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EMBEDDED WORLD **2024** Bonus Edition!

ESP32-CAM Programmer

Customize Your Module With an Inexpensive Tool

Bonus Edition

embeddedworld
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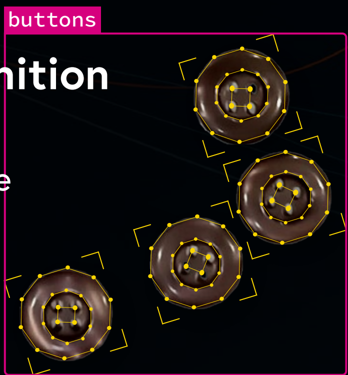
NXP i.MX RT1010 Evaluation Kit

Ideal for Audio Applications

Image Recognition Made Easy

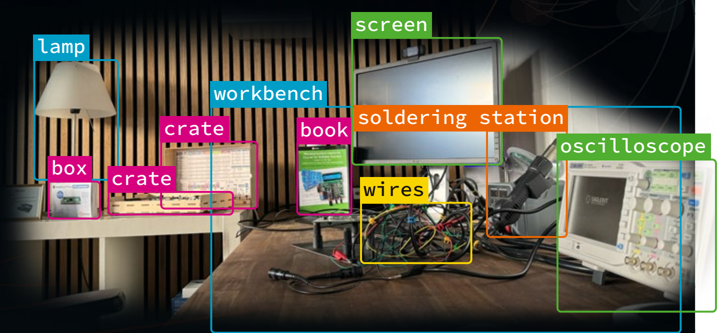
With Edge Impulse Framework



Bonus articles for Pros, Makers, and Students!

Audio DSP with the NXP MIMXRT1010 Development Kit

An Intro to Arm Cortex-M7-Powered Sound Processing



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The **March/April 2024 edition** of *ElektorMag* is available at newsstands and in the Elektor Store. You also can grab an extra-thick copy at the 2024 embedded world Exhibition & Conference in Nuremberg, Germany (April 9-11).

EDITORIAL

C. J. Abate
Content Director, Elektor

A Focus on Embedded & AI

We've prepared this digital bonus edition of content as a companion to both the March/April edition of *ElektorMag* and the 2024 embedded world trade show, which takes place in Nuremberg, Germany, from April 9-11. An extra-thick print edition of *ElektorMag* will be available for everyone visiting the show. If you attend, don't forget to grab a copy and then stop by Elektor's booth (Hall 5, Booth 5-181), where many of our engineers and editors will be working for the duration of the event!

Curious what's inside this bonus edition of your favorite magazine? We're continuing to focus our March/April theme: embedded systems and artificial intelligence. The magazine includes a variety of articles: an ESP32-CAM programmer project, an introduction to Arm Cortex-M7-powered sound processing, a review of a kit for audio applications and motor control, and insights about embedded systems and AI from industry thought leaders, including Prof. Dr. Sebastian Steinhorst from the Technical University of Munich, Germany.

After reading this bonus edition, I encourage you to hit the workbench and dive into new projects of your own. Make sure you share your progress at www.elektormagazine.com/labs. If you visit embedded world 2024, head over to our booth to chat about technology with our engineers. We look forward to learning about your innovations.

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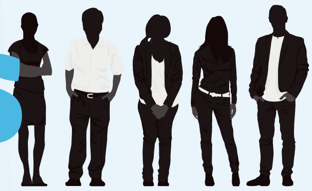
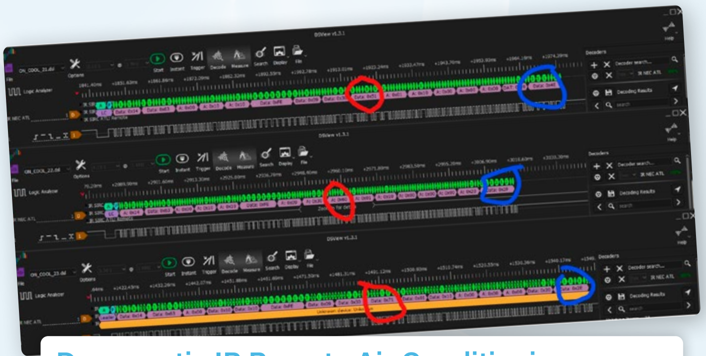
STM32 Wireless Innovation Design Contest: The Nominees



By The Elektor Content Team

After hours of studying the innovative projects entered in the STM32 Wireless Innovation Design Contest, the judging panel has nominated five standout projects that exemplify technical excellence, functionality, and creativity. Congratulations to all the nominees!

With a share of €5,000 in cash prizes up for grabs in the STM32 Wireless Innovation Design Contest 2024, innovators from around the globe have been working hard over the past few months with STM32 solutions to develop various creative wireless applications. In the end, 26 projects were submitted. We were just as positively surprised by the range of applications as we were by the technical quality; moreover, the vast majority of projects were professionally documented. Hats off! It was not easy for the six-person jury (STMicroelectronics, Elektor) to nominate the best five of the many good projects. We present the nominated projects here.

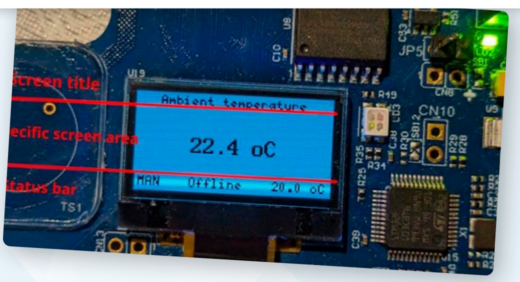


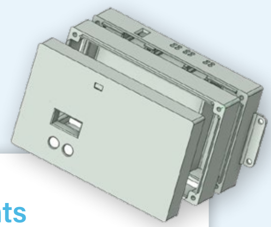
Democratic IR Remote Air Conditioning

Submitted by tdo

The project introduces an innovative solution for collectively managing air conditioning temperatures in shared workspaces. Using the STM32WB5MM-DK board paired with an Atlantic Fujitsu air conditioner, it enables coworkers to democratically vote on their preferred temperature through a smartphone app. The system operates in two modes: Manual for direct overrides like a traditional remote, and BLE for smartphone-based voting, automatically adjusting to the majority's preferred temperature.

www.elektormagazine.com/STM32Contest/AC



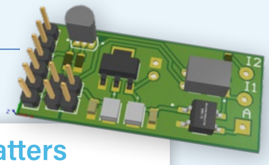


ZigBee Environmental Measurement Center for Plants

Submitted by Alain Romaszewski

This project aims to revolutionize the care of indoor plants or greenhouse environments. It integrates a suite of sensors to monitor conditions such as soil humidity, temperature, CO_2 levels, air quality, and light, while enabling automated watering and illumination based on these environmental measurements. This project uses the STM32WB5MM-DK kit to connect to an MQTT server via Zigbee, which allows data processing and automation through Node-RED with a web interface. A custom 3D-printed enclosure and hardware setup support various sensors and actuators for comprehensive plant care management are part of its innovative design.

www.elektormagazine.com/STM32Contest/plants



The Electric Meter That Matters

Submitted by BDeliers

This project transforms traditional electric meters, specifically Linky meters used in France, into smart devices capable of integrating with modern smart home ecosystems using the Matter Over Thread protocol. Utilizing the STM32WB5MM-DK, the project captures real-time data on power consumption, including current, voltage, and total energy consumed, and transmits this information wirelessly to a user's smartphone. A custom PCB interfaces with the electric meter to collect data, which is then processed by the microcontroller and shared via the smart home network. The project's comprehensive documentation, including schematics and source code, is available on GitHub.

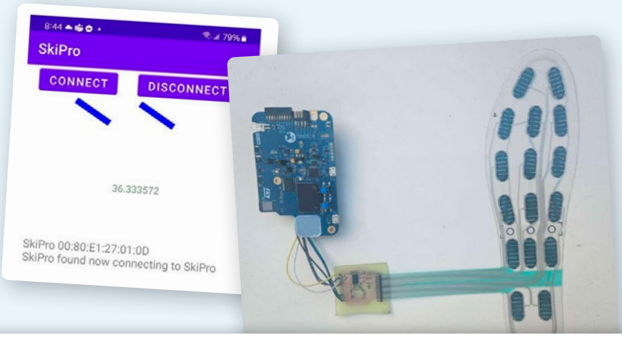
www.elektormagazine.com/STM32Contest/meter

Open-Source Multifunction Variometer for Paragliding

Submitted by CJZ

This project offers a variometer for paragliding and hang gliding. It features GNSS positioning, accelerometer data, temperature sensing and extensive flight data recording, all built on the STM32WB5MM-DK kit. The hardware design is compact and robust and ideal for flight conditions. The device's software, which was developed in C++17, is open-source and employs effective libraries to ensure optimal functionality.

www.elektormagazine.com/STM32Contest/variometer



BLE Ski & Snowboard Performance Evaluation

Submitted by Vir

This project utilizes the STM32WB5MM Discovery Kit to provide real-time analysis of edge angles and pressure distribution for skiers and snowboarders. This technology aims to help users improve their techniques by offering insights into crucial performance metrics, including the ability to achieve higher edge angles for better carving and understanding foot pressure distribution to enhance overall performance. The system includes a mobile app for visualizing data, making it a valuable tool for athletes looking to refine their skills on the slopes.

www.elektormagazine.com/STM32Contest/ski

Winners' Announcement: April 10, 2024

Jury members from STMicroelectronics and Elektor will now once again review the five nominated projects and then select the top three for prizes. The official announcement is scheduled to take place at the ST booth (Hall 4A-148) during the embedded world Exhibition & Conference in Nuremberg, Germany on Wednesday, April 10, 2024, at 5:00 PM. All participants, and the five nominees in particular, are cordially invited to attend the prize-giving ceremony. During the ceremony, we will look back at the contest one more time. We hope to hear from the winners about how their projects came about.

With the code **ew24ELE**, you can order a free entrance ticket from the embedded world website. For those who cannot attend embedded world in person, the winners will also be announced on the contest page and in various Elektor newsletters on April 12.

STM32 Wireless Innovation Design Contest: Details and Prizes

The contest challenged participants to display their engineering creativity and design skills by developing innovative wireless-less applications with STM32 solutions from STMicroelectronics. The judges are assessing the submissions based on the following criteria: creativity and innovation; technical excellence; functionality and practicality; aesthetics and user experience; and documentation and presentation.

The judges will select three prize winners:

- 1st Prize: **€2,500**
- 2nd Prize: **€1,500**
- 3rd Prize: **€1,000**

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Good luck to all the nominees!

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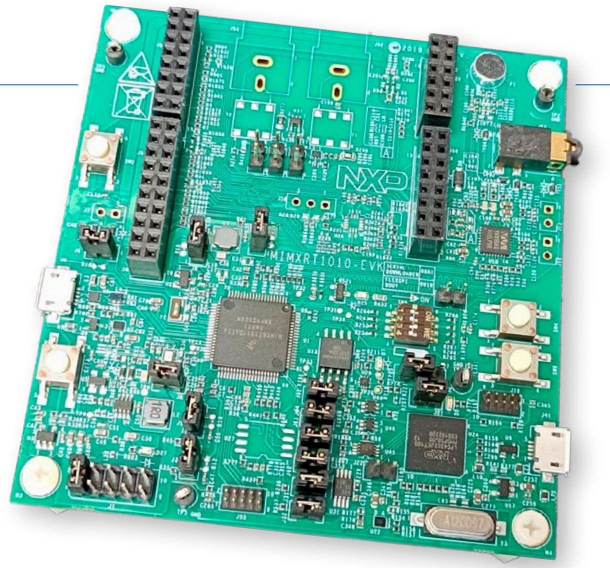


NXP i.MX RT1010 Evaluation Kit

Ideal for Audio Applications and Motor Control

By Clemens Valens (Elektor)

The MIMXRT1010 Evaluation Kit (EVK) is based on NXP's i.MX RT1010 microcontroller unit (MCU). This MCU is part of the i.MX RT Crossover family, featuring high-performance Arm Cortex-M cores. Although most members of this family are optimized for real-time Ethernet protocols in industrial IoT and automotive applications, the RT1010 is not.

The MIMXRT1010-EVK (Evaluation Kit) is based on NXP's i.MX RT1010 microcontroller unit (MCU) [1]. This MCU is part of the i.MX RT Crossover family that features high-performance Arm Cortex-M cores (some even have two). Most members of this family are optimized for real-time Ethernet protocols in industrial IoT and automotive applications, but the RT1010, one of the family's smaller devices, is more general purpose.

Inside the MCU

The iMX RT1010 is based on an Arm Cortex-M7 core, operating at speeds up to 400 MHz. More powerful members of its family add an Arm Cortex-M4 core to this. The processor has 128-KB on-chip RAM, configurable as tightly coupled memory (TCM) or general-purpose RAM. The SoC integrates a power management module that greatly simplifies powering the device. Of course, there is a range of connectivity interfaces, including UART, SPI, I^{2}C, I^{2}S, and USB. An ADC and temperature sensor have not been forgotten either.

Audio Applications

The iMX RT1010 is a general-purpose device with a slight preference for audio applications, as it has rich audio features, including SPDIF and I^{2}S audio interfaces. The evaluation kit the MCU is mounted on accentuates this by integrating a WM8960 audio stereo CODEC from Wolfson, a headphone socket, loudspeaker connections, an on-board condenser microphone and (unpopulated) footprints for SPDIF connectors.

Other Applications

Besides audio applications, the iMX RT1010 is also good for motor control. To facilitate this, the EVK has connectors exposing PWM signals generated by the MCU's eFlexPWM module together with analog inputs for measuring currents and voltages. The MIMXRT1010-EVK is also supported by the Zephyr RTOS [2].

Other Peripherals

As is customary for evaluation boards, there is some more stuff on it intended to make application development a bit easier. MIMXRT1010-EVK is no exception. Besides the already mentioned audio and motor control peripherals, the board also has 128-Mbit QSPI flash memory (for program and data storage as the MCU doesn't have any) and 4 Mbit LPSPI flash memory, USB OTG, a user button and LED, and a 6-axis motion sensor with 3-axis accelerometer and 3-axis magnetometer.

Arduino Shields Are Supported Too

Arduino-UNO-style extension headers are available too, but in a special way, as they consist of double-row headers instead of single-row. The inside rows are Arduino shield compatible, while some of the outside rows provide access to the motor control interface.

Debugging Made Easy

To facilitate application development, the EVK comes with built-in debug support. Besides a JTAG header, there is also a Freelink Interface (a leftover from Freescale) with a USB port (also provides power to the board). This interface is supported by MCUXpresso, NXPs Eclipse-based integrated software development platform.

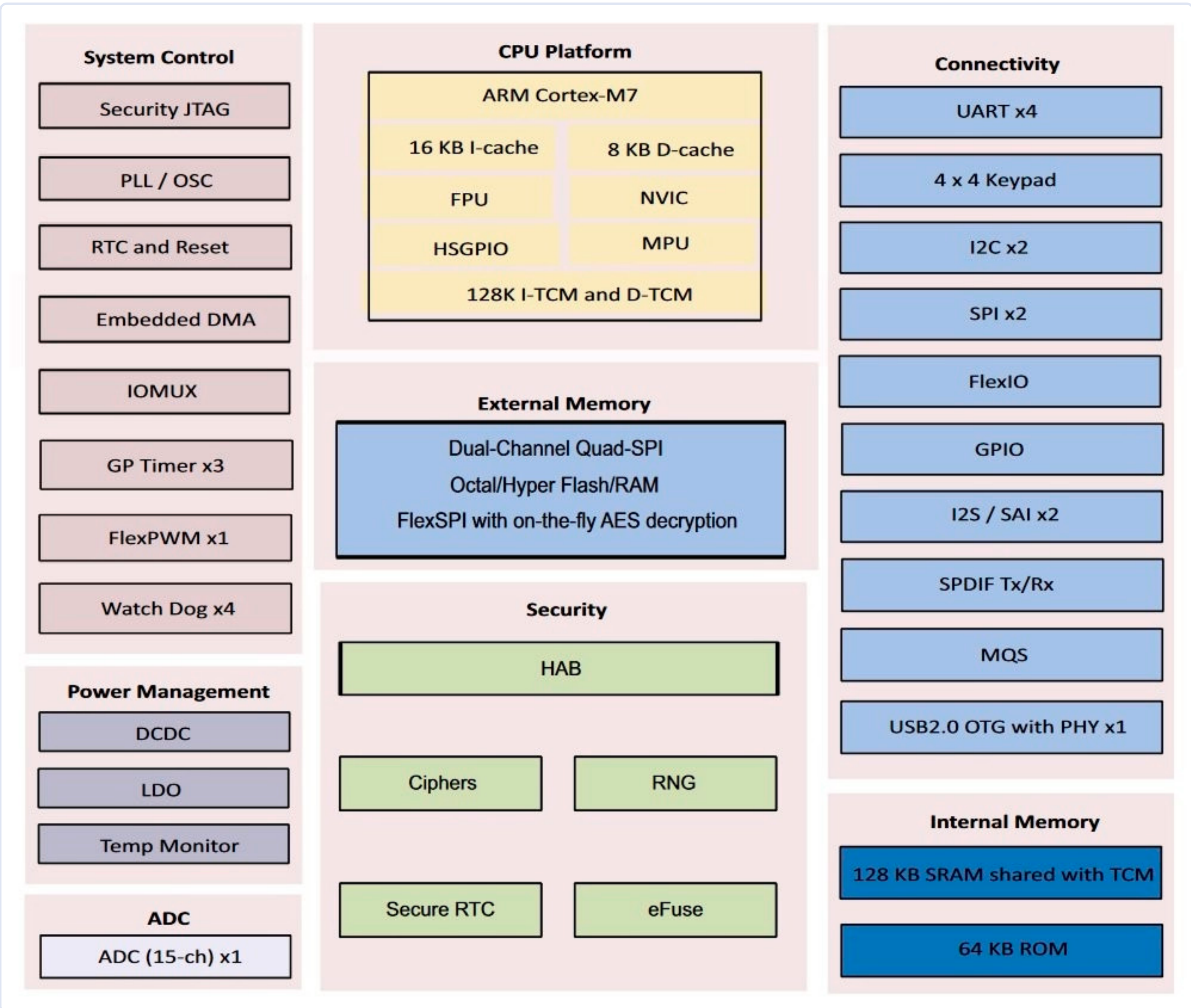
MCUXpresso and Examples

This brings us to software development. As said above, MCUXpresso is the cheapest way to get started with the MIMXRT1010-EVK as it is free of charge. It comes with an extensive SDK providing many examples for almost all the peripherals available on the MCU and on the EVK. All you need to do is import the example you are interested in, compile it, and upload it to the board.

Many examples come in three versions: *bm*, *lite_bm* and *freertos*. BM stands for bare metal (i.e., without an operating system like FreeRTOS). The lite examples are bare-metal examples but with a minimal USB stack. The more complex examples come with some documentation, but deeply hidden away in a subfolder

Figure 1: Block diagram of the iMX RT1010 microcontroller. (Source: NXP)

▼



of a folder with the name of the board (*evkmimxrt1010*) which also holds a precompiled executable.

I tried a few examples, and they all worked without a hitch. Once uploaded, you can immediately run or debug the code by stepping through it or by setting breakpoints.

A Surprising Demo

A curious example that I tried is *evkmimxrt1010_dev_audio_generator_bm* that emulates a USB audio playback device. After compiling and uploading the code, Windows discovers a *USB AUDIO DEMO* device that you can listen to. However, instead of playing some sweet music, the demo cries: "Out! Out! Out! Out! ...".

Of course, the EVK and the iMX RT1010 processor are also supported by the established tool chain manufacturers.

Documentation?

Because getting started with a new processor is always a bit daunting, and even more so when it comes packed with many complex peripherals, good documentation is important. This is, unfortunately, the weak spot of the MIMXRT1010-EVK. There isn't much and what there is, doesn't tell you a lot. It does, however, include the board design files with a schematic in PDF, so you can find out how e.g. the extension ports are wired. For everything else, you should consult the MCU's datasheet.

Get the Book!

As documentation is lacking, you may want to read the new Elektor book entitled *Get Started with the NXP iMX RT1010 Development Kit* [1] by Dogan Ibrahim. The book describes the processor, the evaluation board, and how to develop applications for it with MCUXpresso in much more detail than NXP, so it is a great way to get started.

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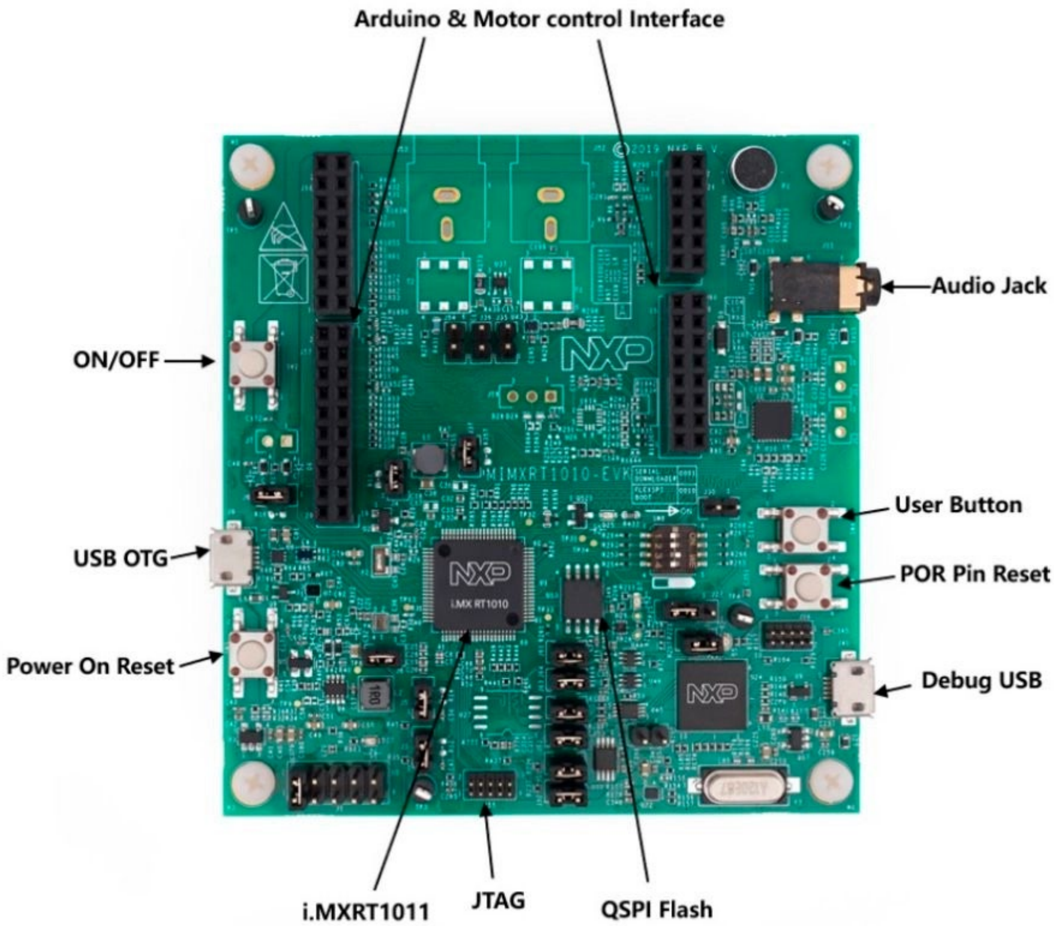

Figure 2: Location of the peripherals on the MIMXRT1010-EVK. (Source: NXP)

WEB LINKS

[1] Get Started with the NXP iMX RT1010 Development Kit: https://elektor.com/get-started-with-the-nxp-i-mx-rt1010-development-bundle
[2] Zephyr RTOS: https://docs.zephyrproject.org/latest/boards/arm/mimxrt1010_evk/doc/index.html

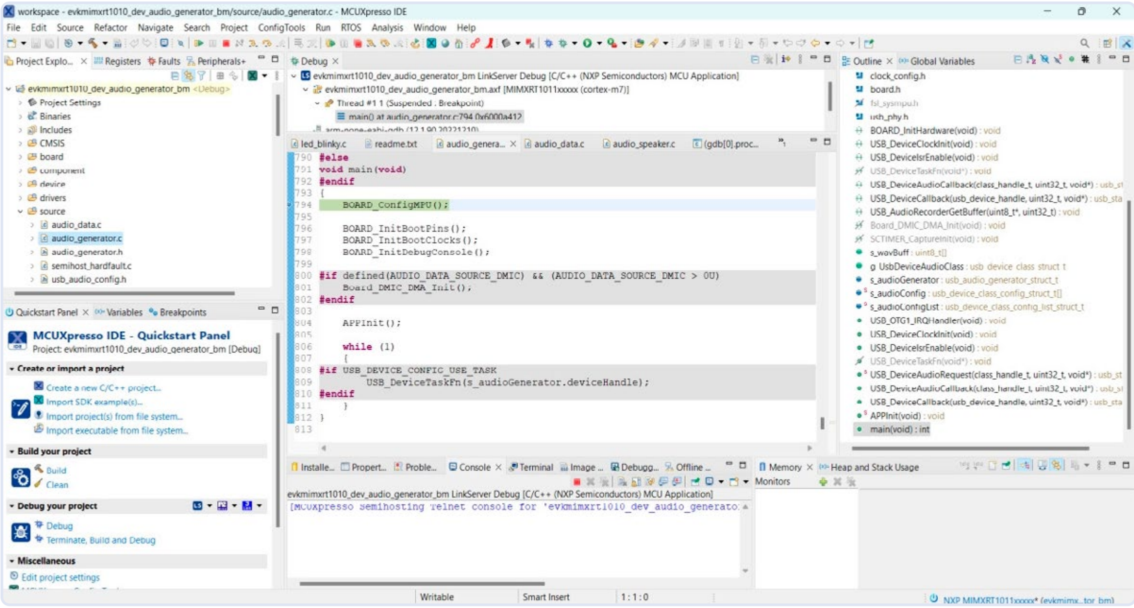

Figure 3: Stepping through a code example in MCUXpresso.

