/20274

Elektor CheatKard – Electrical Engineering Reference Cards

-14%

€29.95
instead of
€34.95

www.elektor.com/20080

MakePython ESP32 Development Kit

-19%

€64.95
was €79.95

www.elektor.com/20137

RISC-V Assembly Language Programming

Includes ESP32-C3-DEVKITM-1 Development Board

Price: €37.95
Member Price: €34.16

www.elektor.com/20296

Elektor Dual DC LISN 150 kHz – 200 MHz **(Pre-order)**

Price: €129.95
Member Price: €116.96

www.elektor.com/19869

Hexadoku

Puzzles with an Electronic Touch

Traditionally, the last page of *Elektor magazine* is reserved for our puzzle with an electronics slant: welcome to Hexadoku! Find the solution in the gray boxes, submit it to us by email, and you automatically enter the prize draw for one of five Elektor store vouchers.

The Hexadoku puzzle employs numbers in the hexadecimal range 0 through F. In the diagram composed of 16 × 16 boxes, enter numbers such that **all** hexadecimal numbers 0 through F (that's 0-9 and A-F) occur once only in each row, once in each column and in each of the 4×4 boxes (marked by the thicker black lines). A number of clues are given in the puzzle and these determine the start situation.

Correct entries received enter a prize draw. All you need to do is send us **the numbers in the gray boxes**.

Elektor Store Voucher €50,-*

Flip to see your unique code!

SOLVE HEXADOKU AND WIN!

Correct solutions received from the entire Elektor readership automatically enter a prize draw for five Elektor store vouchers worth **€50.00 each**, which should encourage all Elektor readers to participate.

PARTICIPATE!

Ultimately December 15th, 2022, supply your name, street address and the solution (the numbers in the gray boxes) by email to: **hexadoku@elektor.com**

PRIZE WINNERS

The solution of Hexadoku in edition 9-10/2022 (September & October) is: **60E5A**.

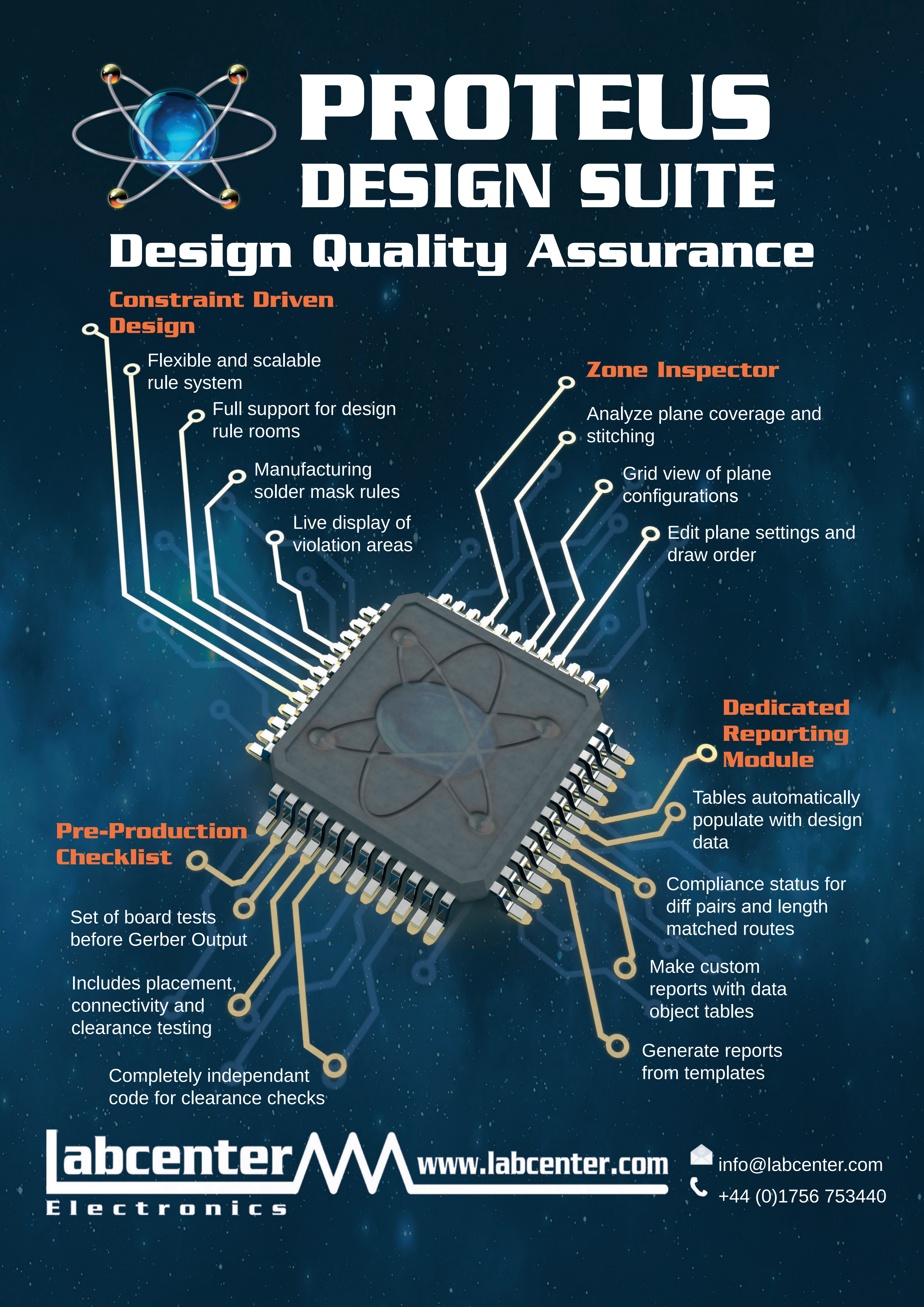
Solutions submitted to us before October 17th were entered in a prize draw for 5 Elektor Store Vouchers.

