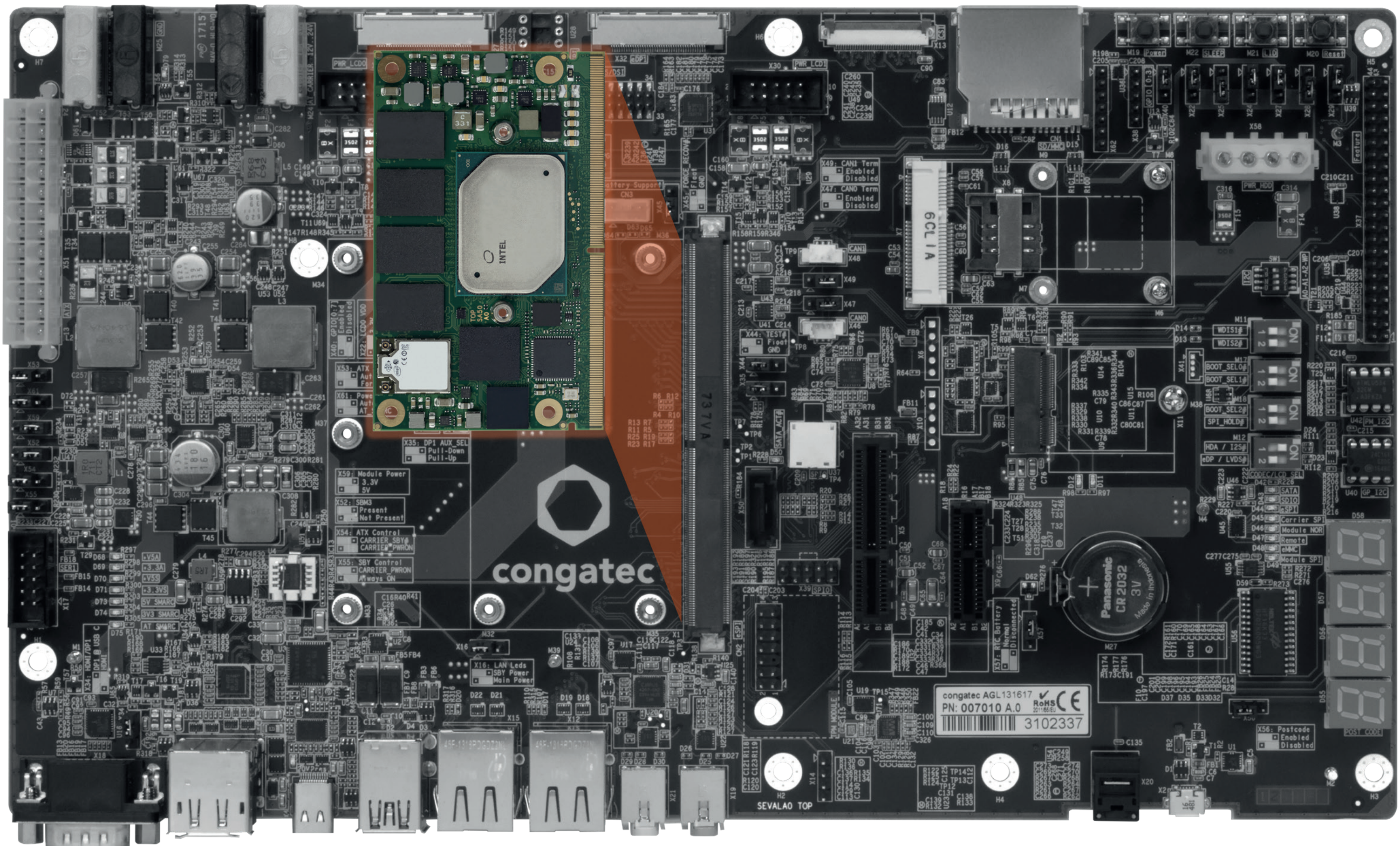
congatec



Whitepaper

Device development with SMARC 2.0

Device development with SMARC 2.0

Developers often face the challenge, that they require a specific design but none of the available designs fulfils their demands. They either do not provide the required performance or the interfaces to get the application up and running. So they look for the best way to design their own solutions. Should they develop everything by themselves or can they leverage off-the-shelf components, and if so which should they buy? If the computing element is only a means to an end, why not try one of the industrial Computer-on-Module (COM) standards? Just plug in the high-power computing core with a computer module and benefit from drastically simplified design, as this just leaves the fine-tuning to be done. This whitepaper describes the typical factors to be considered and steps to be taken so that an idea will make it to market faster and with greater ease using Computer-on-Modules.

The Idea – Build an industrial HMI

Say the idea is to build a battery-powered, mobile HMI with which service technicians can operate a machine or robot from any location. From a technical point of view, such a configuration is one of the most demanding designs, as it requires high performance paired with a broad range of interfaces including wireless options and USB-C. And all this condensed in a Small Form Factor design with lowest power consumption. The idea is to use standardized x86 based Embedded Computing Technology.

First the suitable embedded form factor has to be evaluated. For such a device typical ATX compatible board standards such as Mini-ITX or the smaller Pico-ITX won't do, as they are too bulky for hand held devices like industrial tablets. Another drawback is their fixed range of interfaces. In contrast to PC-like designs mobile devices need only a selection and at different locations. This is not only a question of space, but sometimes also of safety and reliability as every external interface is prone to damage by dirt, dust and fluids. Another important factor is the scalability of the design. Cost savings and long term usability of the design by implementing newer processors are usually the reasons. Embedded board designs use soldered CPUs, so a quick change of the processor itself is usually not common. But there is a design approach that offers all these benefits: Computer on-Modules.

Fast Fact I: Use Computer-on-Modules for Small Form Factor (SFF) designs

that feature only the interfaces that are really required and to have the option of exchanging the CPU with relative ease for different performance classes and for upgrades as soon as more powerful processors or ones with a better balance between power consumption and performance appear on the market.

The Computer-on-Module Concept

A computer module is a small circuit board that is plugged via a standardized connector on an application-specific carrier board. The computer module contains the processor with all core components such as RAM, controllers for PCI Express, Ethernet, SATA, display interfaces, general purpose I/O, and others. The interfaces are routed to the appropriate ports on the carrier board. The application-specific circuitry is accommodated on the carrier board. When designing the carrier board, it has to be decided which of the electrically available computer properties will be executed, where the external interfaces are to be located and which other extensions are required.