Questions or Comments?

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

About the Author

After a career in marine and industrial electronics, Clemens Valens started working for Elektor in 2008 as Editor-in-Chief of Elektor France. He has held different positions since and recently moved to the product development department. His main interests include signal processing and sound generation.

Related Products

- Dogan Ibrahim, ***Get Started with the NXP i.MX RT1010 Development Bundle* (Elektor 2023)**
  www.elektor.com/20699

Open Source
and Its Significance for the Electronics Industry

Arduino UNO and Raspberry Pi are two long-standing open-source solutions. (Source: Mouser Electronics)

By Mark Patrick (Mouser Electronics)

Using open-source software solutions can quickly provide engineers with a wealth of resources, which helps reducing development time and costs. Can these benefits also apply to the hardware? In this first article of a two-part series, we will discuss what is meant by open source for both software and hardware, before exploring success stories from within the electronics industry.

With embedded and miniaturized hardware solutions continuing to expand their reach by fulfilling new uses, increasing in performance, and reducing in cost, more developers are turning to standardized, open-source or license-free software solutions. Due to the complexity of many of the latest implementations, the development of software for embedded hardware, such as real-time operating systems (RTOS), can be time-consuming and costly.

Using open-source or license-free software solutions can quickly provide engineers with a wealth of resources that are both ready to implement and free to use. This helps to generate faster development cycles through knowledge sharing and overcome issues related to proprietary development, such as slow updates and a lack of interoperability.

Can these benefits also apply to the hardware? Open-source hardware has long been a difficult-to-navigate landscape with potential vulnerabilities, including a lack of intellectual property (IP) protection and higher component costs, but there are some areas such as education and prototyping where it has already been incredibly successful.

Defining Open-Source Software and Hardware

For many people, the term "open source" is intrinsically linked to freeware or the public domain. But, in reality, this is not quite the case. While many open solutions are free, this does not mean they grant complete ownership. Similarly, closed-source products do not necessarily incur costs, and there are key distinctions between freeware, open-source, and closed-source, along with specific nuances that vary depending on whether we refer to hardware or software systems.

The significant difference, which is often missed, is licensing. While freeware should have no usage rights or license, all open-source solutions are licensed, and there are strict definitions for both software and hardware.

Open-Source Software Definition

The Open Source Initiative (OSI) [1] is a non-profit organization founded in California during the late 1990s. They are the software industry's steward for open-source applications, and their aim is to build education and promote awareness of the importance of non-proprietary software.

For software solutions, ranging from personal computer applications to wireless protocols and RTOS, the software must meet a strict ten-point criteria in order to be classified as open-source.

Within this criterion, the OSI states that open-source software must be freely distributed, but in contrast to freeware, it is licensed. Under this license, all source code must be available, compiled, and further distribution allowed. Deliberately obfus-

Figure 1: The OSHWA logo carried by certified open-source designs. (Source: OSHWA)

cated source code is not allowed; neither are intermediate forms, such as the output of a pre-processor or translator. An open-source license should allow code modification for developers to create their own derivative works, and to redistribute these licenses under the same terms as the original software. The software cannot be specific to a single product or hardware solution, and it should not discriminate against certain fields of endeavor or groups. The technology must be neutral and not infringe on other software.

Therefore, while licensed, all open-source software must be readily available for anyone to study, modify, distribute, or sell. Systems such as the Apache web server, Zephyr RTOS, Matter, and Linux are all open-source solutions reliant on a combination of user and industry collaboration for development.

Open-Source Hardware Definition

The open-source hardware definition is governed by the Open Source Hardware Association (OSHWA) [2], founded in 2012. It is based on the OSI's software definition but comes with some further criteria that must be met to achieve open-source certification. In line with the OSI's requirement for open-source code, the Open Source Hardware (OSHW) Definition 1.0 [3] requires published CAD design files in common file types.

OSHWA's definition outlines strict contingencies for hardware solutions that are reliant on software for operation, such as microcontroller units (MCUs). For these hardware solutions, embedded or otherwise, any required software must also be open source. Or, if only closed-source software is provided, the hardware architecture and interfaces must be documented so that developers can easily produce software that fulfills all essential functions.

Any hardware meeting this definition should also be made publicly available so that anyone can study, modify, or distribute the solutions. It should enable people to reproduce the hardware based on the design's schematics and redistribute the design themselves with the same license agreement.

The majority of open-source hardware solutions are microcontroller-based, where value is delivered through user development. Examples include the Arduino UNO R4 Minima [4][5], Raspberry Pi 5 Single Board Computer [6][7], and Adafruit Feather M0 Bluefruit LE [8][9].

Certified Hardware

To aid engineers looking for open-source solutions, OSHWA introduced the Open Source Hardware Certification program. This certification verifies that the project's open-source hardware definition aligns with OSHWA's definition of open source.

With the certification comes the legal right to use the OSHWA certification logo, making it easy for engineers to identify designs. Alongside this, every design is cataloged and listed online, with its documentation on the OSHWA certification site [10] (**Figure 1**).

To ensure the program is widely available, it is self-certified by designers and there is no cost associated. In order to earn the certification, a design should, where conceivable, use entirely open-source components. However, OSHWA acknowledges that this is not always possible, and some third-party closed source components are allowed where no open-source option is available.

Open-Source Enforcement

Despite OSHWA's clear definitions and certification program, the criteria are not always correctly understood or implemented, which can create a number of issues for engineers using the design, ranging from incompatibility to liability.

To ensure that any design using the mark is truly compliant, in addition to conducting their own checks, OSHWA encourages the community to raise concerns immediately with them for investigation.

To help manufacturers achieve — or regain — compliance, OSHWA's penalty system for incorrectly using its logo is time-based. When manufacturers suspected of breaching the certification respond to OSHWA or alter their designs within a reasonable time period, no fines are imposed. However, continually failing to modify a design can lead to significant fines of up to $10,000 per month [11].

Open-Source Hardware Success

There is no doubt about the power of open-source hardware for educational and development services. The previously mentioned UNO R4 Minima [5] from Arduino is a perfect example (**Figure 2**).

The UNO R4 Minima comes with a wide range of on-board peripherals, such as the 12-bit DAC, an OpAmp, and CAN Bus interface, as well as 14 digital I/O pins, and supports a wide range of shields and carriers. This adaptable package is also backed by Arduino and its wider community's extensive library of reference codes and projects.

Figure 2: Arduino UNO R4 Minima. (Source: Mouser Electronics)

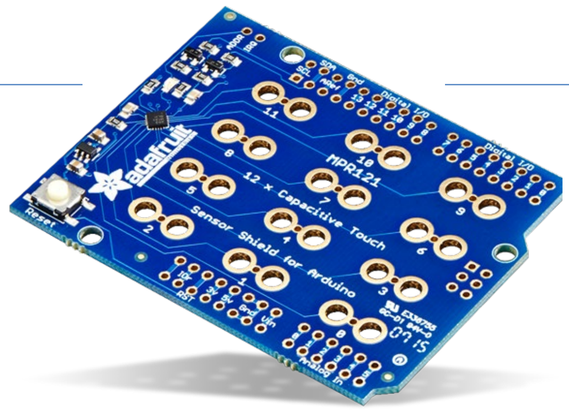

Figure 3: Adafruit 12x Capacitive Touch Shield. (Source: Mouser Electronics)

For pre-production development, single application, and student projects, such as a bespoke PLC or measurement instrument, the R4 is an ideal solution that uses the strengths of open source to benefit the engineer and end user. Such is the success of the UNO, as 2021 saw Arduino celebrate sales of over 10 million boards worldwide with a limited-edition board [12].

The open-source nature of the UNO R4 Minima enables simple development of a wide range of Arduino and third-party add-ons, referred to as "shields." The 2024 12x Capacitive Touch Shield [13] (**Figure 3**) from Adafruit is based on NXP Semiconductors' [14] proximity capacitive touch sensor technology and is compatible with the latest Arduino UNO R4 family [15].

Through this Adafruit board, the Arduino UNO R4 can connect to 12 capacitive touch sensors through a simple crocodile clip connection. In an educational or development environment, this shield allows for the rapid evaluation or modification of touch-sensing solutions for applications, including remote controls and peripherals, without extensive and costly redesign.

Speeding Up Projects

Open-source solutions and wider industry collaboration will always play a vital role within the electronics industry, but the overall viability of any solution will often depend on the application. For development, educational, and prototyping solutions, there can be no doubt about the ability of open-source software and hardware to remove barriers, speed up projects, and enable wider community collaboration.

But, for commercial solutions going to the market, the pros and cons of open-source systems must be fully understood to determine their true feasibility. In part two of this series, we will explore the value of open-source designs for the electronics market, the challenges of open-source hardware, and how to use open-source solutions successfully for products going to the market.

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About the Author

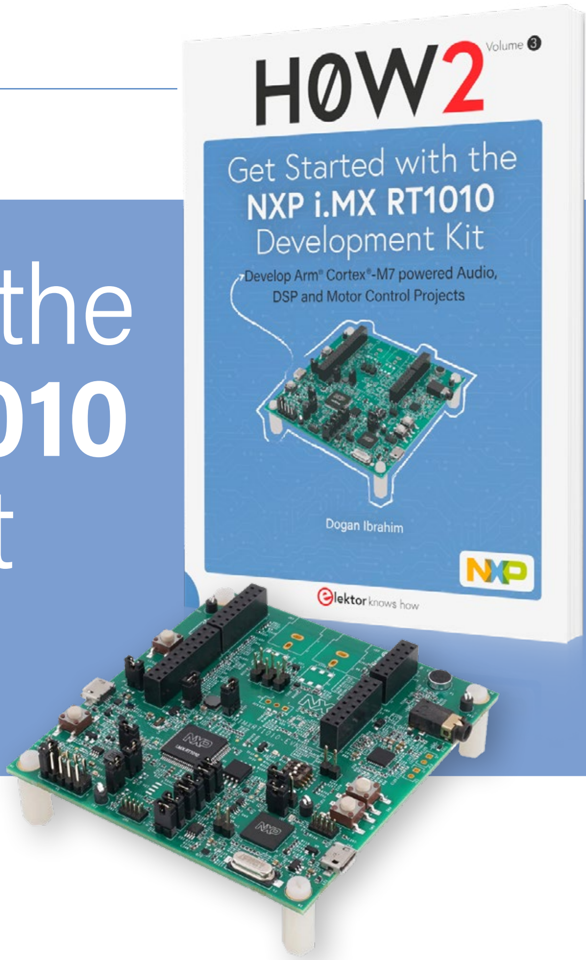
As Mouser Electronics' Director of Technical Content for EMEA, Mark Patrick is responsible for creating and circulating technical content within the region – content that is key to Mouser's strategy to support, inform, and inspire its engineering audience. Before leading Technical Content, Mark was part of Mouser's EMEA Supplier Marketing team and played a vital role in establishing and developing relationships with key manufacturing partners. Mark's previous experience encompasses hands-on engineering roles, technical support, semiconductor technical sales, and various marketing positions. A "hands-on" engineer at heart, Mark holds a first-class Honors Degree in Electronics Engineering from Coventry University. He is passionate about vintage synthesizers and British motorcycles and thinks nothing of servicing or repairing either.

WEB LINKS

[1] Open Source Initiative (OSI): https://opensource.org
[2] Open Source Hardware Association (OSHWA): https://oshwa.org
[3] Open Source Hardware (OSHW) Definition 1.0: https://oshwa.org/definition
[4] Arduino Boards [mouser.com]: https://tinyurl.com/arduino-manufacturer
[5] Arduino UNO R4 Microcontroller Board [mouser.com]: https://tinyurl.com/arduino-uno-rev-4-boards
[6] Raspberry Pi [mouser.com]: https://tinyurl.com/raspberry-pi-manufacturer
[7] Raspberry Pi 5 Single Board Computer [mouser.com]: https://tinyurl.com/raspberry-pi-5-sbc
[8] Adafruit [mouser.com]: https://tinyurl.com/adafruit-manufacturer
[9] Adafruit Feather M0 Bluefruit LE Development Board [mouser.com]: https://tinyurl.com/adafruit-feather-m0
[10] OSHWA certification site: https://certification.oshwa.org/list.html
[11] OSHWA Certification License Agreement: https://certification.oshwa.org/license-agreement.html
[12] Arduino UNO Mini Limited Edition: https://store.arduino.cc/pages/uno-mini-le
[13] Adafruit 2024 12x Capacitive Touch Shield [mouser.com]: https://tinyurl.com/adafruit-2024-capacitive-touch
[14] NXP Semiconductors [mouser.com]: https://tinyurl.com/nxp-semiconductors
[15] Arduino UNO R4 Shield Compatibility: https://docs.arduino.cc/tutorials/uno-r4-minima/shield-compatibility

Audio DSP with the **NXP MIMXRT1010** Development Kit

An Intro to Arm Cortex-M7-Powered Sound Processing



By Dogan Ibrahim (United Kingdom)

At the heart of NXP Semiconductors' MIMXRT1010 Development Kit is the i.MX RT1010 Crossover MCU sporting an Arm Cortex-M7 core truly capable of running power- and memory hungry DSP applications. The popular MCUXpresso IDE is key to creating software for the development kit, while a powerful SDK is provided to reduce program development time and effort. Find out for yourself if you're a DSP programmer or even a fan, with this get-u-going article.

Editor's Note: *This article is an excerpt from the 275-page "HOW2" series book:* Get Started with the NXP i.MX RT1010 *(Elektor, 2023). The excerpt was formatted and lightly edited to match Elektor Mag's editorial standards and page layout. The author and editor have done their best in such editing and are happy to assist with queries. Contact details are in the* **Questions or Comments?** *box.*

The acronym DSP stands for one of two things: digital signal processor, or digital signal processing. A digital signal processor refers to specialized microcontroller hardware designed to execute specialized instructions in real time.

DSP is a very broad field covering signals from very low to very high frequencies. Here, we are interested only in audio signals which cover the frequency range of 20 Hz to 20 kHz. In a typical DSP application, the input signal (e.g., from a microphone) can either be digital or analog. In the case of analog input, the signal is converted into digital form using an ADC (analog-to-digital converter) and is fed to a microcontroller for further processing. The signal is then processed, such as filtered to remove unwanted high-frequency noise, noise is canceled using special noise-canceling algorithms, the frequency spectrum of the signal is extracted and analyzed, signal shape is modified, audio signals are synthesized, and so on, and the resulting digital signal is converted back into analog using a DAC (digital-to-analog converter) and sent to a speaker or to some other output device.

All of the signal processing is carried out using software algorithms with the target microcontroller. It is much easier to edit and manipulate digital signals than analog signals. DSP is used extensively nowadays by professional music makers. Many plugins are available on PCs which simplify the editing and processing of already recorded music files and other audio files. The global audio DSP market size was valued at $11.06 billion in 2019, and is projected to reach $23.43 billion by 2027 (*Allied Market Research*). In this chapter, you will be using the MIMXRT1010-EVK development board for some real-time DSP projects.

The SAI Module

SAI is a Serial Audio Interface module that can be used to send and/or receive audio. In addition to I²S, it supports other audio interfaces as well. The MIMXRT1010-EVK development board includes two synchronous SAI modules, which support I²S, AC97, TDM, codec/DSP

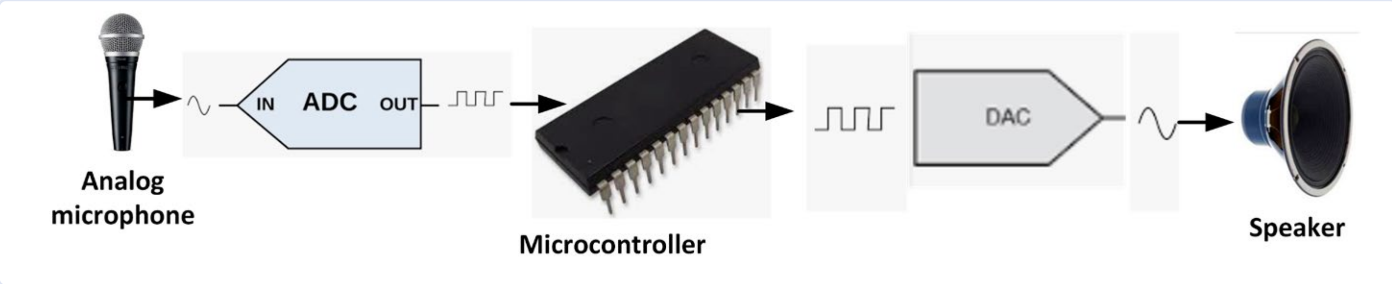


Figure 1: Conventional audio DSP system.

interfaces, and MQS interface for medium quality audio via GPIO pad. MQS is used to convert I²S audio data from SAI3 to PWM, and then can drive external speakers, but in practical use, an amplifier drive circuit is required. Additionally, a headphone jack, external speaker connections, and a microphone are provided on the board.

The I²S Bus

The I²S (Inter-Integrated circuit Sound protocol) is a serial bus interface standard used commonly to connect digital audio devices together. It was introduced in 1986 by Philips Semiconductors (now NXP Semiconductors) and then revised in 1996 and 2022. The I²S protocol sends pulse-code modulation (PCM) digital audio data from a controller to a target. The bus has at least 3 lines: **bit clock**, **word select**, and **data line**. Word select is used to specify which of the stereo channels, left or right, the data should be sent to. Readers should understand that the I²C and I²S are entirely different bus protocols, and they are unrelated.

Figure 1 shows the block diagram of a conventional audio DSP system which does not use the I²S bus. Here, the audio signal is received from an analog microphone. This signal is then converted into digital form using an ADC. The resulting digital signal is then fed to a microcontroller, which processes this digital signal. At the end, the signal is converted back into analog using a DAC converter and is fed to a speaker. An analog amplifier is usually used (not shown) to increase the signal level for the speaker. In most low frequency applications, the ADC and DAC can be part of the microcontroller. In high-speed and high-quality applications, it may be necessary to use external professional quality ADC and DAC converters.

Figure 2 shows the block diagram of a digital audio DSP system using the I²S bus interface. Here, a digital microphone is used, compatible with the I²S bus. The output of the microphone, which is a digital signal, is fed to the microcontroller's I²S bus input. The signal is processed by the microcontroller as required and is sent in digital form to an I²S compatible amplifier module. The output of the amplifier is an analog signal which drives the speaker.

The functional definitions of the I²S bus lines are summarized below.

Bit clock: this pin is the serial clock line, usually denoted as BCLK. The clock runs continuously.

Word select: this pin is usually denoted by WS, and it selects the channels. 0 corresponds to the left channel, while 1 corresponds to the right channel.

Data: This pin is usually denoted by SD, or SDATA and is the serial data line. The data is sent out in 2's complement format, with the MSB bit first. The transmitter and receiver do not need to have an agreed-upon word length; the transmitter sends what it has, and the receiver takes what it can use. New data bits can be clocked out on the rising or falling edge of the clock. However, they must be clocked in on the rising edge.

The bit clock is sent out for each bit of data on the data line. The frequency of this clock is the given by the product of the sample rate, the number of bits per channel, and the number of channels. In a typical audio CD, the standard is 44.1 kHz sample rate with 16 bits of data. Assuming 2 channels (i.e. stereo), the bit clock frequency will be:

$$44.1\ \text{kHz} \times 16 \times 2 = 1.4112\ \text{MHz}$$

Therefore, if you want to send two channels of high-quality audio, you would need a clock rate of 1.4112 MHz. The telephone quality sound is sampled at 8 kHz with 8 bits and there is only one channel. Therefore, to send telephone quality audio, you will need a clock frequency of:

$$8\ \text{kHz} \times 8 \times 1 = 64\ \text{kHz}$$

I²S allows up to two channels to be used on the same data line, and this is selected by the Word select bit. For 2-channel stereo

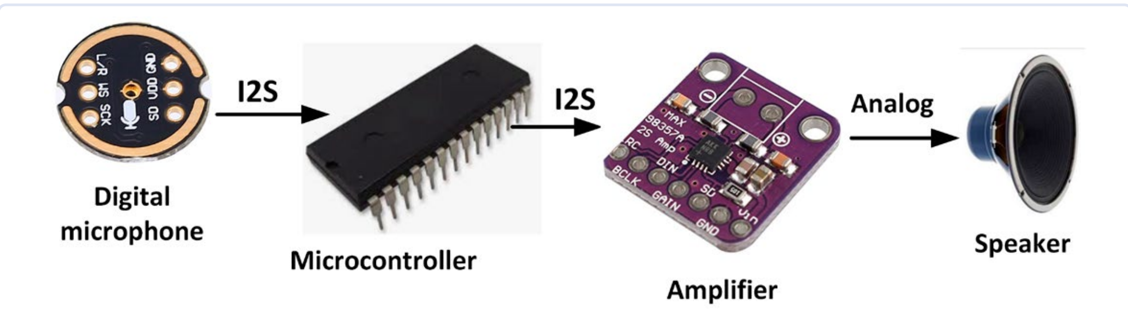


Figure 2: Digital audio DSP system.

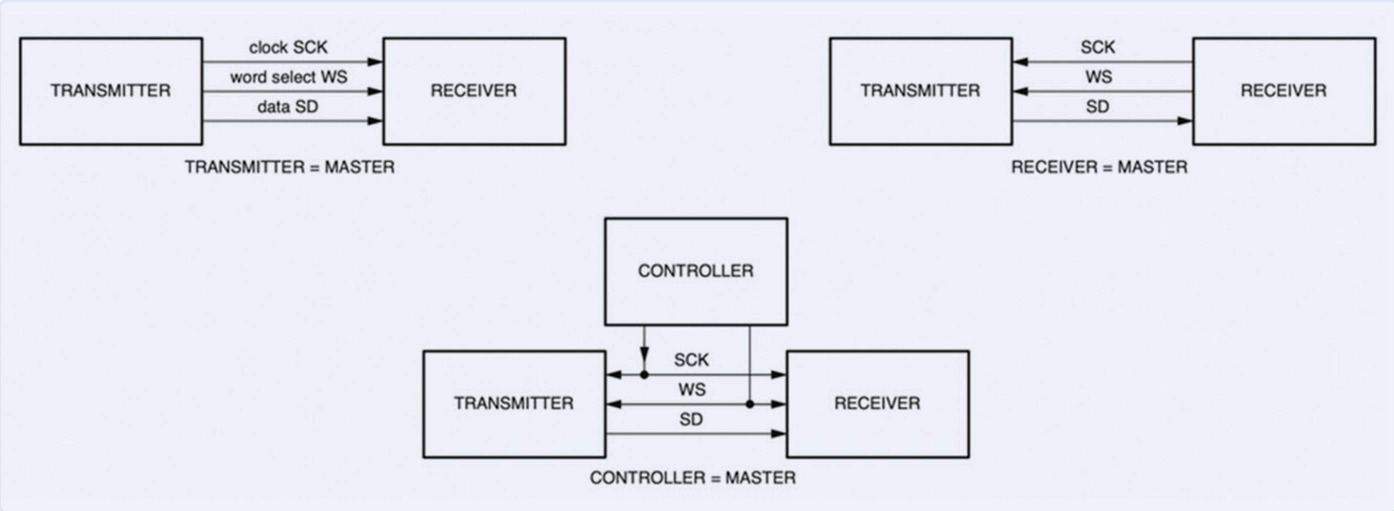


Figure 3: I²S configurations (taken from the I²S specification).

operation, the left audio is transmitted on the low cycle of the Word select, and the right channel is transmitted on the high cycle. The I²S bus is not like the I²C bus, where multiple devices can be connected on the same bus line. With I²S, only two channels of a device can be used; multiple devices cannot be connected to the bus. The maximum length of the I²S bus is specified as 3 meters.

The bit clock and Word select signals can be generated with a receiver, transmitter, or a third-party controller (see **Figure 3**).

Figure 4 shows the timing diagram of the I²S bus. The advantages of the I²S bus include:

- No data synchronization issues since there is a single master device.
- An I²S microphone does not require an analog front end.
- Separate clock and data lines are used, resulting in low jitter.
- Neither ADC nor DAC are required since the signals are digital.

The disadvantages of the I²S bus are:

- No error detection or correction — consequently, errors can occur on the line.
- As a result of the propagation delays, potential synchronization problems at high clock rates.
- No standard I²S cabling or connector procedure — manufacturers use proprietary cables and connectors.

The SAI Bus

The SAI module on the MIXRT1010-EVK development board contains a Transmitter and Receiver with the following signals:

- SAI_MCLK: master clock, used to generate the bit clock, master output, slave input.
- SAI_TX_BCLK: Transmit bit clock, master output, slave input.
- SAI_TX_SYNC: Transmit Frame sync, master output, slave input, L/R channel select.
- SAI_TX_DATA[4]: Transmit data line, 1-3 shared with RX_DATA[1-3]
- SAI_RX_BCLK: receiver bit clock
- SAI_RX_SYNC: receiver frame sync.
- SAI_RX_DATA[4]: receiver data line.

