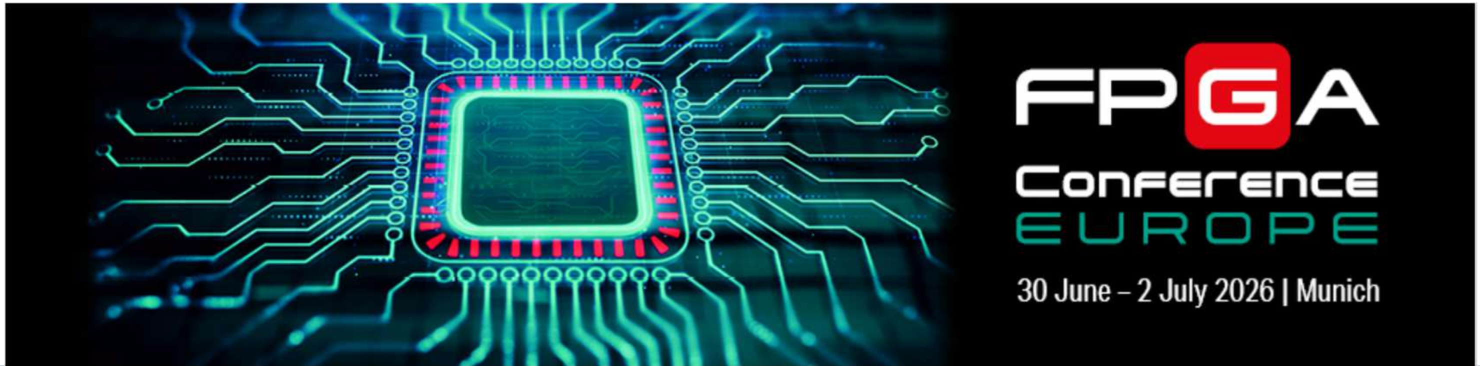
FPGA Conference
Europe

Cost-effective industrial functional nodes with USB 3 on Spartan UltraScale+ platform

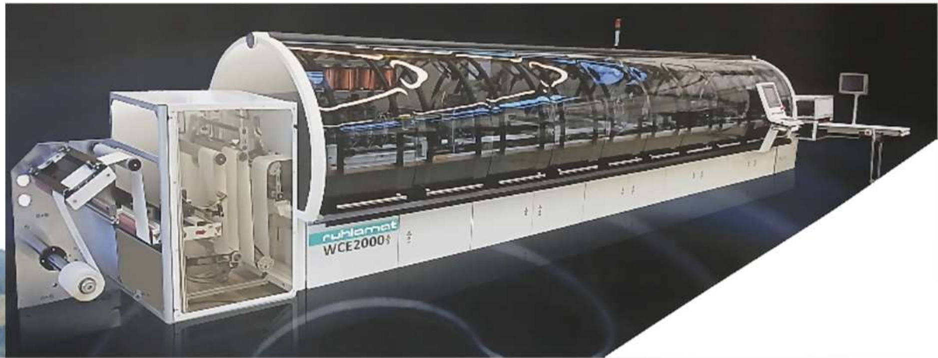
FPGA-based real-time nodes for industrial control, measurement, and AI applications -
Description of a (our) decision-making and realization process



Dr. Jörg Pospiech
CEO AVT GmbH

30.06.2026
München

Content



Brief description of company AVT GmbH

AVT ILMENAU

Founded april 1990

Solving the impossible …
… in the heart of Thuringia

MathWorks®
Partner Programm

areas of operation

Development

- FPGA-Design
- IP-Core Development
- Realtime image processing
- Software development
- Seminar and Consulting Services

EMC-hardened products

- Cameras (visual, LWIR)
- Interference-free lighting
- USB-Converter
- AI Imageprocessing software for automated test procedures

Smart Lighting Control

- for chandeliers and high-end lighting
- in museums, churches, and castles

Local mountain: Kickelhahn (861 m)

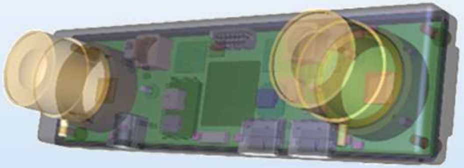
Brief description of company AVT GmbH

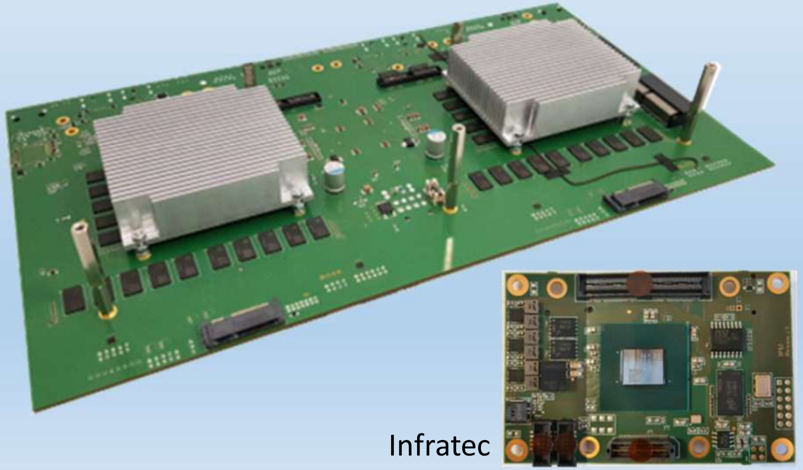
areas of operation

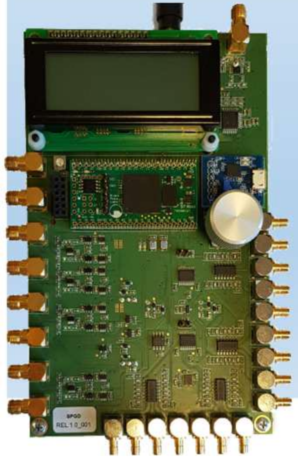
Development

Solving the impossible …
… in the heart of Thuringia

Fast SERDES

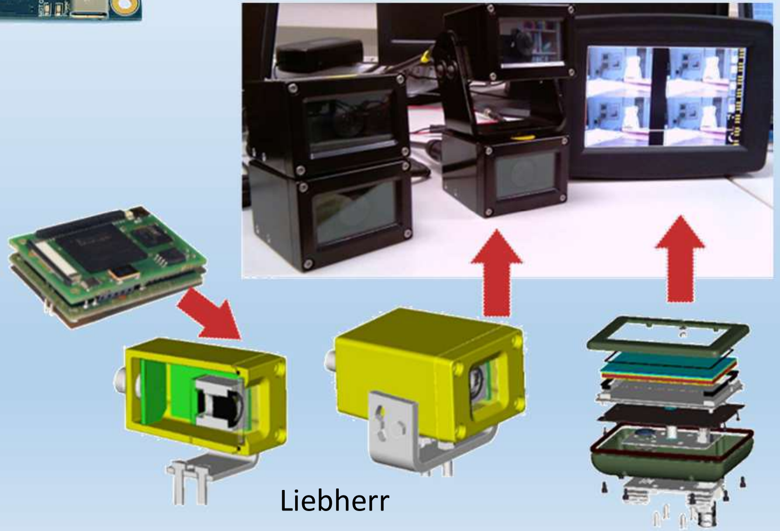






Fraunhofer

Infratec



Liebherr

Local mountain: Kickelhahn (861 m)

Brief description of company AVT GmbH

areas of operation

EMC-hardened products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Brief description of company AVT GmbH

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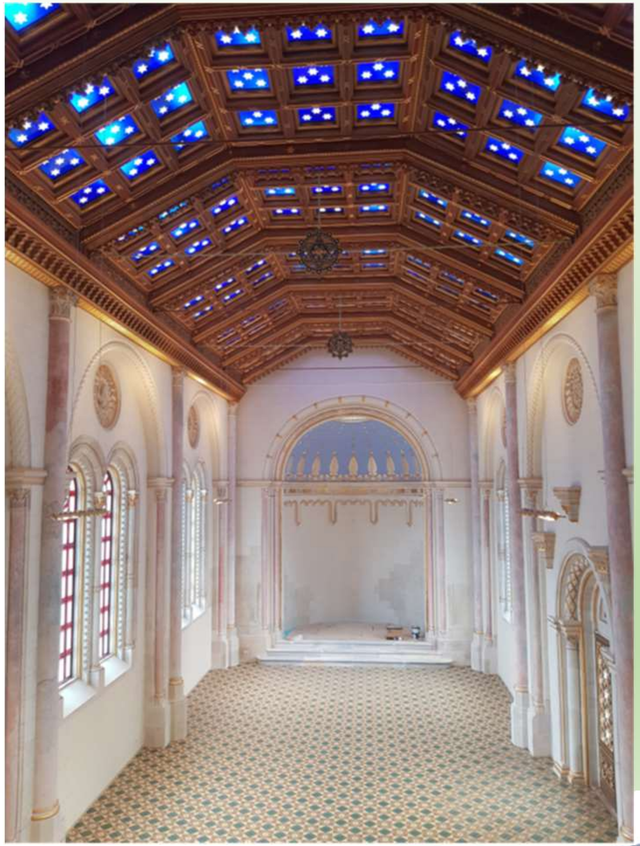
Smart Lighting Control



Reinhardsbrunn

Greiz

Cottbus

- High quality (CRI = 97)
- Long-term stability (> 20 yr)
- Combination with safety lighting
- Complex controls with FPGA

Dresden

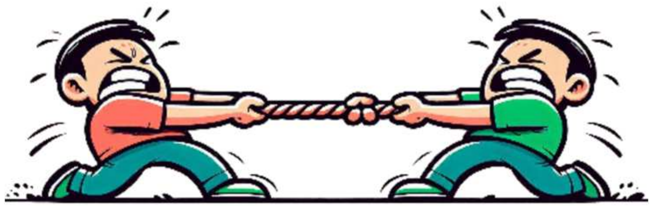
Local mountain: Kickelhahn (861 m)

Industrial Applications - Motivation

Today, industrial systems operate between two worlds

The IT world demands

- Cloud connectivity
- AI (Edge and/or cloud)
- Python
- Linux
- Databases
- Web technologies
- Modern HMI
- Cyber resilience



The machine demands

- Determinism
- Motion control
- Fast I/Os
- Microsecond response times
- Synchronization
- Reliability
- Signal processing
- 24/7 operation

→ How to connect both worlds easily?