TSC Design-In Services

- Signal Integrity Simulation
- Signal Integrity Measurement (PCIe, SATA, USB, etc.)
- Pre-Compliance Measurement
- Schematic Review
- Layout Review
- Debugging & Bring-Up Support
- BIOS Customization
- Power Consumption and Performance Comparisons
- EMC Measurement
- Thermal Solutions and Support
- Driver and OS Support
- MTBF Calculation

TSC Documentation

- User's Guides for congatec Products
- Application Notes (AN)
- Tech Notes (CTN)
- Design Guides
- Reference Schematics
- Product Change Notification

Fast Fact II: Concentration on core competencies

The industry regards Computer-on-Modules as a common and low-risk way of accomplishing complex development tasks with few resources. It enables OEMs to focus on their own core competencies. Thanks to its well-equipped toolkit, module manufacturer congatec simplifies carrier board designs. Reference designs and the associated schematics, application notes, drivers, operating systems, and module-specific firmware are available for a quick start. The congatec Technical Solution Center (TSC) offers many additionally services (see separate box) on demand to help developers get the best out of their design.

Checklist of General Considerations

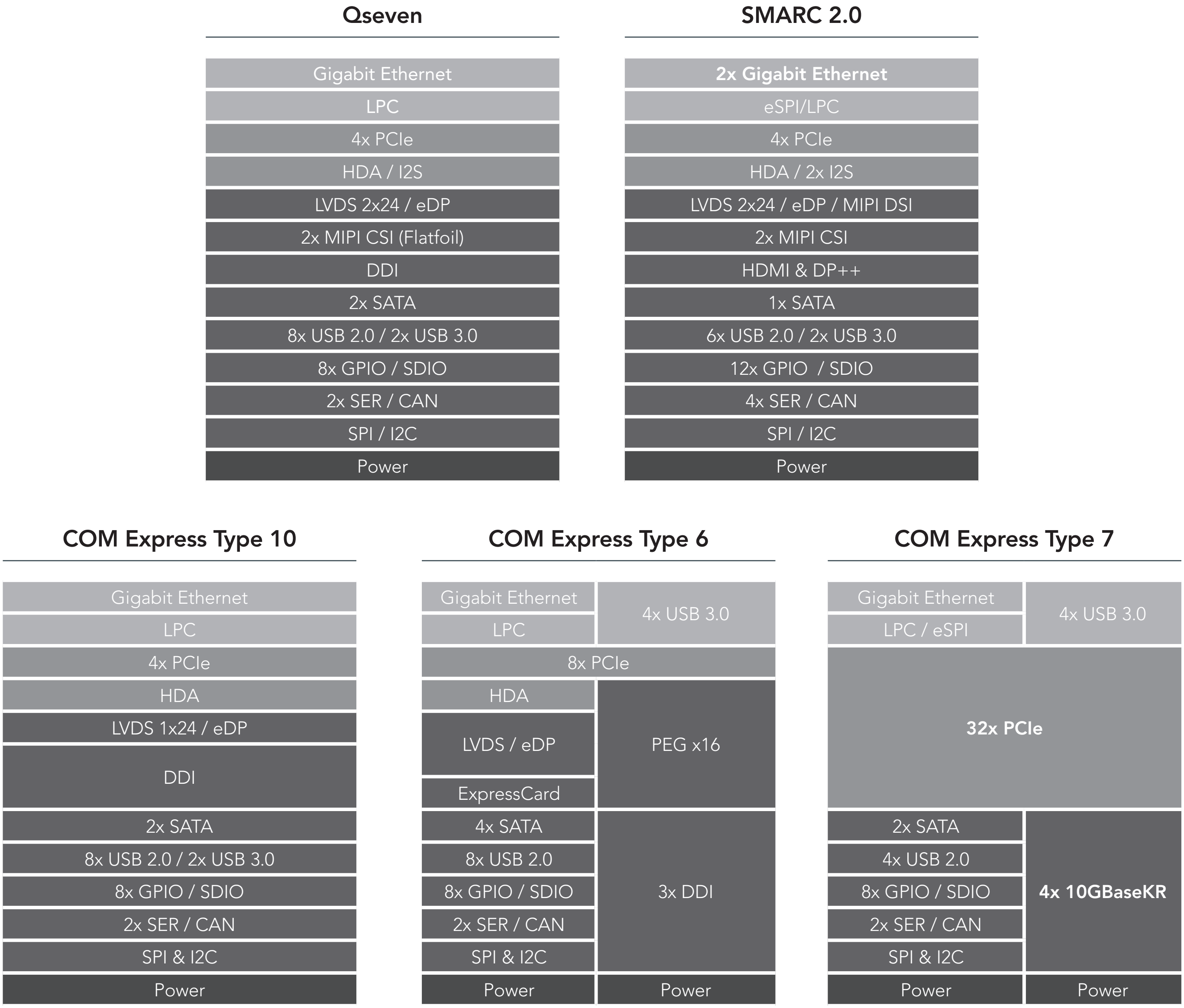
But before diving into the technical details of the design process, there are a few general considerations to make. This is required for any device that is to be developed, and can lead to questions like: In which environment does the device have to perform? What should it be able to do? Will it target the high-performance and high-end market or should it be suitable for price sensitive applications? Is it a single product or is a product family required that spans from entry level to high-performance? This determines which module standard is the best fit.

General consideration checklist

1. Which idea should be realized?
2. Which module concepts are available?
3. Which concept is appropriate for the application?
4. How much space is available?
5. How much computing power does the device require?
6. Which interfaces are required, which can be omitted?
7. What will the environmental conditions be? Will the device be used outdoor, or will it be a mobile device in a vehicle?
8. Should the device be battery-operated?
9. Where can the components be purchased?
10. Which software and hardware support is available?
11. Which other tools are there?

Computer-on-Module Standards

Various module standards have become established on the market over the last 15 years. The most relevant Computer-on-Module standards are COM Express, SMARC, and Qseven.