The SAI module clocks are audio master clock, bus clock, and bit clock. The SAI module Frame sync has 3 modes:

1. Transmit and receive using its own BCLK and SYNC.
2. Transmit async, receive sync: use transmit BCLK and SYNC, transmit enable first, disable to close.
3. Transmit sync, receive async: use receive BCLK and SYNC, receiver enable first, disable to close.

The MIMXRT1010-EVK Development Kit Audio Demo Project Files

Several audio demo project files are included in the MCUXpresso SDK. These files are in the demo folders *demo_apps* and

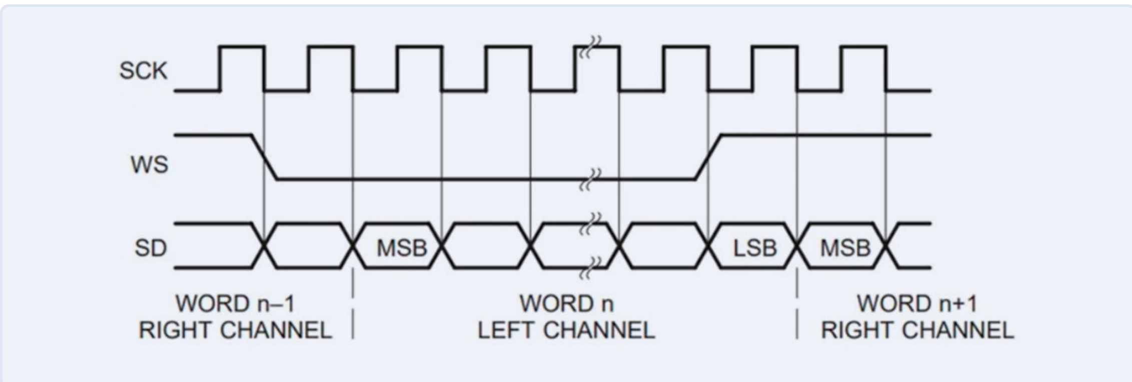


Figure 4: I²S bus timing (taken from the I²S specification).

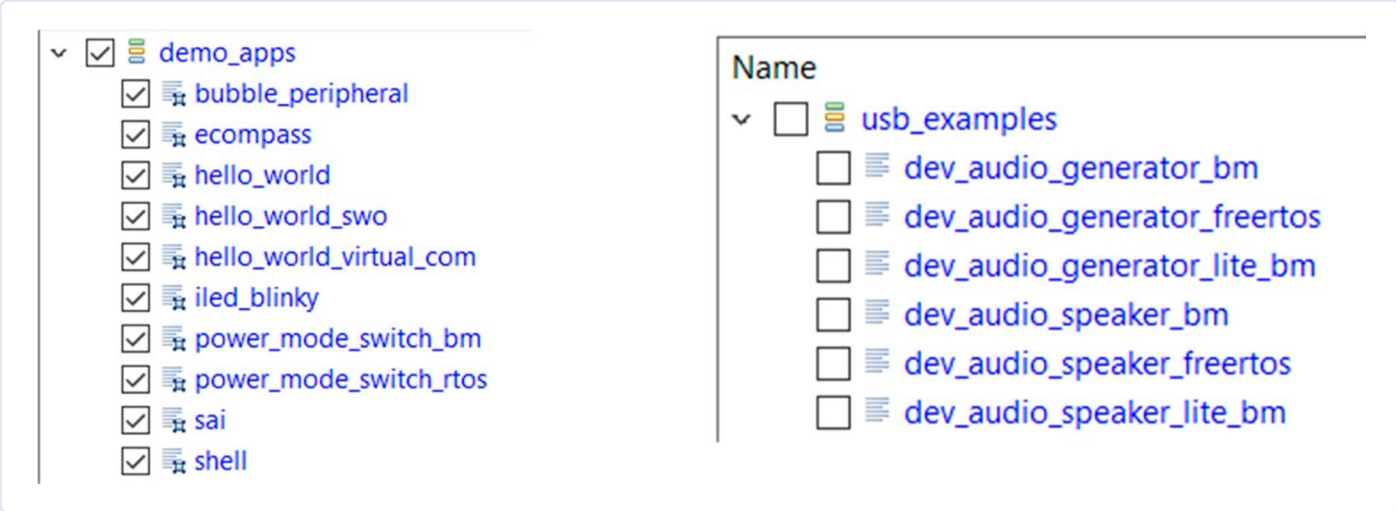


Figure 5: Audio demo project files.

usb_examples (**Figure 5**). There is only one file (*sai*) in *demo_apps*, and six files in *usb_examples* (*dev_audio_...*). You can modify and use these project files in your own projects.

The programs discussed here are included in the software archive released in support of the book and project bundle. The archive is available for free downloading from the Books section of the Elektor Store website [1]. Once on the web page, scroll to *Downloads* and locate the file: *Software_Get Started with the NXP i.MX RT1010 Development Kit* (256.87 MB Zip file), download it, then save it on your system. Unzip the archive file and locate the sample program(s).

Now let's look at some details of project file *sai*. When this project file is run in debug mode, the following options are given to the user:

- Record and playback at the same time
- Playback sine wave

You can use the on-board analog microphone to record and at the same time play the recording. There is also the option of using an SD card and an external digital microphone, but these are disabled in the code and are highlighted. First, load the project files in the *sai* folder:

- Start the MCUXpresso IDE by specifying a workspace name.
- Click IDE.
- Click *Import SDK Examples* under the *Quickstart Panel*.
- Click to select *MIMXRT1011xxxxx* under *MIMXRT1010* and click *Next*.
- Click to expand *demo_apps* and select *sai* to load the project files and click *NEXT* followed by *FINISH*.

You should see the project files loaded. Click to expand *source* and you should see the following C programs:
playbackSineWave.c
recordPlayback.c
sai.c

sai program: This is the main program that runs when debugging is started. At the beginning of the programs, the required header files are included in the program and various CODEC and audio definitions are declared. Notice here that the headphone volume is set to 100 which is the maximum value (the range is 0 to 100). Then, the SAI1 clock source and frequency are defined. The *wm8960* Codec is initialized by specifying the route, left and right input sources, play source, the I²S bus, the format of the data (16-bit data with 16 kHz sample rate), and the *master_slave mode* is set to false. Code relating to the SD card and external digital microphone are highlighted and are not compiled.

The WM8960 Codec is initialized with the following options:

```
wm8960_config_t wm8960Config = {
.i2cConfig = {.codecI2CInstance = BOARD_CODEC_I2C_INSTANCE,
.codecI2CSourceClock = BOARD_CODEC_I2C_CLOCK_FREQ},
.route = kWM8960_RoutePlaybackandRecord,
.leftInputSource = kWM8960_InputDifferentialMicInput3,
.rightInputSource = kWM8960_InputDifferentialMicInput2,
.playSource = kWM8960_PlaySourceDAC,
.slaveAddress = WM8960_I2C_ADDR,
.bus = kWM8960_BusI2S,
.format = {.mclk_HZ = 6144000U, .sampleRate = kWM8960_AudioSampleRate16KHz, .bitWidth = kWM8960_AudioBitWidth16bit},
.master_slave = false,
};
```

Where `kWM8960_InputDifferentialMicInput2` refers to the on-board analog microphone, and `kWM8960_InputDifferentialMicInput3` to the headphone microphone.

Inside the main program loop, the LPI2C and SAI1 clocks are set and MCLK is enabled. Function `CODEC_Init()` initializes the Codec. Function `CODEC_SetVolume()` sets the volume to `DEMO_CODEC_VOLUME` on the right headphone. The program displays the message `SAI Demo Started` on the console, initializes the SAI, configures I²S, enables interrupts to handle FIFO errors, and then displays the following menu (note that the SD card and external digital microphone options are disabled):

Please select the option:

- Record and Playback at same time
- Playback sine wave
- Quit

If option 1 is selected: The board is configured for record-playback by calling function `BOARD_CONFIGCODEC_FOR_RECORD_PLAYBACK()`. Finally, the function `RecordPlayback()` is called (program: `recordPlayback.c`) to record audio and playback on the headphone.

If option 2 is selected: function `BOARD_CONFIGCODEC_FOR_RECORD_PLAYBACK()` is called, followed by function `PlaybackSine()` (program: *playbackSineWave.c*) to play a sine wave on the headphone.

playbackSineWave(): This function has three arguments: `base address`, `frequency` in Hz, and `duration` in seconds. The function `arm_sin_q15()` is called to generate values for trigonometric sine in q15 format. The generated sine wave values are stored in `audioBuff()`. The frequency of the data is then calculated by calling the FFT function `do_fft()`. The calculated frequency is displayed on the Console. The function plays a 250 Hz sine wave for 5 seconds. The Function `SAI_TransferSendEDMA()` is called to perform a non-blocking SAI transfer to the headphone using DMA. All the prepared data in `audioBuff()` is transmitted.

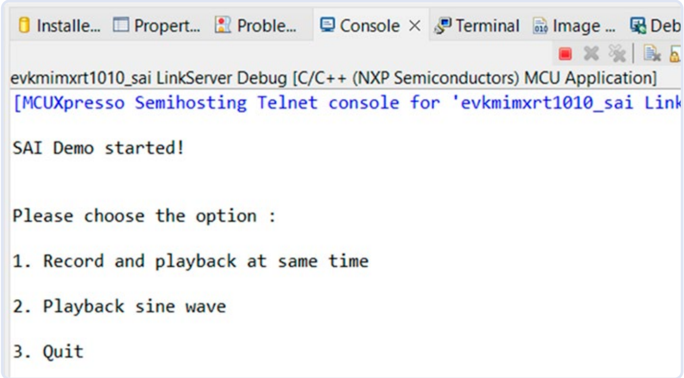


Figure 6: The menu.

recordPlayback(): This function has 2 arguments: the `base address` and the `duration` in seconds. In this project, the duration is set to 30 seconds by the calling program *sai.c*. This function calls `SAI_TransferReceiveEDMA()` to read non-blocking data using DMA from the microphone into structure `xfer` and then to transfer this data to the headphone by calling function `SAI_TransferSendEDMA()`, in non-blocking mode using DMA.

Testing (1, 2, 3…)

The steps to test the Audio DSP configuration are:

- Connect the MIMXRT1010-EVK development kit to your PC.
- Connect a headphone to the headphone jack.
- Click on the project name (*evkmimxrt1010_sai<Debug>*) in *Project Explorer*. Click *Quick Settings SDK Debug Console* and make sure that *Semihost console* is selected.
- Click *debug* under the *Quickstart Panel* to load the programs and start debugging.
- Click *Run* followed by *Resume* to start the program running in debug mode.
- You should see the menu displayed (**Figure 6**). Choose option 2 to hear the 250 Hz sine wave played for 5 seconds. You may find that the volume is very low.
- Choose option 1. Speak to the on-board analog microphone, and you should hear the sound on the right speaker of the headphone.
- Repeat the testing as many times as desired.
- Click *Run* followed by *Terminate* to exit the debug mode.

The dev kit offers great connectivity through its audio codecs, four-way headphone jack, external speaker connection, microphone, and Arduino interface. Conveniently, several on-board debug probes are supplied with the kit allowing you to debug your programs by talking directly to the MCU. Helped by the debugger, you can single-step through a program, insert breakpoints, view and modify variables, and so on. Using the MCUXpresso IDE and the SDK, many working and tested projects are developed in the book based on parts, modules, and technologies, including: LED and LCDs, ADC, I²C projects, SPI projects, UART projects, motor control, audio, and, as you've seen and heard (hopefully), digital audio processing (DSP)!

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About the Author

Prof. Dr. Dogan Ibrahim has a BSc degree in electronic engineering, an MSc degree in automatic control engineering, and a PhD degree in digital signal processing. Dogan has worked in many industrial organizations before he returned to academic life. Prof Ibrahim is the author of over 60 technical books and over 200 technical articles on microcontrollers, microprocessors, and related fields. He is a Chartered electrical engineer and a Fellow of the Institution of Engineering Technology.

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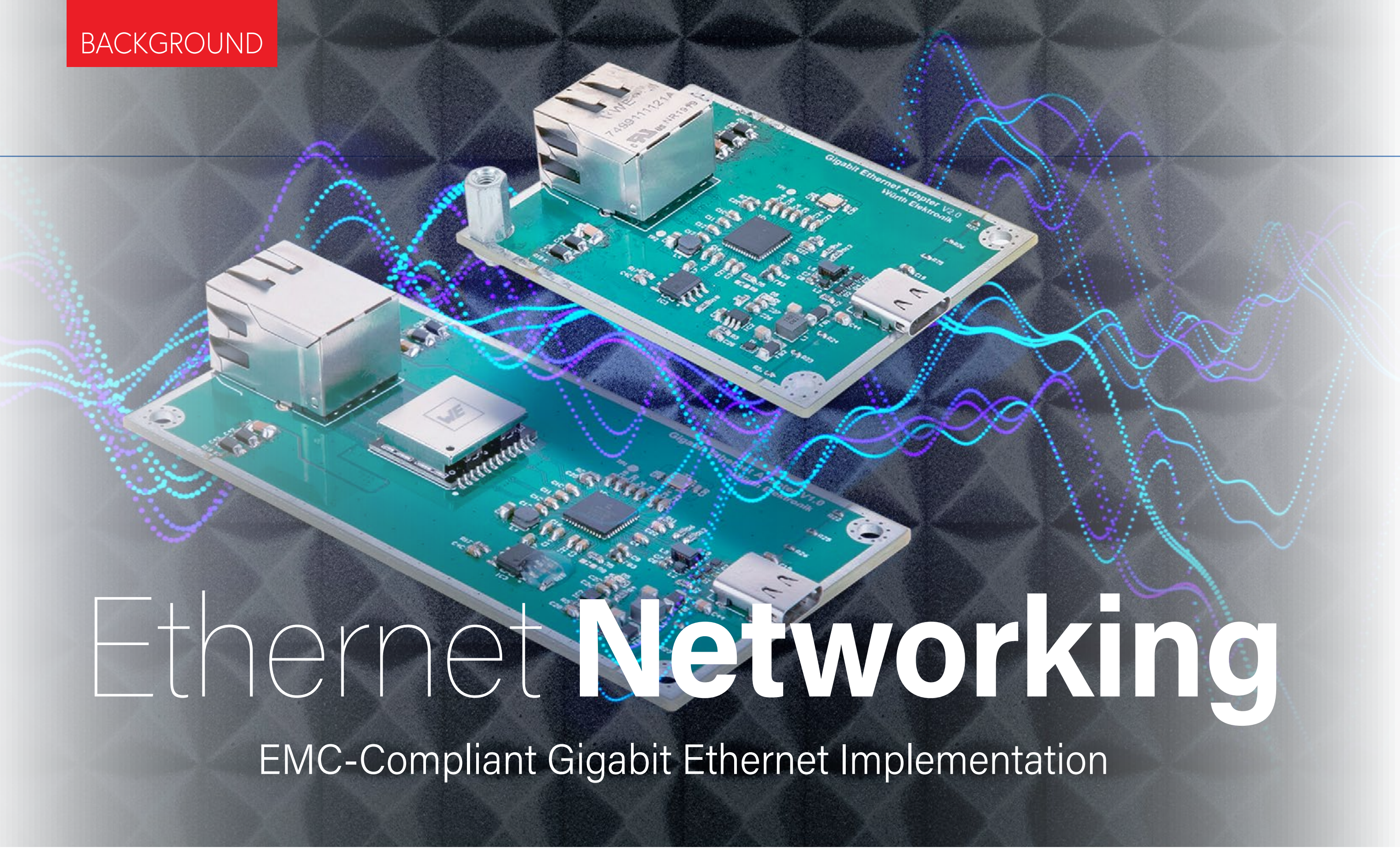
[1] Sample programs: https://elektor.com/get-started-with-the-nxp-i-mx-rt1010-development-bundle



Ethernet Networking

EMC-Compliant Gigabit Ethernet Implementation

By Dr. Heinz Zenkner (Würth Elektronik eiSos)

Gigabit Ethernet is currently the networking standard par excellence, both in the office and in industrial environments. However, there are a few pitfalls to avoid in terms of RF technology and EMC aspects. The Gigabit Ethernet reference design from Würth Elektronik provides a solution.

Gigabit Ethernet is a communication standard that has become widely accepted, whether in the home, in offices, or in factories. As a result, developers of network-capable electronic devices cannot avoid implementing a Gigabit Ethernet interface. With the 1 Gigabit Ethernet reference design from Würth Elektronik, circuit developers now have access to an optimized circuit design and layout with all technical data.

The RD016 reference design includes two interfaces, a USB Type C (USB 3.1) and a 1 Gigabit RJ45/Ethernet interface [1]. The Gbit-Ethernet-USB adapter is based on the EVB-LAN7800LC evaluation board from Microchip and was implemented on a four-layer PCB with power supplied via USB.

Ethernet Basics

Ethernet was first distributed worldwide at 10 Mbit/s over coaxial cable and later over unshielded twisted pair cables as 10BASE-T. Currently, 100BASE-TX (Fast Ethernet, 100 Mbit/s), Gigabit Ethernet (1 Gbit/s), 10 Gigabit Ethernet (10 Gbit/s), and 100 Gigabit Ethernet (100 Gbit/s) are available. For most purposes, Gigabit Ethernet works well with regular Ethernet cables, specifically CAT5e, CAT6 and CAT6a cabling standards. These cable types follow the 1000BASE-T cabling standard, also called IEEE 802.3ab.

Due to various factors such as network protocol overhead, retransmissions due to collisions on the transmission path, or sporadic data errors, the maximum usable data rate under normal conditions is 900 Mbit/s. The average connection speed varies due to many factors, such as the PC's hardware configuration, the number of clients at the router and, ultimately, the "quality" of the Ethernet cabling.

The 1-Gbit Ethernet interface operates according to the 802.3ab-1999 (CL40) standard and requires four channels of wire pairs for signal transmission. This results in a symbol rate of 125 Megabaud (MBd) with a bandwidth of 62.5 MHz per channel (2 bits per symbol). The Gigabit Ethernet protocol is characterized by some special features. The 1000BASE-T (Gigabit Ethernet) PHY performs a link configuration protocol called auto-negotiation. 8-bit data bytes are converted to 10-bit code groups. The 8B/10B code is robust and features useful properties such as transition density, run length limitation, DC compensation, and robust fault tolerance. All single-, double-, and triple-bit errors in a frame are detected with 100 percent reliability. Signal voltage at 1000BASE-T averages 750 mV differential, and limits are >670 mV, <820 mV at a load of 100 Ω.

Interface Structure and Required Hardware

RJ45 interfaces are designed for full-duplex transmissions, i.e., simultaneous transmission of send and receive data. This is possible because the connector has four pairs of wires, where one pair is always required for one direction (differential voltage principle). In principle, UTP (unshielded twisted

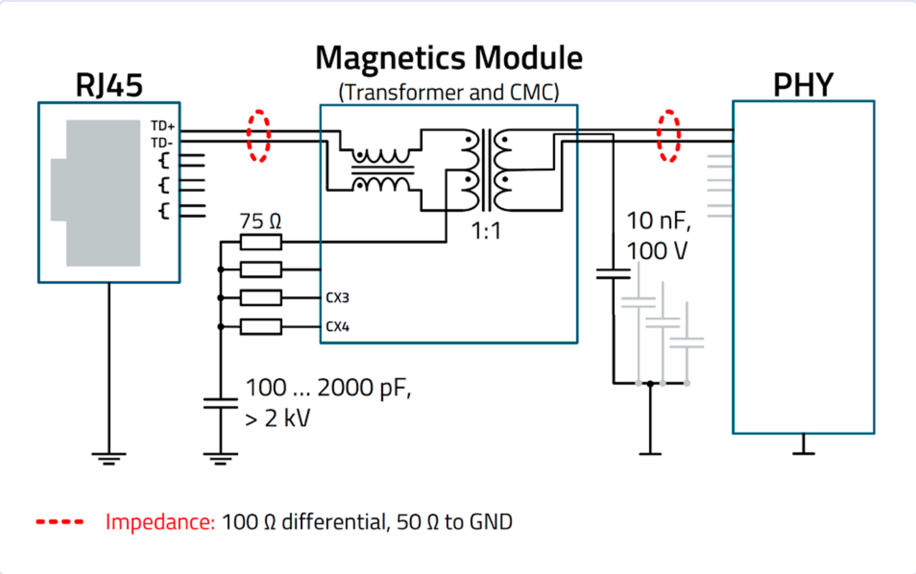


Figure 1: Schematic circuit of a 1 Gbit Ethernet interface. Only one of four channels is shown in the picture. (Source of all images: Würth Elektronik eiSos)

pair) has an impedance of 100 Ω and STP (shielded twisted pair) 150 Ω (1000BASE-T: IEEE 802.3, e.g. section 39). In the case of branded cables, categories 5e, 6 and 6a are available both shielded and unshielded, and categories 7 and 7a are always shielded. For each RJ45 connection, the IEEE standard requires galvanic isolation via a transformer. This transformer protects the devices from damage caused by high voltage on the line and prevents voltage offsets that can occur due to potential differences between the devices. **Figure 1** shows the principal circuit of the interface.

Coming in via the RJ45 interface, the Ethernet signal reaches the transformers via a common-mode choke. Figure 1 shows only one of four channels. The transformer has a center tap which, from a signal engineering point of view, represents a zero potential. Unbalances act as voltage at the center tap and are terminated to ground via the 75 Ω resistors, which are DC decoupled via the capacitor. The transformer has a transformation ratio of 1:1. On the secondary side, the Ethernet signal reaches the PHY via the four channels. Here, too, the impedance is 100 Ω differential, or 50 Ω each to ground (GND). The center tap of the transformer is AC-terminated to ground on the secondary side via capacitors.

1 Gbit Ethernet Adapter Board

The Gbit-Ethernet-USB adapter board is available in two different versions. V1.0 includes discrete components in the Ethernet interface area. That is, the matching network and the inductor block, consisting of common-mode chokes and transformers, are individual components placed on the PCB (**Figure 2**). In V2.0, the components mentioned are integrated into the housing of the RJ45 socket (**Figure 3**).

Block Diagram

The LAN7800 USB 3.1 Gigabit Ethernet controller connects the USB interface with the Ethernet interface as a “bridge” (**Figure 4**). Thus, only the signaling adaptations and decouplings must be implemented for the wiring of the interfaces. On the USB side, a DC/DC converter is used to generate the 3.3 V supply voltage required for the LAN7800. The LAN7800 needs an additional 4 Kbit EEPROM to store the firmware.

Circuit Elements

The controller, power supply, and USB 3.1 interface circuit elements are only touched upon here since the focus of this article is on the 1 Gigabit Ethernet interface.

Controller

The LAN7800 is a high-performance USB 3.1-to-1 Gigabit Ethernet controller with integrated Ethernet PHY. An external 4 Kbit EEPROM was added for the onboard software.

+5 V to +3.3 V Power Supply

The controller needs a supply voltage of 3.3 V. This is generated here with the TLV757P linear regulator. The LDO (low-dropout regulator) reduces the voltage from 5.0 V to 3.3 V. The 10 µF input and output electrolytic capacitors ensure stable operation, and the 100 nF X7R capacitor reduces high-frequency noise on the output side.

USB 3.1 Interface

The data lines of the USB interface are wired with common mode chokes against radio interference and with TVS diode arrays against transient overvoltages.

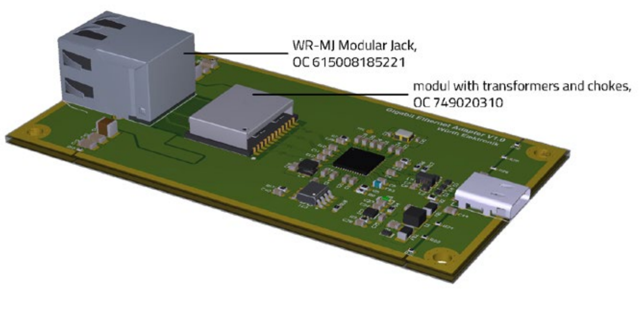


Figure 2: Gigabit Ethernet USB adapter board in the discrete version V1.0: The module with the transformers and common mode chokes is placed next to the RJ45 jack.

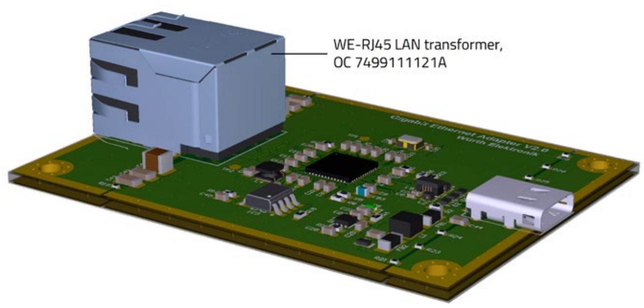


Figure 3: Gigabit Ethernet USB adapter board in the discrete version V2.0: The module with the transformers and common mode chokes is integrated in the RJ45 socket.