1
2
3
4
5
6
7

Industrial Applications - Typical Project Requirements

Common customer requirements we often receive include:

- 100 digital I/Os with deterministic response times
- Encoder acquisition in the MHz range
- Data acquisition at several hundred MB/s (ADCs)
- PWM-outputs to motors or DACs
- Linux integration
- Web visualization
- Cloud data logging
- AI analysis of sensor data
- Optional: Sensors also include high-speed cameras operating in various spectral ranges

Conclusion:

For such applications, PLCs are often too expensive or too slow, and traditional microcontroller based embedded systems are often not deterministic enough

Industrial Applications - Trends in Requirements

More sensors with ever-increasing performance:

- generate more data (bit width/speed increases)
- generate higher data throughput
- stricter real-time requirements
- shorter response times
- in some cases, cameras with standard interfaces (USB-UVC, MIPI)

Real-Time Responses to Actuator Systems

- Security features must respond in real time (without requiring feedback from the cloud)
- Other fast, necessary changes to process and sensor parameters
- reaction times in micro- and also some 10th nanoseconds

More and more custom solutions instead of standard processes

Industrial Applications - Cyber Resilience Requirements

AVT ILMENAU

Manufacturers of smart products must comply with the Cyber Resilience Act

- The European Union's Cyber Resilience Act (CRA) is a framework for products with digital elements
- The goal is to improve the security of networked devices, machines, and software products (throughout their entire lifecycle)
- Officially entered into force on **December 10, 2024**
- The first phase begins on **September 11, 2026**, with a requirement to report actively exploited vulnerabilities and serious security incidents
- The regulation will take full effect on **December 11, 2027**; by that date, all necessary safety requirements must be met:
  - Security-by-design principles,
  - consistent security updates throughout defined product lifecycles,
  - verifiable evidence of security risk management,
  - Systematic identification, assessment, remediation of vulnerabilities,
  - Software-BOM (programs, frameworks, libraries and dependencies)

→ Optimal usability with a powerful operating system

Possible solutions to date - PLC

1
2
3
4
5
6
7

Programmable Logic Controller (PLC)

Where PLCs shine

- Conventional machine controls
- Digital I/Os
- Sequence controls
- Safety functions
- Long-term maintenance
- Standardized fieldbus communication

Limits of PLCs

1. Growing volumes of data from cameras, laser scanners, high-resolution encoders, vibration sensors, power analyzers and more
2. Increased Real-Time Requirements due to synchronization of multiple axes, signal processing in the (sub-)microsecond range, deterministic triggers, parallel processing, higher safety functions and more
3. Integration of Linux and IT Environments: today, customers expect web servers, REST APIs, MQTT, OPC UA, databases, Python, AI frameworks but no proprietary development environments
4. Costs of PLC-specialists and hardware

In the face of these new challenges, FPGA-based function nodes can usefully complement traditional PLC architectures.

Possible solutions to date – MPSoC

Multiprocessor System-on-Chip (MPSoC/Versal)

Where MPSoC shine

- Ideal for complex machine controls
- Fast digital Inputs/Outputs
- Real-time operation in PL
- Sequence controls
- Safety functions
- High processing power
- Fast Interfaces

Limits of MPSoC

1. Possible limitation in operating systems
2. The team of programmers must understand both the hardware and software worlds
3. Costs of programming team and hardware

A great solution for a team that works well together on both hardware and software.

Possible solutions to date – FPGA and IPC/PC

1
2
3
4
5
6
7

Combination of fast FPGA and IPC/PC

Where this combination shine

- Ideal for very complex machine controls
- Fast digital Inputs/Outputs
- Real-time operation in FPGA
- Fast data transmission via PCIe etc.
- Sequence controls
- Safety functions
- Very high processing power
- Fast Interfaces
- High performance operating system

Limits of this combination

1. The highly experienced programming team must be well-versed in both hardware and software.
2. High costs of programming team and hardware

An excellent solution for an experienced, well-coordinated programming team, complex tasks, and high-speed interfaces (PCIe, 10G–100G Ethernet, etc.).

A possible future solution – FPGA and IPC/PC/Raspi

Combination of cost-effective FPGA and IPC/PC/Raspi

Where this combination shine

- Ideal for complex machine controls incl. cameras etc.
- Many digital Inputs/Outputs
- Real-time operation in FPGA
- Fast data transmission → which?
- Sequence controls
- Safety functions
- High processing power
- Fast Interfaces
- **Linux** as operating system
- **Easy to use** for small machines
- low cost systems

Limits of this combination

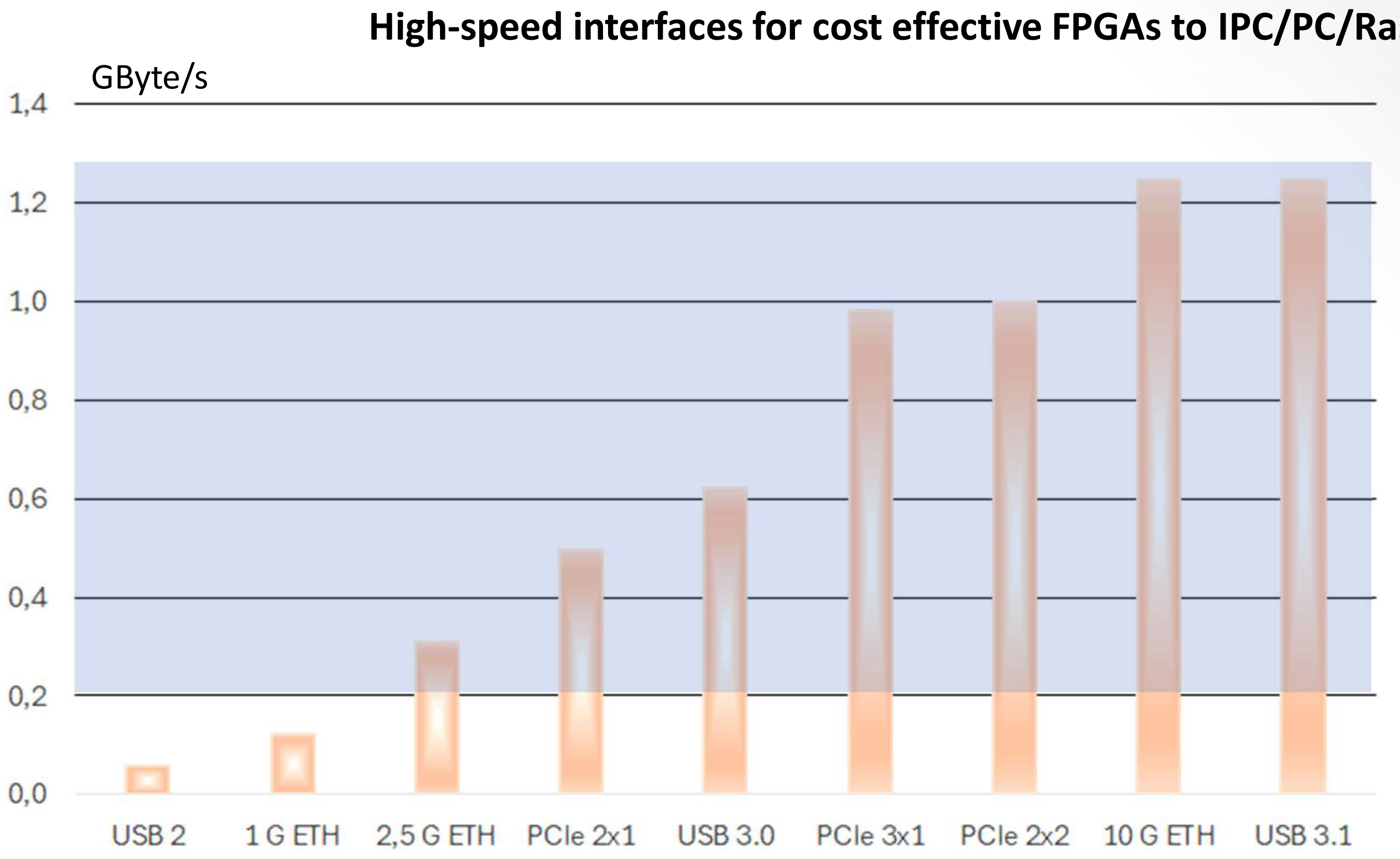
1. Limited to large systems with very high data rates

This would be an ideal combination for simple solutions!

Which components make sense:

- **Which high-speed interfaces?**
- **Which FPGAs?**
- **How versatile is the solution?**
- **What software and services are included?**

A possible future solution – Which high-speed interfaces?