The winners are posted at www.elektormagazine.com/hexadoku.

Congratulations everyone!

7	B		C			6			4			F		9	3
9		E			0	3			F	6			7		C
	0		3		B		7	9		D		5		1	
A		4		9							3		8		E
			8	A	6	B			D	E	0	3			
	1	F		C	3		E	2		4	7		9	5	
C	2			5							F			A	0
		5			F					A			B		
		B			4					0			E		
2	A			6							4			C	1
	C	0		F	9		3	6		8	5		D	2	
			4	E	2	1			A	B	D	7			
5		1		8							A		3		4
	E		B		D		C	4		F		6		7	
8		C			5	7			E	1			A		F
3	F		7			4			5			8		E	D

7	3	C	0	F	8	A	1	E	9	D	2	6	B	5	4
B	D	1	5	2	C	E	0	6	4	F	A	3	7	8	9
E	8	F	4	9	3	B	6	1	7	5	0	A	C	D	2
2	6	9	A	7	4	5	D	B	C	3	8	F	E	0	1
C	E	7	6	8	F	2	9	A	0	4	5	D	1	3	B
4	1	3	8	0	B	6	5	D	E	7	9	2	A	F	C
F	9	5	D	3	7	C	A	8	1	2	B	4	0	6	E
A	0	2	B	E	D	1	4	F	3	C	6	7	5	9	8
0	2	4	1	A	E	7	8	9	F	6	D	C	3	B	5
3	B	6	7	5	1	9	F	0	2	8	C	E	4	A	D
5	A	E	9	4	0	D	C	3	B	1	7	8	6	2	F
8	C	D	F	6	2	3	B	4	5	A	E	0	9	1	7
9	4	A	C	B	5	F	7	2	8	0	3	1	D	E	6
D	7	8	2	C	6	0	E	5	A	B	1	9	F	4	3
6	F	B	E	1	A	8	3	C	D	9	4	5	2	7	0
1	5	0	3	D	9	4	2	7	6	E	F	B	8	C	A


PROTEUS
DESIGN SUITE
Design Quality Assurance
Constraint Driven Design
Flexible and scalable rule system
Full support for design rule rooms
Manufacturing solder mask rules
Live display of violation areas
Zone Inspector
Analyze plane coverage and stitching
Grid view of plane configurations
Edit plane settings and draw order
Dedicated Reporting Module
Tables automatically populate with design data
Compliance status for diff pairs and length matched routes
Make custom reports with data object tables
Generate reports from templates
Pre-Production Checklist
Set of board tests before Gerber Output
Includes placement, connectivity and clearance testing
Completely independant code for clearance checks
labcenter
Electronics
www.labcenter.com
info@labcenter.com
+44 (0)1756 753440