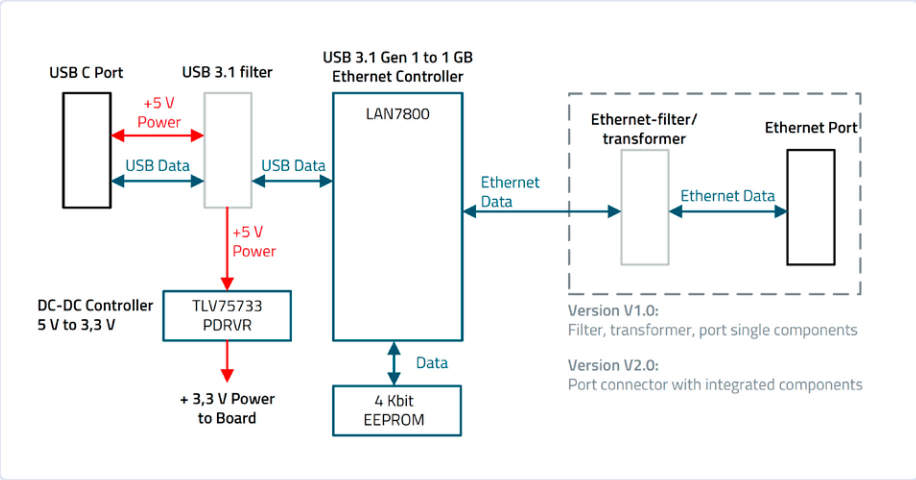


Figure 4: Block diagram of the Gbit-Ethernet-USB adapter board in both versions.

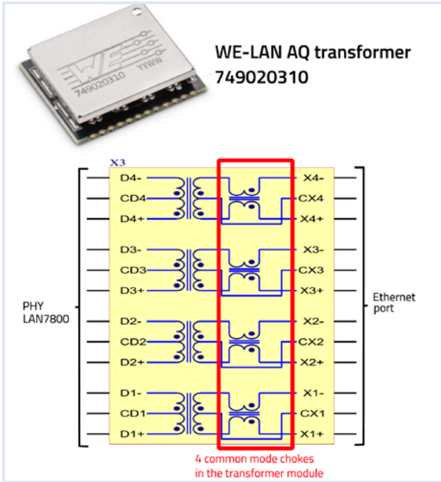


Figure 5: WE-LAN AQ transformer for galvanic isolation between PHY and Ethernet network.

Ethernet Interface

The Ethernet transformer (LAN transformer) is the interface between the device and the Ethernet cable. The transformer provides the safety-relevant galvanic isolation between the device and the cable and at the same time the impedance matching, on the one hand to the internal logic, and on the other to the Ethernet cable's symmetrical wire pairs of the Ethernet cable. Furthermore, the transformer protects the device from transient interference, suppresses common-mode signals between the transceiver IC and the cable, both from the device to the outside and from the external cable to the electronics in the device. However, the LAN transformer must also transmit data up to 1 Gbit/s broadband without significantly attenuating the transmit and receive signals. Additional components are required to meet the matching and EMC requirements. There are two approaches to building the interface:

- The use of a ready-made module in which the Ethernet socket, the transformer and the "Bob Smith" termination are integrated, referred to above as V2.0.
- A setup with discrete technology, here V1.0. All components need to be adapted to each other. However, the solution offers more degrees of freedom. A little more design effort is required, but the discrete version is less expensive and, for special requirements, isolation voltages of up to 6 kV can be achieved.

1 Gbit Ethernet Front End

LAN transformer X3 in **Figure 5** provides DC isolation between the electronics and the network cable. The test voltage for the transformer between the primary and secondary sides is 1,500 V_{RMS}.

The center tap of the primary side winding, i.e., to the Ethernet port, has the "Bob Smith" termination mentioned above. For each pair of wires, a 75 Ω resistor is connected to form a "star point", the entire circuit is then galvanically isolated, connected to the housing ground via two 100 pF capacitors connected in parallel. In the literature, one often finds capacitors with a capacity of up to 2 nF, which is a relatively high value in relation to the frequency range. The capacitors should have a dielectric strength of at least 2 kV.

The Bob Smith termination is used to reduce interference caused by common-mode current flows and to reduce susceptibility to interference from unused wire pairs on the RJ45 connector.

The Bob Smith termination is referred to an impedance of about 145 Ω per wire pair. Due to the market availability of many different cable types, differences in the base impedances of the various cable types, and the fact that the cables do not have a constant impedance over their length due to twisting, common mode chokes were also implemented (Figure 5). Thus, one transformer and one common-mode choke per channel are connected together in module X3. Although these chokes cannot correct the deviations of the impedance matching, they significantly improve the EMC behavior. The circuitry of the elements with passive components and TVS diodes as well as the PCB layout are described in detail [2].

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About the Author

Dr.-Ing. Heinz Zenkner studied electrical engineering with a focus on telecommunication and high frequency engineering and obtained his PhD in this field. He has been an officially appointed and sworn expert for EMC for many years. In addition to numerous scientific publications, he frequently contributes as an author in many works on EMC. Heinz Zenkner has worked at various Universities, at the German Chamber of Industry and Commerce (IHK) and at numerous seminars. He has been involved with industrial electronics for years now, from the first idea of product through to series production. His special interest lies in Wireless Energy Transfer, to which he has developed and patented his own theoretical and practical concepts.

WEB LINKS

[1] Reference Design RD016 – Gigabit Ethernet Front-End: https://we-online.com/RD016
[2] Application Note ANP116 – Gigabit Ethernet Interface from an EMC perspective: https://we-online.com/ANP116

Q&A With Benedikt Weyerer and Prof. Dr.-Ing. Axel Sikora

embeddedworld
Exhibition&Conference

Questions by the Elektor Content Team

In April, the embedded world Exhibition&Conference in Nuremberg, Germany, will unite the entire embedded community, offering an unparalleled overview of the latest innovations in the industry. We asked Benedikt Weyerer (Executive Director of embedded world) and Prof. Dr.-Ing. Axel Sikora (Chairman of the embedded world Conference) about what attendees can expect from the event that will help shape the future of the embedded sector.

Figure 1: Prof. Dr.-Ing. Axel Sikora (Chairman of embedded world Conference)

Figure 2: Benedikt Weyerer (Executive Director of embedded world)

With the embedded world Conference being a pivotal meeting point for experts and industry leaders, how do you ensure the event continues to evolve and stays at the forefront of emerging technologies and embedded industry trends? What is in store for attendees at embedded world 2024?

Axel Sikora: Indeed, the embedded community is developing at a very rapid pace, and it is a challenge to not only keep track, but to shape some discussions. And of course, there is not a simple recipe, but a combination of different activities with manifold stakeholders:

- There are intense discussions with industry, especially in the advisory board, who help to bring in their ideas.
- We have a program committee of more than 50 experienced experts from applied research and sciences, who help to shape the conference program.
- We have a steering board of senior experts, who are driving ideas and ensuring overall quality.
- In addition, we are collaborating with more than 20 worldwide communities and associations, who are specialists in their respective domains. We are trying to bring them together and shape our community of communities.

Networking and knowledge exchange have always been key aspects of the event for visitors and exhibitors alike. Do you have anything special planned for the 2024 event that will help both attendees and exhibitors effectively network and interact with others?

Benedikt Weyerer: Visitors and exhibitors at embedded world can get in touch with each other at the exhibitor's forum and at the expert panels, for example. In 2024, for the first time, we also plan to organize a high-level panel with leading personalities from embedded world. The aim is to discuss general trends, overarching challenges and looming opportunities, and thus to increase the scope of the event.

Source: NürnbergMesse/ Heiko Stahl

The “Promotion” topic is also very well-represented in 2024: For the first time, we have two start-up areas — in Hall 3A and Hall 5 — and an investors’ forum. With this new format, we are building a bridge between the active start-up scene in the embedded community and decisionmakers from the manufacturing and user industry, research and development, and the financial world (VCs).

embedded world Conference attendees will be eager to discuss a wide range of topics and trends, including topics such as hardware, tools, application software, and IC design. Looking ahead, what are some of the core themes or technologies that you and your team believe will dominate the discussions at the conference?

Axel Sikora: Facing the multitude of ongoing trends, this is really a tough question! It is clear that embedded world is concentrating on the technological side of things, not going into deep application issues. Main topics certainly include legacy topics around connectivity in all its different flavours (from cost or performance optimized wired systems over high performance or Low-Power Wide Area Networks), embedded security, safety issues, novel CPU and MCU developments (mostly around RISC-V), new IC architectures for artificial intelligence (about which we will speak later), IC and board level interfaces, embedded vision, and certainly many more!

This naturally leads to the discussion of overarching challenges, like how to cope with increasing complexity, how to meet the demands for updatability and repairability, how to fulfil regulatory and legal requirements, and also how to keep ethical aspects in scope.

Sustainability and technology are increasingly intertwined. How is the embedded world Exhibition&Conference addressing the importance of sustainability within the embedded systems industry? Could you elaborate on any initiatives or programs aimed at promoting sustainability and eco-friendly practices within the fair?

Benedikt Weyerer: The NürnbergMesse Group is constantly striving to improve and promote sustainability and environmentally friendly practices in all areas. For example, our service partners who are responsible for booth construction are instructed to use reusable and durable products, such as environmentally friendly consumables. In addition, 100 % green energy is used to continuously reduce water and energy consumption. Our goal is to inspire innovation and drive positive change towards a more sustainable future.

What measures and strategies do you use to ensure smooth coordination during the build-up phase of the embedded world fair, given the intricate logistics involved with hundreds of exhibitors setting up simultaneously? Were there any challenges in the past?

Benedikt Weyerer: The NürnbergMesse Group switched to a new, dynamic exhibition logistics system in 2023. With just a few clicks, customers can book their time slots for loading and unloading. The system thus smoothes out the peak traffic periods for entering and exiting the exhibition cpentre and within the loading yards, and reduces waiting times for the carriers. Efficient traffic control using the new digital trade fair logistics system offers goods vehicle drivers greater comfort, reduces traffic volumes and carbon emissions on the access roads to the Exhibition Centre, and saves the freight firms time and thus also costs.

What initiatives or programs are in place to ensure inclusivity and diversity within the embedded systems community, especially in terms of supporting women in the industry?

Benedikt Weyerer: We are very proud that our networking event #women4ew is entering its second round. This year, we were able to attract five speakers from the tech industry, who will present various topics in panel and table talks to the participants (as the event is open to all interested parties). Afterwards, there will be room for questions, networking and dialog.

What is the embedded award at embedded world 2024, and how does the community choice award work? Moreover, can you provide additional information on the eligibility criteria for companies to enter the award, along with the benefits they can expect?

Benedikt Weyerer: The embedded award honors the most innovative products from the embedded systems industry. It will be presented in eight categories. The jury has just received this year’s entries and will select three nominees for each category. And therein lies the difference to the community choice award, which will be presented for the first time at #ew24: The winner of the community choice award is not determined by the jury. Instead, the embedded community can vote for their favorite among all the nominees.

What trends and developments do you predict will shape the future of the embedded systems industry in the coming years?

Axel Sikora: In addition to the issues mentioned above, we are facing the challenge that it is not good enough to concentrate on a single challenge only, as complex as it might be. We have to combine the different solutions, weigh them up and find optimum solutions in the growing complexity of systems of systems. And all this against the background of commercial viability and future-proof developments. Consequently, we also believe that embedded world is a unique event that brings together all the different disciplines on a technological level and is more relevant than ever.

How do emerging technologies such as AI, IoT, and edge computing impact the development of embedded systems and their applications?

Axel Sikora: To be honest, I wouldn't call these technologies emerging, as they have been around for many years and even decades. For me, they are rather enabling technologies. Let's go through your list.

- Edge computing is at the core of the "embedded" approach, having computational resources close to the sensor, the actuator, the application. But it is also clear that together with a flexible and powerful team-play together with cloud computing, we are reaching new architectures and solutions. For me, the emerging trend is here rather what we call "fog computing" or "liquid computing," where the different resources can be flexibly and dynamically used.
- Also for this (but certainly not only), the "Internet of Things" or "embedded connectivity" is an enabling technology. We have had it on the agenda for around 25 to 30 years. So, it has very much matured, but is certainly still roaring and innovating.
- When it comes to AI, I love to highlight that the predecessor event of embedded world back in the 1990s was called "embedded intelligence." However, at that time it was rather fiction, whereas nowadays we are getting into the real stuff of "embedded AI" with unforeseen computational performance at the edge, but also interplaying with the cloud.
- Interestingly, all three enabling technologies depend on and drive each other: Modern embedded systems connect intelligent edge devices with cloud based fully-fledged AI.

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embeddedworld
Exhibition&Conference
April 9–11, 2024 - Nuremberg, Germany
www.embedded-world.de

(Source: NürnbergMesse)

Elektor at embedded world: Hall 5-181

About Benedikt Weyerer

Benedikt Weyerer found his way to the NürnbergMesse rather by chance. Before he joined the embedded world Exhibition&Conference, he worked in event management helping to shape the cultural and nightlife in Bavaria and Austria. Today the embedded community continues to benefit from this experience, for example at the legendary exhibitor parties held on the first day of the exhibition.

Trained as a business economist, Weyerer first had to find his feet in the embedded industry. "At the beginning, I knew very little about embedded systems. But I found a great mentor in Prof. Matthias Sturm, our former technical advisor, who imparted knowledge to me with an amazing calmness and serenity and answered all my questions," Weyerer says with a laugh. "Without him, I would not have grown into this industry so quickly." Together with the event team, he has been organizing the embedded world Exhibition&Conference for more than ten years.

About Prof. Dr.-Ing. Axel Sikora

Dr.-Ing. Axel Sikora is a full professor at Offenburg University, Germany, where he founded and leads the Institute of Reliable Embedded Systems and Communication Electronics. Also, he is a deputy member of the board at Hahn-Schickard Association of Applied Research, a major research institute in microsystem technologies, where he manages the Software Solutions division. He is deeply involved in several technology spinoffs. For many years, he has been chairman of the annual embedded world Conference, the world's largest event on the topic, which — after being staged for 20 years in Nuremberg — is now extended to Shanghai and Austin.

NEWS

New 12-Bit Oscilloscopes by Siglent

Address Signal Fidelity Challenges on Every Bench

Source: Adobe Stock / @ALEXEY FILATOV @ARAMYAN

Contributed by Siglent

Siglent is excited to unveil three new series of oscilloscopes designed to improve signal fidelity, visualization, and analysis. These latest additions complete our lineup of oscilloscopes, each equipped with advanced 12-bit analog-to-digital converters (ADCs) and designed for signal quality. With bandwidths ranging from 70 MHz to 4 GHz, Siglent's high-resolution oscilloscopes now provide outstanding signal fidelity for a wide range of applications including power, EMI, frequency analysis, embedded design, and failure analysis.

Design for Signal Quality

These oscilloscopes provide a combination of low noise, gain accuracy, and channel isolation that deliver capability and value to the engineer on the bench. The SDS800X HD (**Figure 1**) and SDS1000X HD (**Figure 2**) are all typically specified at just 70 µVrms noise at 200 MHz bandwidth [1][2]. Across all of Siglent's high-resolution oscilloscopes, the lower ranges are specified at 1.5% DC gain accuracy, with the ranges ≥5 mV/div having a leading 0.5% accuracy. The SDS3000X HD series (**Figure 3**) offers up to 60 dB of channel-to-channel isolation [3]. From 70 MHz and up, engineers looking to solve difficult signal fidelity challenges can now get performance capabilities at an incredible value thanks to Siglent's focus on signal quality and design.

Visualization

To maximize the benefits of high-resolution vertical acquisition, Siglent's oscilloscopes enable simultaneous zooming in both the horizontal and vertical directions on live signals, which, coupled with the advantage of large memory capacity, facilitates extensive analysis and reveals numerous insights that are typically hidden. This works closely with a broad set of ranges designed with high offset capability, enabling engineers to discover smaller signal anomalies further away from ground, by focusing the ADC on smaller areas of interest and bringing these signals into focus. The combination of range and zoom capability gives an engineer unmatched power to view and analyze small signal details. When visualizing signals in the RF space, the ability to calculate deep memory FFTs on low-noise, 12-bit data provides additional methods for debugging and analyzing high-speed signals.

Extensive Functionality

An additional high-resolution mode, called ERES, provides even further noise reduction and flexibility. The equivalent of up to 4 extra bits of resolution is available on the SDS3000X HD. Utilizing the high sample rate and deep memory, this mode further improves noise performance at the expense of bandwidth, enabling engineers to optimize their oscilloscope's performance for any application.

All models are equipped to measure more than 50 parameters, support simultaneous mathematical operations across four channels, and feature a formula editor enabling nested formulas. Additionally, all three oscilloscope series support functionalities such as Mask Test, Bode Plot, Power Analysis, Search, and Serial Decode. Optionally, 16 digital channels can be added to enable analysis of mixed signal designs. Together with Siglent's SAG1021I isolated signal generator or any Siglent arbitrary waveform generator, the loop response test can be carried out to provide the frequency response curve of the device under test. With this, the gain and phase of each frequency point can be easily obtained. Meanwhile, with the help of data list, cursor measurement and automatic measurement functions, the Bode plot curve can be analyzed in detail.

The three new oscilloscopes all have high-definition touch screens (7″ or 10.1″), advanced web control, and network drive data capabilities. The combination of an intuitive user interface with multiple one-button operations on the front panel with seamless remote access greatly improves the operating efficiency in any use mode.

Combined with our SDS2000X HD and SDS7000A series, Siglent has the broadest and most complete portfolio of high-resolution oscilloscopes currently available, ranging from 70 MHz to 4 GHz. The focus on signal quality, visualization tools, and features means that regardless of the application, Siglent has a performance oscilloscope to deliver signal fidelity at an incredible value.

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Figure 1: SDS824X HD digital storage oscilloscope with a bandwidth of 200 MHz and 4 channels.

Figure 2: SDS1204X HD digital storage oscilloscope with a bandwidth of 200 MHz and 4 analog channels plus 16 digital channel mixed signal analysis ability.

Figure 3: SDS3104X HD digital storage oscilloscope with a bandwidth of 1 GHz and 4 analog channels plus 16 digital channels for high performance mixed signal analysis.

WEB LINKS

[1] SDS800X HD: https://siglenteu.com/digital-oscillopes/sds800x-hd-digital-storage-oscilloscope
[2] SDS1000X HD: https://siglenteu.com/digital-oscilloscopes/sds1000x-hd-digital-storage-oscilloscope
[3] SDS3000X HD: https://siglenteu.com/digital-oscilloscopes/sds3000x-hd-digital-storage-oscilloscope

Powerline Communication for eMobility

New Qualcomm-Based RED-BEET-x 2.0 PLC Module

By Christian Nick (Codico)

Codico and its long-standing partner 8devices have now developed a new series of modules, based on Qualcomm's latest PLC chip — the QCA7006AQ — that addresses the needs for electric vehicle charging applications (on both EV and EVSE side).

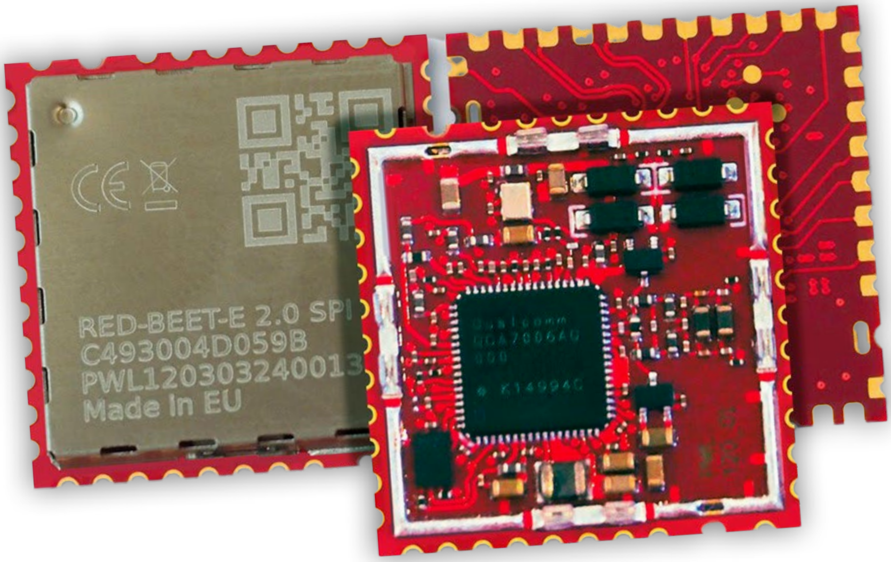

Figure 1: RED-BEET-E 2.0 for electric vehicle supply equipment (EVSE).

HomePlug Green Phy PLC module with improved features, such as a higher operating temperature range, AOI during production, and the latest Qualcomm chip coming along with a new evaluation board for either newcomers to get started or for established users to adapt their next design to the extended features.

International standards ISO/IEC 15118, DIN 70121 and SAE J2847/2 define the use of HomePLug Green PHY for EV identification and charging as well as billing information exchange via PnC (Plug and Charge), for AC as well as DC charging, meanwhile extended for bidirectional power transfer (BPT) applications.

RED-BEET-x 2.0 (**Figure 1**) is a universal power line communication module which provides SPI and Ethernet interfaces to the user to allow HomePlug Green PHY (HPGP) communication for EVSE/PEV and also higher HomePlug AV (HPAV) data rate connectivity. It provides best-in-class analog front-end noise performance, thermal management with a maximum operating temperature of +105°C (ambient), and higher quality by performing automated optical inspection during manufacturing. Just like its predecessors, the RED-BEET-x 2.0 offers a thermal pad to dissipate heat away from the QCA chip.

There are three different versions of the module available, and, despite the primary focus on eMobility (EVSE and PEV), it's also a perfect fit for smart grid, smart meter, IoT, and other long-range communication applications.

- **RED-BEET-E 2.0**
  For electric vehicle supply equipment (EVSE) — either SPI- or Ethernet-preconfigured
- **RED-BEET-P 2.0**
  For plug-in electric vehicles (PEV) — either SPI- or Ethernet-preconfigured

RED-BEET-H 2.0
For IoT, smart grid/meters, long-range PLC —Ethernet-preconfigured

All these modules are based on the Qualcomm QCA7006AQ chip, which, besides the usual SPI interface, now enables a 10/100 Ethernet PHY interface and the ability to run HomePlug AV firmware besides HomePlug Green PHY. This chip meets all ISO 15118-3 requirements and DIN 70121 standards for PLC applications.

Highlights

- Based on the Qualcomm QCA7006AQ all-in-one, automotive-grade HPGP/ HPAV PLC chip
- Compliant with ISO 15118-3, HPGP, and HPAV standards
- Fully interoperable with IEEE 1901 specification products
- Based on OFDM (orthogonal frequency division multiplexing) with a 1.8 MHz to 30 MHz spectrum (2 MHz to 28 MHz on radiating wires and in eMobility)
- Extended PHY rate of 9.8 Mbps via HPGP (QPSK) and 200 Mbps via HPAV (16, 64, 256, 1,024 QAM)
- Host interfaces SPI slave, Ethernet with embedded 10/100 Ethernet PHY, UART
- TCXO with operating temperature range -40°C up to +105°C (ambient)
- Automotive grade components used on module
- Serial flash on module with latest HPAV/HPGP firmware and configuration file (PIB)
- Available configurations are EVSE, PEV, and IoT/Home Control
- Single power supply 3.3 V DC with on-chip integrated power management unit
- Power consumption approx. 1 W (SPI) / 1.2 W (Ethernet) (both at 25°C)
- -95 dBm analog front end noise performance
- 23.3×23.3 mm, 40-pin package
- Castellated vias for enabling of AOI on host PCB, improved mechanical stability, simplified testing
- Automatic optical inspection (AOI) during production to ensure product quality
- Removable clamped EMC shielding
- Laser-engraved marking

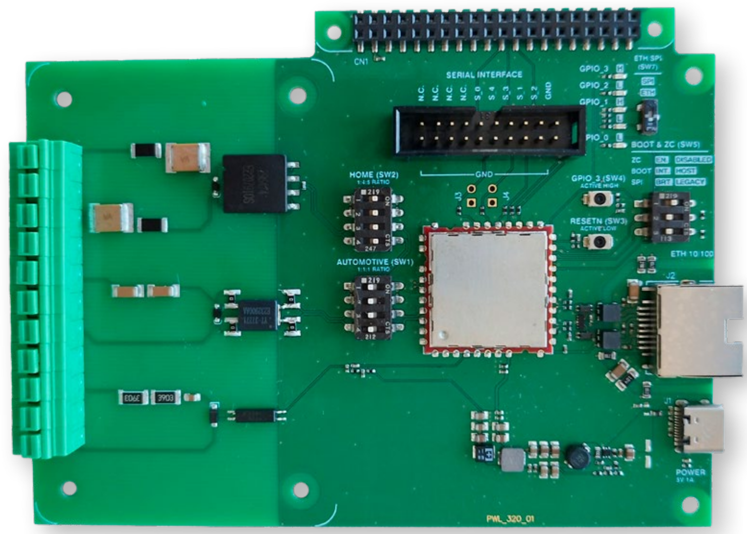

Figure 2: RED-BEET-EVAL-BOARDs for all these types of modules.

- Firmware and configuration on module in serial flash
- Long-term availability

The components on the module are AEC-Q100/ 200 Automotive qualified, making it suitable even for high-end automotive applications. Samples are available at Codico.

The EVSE/PEV modules will be provided pre-configured, either for SPI or Ethernet interface use, while the Home Control (-H) version will be Ethernet pre-configured. Additionally, Codico, together with 8devices, can provide new RED-BEET-EVAL-BOARDs for all these types of modules (**Figure 2**).