Desired working area for fast, simple, and flexible communication with an IPC/PC/Raspberry Pi

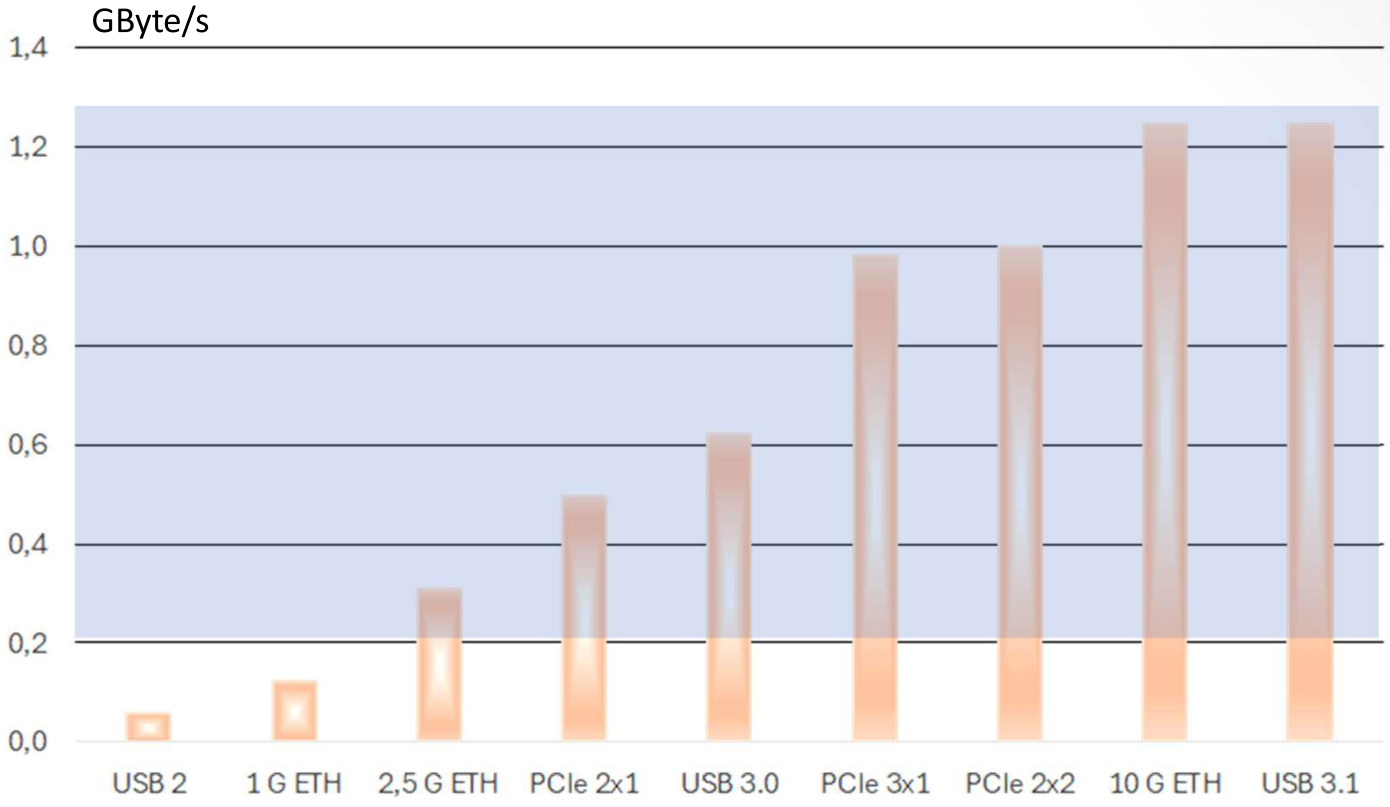
PCIe: fast, but short cable length, not easy

Ethernet: any length, but need protocol stack, 1 GE not fast enough

USB: looks simple, but limited cable length, protocol

A possible future solution – Which high-speed interfaces?

High-speed interfaces for cost effective FPGAs to IPC/PC/Raspi via USB3



Desired working area for fast, simple, and flexible communication with an IPC/PC/Raspberry Pi

USB: looks simple,

- but limited cable length:

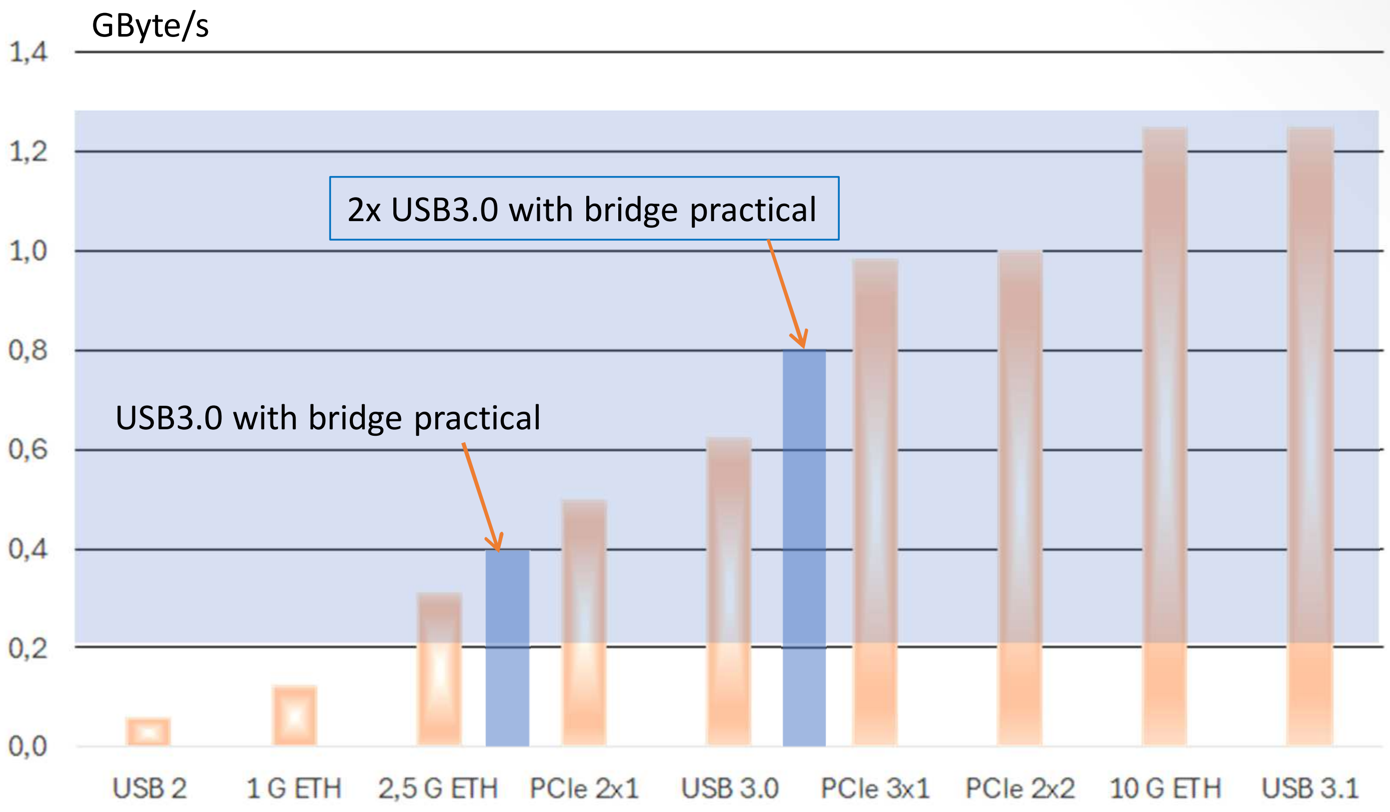
USB2: 5 m, USB3.0: 3 m
but with AOC up to 100m

- protocol:

but with USB to FIFO bridges it's easy to handle (FT601) and wide compatible with UVC (FT602)

A possible future solution – Which high-speed interfaces?

High-speed interfaces for cost effective FPGAs to IPC/PC/Raspi via USB3



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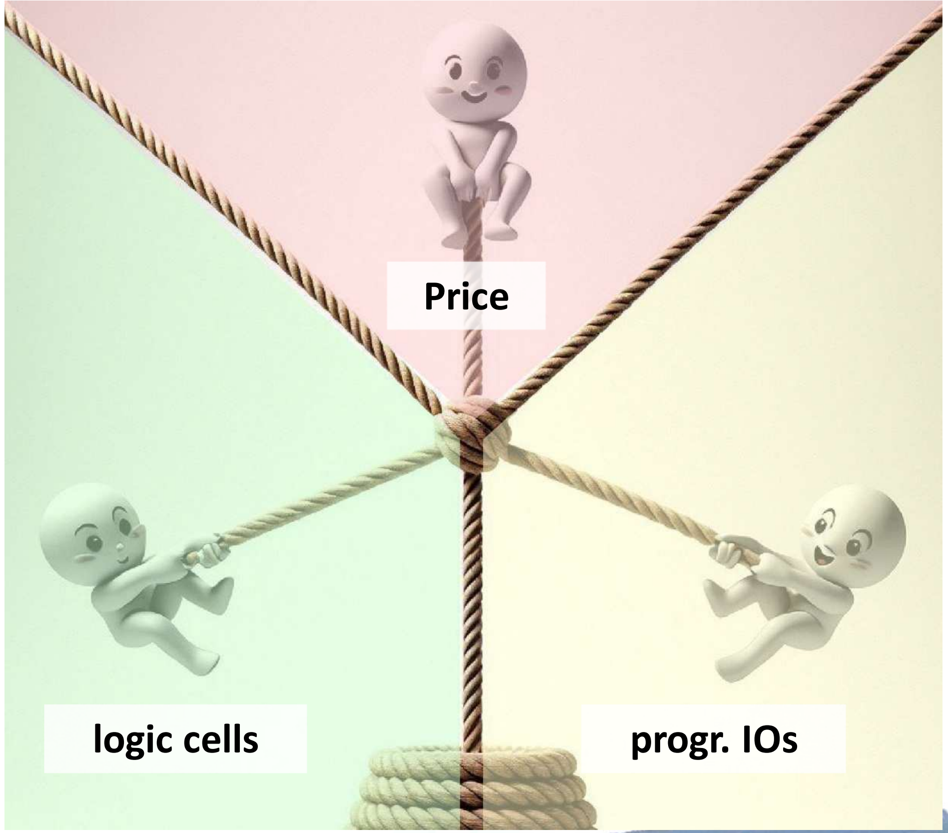
A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks?

For easy integration and low-cost we choose: FPGA without MGT, PCIe and Ethernet Hardware-Blocks.



What else do we need to help us make a decision?

A possible future solution – Which FPGA?