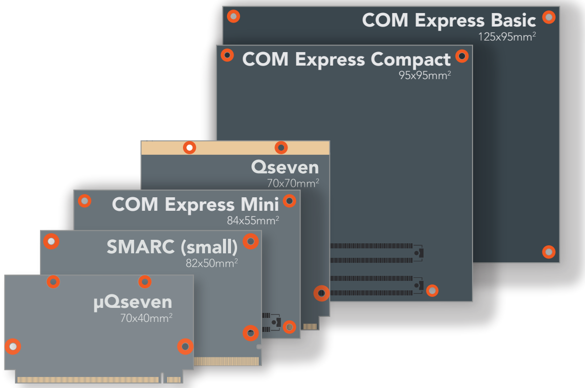


COM Express

has been on the market since 2005 and offers the highest degree of scalability from SFF and low power to server level. Over time various pinout types have come to be defined. Currently, pinout types 6, 7 and 10 are in use. Type 10 uses a 220-pin single-row connector for SFF designs with limited interfaces. Pinout type 6 uses 2 of these connectors summing up to 440 signal pins and covers all generic high-performance applications with up to 4 display outputs and many PCIe lanes. The new COM Express type 7 Server-on-Module implementation offers multiple 10 Gigabit Ethernet ports and an increased PCIe lane count, but omits graphics interfaces. In regards to size, COM Express modules range from the Mini (84 x 55 mm; only type 10) to the Compact (95 x 95 mm) and Basic (95 x 125 mm) form factor for the type 6 pinout. Type 7 modules are currently only available in Basic size.

Qseven

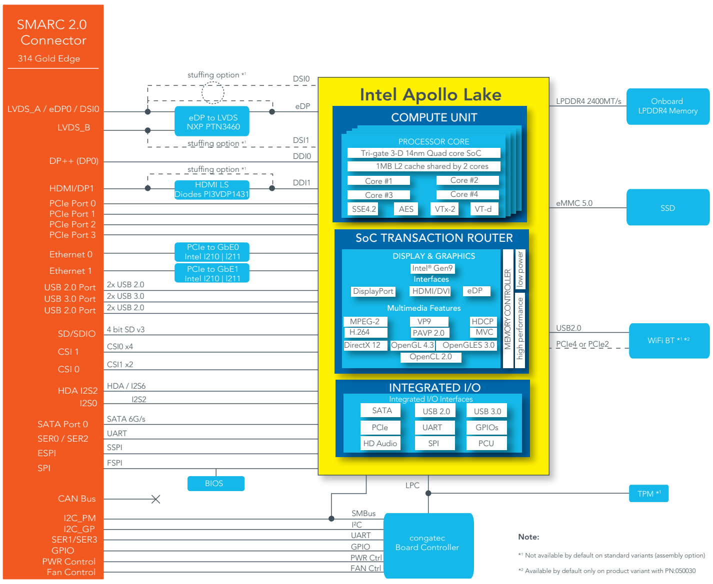
uses a 230-pin edge connector and targets deeply embedded and cost sensitive industrial applications. The fact that it is designed for low-power x86 AND ARM processors for the process and field levels distinguishes it from COM Express. It provides outstanding industrial peripheral support via up to 2x USB 3.0, 8x USB 2.0 as well as up to 4x serial interfaces or CAN bus. Additionally, up to two MIPI CSI cameras can be connected via a flat foil connector on the module. For internet connectivity it further features one Gigabit Ethernet port; as for display support, Qseven modules can drive up to three independent displays. Qseven modules are available in two form factors measuring only 70 x 70 mm or 40 x 70 mm.



Compared: platinum sizes

SMARC 2.0

is comparable to Qseven but features more pins (314 in total), mostly for multimedia oriented applications. SMARC 2.0 supports up to four independent displays. Compared to Qseven, audio is extended with High Definition Audio and I²S in parallel, which is common for many handheld devices. Additionally SMARC 2.0 provides support for wireless connectivity on the module itself. For that task, the specification reserves a special area on the module that is dedicated to the placement of the miniature RF connectors. Most SMARC modules can be found in the short form factor with 82 x 50 mm.



Block diagram conga-SA5

Fast Fact III: Which module for which application?

In general, COM Express should be used whenever a highly scalable product family from low power to high-end is required. Qseven is ideal for any deeply embedded industrial and cost sensitive solutions. SMARC targets multimedia intensive designs. If x86 and/or ARM technology is to be used, Qseven and SMARC are a must.

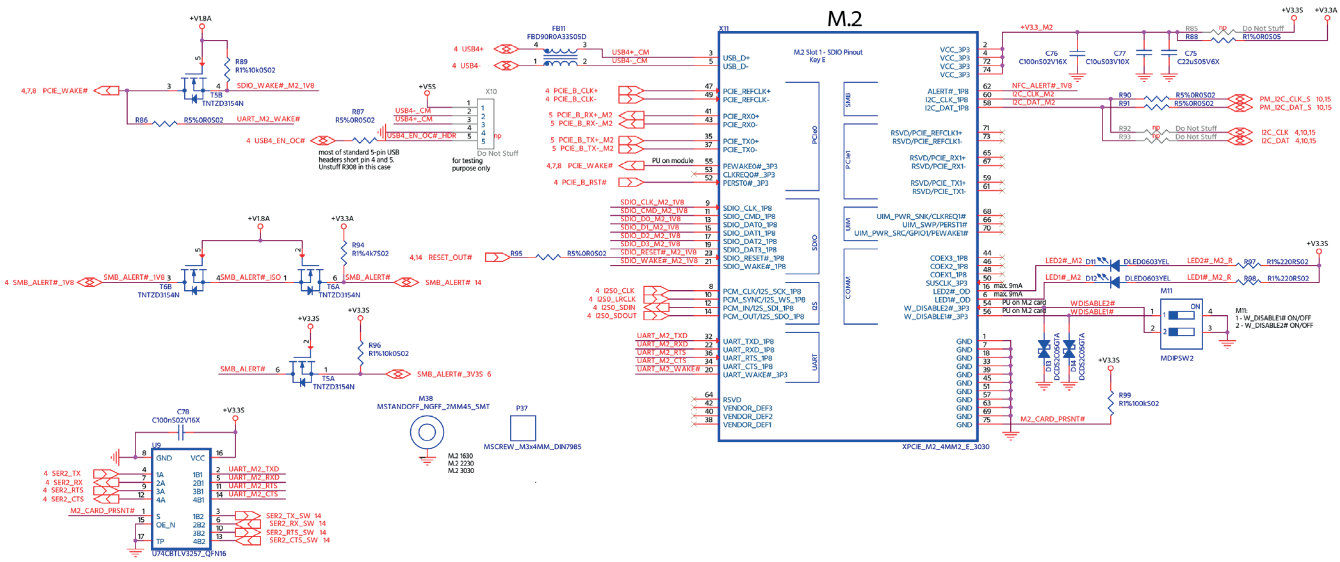
Choosing the module

For battery-driven mobile HMIs, the SMARC 2.0 module conga-SA5 is one of the best options, especially with its pre-integrated wireless functionality. Through the well-known x86 technology of the Atom® Apollo Lake, the module leverages familiar x86 technology and can run Windows as well as Linux. Fans of ARM technology will have to wait a little while until ARM-based SMARC

2.0 modules will become available, which is supposed to be in early 2019 with the launch of i.MX8 based modules. But with the modular concept, developers can start the design with the Apollo Lake and switch to a different processor generation or technology with lightning speed due to the clearly defined interfaces in the standard. To ensure a smooth changeover, congatec delivers all necessities, such as firmware, drivers, and similar, with the respective module. This is one reason why the congatec module has captured the lead position in Computer-on-Modules.