The boards have line coupling for EV-charging applications. A standard 20-pin header connector is available for the connection to an external MCU via SPI — you can easily plug in a Raspberry Pi board upside down, for example, to avoid flat cable or wires.

For EVSE/PEV these boards offer the ability to choose between either the 1:1:1 transformer or the 1:1 transformer with a remarkably smaller size. Both transformers are also available in the Codico portfolio. For home control, the board is equipped with the known 1:5:4 transformer.

RED-BEET-EVAL-BOARD-E/-P 2.0 is configured for eMobility applications, for EVSE and PEV according to ISO/IEC15118-3, DIN 70121, and SAE J2847/2.

RED-BEET-EVAL-BOARD-E 2.0
For electric vehicle supply equipment (EVSE), Ethernet-preconfigured

RED-BEET-EVAL-BOARD-P 2.0
For plug-in electric vehicles (PEV), Ethernet-preconfigured

RED-BEET-EVAL-BOARD-H 2.0
For IoT, smart grid/meter, long-range PLC, Ethernet-preconfigured

All products are available in the Codico Sample Shop [1].

Want to find out more? Visit us from 9–11 April at embedded world 2024 in hall 3A, stand 211.

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WEB LINKS

[1] Codico Sample Shop: https://codico.com/shop

Profile Heat Sinks

Efficient Thermal Management for High-Power Light Sources

Figure 1: The luxyr LED MAGNA compact two-channel LED fluorescent light source supports both simultaneous and separate light output in the UV and VIS range. (Source: Leistungselektronik Jena)

Contributed by CTX Thermal Solutions

To cool its latest lighting solution for microscopy applications and multispectral cameras, Leistungselektronik Jena GmbH relies on CTX extruded heat sinks.

Modern microscopy applications require high-power light sources to illuminate the base material for analysis. Multispectral imaging, which makes it possible to see objects invisible to the human eye using various optical filters, subpixel structures, or special prisms, likewise requires illumination in specific wavelength ranges. Such a high-power light, which is ideal for both applications, is the compact luxyr LED MAGNA (Magna) two-channel LED fluorescent light source from Leistungselektronik Jena GmbH (LEJ) (**Figure 1**) [2]. LEJ specializes in lighting and power electronics solutions for microscopy, semiconductors, analytics, imaging and medical technology, and has been supplying famous brand-name manufacturers around the world with state-of-the-art OEM products for more than 30 years. The Thüringian company also has two proprietary brands. LUXYR is the brand name for high-end light sources. AMPYR comprises devices for the fast, reliable power supply of diverse light sources.

Magna is a compact and mobile light source that supports both simultaneous and separate light output in the UV wavelength range and the visual light range — depending on the requirement — and can be equipped with additional types of LEDs in other wavelength ranges, on request. Unlike comparable products, it is designed for direct microscope coupling. The light output of this particular LED technology is of very high intensity, which makes the Magna a viable alternative to conventional halogen and short-arc cold light sources in forensics and multispectral imaging.

Profile Heat Sink for Reliable Operation

A black anodized aluminum profile heat sink designed for this application minimizes heat in the heat sink, despite its high performance (**Figure 2**). The extruded heat sink with nine fins reliably dissipates the heat and is mounted as a visible component on the rear of the light source. It measures 106×122×83 mm (L×W×H), which makes up half of the device's volume [3].

Figure 2: The black anodized aluminum profile heat sink is a visible design element of the luxyr LED MAGNA. (Source: Leistungselektronik Jena)

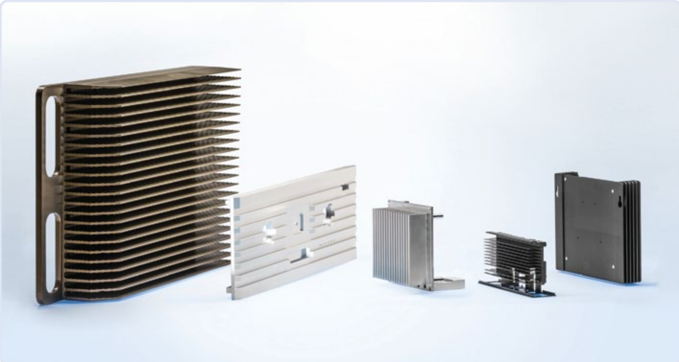


Figure 3: Profile heat sinks offered by CTX include both extruded heat sinks based on standard profiles and custom-tailored extruded heat sinks. (Source: CTX Thermal Solutions)

Figure 4: Effective and efficient cooling of power electronics — with CTX cooling solutions. (Source: CTX Thermal Solutions)

The heat sink is supplied by CTX Thermal Solutions GmbH (**Figure 3**) [1]. Since there are two variants of the high-power light, depending on the orientation of the light source on the microscope, there are also two different versions of the heat sink — one with vertical fins, and one with horizontal fins. The hole pattern for mounting the heat sink on the power electronics module of the light source varies accordingly.

Surface Finishing Is Not Just for Appearance

The Nettetal-based thermal management specialist manufactures the extruded heat sinks according to LEJ drawings and provides them with a black anodized surface finish to the specifications of DIN17611-E1/EV6-10. However, other types of surface finishing are possible, including lacquer, powder coating, and anodized coating, to match the particular corporate design. And, the surface finishing is not just for appearances: Specifically, thick anodized coatings provide protection against corrosion, for example, if a heat sink designed as a visible component (or housing with a cooling function) is exposed to aggressive ambient conditions. Black coatings, which also appear as black in the infrared range, improve the thermal radiation of the heat sink. If a heat sink is a design element, as in the case of the Magna, the superior quality of the surface coating is especially important.

Comprehensive Support and Thermal Simulation

CTX produces the heat sinks required by the customer, LEJ, according to drawings (**Figure 4**). However, it is not always clear from the outset which cooling solution is right for the particular application. In such cases, the experts for thermal management of power electronics use a thermal simulation to calculate the optimal heat sink or a custom cooling solution. The calculation is based on the customer's requirements and the thermodynamic conditions of the system. These include the design and the expected heat load of the electronic component where the dissipation occurs. Additional simulation parameters that have to be considered include the size of the existing installation space and the maximum permissible surface temperature of the component for safe operation. It is then easily determined whether the best solution is a classic profile heat sink, a combination of high-performance heat sink and fan, or whether fast dissipation of the heat requires a liquid-cooled heat sink or heat pipe solution. A simulation also detects thermal problems early on — thus reducing the number of prototypes and test runs required during the development phase. Optimization of the heat sink design using a thermal simulation also helps to reduce the amount of material and the weight of the heat sink, to optimize costs.

Individual Logistics and Warehouse Service

The OEM in Jena stocks the required quantity of heat sinks in their in-house warehouse. For customers who cannot or prefer not to do this, the heat sink specialists in Nettetal offer a warehousing service including all logistical processes, so that only the required number of heat sinks is delivered, just in time. This individual logistics service is built on optimized supply chains and the uninterrupted flow of goods. To guarantee this, CTX uses all available means of transport, operates a large reserve warehouse in Nettetal, and supplies consignment and buffer warehouses. In addition, the company offers its customers the use and maintenance of their logistics portals, as well as integration in their Kanban systems.

The cooperation between the two companies started in 2010 with a small order for extruded heat sinks. In the following years, CTX delivered profile heat sinks manufactured according to drawings based on existing extrusion tools to Thüringia regularly — for example, eight-channel multichannel LED fiber optic light sources for LQ-LED. The successful cooperation has proven worthwhile.

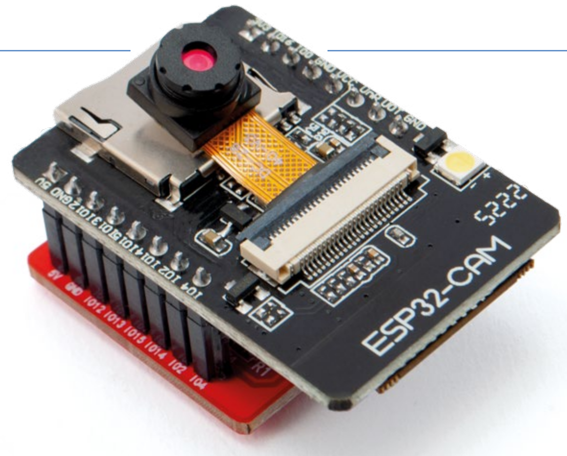
240162-01

The luxyr LED MAGNA at a glance

- High-performance UV/VIS-LED light source for dry, indoor areas
- Silent and vibration-free operation
- Direct microscope coupling
- Pulsed-mode operation with TTL trigger up to 100 kHz
- Different LED types / spectra available

WEB LINKS

[1] CTX website: https://ctx.eu/en
[2] Leistungselektronik Jena website: https://lej.de/en
[3] Profile heat sinks by CTX: https://ctx.eu/en/products/heat-sinks/profile-heat-sinks



ESP32-CAM Programmer

Customize Your Module With an Inexpensive Tool

By Boris Landoni (Italy)

"Basic and inexpensive" doesn't always mean "ineffective!" This simple but smart dedicated programmer project can be interfaced with via USB, and makes it possible to take full advantage of the libraries that Espressif released for programming via the Arduino IDE. It makes the ESP32-CAM accessible even to those who've never intended to purchase a dedicated development system.

Elettronica In
WWW.ELETTRONICAIN.IT

The ESP32-CAM-CH340 Development Board is a special version of the popular ESP32, a development and prototyping board based on an ESP32 SoC (system-on-chip), equipped with a two-megapixel camera (OV2640) with adjustable frame rate and a slot for up to a 4 GB miniSD memory card, some firmware-configurable GPIO lines to interface with the outside world, as well as connections for the most popular communication interfaces. The on-board equipment also includes a high-brightness LED that can be used as a flash for taking photographs or as an illuminator when shooting a movie.

The programmer is basically a board designed to host the ESP32-CAM module and interface it to a PC via USB to load sketches and possibly a bootloader; this board, which we can consider both a physical and electronic adapter, allows the module's native UART interface to be adapted to the more common and versatile USB interface, handling some control signals such as RTS and DTR. It practically implements what would otherwise have to be accomplished by interfacing the serial port (TXD/RXD) of the ESP32-CAM with one of the classic USB-to-serial converter modules, while also solving the problem of voltage level adaptation on board.

Schematic

We can see these details more clearly by analyzing the circuit diagram in **Figure 1**. It's built around IC U1, which is a CH340C-type serial-to-USB converter, popular because it is also used in some non-original Arduino boards. The CH340 is a conversion chip from the USB bus to the classic DB9 bidirectional serial port.

The CH340 supports full-speed USB mode conforming to the USB 2.0 specification and is straightforward to implement and configure, as it requires only a crystal and two external capacitors for clocking, but can also operate with its internal oscillator. The hardware serial interface is full-duplex, supporting various baud rates from 50 bps to as high as 2 Mbps. It operates in DTE (data terminal equipment) mode having the signals suitable for the control of standard DCE (data communication equipment) modems which are:

- RTS (request to send): Output used by the DTE to request that the connected device (typically a DCE) send data; the RTS line connects to the CTS of the connected device.
- DTR (data terminal ready): Indicates to the DCE that the terminal is ready for communication.
- DCD (data carrier detect): Indicates that the carrier (modulated by data for communication) has been detected.
- RI (ring indicator): Used by modems to alert the computer (or otherwise DTE device) that a public switched telephone network (PSTN) call is incoming.
- DSR (data set ready): Used to indicate to the DTE that data is ready.
- CTS (clear to send): Used by the DCE to notify the terminal (DTE) that data transmission may begin.

As can be deduced from the schematic, out of these signals we use RTS and DTR which, with the help of T1 and T2, control Q1 to turn the ESP32-CAM module on and off and set the IO0 line on pin 14 to low, switching the module into programming mode.

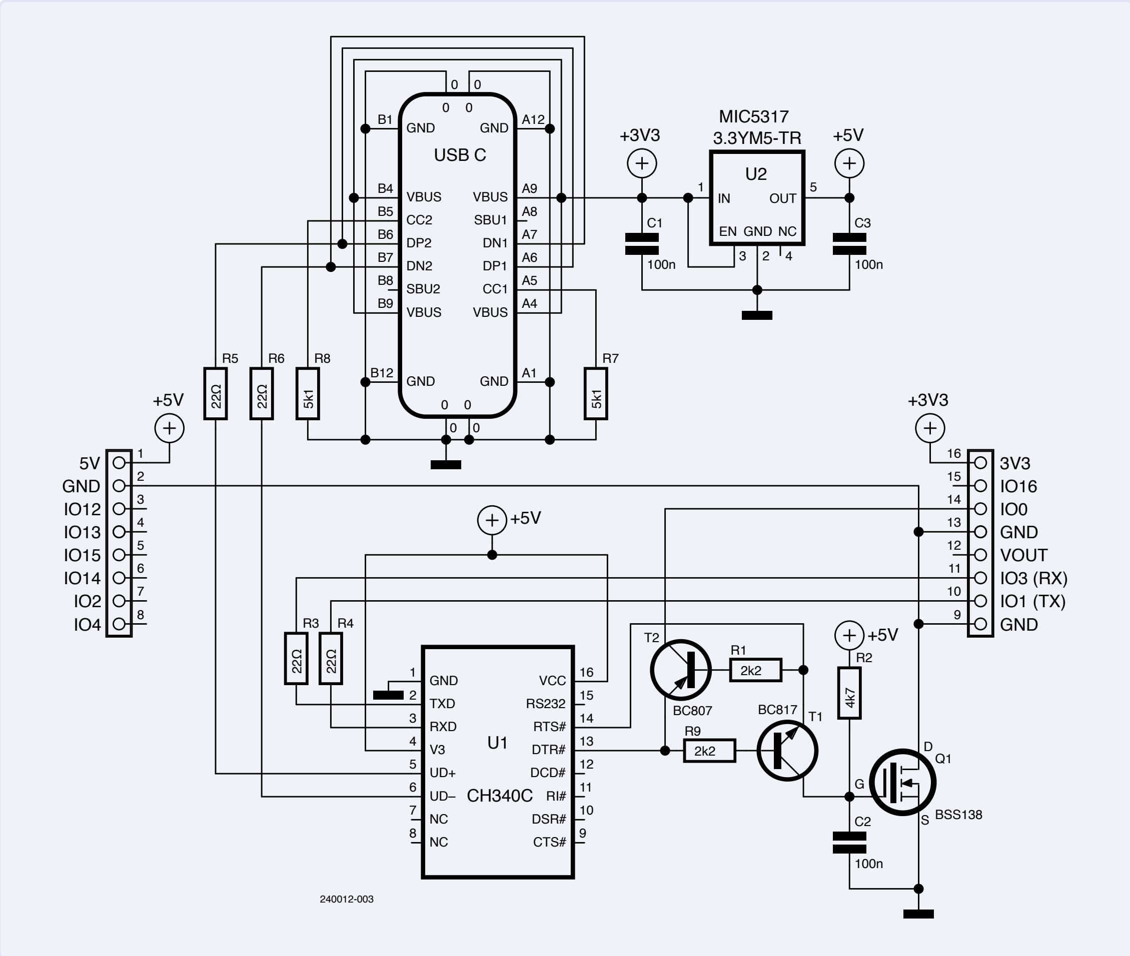


Figure 1: ESP32-CAM programmer schematic.

For programming, we obviously use the TX-RX bidirectional data channel of the module's UART port. The USB side of U1 is connected to the USB-C connector (male, PCB-type) to carry the DP and DN bus signals to and from the converter. Note that since we have chosen a USB-C connector and have an IC that supports USB 2.0, we have configured the connection for use according to this protocol, so you see that the DP1 and DP2 lines are connected and so are DN1 and DN2. The connections between these pins are because the USB-C connector is symmetrical and can be inserted either way. Therefore, whichever way you plug it in, the polarity and the effectiveness of the connection remains the same.

Furthermore, the CC1 and CC2 lines of the connector have been grounded through two limiting resistors (R7 and R8, respectively). In fact, in the USB-C standard, the CC1 and CC2 pins allow the configuration of the data channel (they are, in fact, called configuration channel) and, in detail, they're involved in the setting of the data transport mode, which in our case is the USB 2.0-compliant one.

The CH340 integrated circuit operates with a DC voltage between 3.3 V and 5 V. In this circuit design it is fed by IC U2 (pin 5, OUT), a MIC5317-3.3 LDO voltage regulator, which takes its input from the USB-C connector's VBUS line (5 V DC) and outputs a stabilized 3.3 V.

Note that, although the chip features a standby mode, activated via the EN line, in this application it is kept active at all times by connecting pin 3 to pin 1 (VIN). Electrical noise on the 3.3 V and the 5 V VBUS power supply lines are adequately filtered out by ceramic capacitors C1 and C3.

Let us now analyze the RS-232 serial side of the CH340: The chip features a data channel consisting of TX (transmission from the chip to the ESP32-CAM) and RX (reception of data coming from the ESP32-CAM) lines, in addition to the communication control signals that are used to synchronize the data flow. In detail, the circuit utilizes only RTS and DTR, interconnected through a network of two bipolar transistors interacting with the ESP32-CAM module, connected through the ESP32 headers (left and right in the schematics). This is well visible in the prototype on **Figure 2**.

The circuit formed by the transistors has also the purpose of turning on the ESP32-CAM module through N-channel MOSFET Q1. Since the latter is enhancement-mode, it will go ON when a voltage of at least 3 V is applied between gate and source, grounding the Vss lines and thus turning on the module.

Figure 2: The board hosts the ESP32-CAM using two female headers.

This condition will occur whenever the DTR line is at a logic low and the RTS at logic high, thus during data sending. Let's look at the various possible combinations: When DTR is logic low and RTS at logic high, transistors T1 and T2 are both off because the former (which is an NPN) has the emitter positive with respect to its base, and the latter (PNP) has the base positive with respect to its emitter. Under these conditions, the MOSFET is in the "on" state because its gate is brought to 3.3 V (high level) by resistor R2, so its channel conducts.

If the RTS pin goes to zero as well, the bipolar junction transistors (BJTs) transistors are still off because both have zero V_{BE}, their base and emitter leads being equipotential. The same happens if RTS and DTR are both at logic high.

Conversely, if RTS goes low when DTR is high, the base of T1 becomes positive with respect to the emitter and the transistor conducts, lowering the voltage on the MOSFET's gate to a few hundred millivolts, which will then go "off," turning the ESP32-CAM module off as well. T2 also conducts because its base becomes negative with respect to the emitter. So, the module is turned on when at least DTR is low, that is, when the computer notifies the ESP32-CAM via USB that it is ready to communicate data, regardless of the status of the RTS line.

To summarize, the function of the two transistors is as follows: T1 is used to control the supply of the ESP32-CAM module by acting on the gate bias of the MOSFET, so whenever it remains off (RTS is high or DTR is low) the module is powered, while if it goes on (RTS low and DTR high) the ground connection of the same module is removed, and the ESP32 is turned off.

As for T2, it functions as a static switch to control the IO0 line, connected to the ESP32-Cam's header connector's pin 14, which, during programming, must be held low. So, during firmware uploading, T2 must remain off, while at other times it must conduct (a condition that occurs when RTS is low and DTR is high) to bring the IO0 line to logical high (+3.3 V).

Pins U0TXD (TX) and U0RXD (RX) that allow us to upload code to the ESP32-CAM module are connected, respectively, to pins 10 and 11 of the ESP32 header, on which a second serial line, U2RXD (RX), is also present (pin 15) and can be employed if needed. These pins can also be used as GPIO1 (U0TXD) and GPIO3 (U0RXD), respectively, in applications where the UART is not needed. As for PC control, the CH340 chip uses software drivers compatible with the CH341, so this board will be recognized by Windows as a CH341, using its driver.

Practical Realization

This programmer is based on a minimal double-sided PCB. You can make it by photo-engraving, starting with the copper-side trace layout that you will find available for download on the Elektor Labs web page [1]. This should be printed on tracing paper or acetate to obtain the needed films. Once the printed circuit board has been etched and drilled, you will need to proceed with the assembly of the few components, all SMDs, which will require some manual dexterity and tweezers to set them upon the pads. A very fine-tipped soldering iron (or a hot-air soldering station), a magnifying glass, some solder wire with a maximum diameter of 0.5 mm, as well as some flux paste to spread on the pads before component placement.

Start by centering the CH340 on its respective pads, after orienting it as shown on the mounting diagram, tinning one pin in a corner and then, having ascertained that the chip is in the correct position, one in the opposite corner to hold it in place, then proceed by tinning the various pins, going from one side to the other. The CH340 is housed in an SSOP-20 package so, although it is an SMD, it is fairly easy to solder. With your magnifying glass, check for the absence of joints between adjacent pins, and, if any, smear them with plenty of flux

The ESP32-CAM Module

The ESP32-CAM Development Board is a PCB module that integrates a Wi-Fi 802.11 b/g/n interface, dual-mode Bluetooth (Classic and Low Energy), a small two-megapixel camera (OV2640), a slot for a miniSD memory card of up to 4 GB, and nine I/O pins. It also has a high-brightness LED, which can be used as a flash for photos and videos.

Programmable directly via the Arduino IDE, it can be used in various applications such as in home automation devices, industrial wireless control, wireless monitoring, wireless identification via QR code, and many other IoT applications.

The module integrates an 802.11 b/g/n Wi-Fi transceiver and a Bluetooth 4.2 LE with a PCB antenna capable of 2 dBi gain (a u.FL antenna connector is also provided). The Wi-Fi transmitter power is about 17 dBm for the 802.11b (@11 Mbps), 14 dBm for 802.11g (@54 Mbps) and 13 dBm for 802.11n, while receive sensitivity is -90 dBm in CCK at 1 Mbps and drops to -67 dBm in MCS7 (65 Mbps, 72.2 Mbps).

For memory, the SoC has a 32 Mbit SPI flash, a 4 MBit PSRAM, and a miniSD card slot that supports up to 4 GB card. The SoC can communicate with the outside world through wired UART interfaces at up to 115,200 bps, SPI, I^2C, and 9 GPIOs. It supports WPA/WPA2/WPA2-Enterprise/WPS security protocols. The on-board camera (an OV2640) is connected via FPC connector and returns images in JPEG (only on the OV2640), BMP, and grayscale formats. The module also supports the OV7670 camera module.

The module is manufactured by Ai-Thinker, but there are equivalent solutions from other manufacturers on the market.

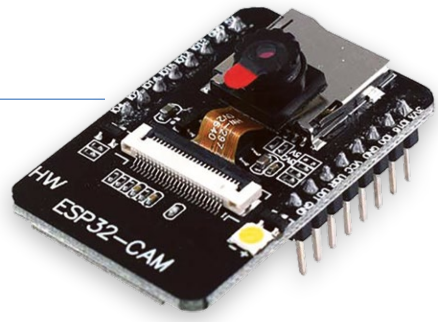


Figure 3: ESP32-CAM module top view.

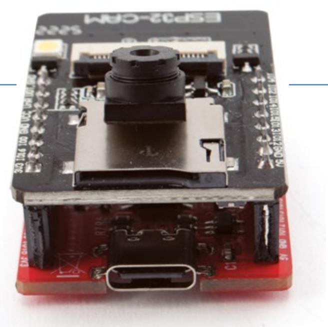


Figure 4: The ESP32-CAM should be inserted in such a way that the socket for the SD card and the USB connector are on the same side.

Related Products

- **ESP32-CAM CH340 Development Board**
  www.elektor.com/19333
- **D. Ibrahim, *The Complete ESP32 Projects Guide*, (Elektor 2019)**
  www.elektor.com/18860

paste and then melt the solder to remove the shorts. Once that's done, mount the passive components, such as resistors and capacitors, then the USB-C connector (with a steady hand and precision because its pins are very close to each other) and the MIC5317-3.3 IC, orienting it as shown on the mounting plate. Note that in any case, on the PCB, regulator U2 has a unique mounting direction, since it is housed in a three-terminal SOT-32 package and is thus asymmetrical.

Take care to tin the USB-C connector's anchor tabs generously to make sure that it resists the mechanical stress introduced by plugging and unplugging the cable. Complete the assembly of the board by inserting and soldering — into the side pads — 2.54 mm-pitch female strips that will allow you to plug the ESP32-CAM board in, taking care of the orientation indicated in the mounting diagram. You you must already have provided the appropriate male headers to be soldered into the side pads (see **Figure 3**). Remember that the ESP32-CAM should be oriented so that the side of the SD Card socket faces the USB Type-C connector side of the demo board, as shown clearly on **Figure 4**.

Wrapping Up

Once you have completed the soldering and verified that everything is in place, the programmer board is ready to use: You can plug in your ESP32-CAM, paying attention to the orientation (there are no keys on the headers, so the module could also accidentally be inserted upside-down), connect it to a PC via a USB-A-to-Micro USB-B cable and start running the firmware, i.e., programming the module. The programmer board and ESP32-CAM together draw a maximum of 360 mA from the USB-C connector: This current can be drawn from any USB port, even those that are not necessarily C-type. The drivers for the USB-to-serial converter, as well as plenty of other useful resources, can be downloaded at the Elektor Labs webpage for this project [1].

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Questions or Comments?

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

About the Author

Boris Landoni is an electronics expert and a true enthusiast in the field. His dedication led him to become the Managing Director of Elettronica In (futuranet.it), the most popular electronics magazine in Italy. He is also the curator of open-electronics.org, a platform dedicated to open-source projects that brings together enthusiasts and professionals, as well as Technical Manager for Futura Elettronica, a leading company in the supply of electronic components to the world of makers and professionals.