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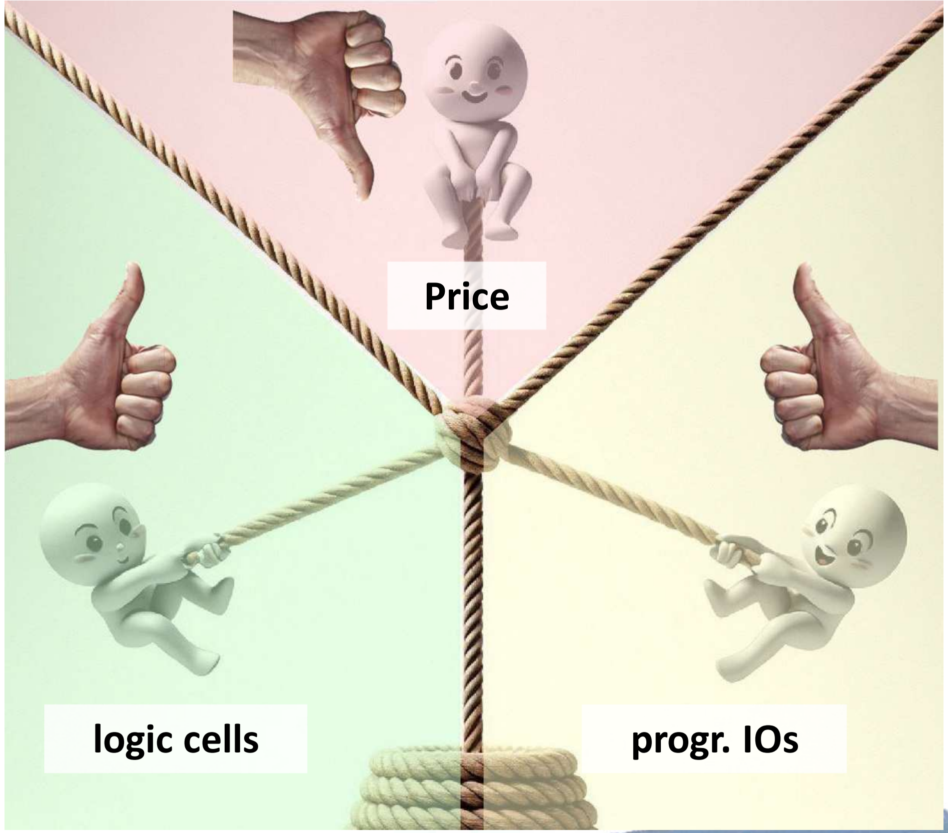


What else do we need to help us make a decision?

We want to have as many **logic cells** as possible for the controller as well as processing
AND
freely **programmable I/Os** at the lowest possible cost!

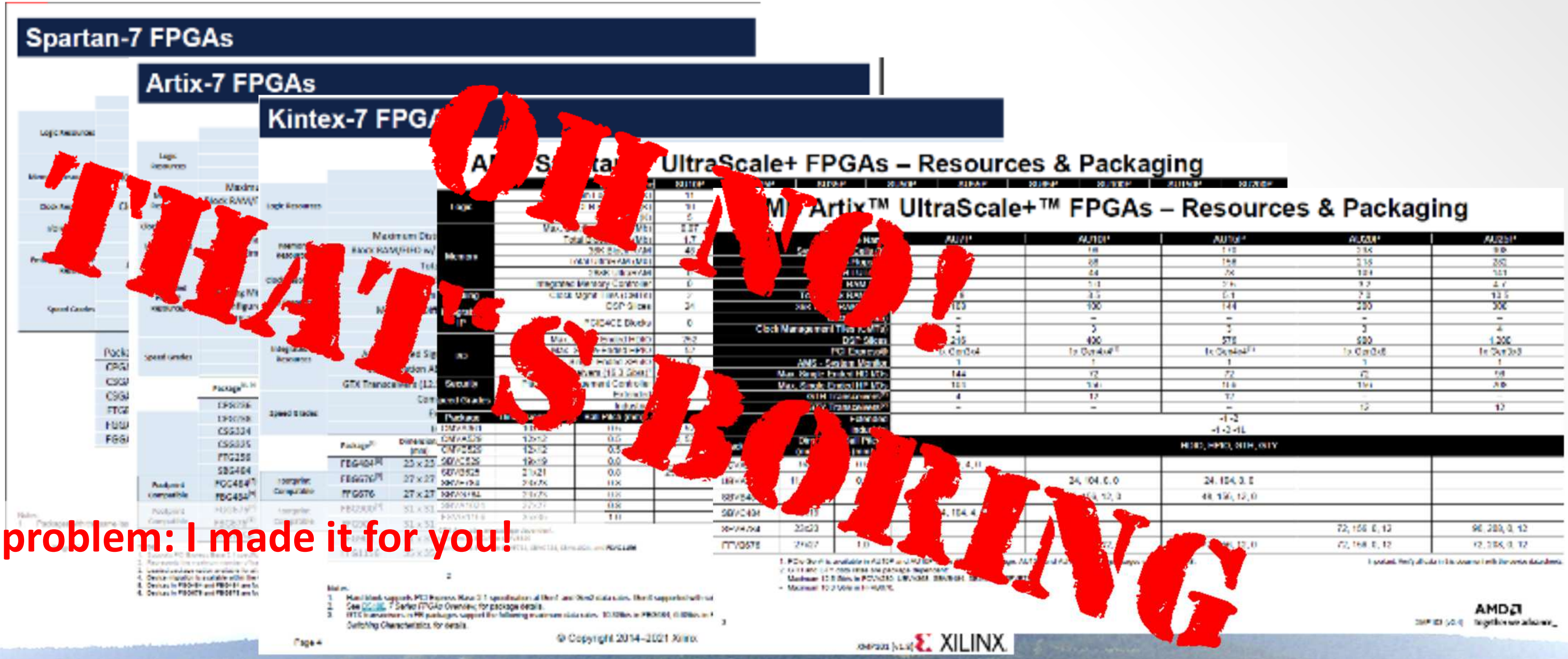
Let's take a closer look at the affordable AMD FPGAs!

A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks?

We are considering all AMD FPGAs whose price, for the most affordable model, is less than 250 € and does not exceed 400 €, but we like FPGAs below 50… 100 € (all list prices by mouser).

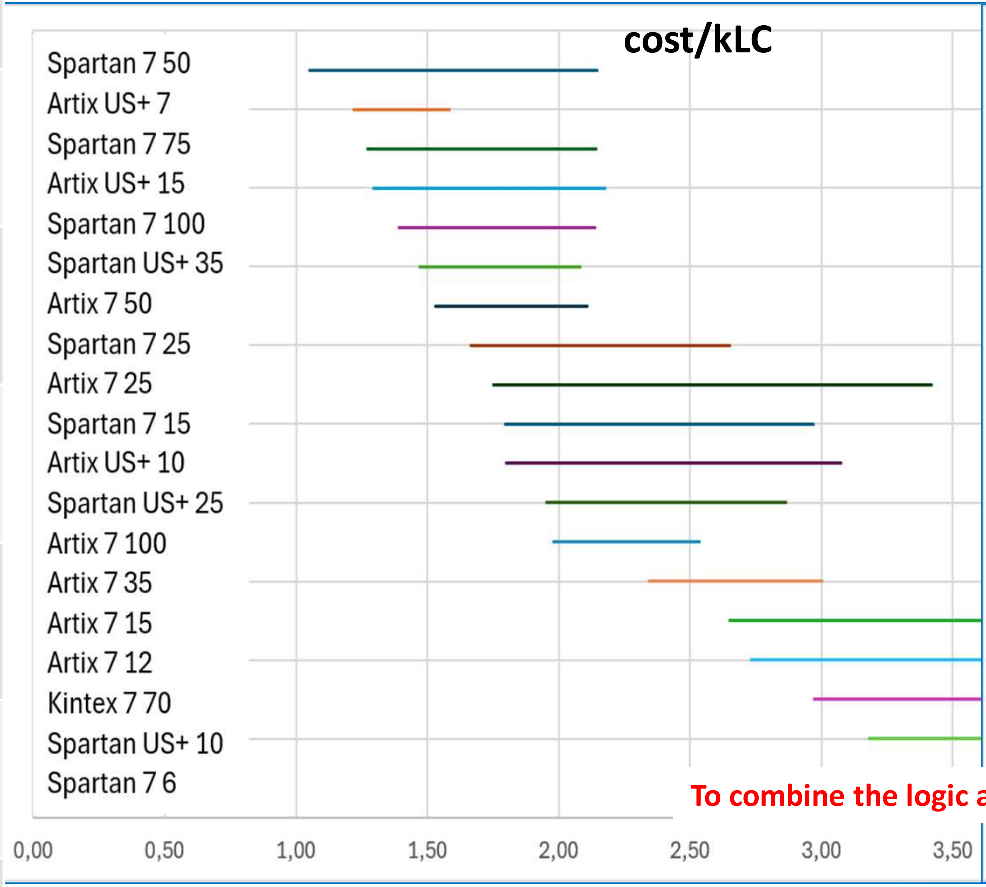
One option now is to go through and compare all the tables for AMD FPGAs!