Dimensions and Space

The conga-SA5 module is a finely coordinated mixture of size, performance, and power consumption. In the SMARC 2.0 short form factor at 82 x 50 mm, it is built for the upper SFF performance class. For the project, a decision has to be made regarding the housing. Standard housings are available on the market, but in-house and 3D-printed versions are also options for an ergonomic design. The geometry of the carrier board depends on the housing dimensions and the positioning of the external interfaces.



The Socket 1-SD (Key E) Reference Design

Interfaces

Characteristics of our special-class mobile HMI:

- Wireless network connectivity
- Hard drive for operating system
- Connections for mouse and keyboard
- Connections for microphone and loudspeaker
- 11.6-inch internal display with touch control
- Connection options for external monitor for service monitoring
- Battery solution
- Charging via USB

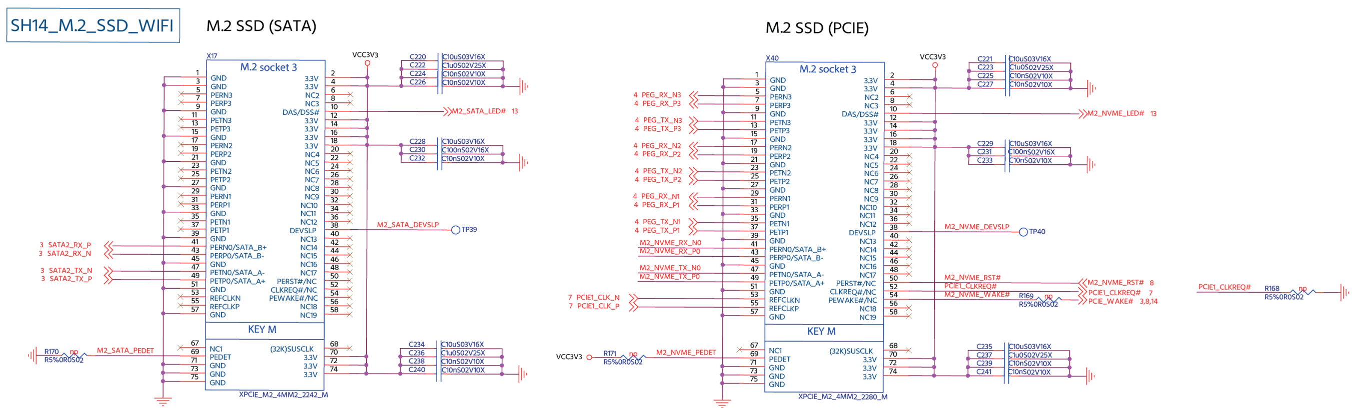
Interfaces derived from this:

Wireless Connection to Network

Wireless LAN can be realized in different ways. The easiest and fastest solution would be to select the high-end conga SA5 x7i3950 module with Intel Atom® x7-E3950 processor, on which the wireless connection is already implemented. The hardcore variant would be to develop this functionality in-house with a wireless chip on the carrier board, but this would require major investment. A possible middle ground between these two solutions uses commercially available WLAN M.2 cards on the carrier board. M.2 cards can be connected via PCIe, SATA, USB, DisplayPort, SDIO, UART, or I2C. With M.2, different sockets are defined depending upon the application. Socket 1 is the connectivity socket and is typically used for Wi-Fi. Each socket has a mechanical "key". In this case, an M.2 card with key E is recommended, which connects to the host system via PCIe and USB. The circuit diagrams for congatec's evaluation carrier board are available for this. However, the best solution for this design is the SA5 x7i3950 with wireless connector soldered onto the module. This reduces the chance of detachment, loosening, or popping out, ensuring the sturdy robustness required for an HMI designed for rugged industrial use.

SSD Hard Drive for Operating System

For the operating system, developers can use either an M.2 card or the eMMC 5.0 onboard flash with its up to 64 gigabytes. The onboard flash is the more rugged and cost effective path of the two. Designers who prefer the M.2 card solution for greater flexibility and speed, are advised to use the PCIe variant, Socket 3 (Key M) for SSDs, because PCIe has become the primary bus. With the new processors supporting an ever-increasing number of PCIe lanes, its use will increase. Although SATA based drives are still common, its days seem to be numbered and this interface will be replaced in the coming years. PCIe is the current point-to-point serial bus for very fast data transfer. More in-depth information on PCIe can be found at www.pcisig.com/.



The SSD Interface circuit diagram

Connections for Mouse and Keyboard

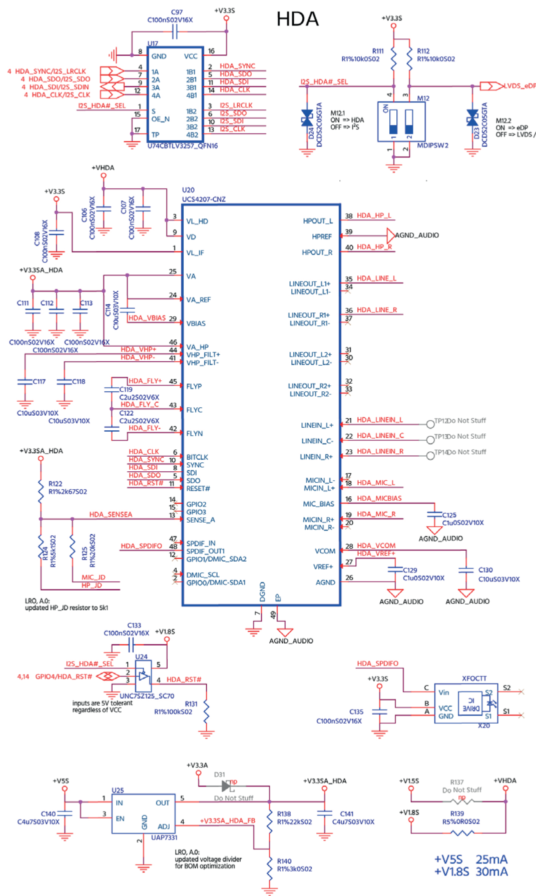
The chosen congatec module provides a standard USB 2.0 port each for the mouse and keyboard. The USB host bus connector utilizes 4 pins, a power supply (5 V), a differential pair (D+ and D- pins) and a ground pin. The USB ID on the fifth pin is initially irrelevant for this application. SMARC USB1 and USB2 are defined as the hosts. To enhance the robustness of the design, the external USB ports on the carrier board can be protected with rubber dust covers.