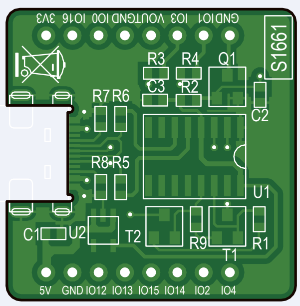
Component List

Resistors
R3...R6 = 22 Ω
R7, R8 = 5.1 kΩ
R1, R9 = 2.2 kΩ
R2 = 4.7 kΩ

Capacitors
C1, C2, C3 = 100 nF, ceramic

Semiconductors
T1 = BC817
T2 = BC807
Q1 = BSS138
U1 = CH340C
U2 = MIC5317-3.3YM5-TR

Miscellaneous
USB: Molex USB connector 2169900002
Pin strip, female, 8 way, pitch 2.54 mm
PCB S1661 (60×56 mm — see text)



WEB LINKS

[1] Elektor Labs webpage for this article: https://elektormagazine.com/labs/esp-32-cam-programmer

Development Boards in Industrial Applications

By Malte Janssen (Reichelt Elektronik)

Boasting benefits such as a compact design, low-power consumption and an affordable purchase price, developer boards are suitable for a wide range of projects. They are also being increasingly used in industrial applications. Engineers now have a number of interesting development boards at their disposal for this purpose — with Arduino products coming in first. Here we take a look at the criteria that must be met for industrial applications, how much progress development boards have already made and provide examples of how developer boards can be used in industry.

What Do Industrial Applications Require?

Industrial companies have long been reluctant to use development boards, and for good reason. The industrial environment demands a range of requirements including maximum robustness, reliable performance — even for prolonged and intensive applications — as well as interoperability with common transmission protocols, firmware and software. How do development boards intersect in this respect for companies?

In essence, a distinction must be drawn between two different application types: application in a product or application within your own company, for example as a control element in the production process.

Development Boards in Products

Thorough preliminary considerations must be taken about the product if a development board is to be installed in said product. The beginning of the product development process involves specifying the end requirements for the product in full, to prevent any unpleasant subsequent surprises. Of course, these requirements include technical features such as size, weight, data transfer rates, connection protocols, and more.

A number of commercial aspects must also be considered. These include the product lifetime: What is the anticipated lifespan of the planned product, and can a development board satisfy it? The development board's service life must be covered by the manufacturer's delivery commitments. It goes without saying that the development board must also be available in the planned quantities. Here, too, a commitment must be obtained from the manufacturer.

The issue of the planned sales regions should not be underestimated, as this in turn has an impact on approvals and standards. Different standards and certifications may apply when selling to different markets. For example, a CE certification based on European standards may be of no value for the American or Asian market. The pre-certification of supplied components is therefore helpful but does not relieve the manufacturer of its responsibility to conduct tests required for certification of the entire device. These standards and certifications guarantee the safe use of the product — for example, regarding safe use at different temperatures or varying humidity.

Utilizing Development Boards for In-House Processes

In addition, development boards can be used to control processes within the company itself, such as in production processes or in the in-house logistics center. Development boards can partially take over the tasks of industrial controllers or even pre-process the data collected by sensors and send it to the cloud or central servers.

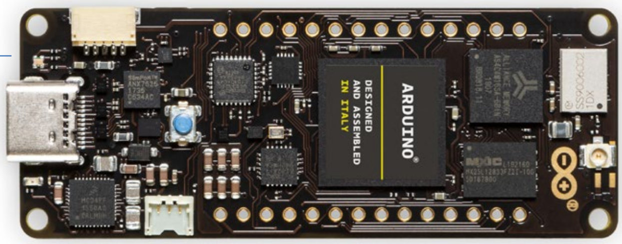


Figure 1: Arduino Portenta H7.

Figure 2: Arduino Portenta Vision Shield.

By assuming these tasks, particularly high demands are placed on data transfer speed, computing power, and memory. In addition, industrial connection standards must, of course, be in place.

Being resistant to extreme conditions is crucial for industrial applications. Products must often withstand very high temperatures of up to 50 °C, negative temperatures and wide temperature fluctuations. Ruggedness in high humidity can also be a vital requirement. What's more, industrial applications may necessitate particularly high resistance to shock or vibration.

What Do Development Boards Offer at Present?

Can development boards originally built for students and tech enthusiasts meet these requirements? In recent years, much has been done to ensure that Arduino boards and such also exist in industrial environments. For example, development boards are now very flexible in terms of temperature range: They are designed to deliver consistently high performance in an environment from 0°C to +50°C. This means that they can be used in hot machine rooms as well as in refrigerated storage rooms.

And, as the boards are manufactured in large quantities, the assembly and function tests are usually carried out under automated production conditions. Engineers can put their confidence in excellent production quality. A variety of hats and shields also ensures a high degree of interoperability with industrial transmission protocols and buses.

Development boards are known, above all, for their ease of programming and their wide range of applications. The majority of development boards rely on open-source code, making work accessible to a large community, which can be a real treasure trove, especially when developing prototypes. On the other hand, you need to be secure in your expertise to pick the right solution from a wide range of solutions. It is also important to remember that open-source solutions consider conformity of licenses for the required application. Depending on the level of knowledge in the company and the complexity of the project, the decision must be taken on what is the better route.

Development Boards Already Being Used in Industrial Applications

There are already several development boards that offer these features. Among these is the all-rounder Arduino Pro — the Portenta H7 and X8 models in particular, as well as the numerous extensions (**Figures 1, 2, and 3**). The wide range provides the right product for companies in all industries to design and implement smart solutions according to their requirements. One example is the use of an Arduino board in conjunction with a liquid sensor.

It was by adopting this approach that a Canadian startup was able to better assess the quality of the oil in heavy industry. Oil is often changed much too early, because the quality is difficult to determine externally and damage caused by contaminated oil needs to be prevented. When a sensor can provide accurate information about the quality of the oil in the machinery, companies save valuable resources and also have a more sustainable work process.

Another development board that is already in wide use in the industrial environment is the Raspberry Pi product family. In particular, it excels with its large developer community and the many HATs that make the board suitable for projects of all kinds. In this context, the Revolution Pi, an industrial mini-PC based on the Raspberry Pi and designed for automating industrial processes, is particularly noteworthy. This means that the Revolution Pi is equipped with high-performance connection standards and a particularly robust case that fits perfectly in DIN-standard control cabinets, making it ideal for production plant control or building automation.

Other manufacturers also offer development boards used in industrial environments. These include boards based on the Espressif ESP8266 and ESP32 models, which have made a name for themselves in IoT projects. The manufacturer's product portfolio includes not only the boards, but also matching modules and SOCs. The Adafruit Feather series is particularly light and compact, making it very suitable for portable devices, such as for monitoring ambient conditions such as the temperature, humidity, or air pressure.

Justified Utilization

Originally designed for private use, development boards are increasingly being used in industrial applications. This utilization is justified because the boards boast many characteristics that facilitate industrial production processes and operational processes. Companies can therefore open up new avenues.

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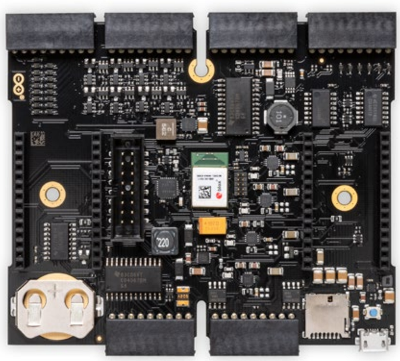


Figure 3: Arduino Edge Control.

Sunnyway
— The Antenna Specialist

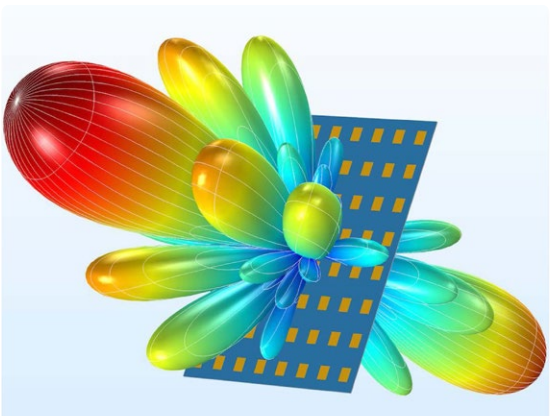
10 Questions and Answers

Questions by the Elektor Content Team

Global antenna specialist Sunnyway is the leading manufacturer in China — the first antenna-only company that expanded globally from there. The company predominantly offers solutions customized to clients and their applications, including testing, matching, and tuning of the antennas. A major asset is transparency; Sunnyway invites every partner and customer to visit their offices, R&D centers, and the factory.

What range of applications does Sunnyway's products cover? Could you provide examples of unique or challenging environments where your antennas are used?

Sunnyway has been in the market for over 15 years, and our antennas power a vast array of applications, from Industrial IoT, point-of-sale solutions, gateways, smart meters, trackers, and wearables to specialized sectors such as mining and agriculture. Our custom solutions thrive in extreme conditions, offering unparalleled reliability and performance. For instance, our combo antennas are tailored to navigate the rigorous demands of mining operations and smart agriculture, ensuring connectivity even in the most challenging environments.



SUNNYWAY
IOT ANTENNA SUPPLIER

How does Sunnyway prioritize innovation in its R&D process for IoT antenna solutions?

Our R&D capacity is our biggest strength. It's part of our commitment to innovation, fueled by our extensive R&D facilities, including three centers and over 10 OTA chambers — massive for an antenna-only company. This infrastructure, coupled with plans to expand our R&D footprint into Europe, underscores our dedication to leading the IoT antenna industry into the future.

What approach does Sunnyway take to meet the unique antenna design needs of its global customer base?

Understanding the unique challenges faced by our global clientele, Sunnyway prides itself on delivering bespoke antenna solutions. Our approach integrates customer insights from the design phase through to testing and manufacturing, ensuring a product that not only meets but exceeds expectations. Unlike those of other providers, the majority of our products are built for specific customers' needs.

How does Sunnyway tackle the design challenges posed by new wireless standards such as 5G, NB-IoT, and the upcoming 6G?

With the advent of new wireless technologies such as 5G, NB-IoT, and the anticipation of 6G, Sunnyway leverages its robust R&D capabilities to design antennas that not only comply with these standards but set new benchmarks for performance and reliability.

How has the IoT boom shaped Sunnyway's antenna development strategy?

The IoT revolution has been a catalyst for Sunnyway, steering our development strategy toward creating antennas that are as versatile as they are powerful. By addressing the full spectrum of frequencies and verticals, we remain at the forefront of connectivity solutions.

Can you share how sustainability is integrated into Sunnyway's antenna design and production for IoT?

Embedded in Sunnyway's ethos is a commitment to sustainability. Our end-to-end control over the manufacturing process enables us to enforce stringent quality standards while exploring environmentally friendly practices in antenna design and production.

What solutions does Sunnyway offer to combat signal interference in dense IoT networks?

In the crowded landscape of IoT networks, Sunnyway's antennas stand out for their ability to minimize signal interference. Through innovative design and materials, we ensure that our antennas deliver reliable connectivity in even the most densely populated IoT environments.

What future IoT and communication trends is Sunnyway preparing for?

Sunnyway is not just responding to current trends; we're anticipating the future of IoT and communications. Our ongoing investments in R&D prepare us for the next wave of technological advancements, ensuring that Sunnyway remains synonymous with cutting-edge connectivity.

How does collaboration with partners influence Sunnyway's product development?

Collaboration is key to Sunnyway's success, with partnerships that span continents and industries. These collaborations enrich our product development process, infusing our offerings with a diverse array of perspectives and expertise.

Could you highlight the diversity of Sunnyway's client portfolio and how it reflects your company's capabilities?

Serving over 1,000 brand customers globally, Sunnyway's diverse client portfolio showcases our adaptability and expertise across various industries. From leading players in the automotive sector to pioneering IoT startups, our ability to meet the nuanced needs of a broad client base reaffirms our position as China's premier antenna provider.

Sunnyway's journey reflects a relentless pursuit of excellence, innovation, and customer satisfaction. As we continue to expand and evolve, our focus remains on delivering tailored, high-quality antenna solutions that not only meet the current demands of the global market but also anticipate its future needs.

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BACKGROUND

Exploring **Wireless** Industrial **Network** Protocols

Contributed by Farnell

Industrial wireless networks are a key enabler of many aspects of advanced manufacturing. Wireless networks can be quickly deployed to transmit data to areas without existing cable infrastructures. These technologies are ideal for highly flexible and efficient network connectivity for constantly changing hard-to-wire locations and worksite landscapes. Industrial wireless networks promise lower installation costs than wired alternatives, increased operational flexibility, improved factory visibility, and enhanced mobility. This article discusses different types of wireless networking protocols used in industrial installations.

Industrial Wireless Technology

The critical objective of wireless communications networks must be to achieve similar capacities, bandwidths, responsiveness, and availability to wire-based communications systems. Various wireless technologies based on unlicensed spectrum are available for the industrial automation sector. Here are some of the popular wireless communication technologies that are being applied to industrial applications.

ZigBee

ZigBee is a mesh-networking standard based on IEEE 802.15.4 radio technology targeted at industrial control and monitoring, building and home automation, embedded sensing, and energy system automation. It was developed as an open global standard to address the unique needs of easy implementation, high reliability, low-cost, low-power, and low-data rate wireless device networks. ZigBee operates the unlicensed bands, including 2.4 GHz, 900 MHz, and 868 MHz, at a maximum transfer rate of 250 Kbps, enough to satisfy sensor and automation needs using wireless. ZigBee also creates larger wireless networks, not demanding high data throughput. Two different device types can participate in a ZigBee network: Full-function devices (FFD) and reduced-function devices (RFD). FFDs can operate in three modes: WPAN coordinator, coordinator, or device. RFD is only intended for simple applications, such as light switches. ZigBee supports three different topologies: star, mesh, and cluster tree. The star topology establishes communication between devices and a single central controller called the wireless personal area network (WPAN) coordinator. In a mesh topology, each of the network nodes, computers, and other devices are interconnected with one another. The cluster-tree network is a special case of a mesh network in which most devices are FFDs, and an RFD may connect to a cluster-tree network as a leaf node at the end of a branch. Any FFD can act as a router and provide synchronization services to other devices and routers. Only one of these routers is the WPAN coordinator.

Wireless HART

Wireless HART was created to fulfill the existing gap in industrial wireless standardization. It was born as an extension of the widely used HART communication protocol. It is designed to be simple-to-use, self-organizing and self-healing, flexible, reliable, secure, and supports the widely used HART technology. Wireless HART is a centrally managed mesh network. It is built upon the IEEE 802.15.4 physical layer and adds its own Data Link, Network, and Application Layer. Industrial security and authentication are reached through 128-bit AES (Advanced Encryption Standard) algorithms that cover end-to-end and hop-to-hop communications. Medium access control (MAC) is based on a TDMA schedule with frequency hopping. Reliability is achieved using methods of frequency diversity, path diversity, and message delivery retrials. Power consumption can be efficiently optimized through proper management of the communication schedule.

Bluetooth

Bluetooth has been considered one alternative for WSN implementation. However, due to its high complexity and inadequate power characteristics for sensors, the interest in Bluetooth-based WSN applications has decreased. Part of the Bluetooth specification, Bluetooth Low Energy is an ultra-low-power technology aimed at devices with very low battery capacity. This extension to Bluetooth allows for data rates of up to 1 Mbit/s over distances of 5 to 10 m in the 2.45 GHz band. Although Bluetooth Low Energy is like Bluetooth and can employ the same chips and antennas, it has some important differences, such as that Bluetooth Low Energy has a variable-length packet structure, as opposed to standard Bluetooth's fixed length.

ISA100.11a

ISA100.11a is an industrial wireless automation standard developed by the International Society of Automation (ISA). The corresponding IEC emerging standard is based on ISA-100 and is called IEC 62734. Unlike WirelessHART, ISA100.11a applies different mechanisms for channel hopping, such as slotted, slow, and hybrid channel hopping, in order to avoid collision with surrounding IEEE 802.11 networks. In addition, ISA100.11a includes backbone routers for bridging subnets, whilst WirelessHART uses access points. The compatibility of ISA100.11a with IPv6 in the network layer allows the users to connect to the internet, thus providing more options. ISA100.11a supports star and mesh network topologies and offers an interface for integration with WirelessHART.

Ultra-Wide Band (UWB)

Ultrawide band (UWB) technology is based on the IEEE 802.15.4 standard, which combines sensors and actuators into a single wireless network. It differs, however, in that UWB is allowed to operate at higher frequency bands and uses a wide spectrum bandwidth (500 MHz or more). Since UWB devices operate in a spectrum that overlaps with preexisting allocations and uses, UWB devices also operate at very low transmit power limits to prevent interference. A UWB transmitter works by sending extremely short pulses across a wide spectrum channel; a corresponding receiver then translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter. The advantages of UWB are good localization capabilities, the ability to share previously allocated radio-frequency bands by hiding signals under noise floors, the ability to transmit high data rates with low power, good security characteristics due to the unique mode of operation, and the ability to cope with multipath environments.

6LoWPAN and Thread

6LoWPAN stands for "IPv6 Over Low-Power Wireless Personal Networks." 6LoWPAN aims for standard IP communication over low-power wireless IEEE 802.15.4 networks utilizing IP version 6 (IPv6). In Ethernet links, a packet with the size of the IPv6 Maximum Transmission Unit (MTU) (1,280 bytes) can be easily sent as one frame over the link. In the case of 802.15.4, 6LoWPAN acts as an adaptation layer between the IPv6 networking layer and the 802.15.4 link layer. It solves the issue of transmitting an IPv6 MTU by fragmenting the IPv6 packet at the sender and reassembling it at the receiver. 6LoWPAN also provides a compression mechanism that reduces the IPv6 header sizes sent over the air and thus reduces transmission overhead. The fewer bits that are sent over the air, the less energy the device consumes. The Thread protocol fully uses these mechanisms to transmit packets over the 802.15.4 network efficiently.

Conclusion

Wireless technology can introduce a completely new range of industrial applications as it has the potential to provide fine-grained, flexible, robust, low-cost, and low-maintenance monitoring and control. It can also improve the productivity of industrial systems by providing greater awareness, control, and integration of business processes.

Farnell provides an extensive selection of components portfolio supporting the above protocols from top suppliers, spanning from Semiconductor ICs to modules to reference designs, enabling swift integration of wireless technologies and accelerating time-to-market. Explore more about LoRaWAN wireless sensors [1], wireless transmitters [2], wireless probes and assemblies, wireless receivers, and wireless monitoring systems [3].

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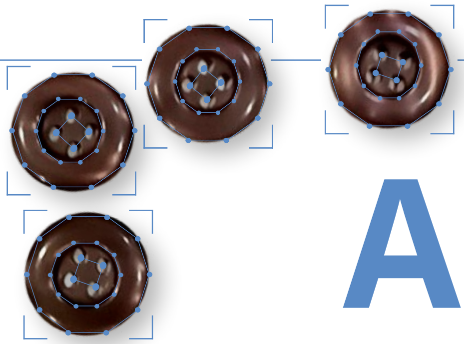
WEB LINKS

[1] LoRaWAN Wireless sensors: https://uk.farnell.com/advantech/wise-2410-mtb01/metal-base-lorawan-wireless-sensor/dp/3583435
[2] Wireless Transmitters: https://uk.farnell.com/c/automation-process-control/industrial-wireless/wireless-transmitters
[3] Wireless Monitoring Systems: https://uk.farnell.com/c/automation-process-control/industrial-wireless/wireless-monitoring-systems



A Smart Object Counter

Image Recognition Made Easy with Edge Impulse

By Somnath Bera (India)

Discover how you can transform a Raspberry Pi and a camera into a smart object-counting tool using the Edge Impulse platform! This fun and accessible project demonstrates the ease of starting with Edge Impulse on a Raspberry Pi, perfect for both beginners and more seasoned enthusiasts.

Edge Impulse specializes in providing tools and platforms for developing machine learning models for edge computing, running particularly on embedded devices. Edge computing involves processing data near the source of data, instead of relying on a remote server. That's perfect to implement on a Raspberry Pi! In this example, we'll count small objects, in this case ordinary buttons found on fabric.

Machine learning platforms such as Edge Impulse use so-called models, which are specific types of algorithms used for data analysis and pattern recognition. These models are trained to recognize patterns, make predictions, or perform tasks based on input data.

Classifying of objects is easily possible by Edge Impulse models. You can identify between a man and animals, between bicycles and cars, and so on. In addition, you can easily count one type of object among other types of objects. All you need to have is a good quality camera, sufficient light, proper focus, and, lastly, a moderately built computer (a Raspberry Pi 3 or Raspberry Pi 4 is good enough), and you are ready to go for counting.

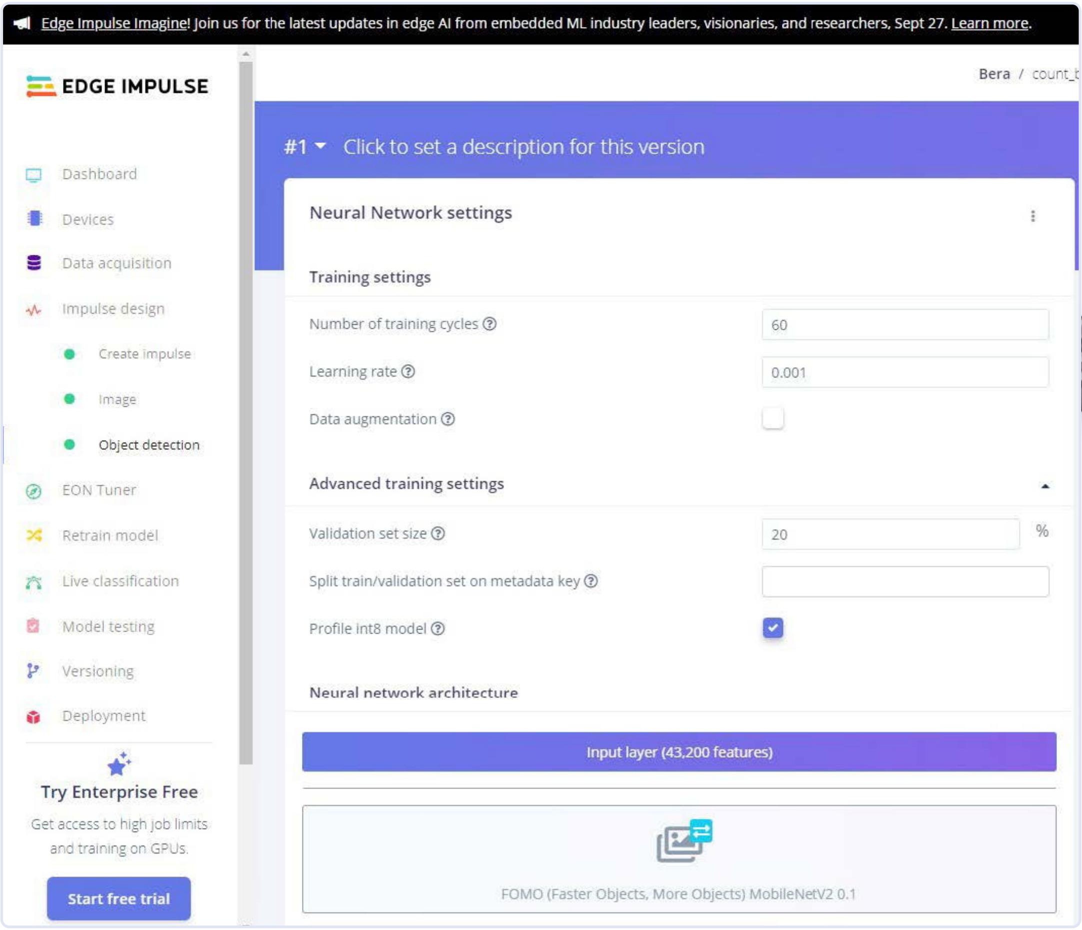
From the start, this project was aimed to be installed on the microcontroller (MCU) level — an Espressif ESP32, an Arduino Nicla vision, etc. And that's why it was made for a very small area of counting (120 pixel × 120 pixel) with a relatively small button as an object of interest. Ultimately, it transpired that even for the smallest area, the MCUs were no match at all. The machine learning models are pre-trained on Edge Impulse servers and a so-called model file is generated to be stored on the embedded device. Here, the model file itself is about 8 MB! Therefore, the project was finally installed in a Raspberry Pi computer, where it works easily.

Knowledge and Wisdom

If you know Edge Impulse [1], then believe me, half of your job is already done. For the rest, you just need to tweak your model to fine-tune it for an acceptable level of performance. A computer AI model works like a child. Imagine how you learned things like, "A is for apple" and "B is for ball." You were shown an apple from various angles, and then you were taught to name it "apple." The same went for "ball." Now, from all possible angles, a child will identify an apple and a ball fairly easily! And so it is with AI, which can identify them easily.

Now consider there is a basket where seemingly apple-sized balls and ball-sized apples are mixed and all look the same from the point of view. Being a child, what would you do? With your only knowledge of apple and ball, you would simply miss! AI would miss too. But consider the fruit basket is displayed by a fruit and vegetable vendor. Then, in all probability, neither of them is a ball! And some or all of them could be apples. This "trick" of connecting an apple with a fruit and vegetable seller is called wisdom, which you cannot expect either from a child or from AI unless it is specifically taught otherwise. However, human beings have learned, over the years, many more associated things that eventually have given us enough wisdom to connect apple with a fruit and vegetable seller.