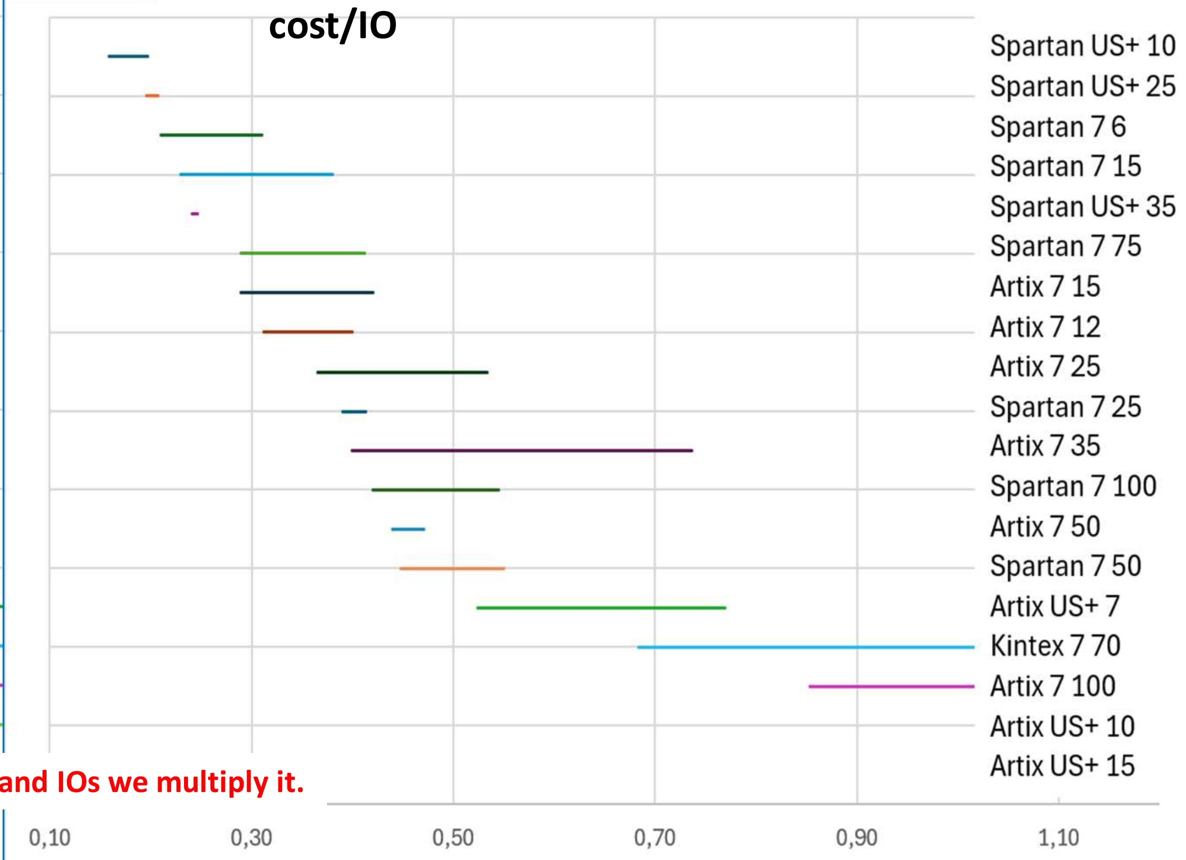


… no problem: I made it for you!

A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks?



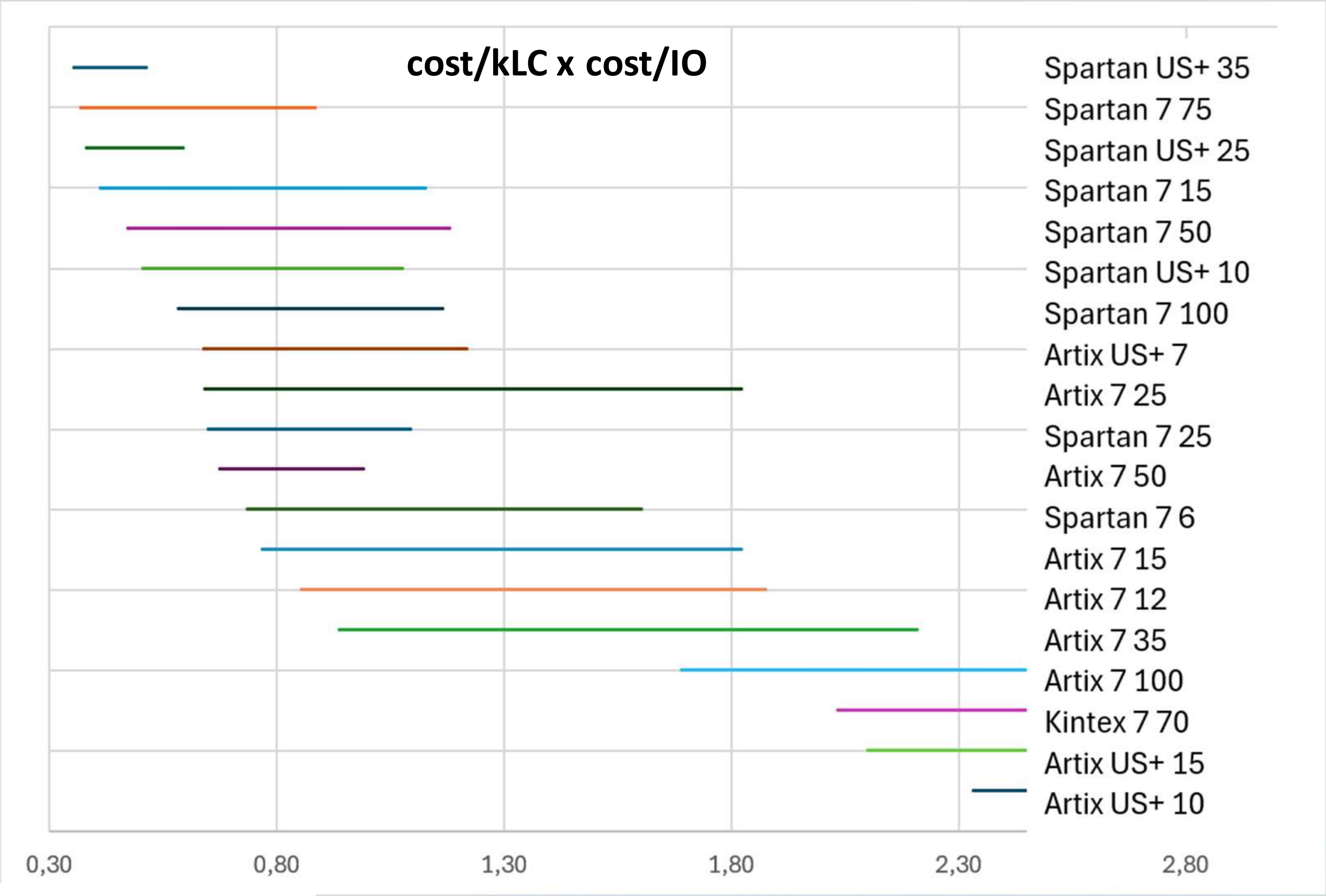


To combine the logic and IOs we multiply it.

This lists are not intended to be exhaustive!

A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks?



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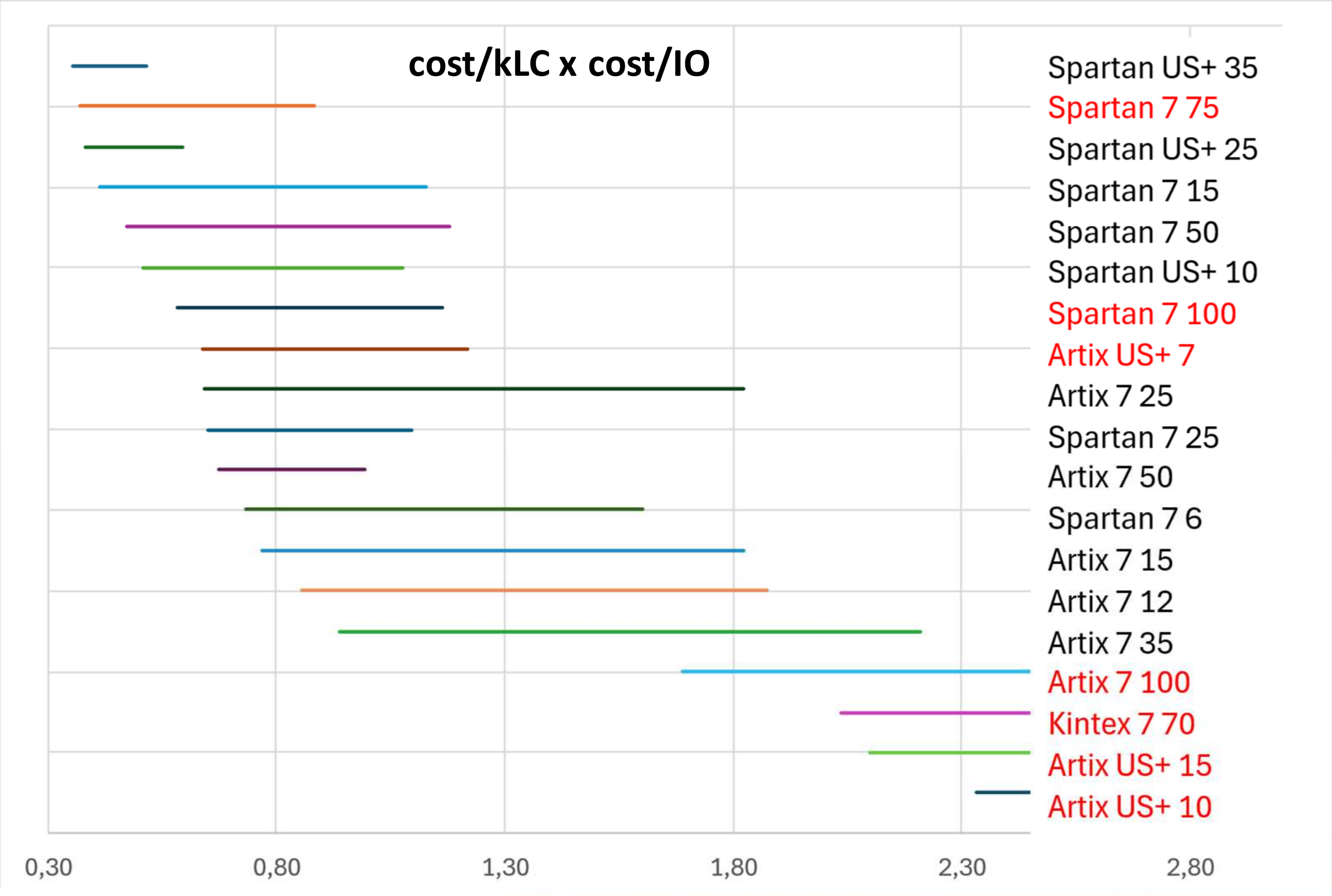
A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks?