Internal Display with Touch Control

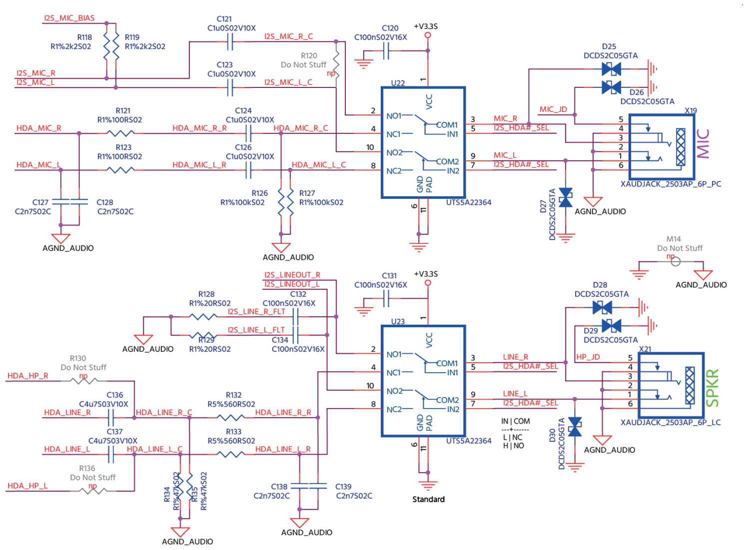
The special features of SMARC 2.0 modules are their up-to-date multimedia capabilities. Up to four video outputs are possible; two 24-bit LVDS/eDP/MIPI DSI plus HDMI/DP++ and DP++ are implemented. Added to this are two MIPI CSI-2 camera interfaces as well as an audio interface via HDA or I2S. eDP is the well-known LVDS successor. Admittedly, LVDS displays are currently still cheaper than eDP displays. For new designs, choosing an eDP1 interface for the internal display of our HMI on our carrier board is recommended because it is the more recent standard. The backlight design depends on the display. LCD displays with multiple sets of LED strips are available for the backlight. Ready-made solutions for power supply and control of the backlight are provided in the SMARC 2 module design guide. Vendors such as Texas Instruments and Analog Devices supply suitable components.

Audio

For audio, the common HDA interface and an HD audio codec are recommended. They can be based on the corresponding section of the circuit diagram for the evaluation board. Normal audio jacks are used for headphones and microphone.



The HDA Interface circuit diagram

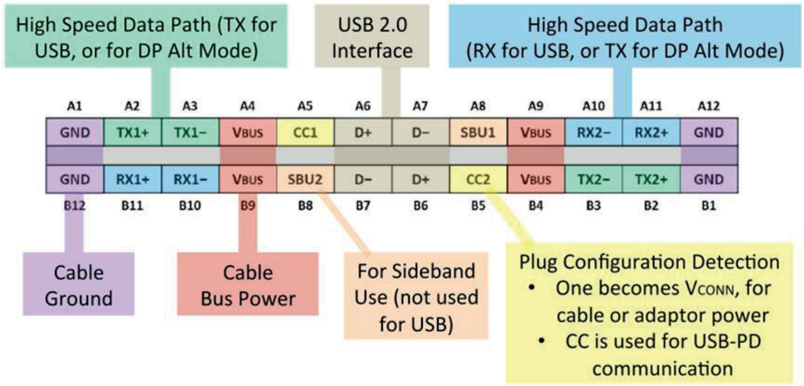


The Audio circuit diagram

Realization

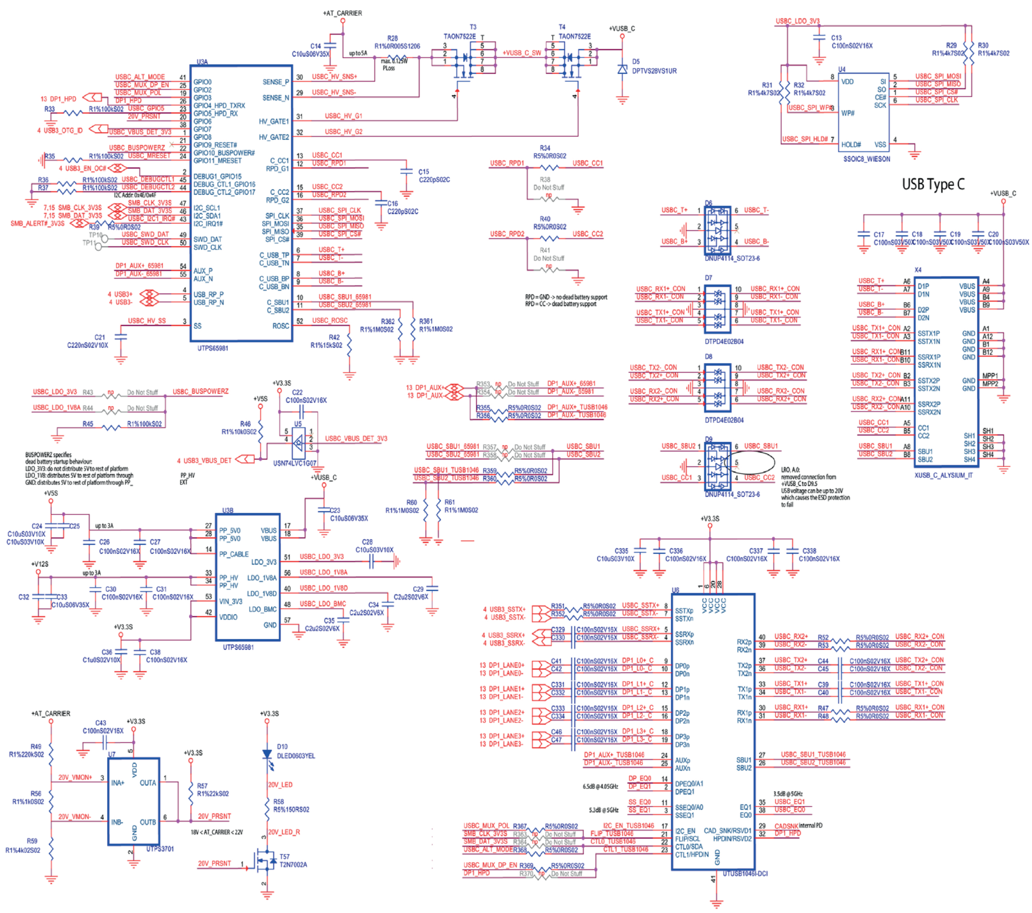
- Wireless connectivity to the network either directly from the module or via M.2 Socket 1 Key E
- Storage for BIOS eMMC 5.0 onboard flash with up to 64 gigabytes
- Connections for mouse and keyboard – two USB 2.0 ports
- 11.6-inch internal display – eDP1
- Connection options for external monitor with USB-C with power delivery
- Battery solution – Conga SBM3
- Charging via USB-C with power delivery
- SMARC module connector
- Reset
- Power supply