However, AI is improving so fast that someday it will have wisdom to work on. For now, you must teach the ML model for apple and ball from all possible angles to perform them without any confusion (e.g., the texture profile of an apple, its stem, its creases on its body, look from top and bottom and much more). In any case,



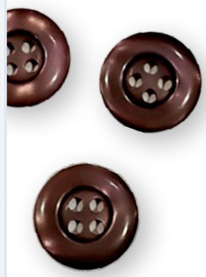


Figure 1: Neural network settings.

many different models with different capabilities are available in Edge Impulse for testing and experimenting.

Getting Started with Edge Impulse

First, open an account in Edge Impulse [1], which requires an email ID. Collect similar types of buttons, a handful number. If you open the site from a Raspberry Pi computer, using the camera of the Raspberry Pi computer (either USB connected or cam port connected), you can collect images of buttons from several angles (which is required while the model is deployed in a real working field). Edge Impulse has also provisions to connect your cell phone or laptop as an input device for collecting data, which is also more convenient for data acquisition in the Edge Impulse project.

The Project

The Edge Impulse project is broadly divided into the following steps, all of which must be followed on the Edge Impulse website.

1. Data acquisition: This could be images, sound, temperatures, distances, etc. Part of the data is separated as test data, while all other data is used as training data.

2. Impulse design: The main part of it being labeled *Create Impulse*. In this context, an "impulse" refers to a pipeline or workflow for creating a machine learning model. This impulse encompasses several stages, including tweaking of input parameters associated with the data that were just collected, signal processing, feature extraction, and the machine learning model itself. "Features" are individual measurable properties or characteristics of a phenomenon being observed. Essentially, features are the data attributes used by models to detect patterns and make decisions. The Impulse pipeline is subdivided:

   - Input parameters: image (width, height), sound (sound parameters)
   - Processing block: how to process the input data
   - Learning block: object data of this model

   You have to select and configure these three steps.

3. Image processing: Generate Features of the collected images.

4. Object detection: Select your Neural Network model and train the model.

For the final part — the object detection part — your expertise is needed, or I would rather call it trial and error effort, so that the accuracy of the model becomes 85% or above. At times, you have to remove some bad images (aka outliers) from the model to improve its efficiency.

There are a handful of models in which you can try and see the accuracy level of the model. Anything above 90% is great; but certainly, it should not be 100% accurate! If it is so, then you have something wrong with your data. It could be very little data or insufficient features are there. Recheck and retry again for that case! For this project, the accuracy was 98.6%. Certainly, our number of data (about 40) was small. However, for a starter project, this is pretty good (see **Figure 1**). The files for this project are available on the Elektor Labs page of this project [4].

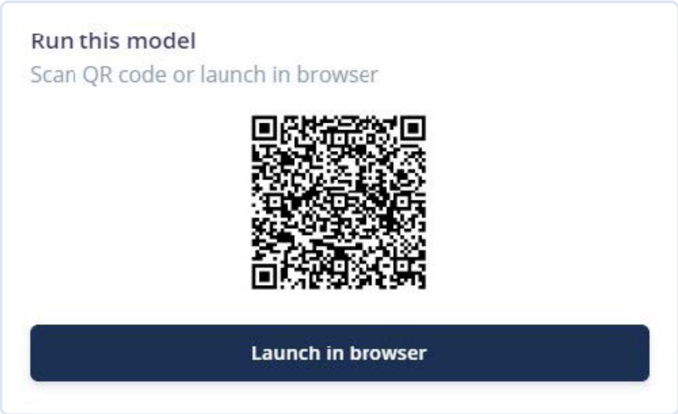


Figure 2: Scan QR code to run this model.

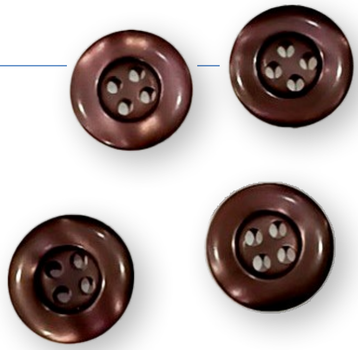


Figure 3: Data Acquisition: Sample-1.

Model Testing

You can test your model on the test data first. Start there, and then point your device to the real-life data and see if it works!

In the dashboard of the Edge Impulse opening page, the test feature is available. You can straight away run the model in the browser, or you can use your smartphone to test it. To do so, Edge Impulse offers a QR code to scan with your smartphone (**Figure 2**). Point the camera to the buttons (**Figure 3**, **Figure 4**, and **Figure 5**) and see whether it can count them or not!

Raspberry Pi Deployment

To run the model on a Raspberry Pi computer, you have to download the **.eim* file. But unlike for other hardware (Arduino, Nicla Vision, or ESP32 where you can download directly), in the case of Raspberry Pi, you have to install Edge Impulse on the Raspberry Pi computer first. From inside that *edge-impulse-daemon* software, you have to download this file. But don't worry, Edge Impulse has devoted a full page to installing Edge Impulse on Raspberry Pi. There are a few dependencies to install first. Look at [2]. It's pretty easy. The process is well described.

OK, so after you install Edge Impulse on the Raspberry Pi computer, the fun begins. Remember to keep the Raspberry Pi connected to the Internet.

Figure 4: Data Acquisition: Sample-2.

Figure 5: Data Acquisition: Sample-3.

Run the command `edge-impulse-linux-runner` from the Raspberry Pi terminal. This will start a wizard which will ask you to log in, and choose an Edge Impulse project. If you want to switch between projects later, run that command again with the `--clean` option. This command will automatically compile and download the AI model of your project and then start running on your Raspberry Pi. Show the buttons to the camera connected to your Raspberry Pi and it should count them. That's good! In the following, we will modify the system using Python and a voice synthesizer which, after counting, speaks up the number of buttons it got to count.

Deploy Model in Python

In the above deployment, it would work as it is intended in the Edge Impulse model. To make it work for your special purpose — for example to sound an audio alarm or light an LED when the count reaches "2 or more" — you have to find some other means! Here comes Python 3 to help you out. *Linux-sdk-python* needs to be installed on your Raspberry Pi computer.

The Edge Impulse SDK Software Development Kit (SDK) is available for many models, including Python, Node.js, C++, etc. Check the SDK Python page [3].

Once the *linux-sdk-python* is installed, go to the *linux-sdk-python/examples/image* directory and run the Python file for image identification. Don't get confused. In the example directory, there are three subdirectories — one each for audio data, image data and custom data. In the image directory, the video classification file is also available for video input data. The custom directory is for customizing other kinds of data (for experts only!).

Now run the command:

```
python3 classify-image.py /home/bera/downloads/model.eim
```

The model file **.eim* is to be loaded from the respective directory of its location. If you prefer, you can copy it into the SDK directory as well!

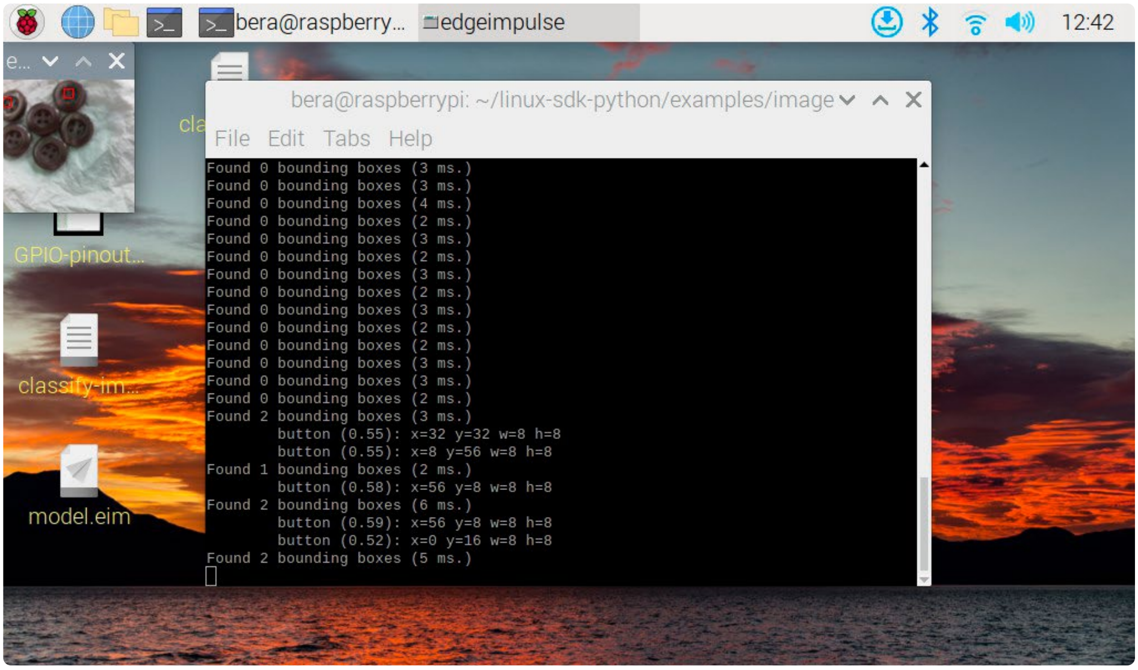


Figure 6: Four buttons are missed because of inadequate focus and light issue.

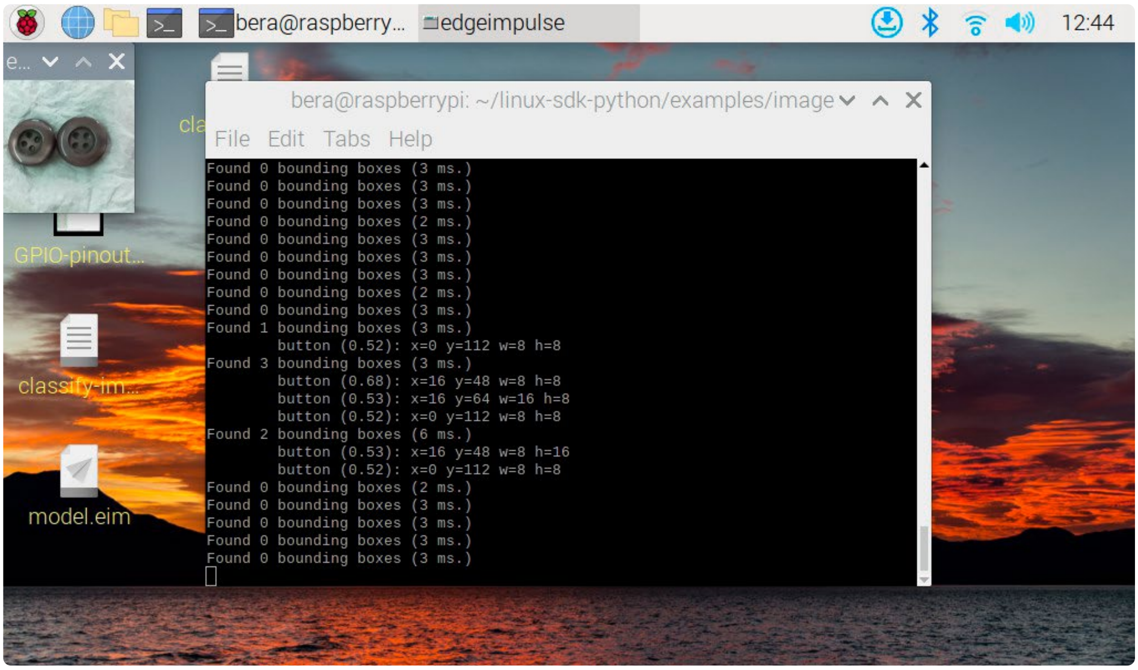


Figure 7: After removing one button, the model counted it right at first.

That's how you have to load the Python file with the downloaded *model.eim* file. The program will automatically find the camera module (USB-connected or Cam-Port connected) and will start running! In the top-left corner, a small 120 × 120 camera window will open, and the identified buttons will be marked with a small red marker. The numbers identified will be shown on the terminal. Please ensure sufficient light is available, and the camera is properly focused for the buttons. This is particularly important for cheap cameras. That's why if you run the model on your smartphone it produces far superior images and counts far more quickly. Nonetheless, ensure proper light and focus, and it will produce better results.

In the following screenshot pictures of the Raspberry Pi computer, on the top left, the small 120 × 120 exposure window is visible wherein all three buttons are identified and counted by the model. See the distinct visible red marker on all three buttons!

In **Figure 6**, four buttons are missed because of inadequate focus and light issue. The camera also does not have a stand to be fixed for this work! That's why I recommend getting the camera fixed on a stand, like in a "microscope setup." Be sure not to look at an angle from the top.

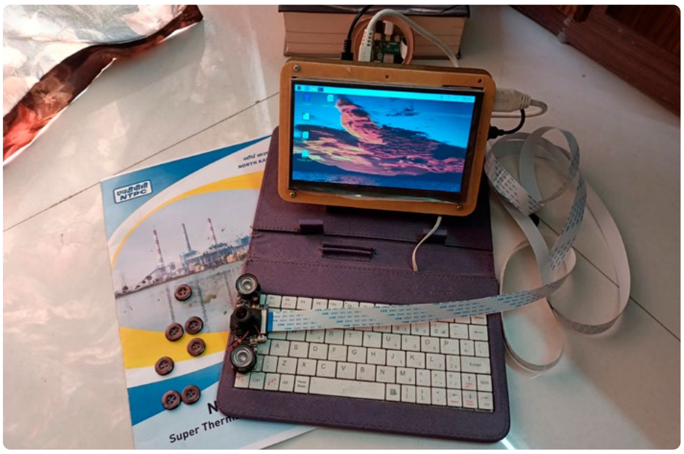


Figure 8: My prototype.

In **Figure 7**, I removed one button and the model counted it right first. It read two buttons, but at the moment I pressed the *pr-screen* button, it got misaligned and missed. Also, ensure the camera has a long cable (ribbon cable — see my prototype in **Figure 8**) to move around. This cable is available on Amazon. However, once the camera is fixed on a stand with a good amount of light/daylight, it will work infallibly.

Customize Your Model

Please have a look at the *classify-image.py* file. It's a simple Python file that can be tailor-made with little difficulty. In this Python file, I've added an *espeak* module such that the moment it finds a button(s), it speaks out the number of button(s) it finds. To install *espeak* on your Raspberry Pi, run the command:

```
sudo apt-get install espeak
```

Refer to **Listing 1** with the Python file including my modifications.

Espeak is a stand-alone text-to-speech module for Python. It does not require an Internet connection to work.

Modified Run

Now you have modified the Python program. If you run the Python file now, it will locate the button (on the top left, a small 120 × 120 camera port will open), and the numbers will be shown on the terminal window and the associated speaker will speak out the number: "Found five buttons / Found two buttons," etc. If you want to run some relay, light an LED, etc., import the GPIO library of the Python and then fire the associated GPIO to run the relay, etc. However, for running a relay, you have to use a switching transistor to increase the amount of current required for running the relay.

Aftermath

Edge Impulse started in 2019 with an objective to enable developers to create the next generation of intelligent devices. Since then, AI-powered programs and devices have appeared on ESP32, Jetson Nano, Raspberry Pi, Orange Pi, Maixduino, OpenMV, Nicla Vision, and many more. This trend will further improve in the coming days! Gone are the days of supercomputers or big-brand computers. Small, low-power modular devices are covering that space fast. And who knows? Maybe soon we will have the built-in wisdom installed and ready right out of the package!

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Listing 1: Python program to speak out the number of buttons with espeak tool.

```
#!/usr/bin/env python
import device_patches    # Device Specific patches - taken care by the software
import cv2  #import Computer Vision
import os
import sys, getopt
import signal
import time
from edge_impulse_linux.image import ImageImpulseRunner
import subprocess    #this one have been added by Bera
…
        elif "bounding_boxes" in res["result"].keys():
                    print('Found %d bounding boxes (%d ms.)' % (len(res["result"]["bounding_boxes"]),
                    res['timing']['dsp'] + res['timing']['classification']))
                    if  (len(res["result"]["bounding_boxes"])>0):
                            exitCode = subprocess.call(["espeak","-ven+f3","-a200"," Found %d Buttons" %
                            len(res["result"]["bounding_boxes"])  ])   #This one have been added by Bera
…
```

Questions or Comments

If you have technical questions or comments about this article, feel free to contact the author by email at berasomnath@gmail.com or the Elektor editorial team at editor@elektor.com.

About the Author

Somnath Bera, a mechanical engineer from Jalpaiguri Govt. Engg. College, India, works as a General Manager at NTPC, the largest power producer in the country. He has a profound passion for electronics, evidenced by his 60+ innovative projects on Elektor Labs, over 10 of which have been featured in Elektor Mag. His projects are often focused on problem-solving in areas like waste and natural resource management. Somnath likes to use innovative approaches and platforms like Arduino, Raspberry Pi, and ESP32 coupled with various kinds of sensors and wireless systems to create efficient and cost-effective solutions.

Related Products

- **Raspberry Pi 4 B (1 GB RAM)**
  www.elektor.com/18966
- **G. Spanner, *Machine Learning with Python for PC, Raspberry Pi, and Maixduino* (E-book, Elektor)**
  www.elektor.com/20150
- **D. Situnayake, Jenny Plunkett, *AI at the Edge* (O'Reilly)**
  www.elektor.com/20465

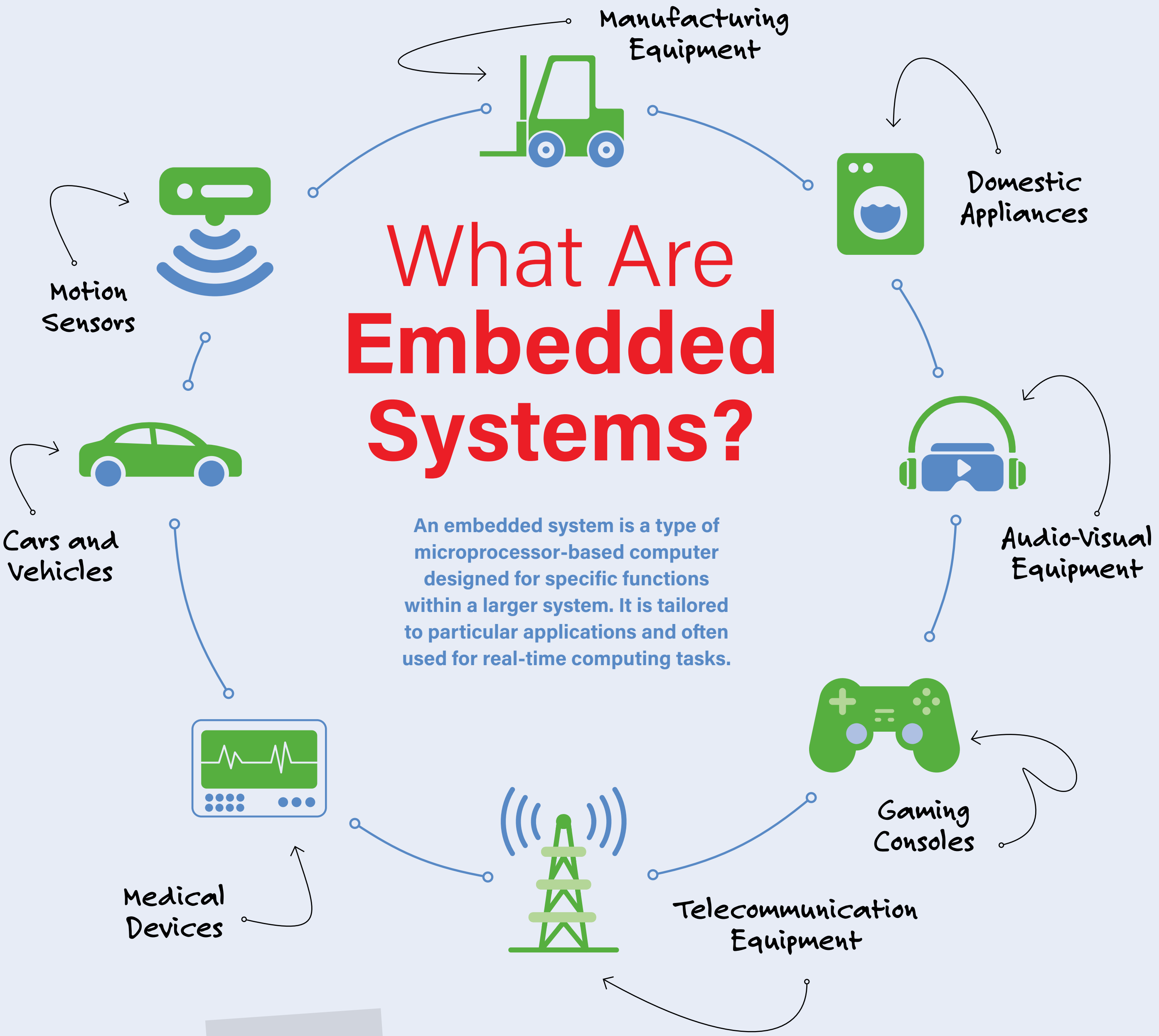
WEB LINKS

[1] Edge Impulse: https://edgeimpulse.com/
[2] Installing Edge Impulse on Raspberry Pi 4: http://tinyurl.com/ysc6mtuz
[3] Linux Python SDK: http://tinyurl.com/2bat4w6z
[4] Project Page on Elektor Labs: https://www.elektormagazine.fr/labs/count-speak-number-of-buttons

Embedded and AI

What Are Embedded Systems?

An embedded system is a type of microprocessor-based computer designed for specific functions within a larger system. It is tailored to particular applications and often used for real-time computing tasks.



Types of Embedded Systems

By Function

- Stand-alone Systems
- Real-time Systems
- Network Systems
- Mobile Systems

Use Cases

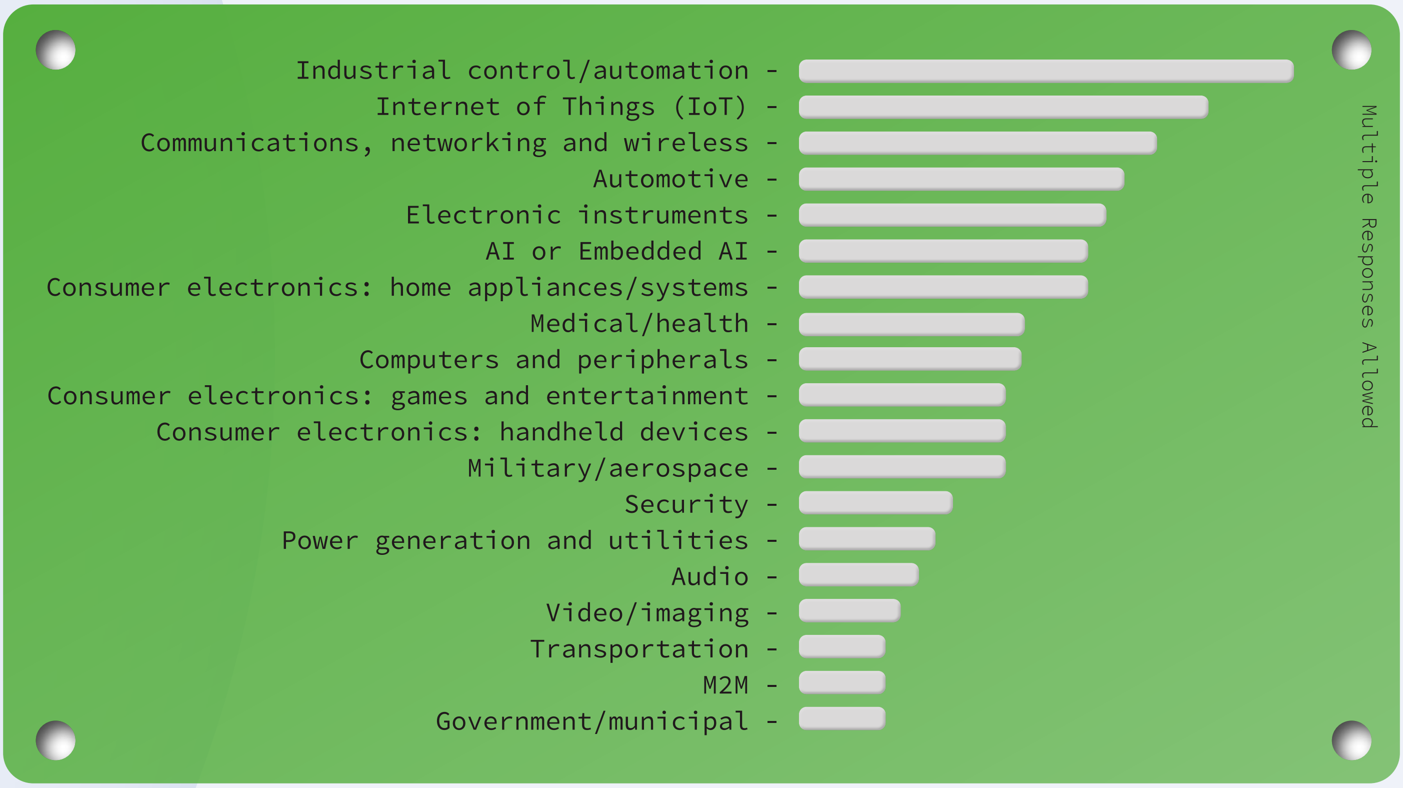
- Automotive
- Consumer Electronics
- Manufacturing
- Retail
- Media and Entertainment
- Aerospace and Defense
- Telecom
- Others

WEB LINKS

[1] Embedded, "embedded survey 2023: more IP reuse as workloads surge," 2023: https://embedded.com/embedded-survey-2023-more-ip-reuse-as-workloads-surge
[2] Accenture, "Technology Vision 2024: Human by design," January 2024: https://accenture.com/gb-en/insights/technology/technology-trends-2024

A Wide Range of Applications

A survey from 2023 [1] shows that most embedded projects are developed for industrial automation, IoT, communications, and automotive applications. Participants could choose multiple answers when indicating the types of applications they work on.