All FPGAs with minimum prices above 100 € are marked in red.

When we look at the list the new Spartan US+ seems to be the best solution!

But which housing?

→ Now we can have a look at the table.

This lists are not intended to be exhaustive!

A possible future solution – Which FPGA?

ILMENAU

Which cost effective FPGA is the best for industrial tasks? - Package

AMD Spartan™ UltraScale+ FPGAs – Resources & Packaging

	Device Name	SU10P	SU25P	SU35P	SU50P	SU55P	SU65P	SU100P	SU150P	SU200P
Logic	System Logic Cells (K)	11	22	36	52	52	65	100	137	218
	CLB Flip-Flops (K)	10	20	32	48	48	60	92	126	200
	CLB LUTs (K)	5	10	16	24	24	30	46	63	100
Memory	Max. Distributed RAM (Mb)	0.07	0.14	0.23	0.41	0.41	0.51	0.79	1.25	1.99
	Total Block RAM (Mb)	1.7	1.7	1.7	2.5	2.5	3.8	5.1	5.9	6.8
	36K Block RAM	48	48	48	72	72	108	144	168	192
	Total UltraRAM (Mb)	0	0	0	0	0	0	0	4.5	18.0
	288K UltraRAM	0	0	0	0	0	0	0	16	64
	Integrated Memory Controller	0	0	0	0	2	2	2	2	2
Clocking	Clock Mgmt Tiles (CMTs)	2	2	2	2	4	5	5	6	6
Integrated IP	DSP Slices	24	36	48	96	96	144	144	384	384
	PCIE4CE Blocks	0	0	0	0	0	1x Gen4x4	1x Gen4x4	1x Gen4x8 or 2x Gen4x4	1x Gen4x8 or 2x Gen4x4
I/O	Max. Single-Ended HDIO	252	252	252	336	168	294	294	336	336
	Max. Single-Ended HPIO	52	52	52	52	52	52	52	104	104
	Max. Single-Ended XP5IO	0	0	0	0	132	132	132	132	132
	GTH Transceivers (16.3 Gb/s)[1]	0	0	0	0	0	4	4	8	8
Security	Platform Management Controller	✓	✓	✓	✓	✓	✓	✓	✓	✓
Speed Grades	Extended					-1, -2				
	Industrial					-1, -2, -1L				

Package	Dimensions (mm)	Ball Pitch (mm)	HDIO, HPIO, XP5IO, GTH							
			SU10P	SU25P	SU35P	SU50P	SU55P	SU65P	SU100P	SU150P	SU200P
CMVA361	10x10	0.5	168, 52, 0, 0	168, 52, 0, 0	168, 52, 0, 0						
CMVA529	12x12	0.5	252, 52, 0, 0	252, 52, 0, 0	252, 52, 0, 0	280, 52, 0, 0					
CMVB529	12x12	0.5					100, 52, 132, 0	100, 52, 132, 4	100, 52, 132, 4		
SBVC529	19x19	0.8					120, 52, 132, 0	120, 52, 132, 0	120, 52, 132, 0		
SBVB625	21x21	0.8	252, 52, 0, 0	252, 52, 0, 0	252, 52, 0, 0	336, 52, 0, 0					
SBVF784	23x23	0.8					168, 52, 132, 0	224, 52, 132, 4	224, 52, 132, 4	224, 52, 132, 4	224, 52, 132, 4
SBVG784	23x23	0.8						120, 52, 132, 4	120, 52, 132, 4	120, 104, 132, 8	120, 104, 132, 8
SBVA1024	27x27	0.8						294, 52, 132, 4	294, 52, 132, 4	294, 104, 132, 8	294, 104, 132, 8
FSVG1156	35x35	1.0						[illegible], 52, 132, 4	294, 52, 132, 4	336, 104, 132, 8	336, 104, 132[illegible]

Low cost

performant

A possible future solution – Which FPGA?

Which cost effective FPGA is the best for industrial tasks? - Package

AMD Spartan™ UltraScale+ FPGAs – R

	Device Name		SU10P	SU25P	SU35P	SU50P
Logic	System Logic Cells (K)		11	22	36	52
	CLB Flip-Flops (K)		10	20	32	48
	CLB LUTs (K)		5	10	16	24
Memory	Max. Distributed RAM (Mb)		0.07	0.14	0.23	0.41
	Total Block RAM (Mb)		1.7	1.7	1.7	2.5
	36K Block RAM		48	48	48	72
	Total UltraRAM (Mb)		0	0	0	0
	288K UltraRAM		0	0	0	0
	Integrated Memory Controller		0	0	0	0
Clocking	Clock Mgmt Tiles (CMTs)		2	2	2	2
Integrated IP	DSP Slices		24	36	48	96
	PCIE4CE Blocks		0	0	0	0
I/O	Max. Single-Ended HDIO		252	252	252	336
	Max. Single-Ended HPIO		52	52	52	52
	Max. Single-Ended XP5IO		0	0	0	0
	GTH Transceivers (16.3 Gb/s)[1]		0	0	0	0
Security	Platform Management Controller		✓	✓	✓	✓
Speed Grades	Extended					
	Industrial					
Package	**Dimensions (mm)**	**Ball Pitch (mm)**	**HDIO, HPIO, XP5IO, (**			
CMVA361	10x10	0.5	168, 52, 0, 0	168, 52, 0, 0	168, 52, 0, 0	
CMVA529	12x12	0.5	252, 52, 0, 0	252, 52, 0, 0	252, 52, 0, 0	280, 52, 0, 0
CMVB529	12x12	0.5				
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SBVB625	21x21	0.8	252, 52, 0, 0	252, 52, 0, 0	252, 52, 0, 0	336, 52, 0, 0
SBVF784	23x23	0.8				
SBVG784	23x23	0.8				
SBVA1024	27x27	0.8				
FSVG1156	35x35	1.0				

Possible packages for SU10P-SU35P:

CMVA361: not enough I/Os (220 I/Os)

CMVA529: looks good (304 I/Os)

SBVB625: too big for small nodes

Best will be CMVA529:

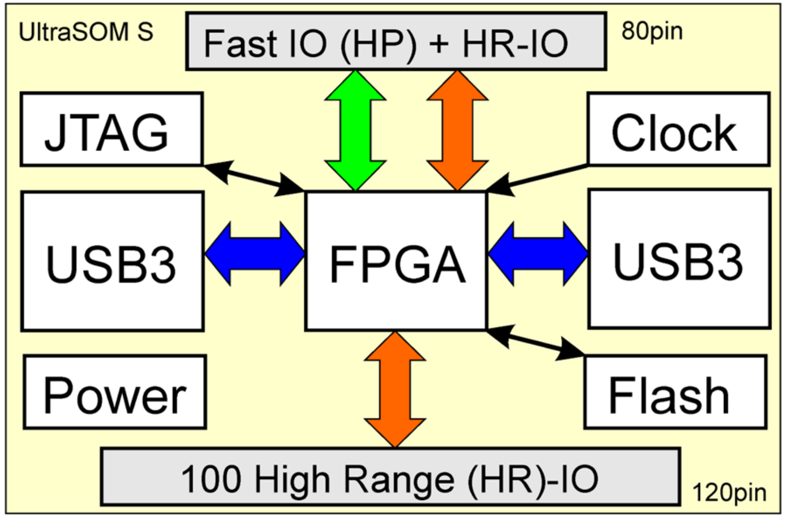
- small package
- a lot of free IOs
- 4 different types with 11… 52 kLC
- but 0,5 mm pitch requires more advanced PCB technology

What is the FPGA function node made of?

Which components are on the function node board?

The board consist of 2 USB3.0-Bridges (and 2 USB-C connectors), the Flash-IC for bitfiles, Clock-oszillator, and especially 2 high-pin connectors (samtec ERF6: high pin-count, but small size).

USB3.0-Bridge



USB3.0-Bridge

What is the FPGA function node made of?

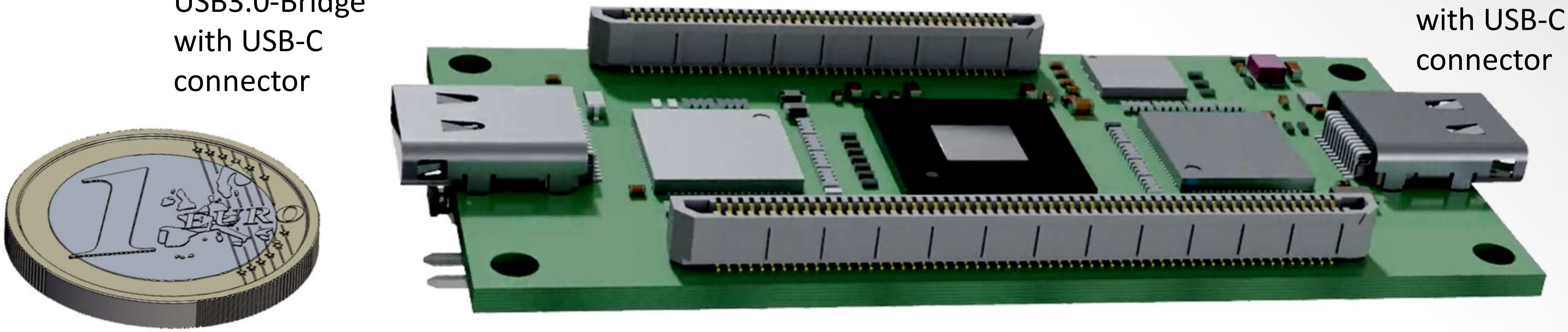
How does it look?