Connection Options for Monitor



The HDMI interface can only be used with a license. More information on this can be found at www.hdmi.org. The definition of USB Type-C was extended to include transmission of display data, in addition to normal USB data. Moreover, adapters for directly connecting an HDMI device to the USB Type-C port are available.

USB-C pinout



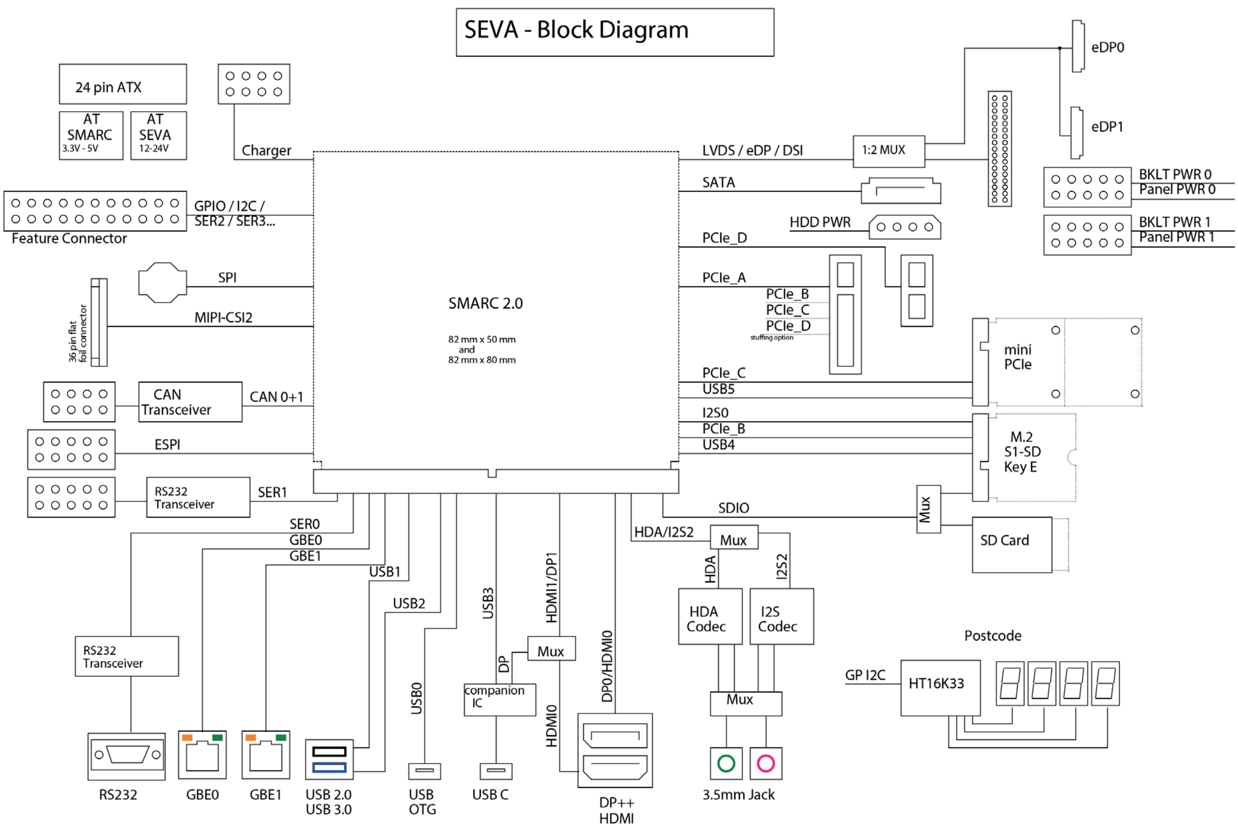
USB-C circuit diagram

Charging Via USB-C

USB Type-C supports the power delivery mode. Up to 100 W can be drawn via the interface. Thus, the battery of the device can be charged completely separately when it is connected to a monitor with power delivery support and power supply. Additionally, it is also possible to drive and power the external screen via the USB-C port. This flexibility and single-cable approach is one of the greatest advantages, besides the convertible connector.

Battery Solution

Next is the need to consider the power concept and analyze the power budget for the different power rails. Some elements expect a 5-V and others a 12-V or 3.3-V supply. As a first step, it is recommended to enter the various supply voltages and power rails into a list with worst-case assumptions. This gives developers an overview of the required power, which forms the basis for dimensioning the supply. The SMARC 2.0 design guide, which can be downloaded from the SGET (https://www.sget.org/standards/smarc.html), contains a sample table with a hypothetical power budget. The SMARC 2.0 standard defines 3-V and 5.25-V modules. The congatec module expects a stable supply of 5 V. IC solutions, e.g. from Linear Technology, are available for voltage supply and battery management. If all of the necessary voltages are generated with switching regulators, it is easy to keep track of the efficiency. Because the primary source is a battery, which means that it can certainly fluctuate, the upper and lower voltage extremes need to be taken into account in the calculation. It is also a good idea to keep an eye on the power rise time. The rise in input voltage to the module should remain well below 50 V/ms. A FET and a hot-swap controller in the input voltage path function here as the safety regulator to limit the voltage ramp-up. Additional information on the supply design can be found in the SMARC design guide. But designers don't need to start from scratch, as congatec already offers the tried and proven conga-SBM3 battery management system. This optimized reference design for mobile battery solutions, which is available for a fee, contains the entire battery management with the corresponding logic, schematics, and documentation. It was originally developed for Qseven and low-power COM Express modules but can also be used for the new SMARC 2.0 modules.