Source: embedded.com / AspenCore Media [1]

Advanced **Technology Capabilities**

The same study [1] reveals a significant focus on embedded AI and machine learning in ongoing projects, with 50% total interest. Embedded vision and speech capabilities follow closely at 47% and 36%. About one in six respondents are engaged in projects involving AI. Currently, 26% use embedded AI, 23% machine learning, 17% embedded vision, and 14% embedded speech. Looking ahead, 24% consider embedded AI, 24% machine learning, 19% embedded vision, and 15% embedded speech for future projects. Other technologies like augmented reality (AR), virtual reality (VR), and model-based capabilities also attract interest.

(Source: embedded.com / AspenCore Media [1])

Key Trends Shaping the Future of Technology

The Accenture Technology Vision 2024 report [2] explores the key trends that will shape the future of technology. One of the trends identified is the shift in the way people interact with information. Instead of the search-based model, there will be a move towards an advisor model, where generative AI chatbots provide direct and conversational answers. This trend is transforming the software market and how businesses leverage data. According to the report, data poisoning (the injection of malicious data into machine learning models) will emerge as a significant cybersecurity threat for enterprises by 2027. By 2029, AI advisors are predicted to surpass traditional search engines in receiving search traffic.

Another trend identified in the report is the innovation in neurotech and body movement tracking, leading to a new human interface that allows technology to understand people in deeper ways. This human-centric approach presents opportunities and challenges, including privacy concerns and the need for updated biometric standards. The report predicts a racing simulator controlled by brain activity and eye movement by 2026, a major bloc of nations passing neurorights legislation by 2029, and a consumer neurotech device transcribing dreams into visualizations and text by 2035.

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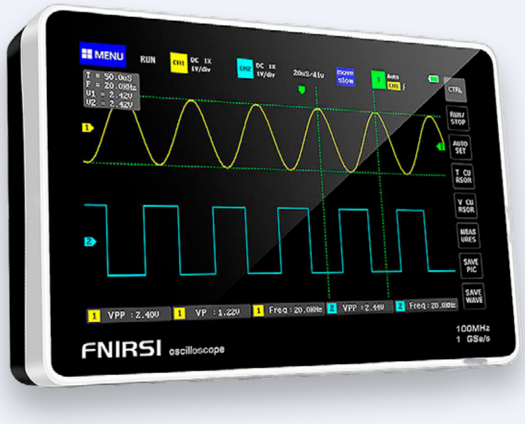
The Elektor Store

Never expensive, always surprising

The Elektor Store developed from the community store for Elektor's own products, such as books, magazines, kits and modules, into a mature web store 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.

FNIRSI 1013D 2-ch Tablet Oscilloscope (100 MHz)



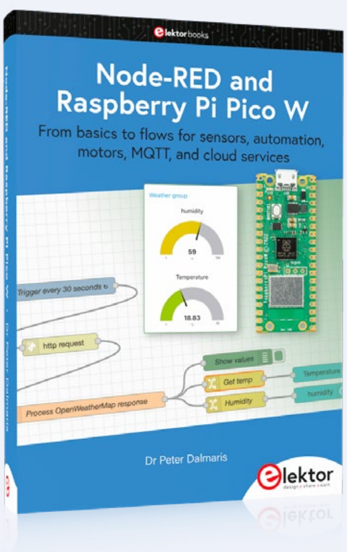
The FNIRSI 1013D is a fully featured 2-channel tablet oscilloscope with a high-resolution 7-inch LCD screen (800 x 480 pixels). The oscilloscope has a real-time sampling rate of 1 GSa/s and an analog bandwidth of 100 MHz.

Price: €159.95

Member Price: €143.96

www.elektor.com/20644

Node-RED and Raspberry Pi Pico W



This book is a learning guide and a reference. Use it to learn Node-RED, Raspberry Pi Pico W, and MicroPython, and add these state-of-the-art tools to your technology toolkit. It will introduce you to virtual machines, Docker, and MySQL in support of IoT projects based on Node-RED and the Raspberry Pi Pico W.

Price: ~~€44.95~~

Member Price: €40.46

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Oxocart Connect Innovator Kit

Price: €89.95

Member Price: €80.96

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SunFounder Kepler Kit (Ultimate Starter Kit for Raspberry Pi Pico W)

Price: €69.95

Member Price: €62.96

www.elektor.com/20730

Temperature-controlled Soldering Station ZD-931

Price: €49.95

Member Price: €44.96

www.elektor.com/20623

FNIRSI DSO152 Mini Oscilloscope (200 kHz)

Price: €39.95

Member Price: €35.96

www.elektor.com/20642

The Future of Embedded Systems

By Prof. Dr. Sebastian Steinhorst (Germany)

Embedded systems are the backbone of modern information technology — enabling energy-efficient and economical devices stretching from industrial automation, autonomous driving, and smart home appliances to the latest AR/VR headsets for entertainment technology.

Over the last decade, we have witnessed a shift from isolated embedded systems powering individual devices towards a seamlessly integrated Internet of Everything in the near future, enabled by autonomously acting intelligent connected devices. These developments have dramatically changed the requirements for embedded systems. While aspects such as reliability, efficiency, and cost-effectiveness remain at the core, we consider extensive communication capabilities as well as hardware accelerators for security and artificial intelligence (AI) as necessary features of up-to-date platforms. Equally, trusted execution environments become a prerequisite, as cyberattacks are omnipresent. If we shift our focus to the near future, we can expect that with the advent of quantum computing, the requirements of post-quantum cryptography (PQC) need to be considered and put established system architectures up for discussion. At the same time, novel application scenarios such as the medical Internet of Things (IoT) demand even more features, where, e.g., on-device acceleration for homomorphic encryption and zero-knowledge proofs emphasize the growing demand for privacy-enhancing technologies, which need to be addressed on eye level with the developments in security.

Despite continuous advancements in cloud computing, processing at the edge remains a core demand for the foreseeable future, exacerbated by ever-growing amounts of data to be processed on-device in real-time, such as video, audio, and high-resolution sensor information for AI-based computing in augmented reality and autonomous systems applications. These real-time requirements promote new research directions in embedded perception and create business opportunities, both on the embedded hardware as well as software levels.

On the hardware level, beyond extremely capable mass-production chips, the advancements in chiplet platforms will allow us to tailor a system-on-chip (SoC) to an application without high design efforts thanks to the concept of combining predesigned building blocks called chiplets. Here, specific building blocks will make the benefits of application-specific integrated circuits (ASICs) accessible to smaller batch sizes and permit to pick the ideal set of hardware accelerators for a given application, which brings optimizations from the economical as well as the efficiency perspectives.

On the software level, we will see the demand for cybersecurity lead to adopting new embedded programming paradigms and languages to promote certifiable security in embedded devices — a trend that will be further accelerated by current legislation efforts such as those of the European Union Agency for Cybersecurity (ENISA). Moreover, as the digital twin paradigm enters all application domains, the research field of embedded digital twins with on-device or edge-level virtual representation of physical assets will certainly rise.

Another interesting development will come from the transition from 5G to 6G with orders of magnitude higher demands for processing throughput due to ultra-low latency high bandwidth communication. On the other hand, Wi-Fi is adopting aspects of 5G such as in Wi-Fi HaLow for extended range as well as multi-link connectivity and advanced handover capabilities together with fully managed networks and ultra-low latency expected in the upcoming Wi-Fi 8. Such developments will open up the application of unlicensed communication in domains previously attributed to 5G. All these aspects will strongly shape the characteristics of embedded platforms, posing unprecedented challenges to staying within embedded operating parameters with respect to energy budget, performance metrics, and cost.

To conclude, given all the exciting trends together with the challenges to be tackled, it is not surprising to see market researchers predict annual revenues in the embedded systems sector will grow from currently about $110 billion USD to roughly $160 billion USD in 2030 [1]. Embedded systems were, are, and will be the core driver of bringing technological innovation into applications. Hence, there is a lot to gain in this dynamic field for those who can keep up with the trends. Let's jointly shape this awesome future!

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About the Author

Prof. Dr. Sebastian Steinhorst leads the Embedded Systems and Internet of Things group in the Department of Computer Engineering at Technical University of Munich (TUM) in Germany. His research focuses on system architectures, design methodologies, and protocols for secure distributed embedded systems in the application areas Internet of Things, Industry 4.0, and autonomous systems. He received his PhD in computer science from Goethe University Frankfurt, Germany, in 2011, worked from 2011 to 2016 at the TUMCREATE research center in Singapore, and joined TUM as a faculty member in 2016.

WEB LINK

[1] The Insight Partners, "Embedded System Market Growth Report | 2022-2030," October 2023: https://theinsightpartners.com/reports/embedded-system-market:

Square Wave Generation Benchmarks

Exploring ESP32, Pico, and Other Microcontrollers

By Saad Imtiaz (Elektor)

Inspired by a function generator's struggle to maintain square wave integrity at high frequencies, this article explores microcontroller capabilities in generating square waves, highlighting the impact of software environments and hardware abstraction layer overhead on performance.

In electronic signal generation, the pursuit of precise waveforms is a fundamental challenge. Function generators are the go-to devices for creating a range of waveforms, including square waves. However, their limitations become evident at higher frequencies. This phenomenon was observed with a function generator struggling to maintain the integrity of a square wave at 20 MHz, where the output more closely resembled a sine wave than a square one. This revelation prompted an exploration into the capabilities of microcontrollers (MCUs) for generating square waves and how they compare to dedicated function generators.

Function Generators: Square Wave Dilemmas

Function generators are designed to provide various waveforms across a broad frequency range. However, at higher frequencies, particularly from around 20 MHz and above, a square wave tends to lose its shape, morphing into something closer to a sine wave. This distortion is primarily due to the bandwidth limitations and the inherent rise and fall times of the generator's output stage. In electronic terms, the sharp corners of a square wave demand rapid voltage changes, which become harder to sustain as the frequency increases. The capacitive and inductive elements in the circuitry introduce delays, leading to rounded edges and a sine-like appearance. **Figure 1** shows the generated square wave by the UNI-T UTG962E at 20 MHz.

Microcontrollers and Square Wave Generation

Microcontrollers offer an easy alternative for square wave generation. They can create square waves by rapidly toggling GPIO (general-purpose input/output) pins. This project aimed to test various MCUs to determine their maximum frequency for accurate square wave generation. **Figure 2** shows square waves at 20 MHz generated by the ESP32-S2 (Blue) and UNI-T UTG962E (Pink). As you can see, the waveform generated by the ESP32-S2 generated a wave closer to a square wave than the function generator was able to.

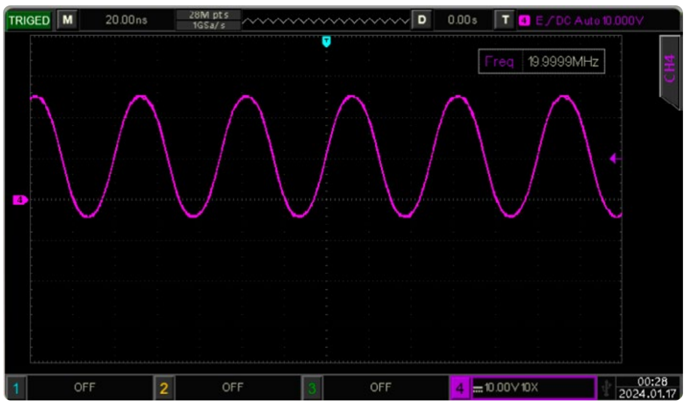

Figure 1: Square wave generated by the UNI-T UTG962E function generator at 20 MHz.

Figure 2: Comparison of square waves between the ESP32-S2 (Blue) and the UNI-T UTG962E (Pink).

Core Speed Versus Pin-Switching Speed

A notable aspect of MCUs is the distinction between the core speed (the processor's clock speed) and the speed at which a GPIO pin can toggle. While modern MCUs boast core speeds upwards of 240 MHz, this doesn't directly translate to the same frequency in pin toggling. The pin switching speed is influenced by several factors, including the microcontroller's architecture, the efficiency of the code, and the physical limitations of the hardware. For instance, the time taken for a signal to propagate through the silicon and the time required for a pin to charge or discharge capacitively limit the maximum achievable frequency.

Influence of Development Environments

A critical observation was the impact of the development environment on frequency generation. Using the Arduino IDE to toggle pins resulted in lower frequencies compared to using native MCU environments or direct register manipulation. This difference underscores the importance of software optimization in maximizing MCU performance. As you can see in **Figure 3**, the ESP32-C3 is programmed from the Arduino framework and reaches only 914.10 kHz, while in **Figure 4** the same board is running code compiled in ESP-IDF, reaching 20 MHz. This highlights the considerable difference that the development environment has on frequency generation. This discrepancy is attributed to factors such as the hardware abstraction layer (HAL) overhead, software optimization, compiler differences, interrupt handling, background processes, clock management, and resource allocation. So, running these boards natively can unlock some hidden potential in the chips, making them more reliable and efficient without using other HALs.

Experiment Methodology and Observations

The experiment involved testing various microcontrollers to generate square waves, measuring the output with an oscilloscope. The focus was on the highest frequency at which each MCU could maintain a true square wave. Observations showed that lower frequencies produced crisp square waves, and, as the frequency increased, the waves began to exhibit rounded edges, much like what was observed in function generators as shown in **Figure 5.** But, most of them were close to a square wave, albeit at a different frequency scale.

The waveform in Figure 5 can be not exact, as it's at about 60 MHz and the oscilloscope used had a maximum sample rate frequency of 100 MHz. As a general rule of thumb, the oscilloscope's maximum sample rate frequency should be five times more than the frequency being measured. In **Figure 6**, we can see a bar graph showing the microcontrollers and their maximum frequency outputs in different development environments. The code used for this test, as well as screenshots of the oscilloscope waveforms, are available at [1].

Further Research

This investigation highlights the inherent limitations in square wave generation, whether using traditional function generators or modern microcontrollers. While MCUs offer a compact and versatile alternative for generating square waves, they too are subject to physical and electronic constraints that affect waveform integrity at higher frequencies. The core speed of an MCU provides a theoretical upper limit, but the actual performance in terms of wave generation is often lower due to the complexities of signal propagation and hardware limitations.

Future exploration could involve delving into advanced techniques such as using direct digital synthesis (DDS) chips with microcontrollers, which might offer better performance for high-frequency

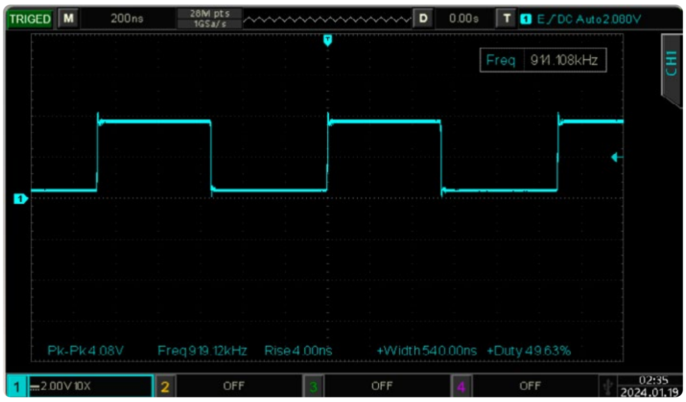

Figure 3: ESP32-C3-DevKit-M1 generating its maximum frequency while running code compiled by the Arduino framework.

Figure 4: ESP32-C3-DevKit-M1 producing its maximum frequency while running code compiled by ESP-IDF.

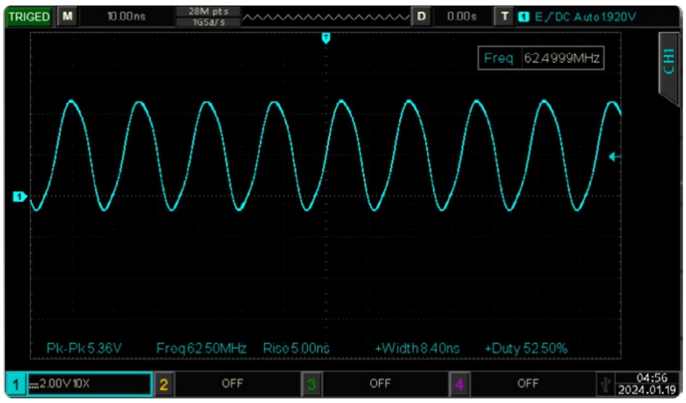

Figure 5: Raspberry Pi Pico W at 62.5 MHz using a PWM function in MicroPython.

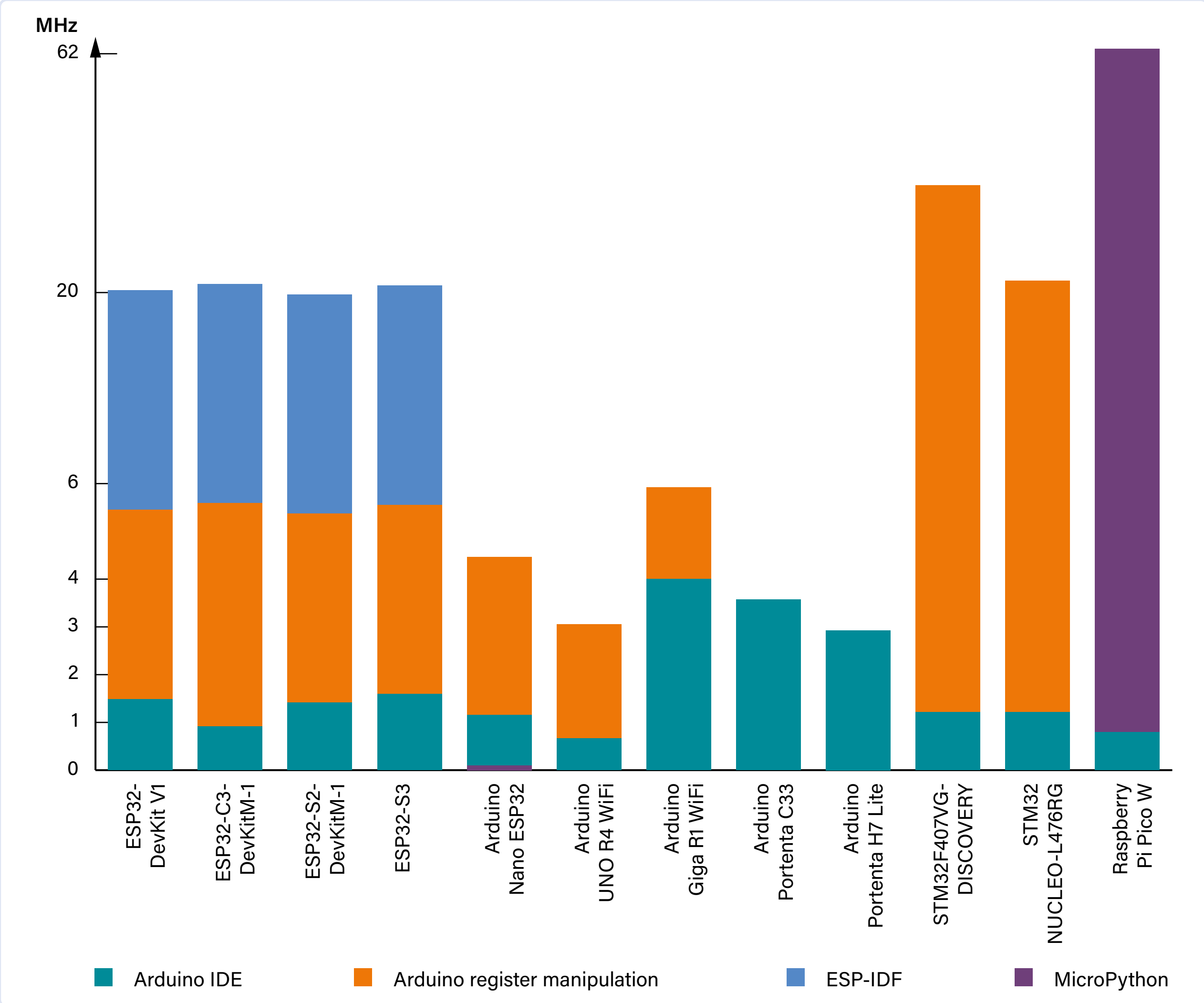

Figure 6: Bar graph showing the maximum output frequencies for the microcontrollers tested.

square wave generation. We can also perform other types of signal and function-generation tests on these and more microcontrollers in the future. Additionally, experimenting with different MCU architectures and programming techniques could further our understanding of the practical limits of these versatile devices for waveform generation.

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Questions or Comments?

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

About the Author

Saad Imtiaz (Senior Engineer, Elektor) is a mechatronics engineer with experience in embedded systems, mechatronic systems, and product development. He has collaborated with numerous companies, ranging from startups to enterprises globally, on prototyping and development. Saad has also spent time in the aviation industry and has led a technology startup company. At Elektor, he drives project development in both software and hardware.

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[1] GitHub Repository for Code and Screenshots: https://github.com/Saad-Imtiaz/SquareWaveBenchmark

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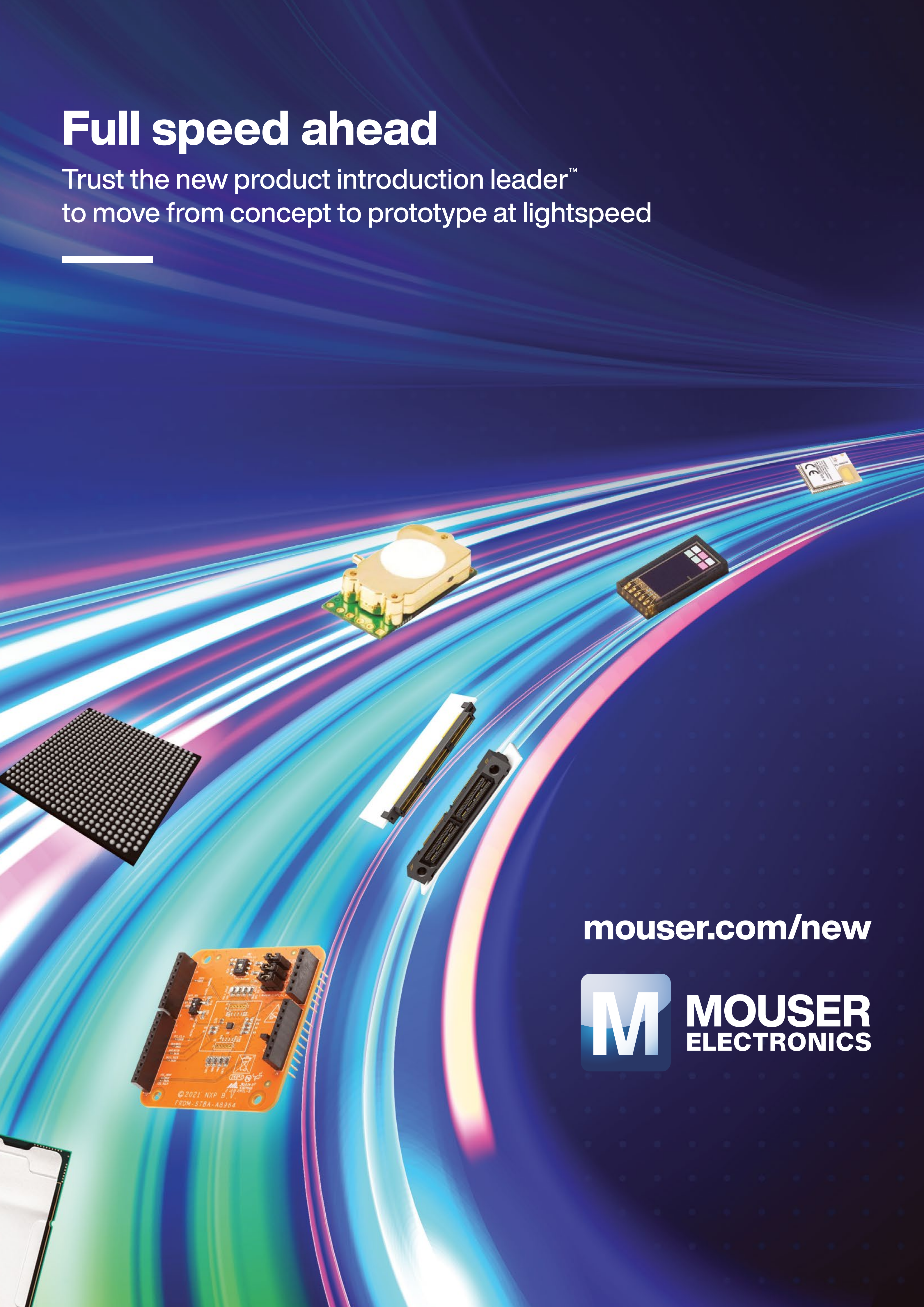
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