Board size: 65 mm x 30 mm

52 High performance IOs + 16 High density IOs

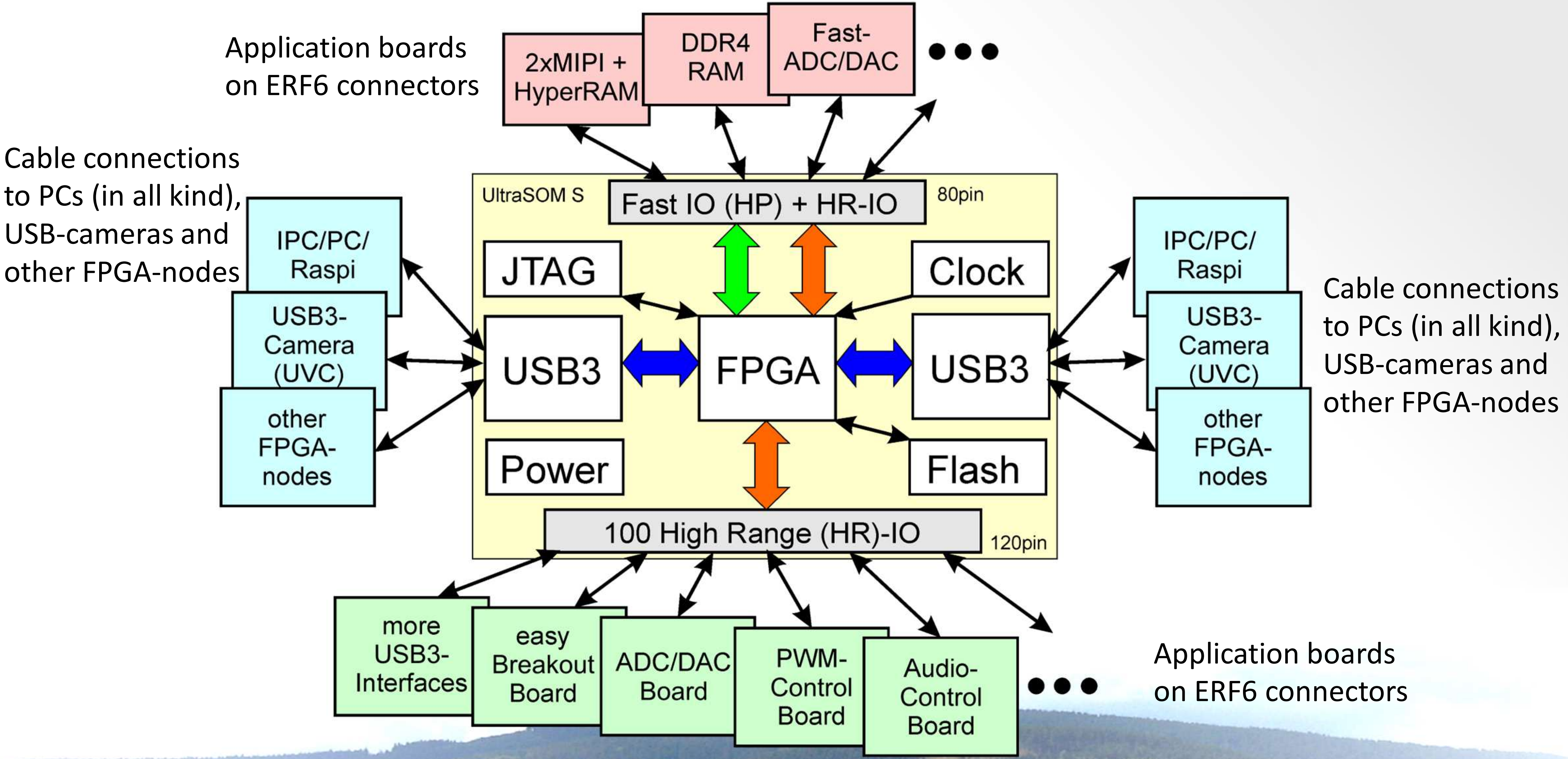
USB3.0-Bridge with USB-C connector

USB3.0-Bridge with USB-C connector



100 High density IOs from 3 banks
possible definition of banks voltage from outside the board

What is the FPGA function node made of?
- possible connections



Example designs with the function node

CamControl for EMC-hardened 4K Cam

CamControl consisting of RaspiPi 5 with 5 inch display

USB 4K camera
(EMC hardened)

From Raspi
→ Connection to PC or Cloud for AI processing via Ethernet or Wifi

FPGA Function node with USB camera input and additional sensor signals für combination and image processing

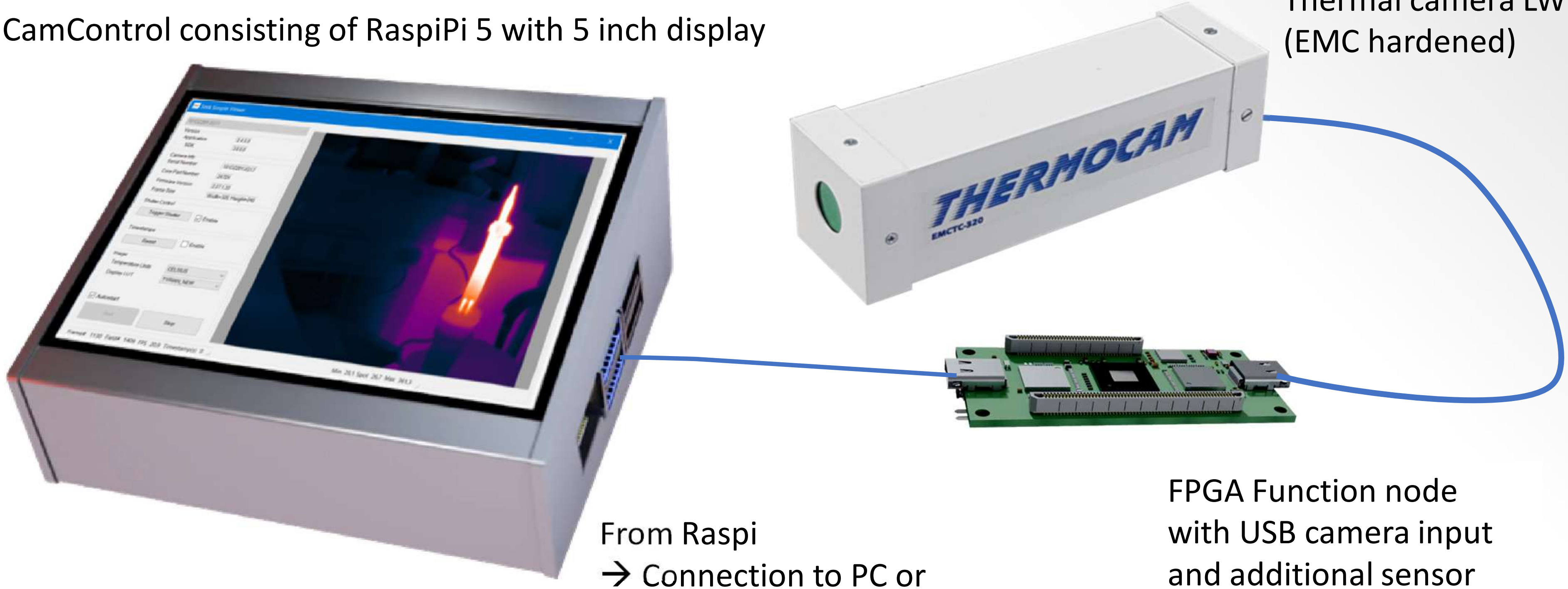
1
2
3
4
5
6
7

Example designs with the function node

CamControl for EMC-hardened thermal camera

CamControl consisting of RaspiPi 5 with 5 inch display

Thermal camera LWIR
(EMC hardened)



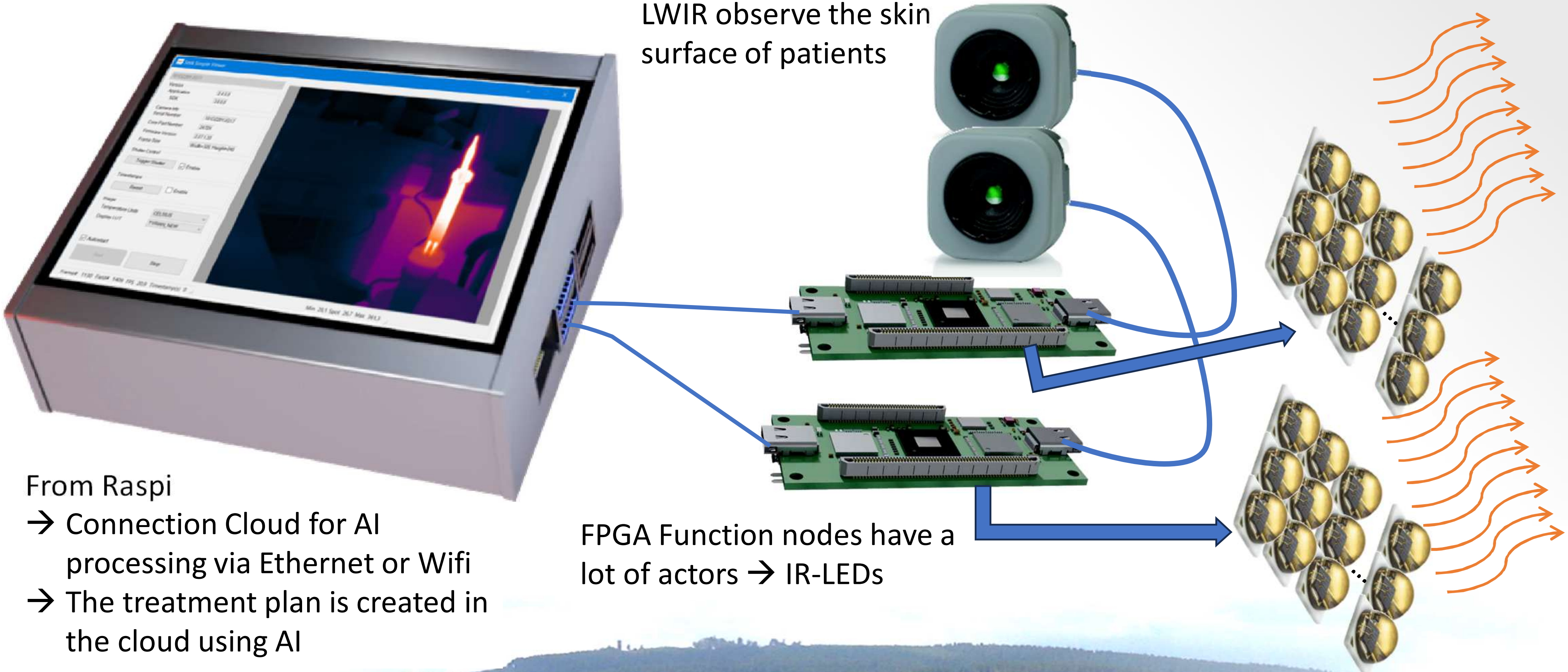
From Raspi
→ Connection to PC or
Cloud for AI processing
via Ethernet or Wifi