The Audio circuit diagram

Emergency Reset

The SMARC RESET_IN# signal can force the SMARC system to clear the memory and to reboot. The signal is an input signal to the module. When the reset switch is sitting on the baseboard, an open-drain device or a switch to GND must be used. An example of an ESD-protected switch can be found in the design guide.

Emergency shut-off

The emergency shut-off switch can be realized via a general-purpose I/O.

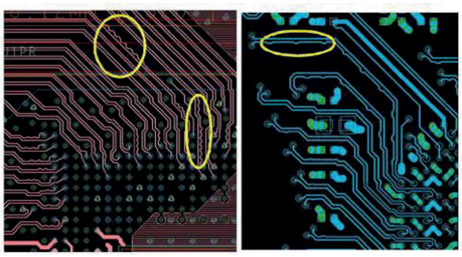
Ready for the Next Step

Following interface definition, drawing the circuit diagram is the next step. Circuit diagram and layout editors are the instruments needed to ensure a reliable design. congatec makes the source data for the evaluation board circuit diagram available as .dsn files on the Internet.

Transition Impedances, Trace Lengths, and Other Challenges

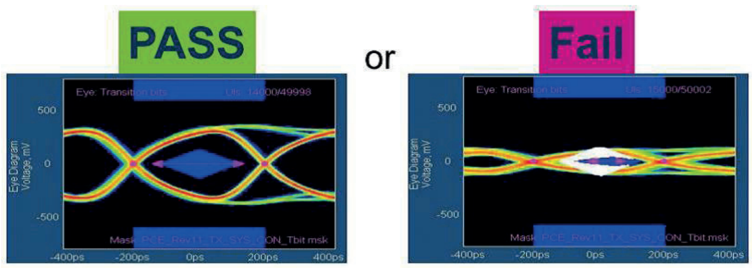
It is highly recommended that designers strictly adhere to the specifications in the design guide for the layout; otherwise the system may not work properly and error free. The design guide provides specifications for trace lengths, transition impedances, dimensioning of capacitors, and similar subtleties. An eight-layer PCB for the carrier board makes the board mechanically stiff and increases the robustness of the system. In addition, developers can easily incorporate four signal layers with ground reference planes. With this solution, which is suitable for high-speed signals, the power supply can also be routed more easily. A small number of transition layers, ideally only two (SMARC connector to internal layer and internal layer to target connector or to part), is optimal. Many of the fast interfaces, including PCIe, SATA, and USB, must be routed as differential pairs over a ground plane as a reference plane. They should be routed as a common pair on the same layer and never follow the same X-Y path as a pair on different layers. The layout of differential pairs is described in detail in the design guide. The pairs should be maximally symmetrical, no stubs are allowed, and no right-angle, tight, sharp bends are permitted. Validation, debugging, and compliance test support services are provided for a fee by congatec.

Fine-Tuning in the Compliance Test



The paths of the differential signals with their curves for the inner curves are checked microm-eter exactly to the same length.

With high data rates, a signal path on the PCB can unfortunately no longer be viewed as a straightforward path between the transmitter and the receiver. The once purely "digital" design turns into an RF design due to the high data rates. Every via, every connector, every cable, and even the geometry of the signal path cause signal shifts or degeneration, reflections, and noise. Rapid switching times, unbalanced impedances, and sources of interference in the frequency range accumulate to yield high bit error rates. Specifications such as USB and PCIe define the electrical and mechanical characteristics. If a device conforms to the specifications, i.e. is compliant, then the transmit-receive connections must meet the requirements of the timing and the voltages in the time domain and in the frequency domain. If potential sources of error are already eliminated in the design phase, OEMs will see the finished product at a lower cost, in a shorter time, and with greater success rates. Unfortunately, the correspond ing test equipment is expensive and specialized know-how rare. The specs for new interfaces foresee both transmit and receive tests, and that means different test concepts and hardware. Both are present in the well-equipped and experienced congatec laboratory. There, the critical section is fine-tuned during the layout review. The paths of the differential signals with their folds for internal bends are checked with micron-scale precision to ensure that they are the same length. With the finest technology and equipment e.g. an Agilent DSA-X 91604A 16 GHz oscilloscope or an Agilent N4903B (J-BERT) high-speed serial BERT, the specialists can track down jittery, damped, or noisy signals from PCIe, SATA, USB 2.0, USB 3.0, Ethernet. 10/100/Gbit, DisplayPort, and HDMI interfaces.



For example a Jitter Pass/Fail test

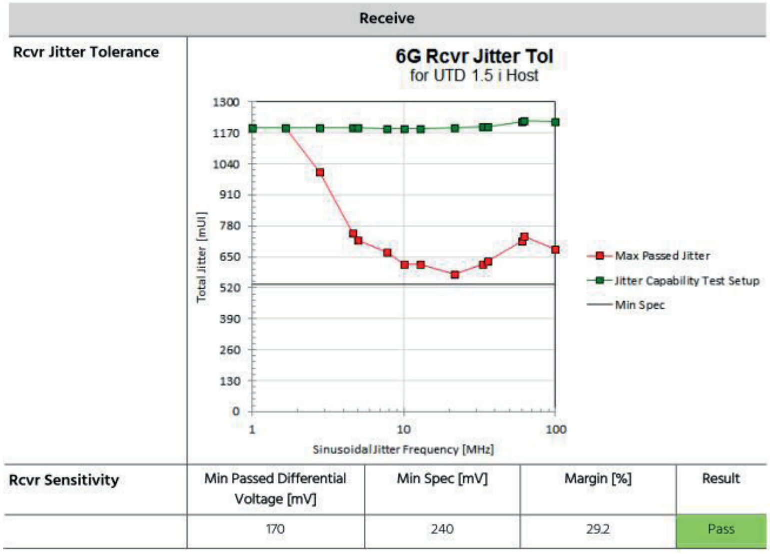
When “Rx and Tx” leave the test station, all of their secrets have been coaxed out of them and recorded in the form of tables and graphs

Pass	# Failed	# Trials	Test Name	Actual Value	Margin	Pass Limits
✓	0	1	PHY-01 : Channel Speed, FBaud & Unit Interval	333.3197 ps	5.4 %	333.2167 ps <= VALUE <= 335.1167 ps
✓	0	1	PHY-02 : Frequency Long-Term Stability	41 ppm	44.1 %	-350 ppm <= VALUE <= 350 ppm
✗	1	1	TSG-01[a] : Differential Output Voltage (Min)	358.36 mV	-10.4 %	VALUE >= 400.00 mV
✓	0	1	TSG-01[b] : Differential Output Voltage (Max) (Informative)	0.00 %	100.0 %	VALUE <= 5.00 %
✗	1	1	TSG-02[a] : Rise Time (Informative)	138.46 ps	-2.9 %	50.00 ps <= VALUE <= 136.00 ps
✗	1	1	TSG-02[b] : Fall Time (Informative)	138.02 ps	-2.3 %	50.00 ps <= VALUE <= 136.00 ps
✓	0	1	TSG-03[a] : Differential Skew, HFTP (Informative)	7.54 ps	62.3 %	VALUE <= 20.00 ps
✓	0	1	TSG-03[b] : Differential Skew, MFTP (Informative)	15.46 ps	22.7 %	VALUE <= 20.00 ps
✓	0	1	TSG-04[a] : AC Common Mode Voltage, MFTP	19.96 mV	60.1 %	VALUE <= 50.00 mV
✓	0	1	TSG-11 : TJ at Connector, HFTP, Clock To Data, fBAUD/500	64.20 mUI	82.6 %	VALUE <= 370.00 mUI
✓	0	1	TSG-12 : DJ at Connector, HFTP, Clock To Data, fBAUD/500	11.20 mUI	94.1 %	VALUE <= 190.00 mUI
✓	0	1	TSG-11 : TJ at Connector, LBP, Clock To Data, fBAUD/500	154.30 mUI	58.3 %	VALUE <= 370.00 mUI
✓	0	1	TSG-12 : DJ at Connector, LBP, Clock To Data, fBAUD/500	99.80 mUI	47.5 %	VALUE <= 190.00 mUI
✓	0	1	TSG-11 : TJ at Connector, SSOP, Clock To Data, fBAUD/500 (Informative)	154.00 mUI	58.4 %	VALUE <= 370.00 mUI
✓	0	1	TSG-12 : DJ at Connector, SSOP, Clock To Data, fBAUD/500 (Informative)	99.70 mUI	47.5 %	VALUE <= 190.00 mUI
✓	0	1	TSG-11 : TJ at Connector, MFTP, Clock To Data, fBAUD/500 (Informative)	70.40 mUI	81.0 %	VALUE <= 370.00 mUI
✓	0	1	TSG-12 : DJ at Connector, MFTP, Clock To Data, fBAUD/500 (Informative)	16.50 mUI	91.3 %	VALUE <= 190.00 mUI
✓	0	1	TSG-11 : TJ at Connector, LFTP, Clock To Data, fBAUD/500 (Informative)	88.10 mUI	76.2 %	VALUE <= 370.00 mUI
✓	0	1	TSG-12 : DJ at Connector, LFTP, Clock To Data, fBAUD/500 (Informative)	35.70 mUI	81.2 %	VALUE <= 190.00 mUI

Knowledge is key

As everyone knows, knowledge is the key to success. That's why the congatec team provides more detailed information on

- ***User Guide***
- ***Design Guide***
- ***Application Notes***
- ***Schematics***
- ***Whitepaper***
- ***Datasheet***
- ***SMARC Youtubefilm***
- ***Smart Battery Solution Youtubefilm***
- ***SGET support***



Summary

The idea of the Computer-on-Module concept scores points with the following:

- CPU easily exchangeable, even across processor generations and architectures (x86/ARM)
- Standard modules are combined with an application-specific carrier board to form an individualized device
- Based on established and evolving standards
- Modules available with numerous combinations of power, performance, and dimensions
- Wide range of modules from different manufacturers

Admittedly, the steps listed above describe an ideal workflow. In the real world, developers will have to master various challenges, some unique. To simplify the use of embedded modules, congatec offers numerous efficient tools for its customers. With these tools and guides, OEMs will be sure to get their individual design running and to market quickly. The SMARC 2.0 evaluation carrier board already integrates M.2 card sockets, SATA, and USB-C. Moreover, the circuit diagrams for these circuit parts are available on request at congatec, so developers can make efficient re-use of the existing know-how. Experienced congatec technicians help customers with their specific design challenges and certification demands. The congatec Technical Solution Center also provides various tools, extensive documentation, and comprehensive tech notes. Thorough training is also provided.

SMARC 2.0 in Detail

Communications Characteristics

SMARC 2.0 added several new ports compared to SMARC 1. Up to six USB ports, including two USB 3.0 ports, a second Ethernet port for segmented IoT connectivity or linear bus and ring topologies, a fourth PCIe lane, and one eSPI leave no communications wishes unfulfilled. Wireless is important. In the SMARC 2.0 specification, a special area is provided on the module for placement of the necessary miniature RF connectors for high-frequency signals. On the congatec modules, corresponding logic modules for WLAN and Bluetooth flexibly shape the choice of the appropriate wireless protocol according to the M.2 1216 interface specification.

Synchronized Down to the Nanosecond Scale

For both Ethernet ports, software-defined pins are routed to the SMARC 2.0 connector. One possibility is to use these configurable inputs/outputs on the Ethernet controller for hardware-based implementation of the precision time protocol (PTP) in accordance with IEEE 1588. (See https://www.nist.gov/el/intelligent-systems-division-73500/ieee-1588)

This type of PTP implemented in hardware achieves nanosecond-scale accuracies and keeps software-based solutions, which are usually in the microsecond range, at bay. This translates into maximum synchronization between multiple local devices, even in combination with WLAN. Powerful IoT gateways can increase their lead over the competition.

For Internal Displays and External Monitors

External monitors can be connected flexibly via the DisplayPorts. Two dual-mode DisplayPorts (also known as "DisplayPort++" or "DP++") are available for this. The advantage: systems that support DP++ functionality for external monitors can provide DisplayPort, HDMI, or even VGA signals . The cable, in part equipped with active electronics, decides which signals are exchanged. The latest version, 1.4, of DisplayPort supports monitor resolutions of up to 7680 × 4320 pixels.

Internal displays can be controlled via LVDS. The two channels are designed for 24-bit data. Via an I²C bus, the configuration data of the graphics are transmitted, two separate signals (VDD_EN) control the power supply to the displays, and the brightness of the backlight is controlled with enable signals (BKLT_EN) and a pulse width signal (BKLT_PWM) separately for two panels.

Alternatively to LVDS, two independent embedded DisplayPort (eDP) signal sets are available in SMARC 2.0 modules for controlling two internal panels. Compared with LVDS, an eDP implementation requires fewer signal wires. For each eDP interface, up to four data channels are supplied for this.

As a third, forward-looking alternative, panels can be connected with the MIPI DSI (display serial interface) specified by the Mobile Industry Processor Interface Alliance. These small, high-resolution displays can be found in smartphones.

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