FPGA Function node
with USB camera input
and additional sensor
signals für combination
and image processing

Example designs with the function node

Medical device consisting of function nodes and RaspiPi 5

some Thermal cameras LWIR observe the skin surface of patients

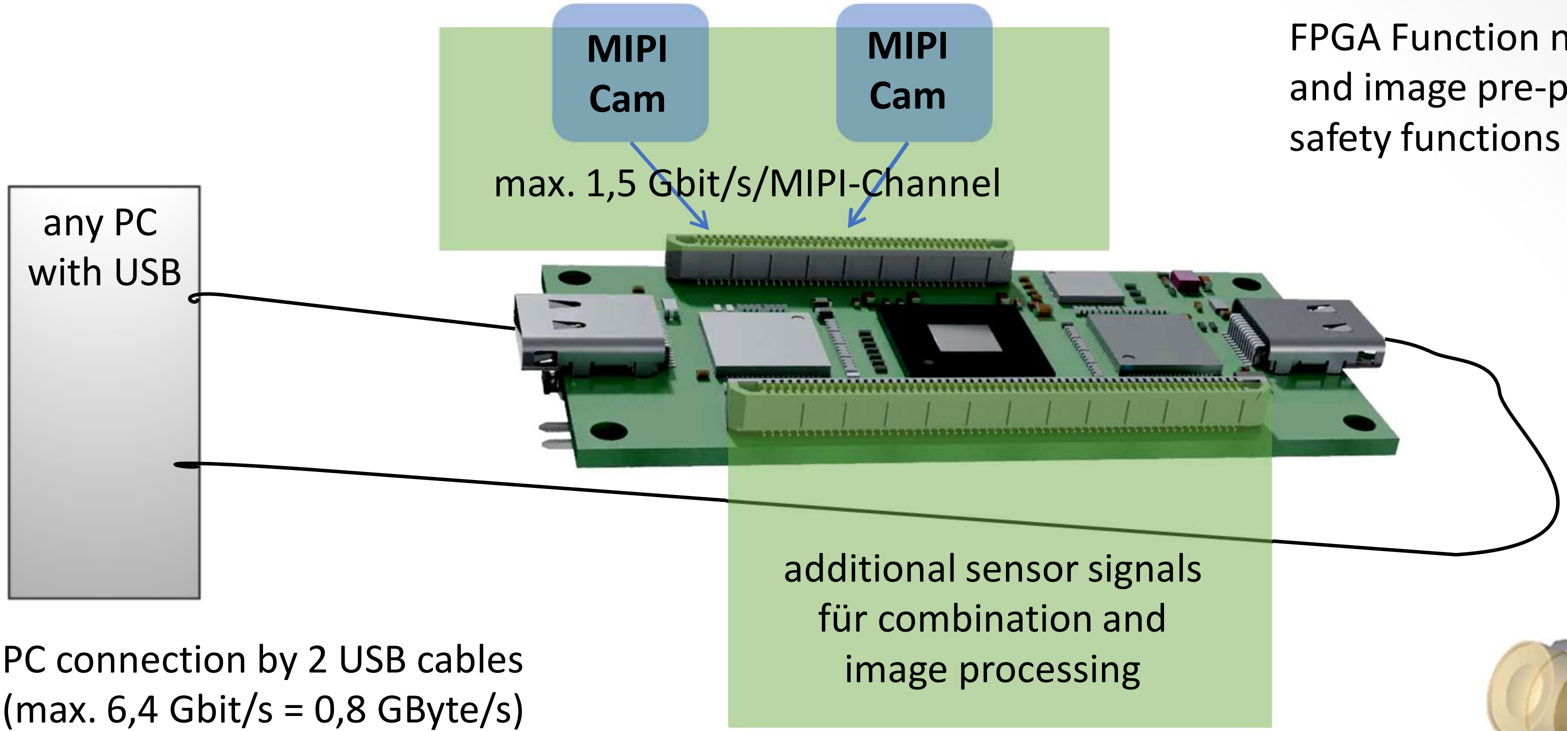


From Raspi
→ Connection Cloud for AI processing via Ethernet or Wifi
→ The treatment plan is created in the cloud using AI

FPGA Function nodes have a lot of actors → IR-LEDs

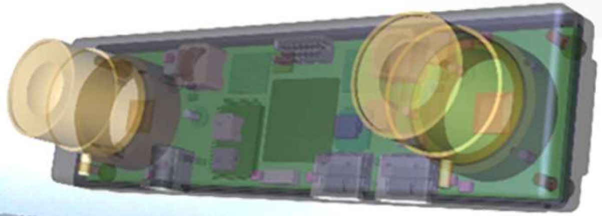
Example designs with the function node

Stereo-Camera with MIPI sensors in combination of a lot of additional sensor data



FPGA Function node sensor combination and image pre-processing and direct safety functions for processes

PC connection by 2 USB cables
(max. 6,4 Gbit/s = 0,8 GByte/s)



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2
3
4
5
6
7

Example designs with the function node

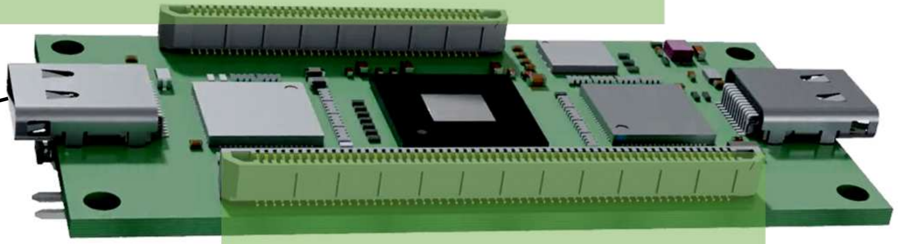
Industrial machine control as sensor-actor system with process control in FPGA

FPGA Function node act as machine control with parameters from HMI (IPC) and sent process data back in real time

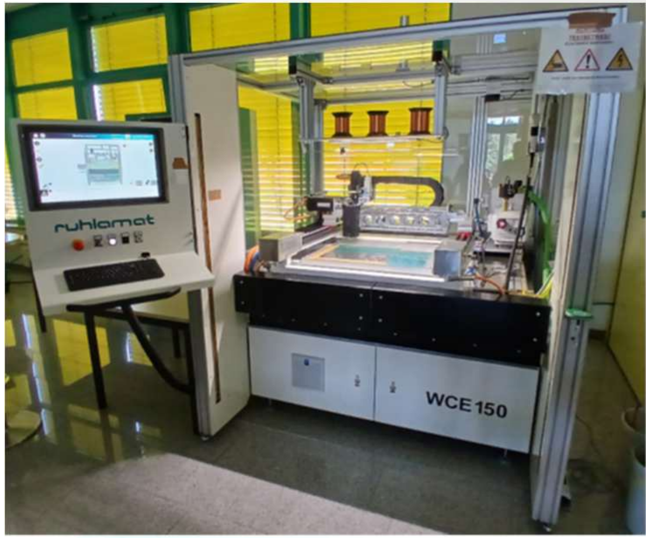
DDR4-RAM

16x 1,25 Gbit/s = 20 Gbit/s = 2,5 GByte/s

IPC with USB
and HMI



sensors and fast ADCs as well as motor control can be connected with a lot of real time processing



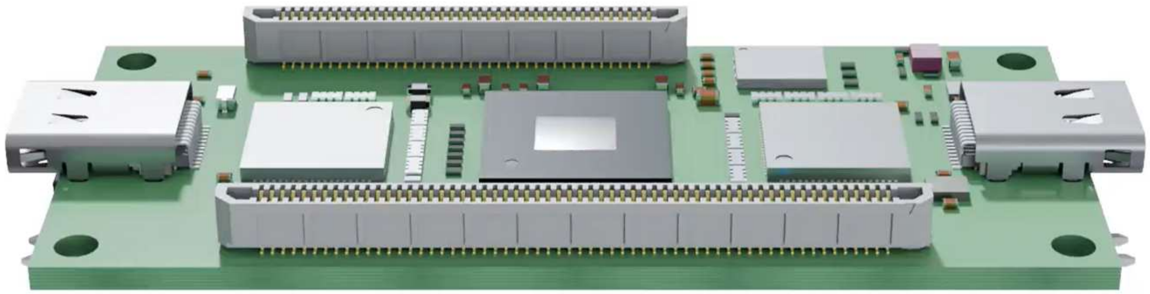
PC connection by USB cables
(max. 3,2 Gbit/s = 0,4 GByte/s)

Summary

- The presentation outlined the **design process** for a cost-effective FPGA solution for industrial machine controls
- Based on the requirements, the **architecture** was designed to consist of FPGA function nodes and IPC/PC/Raspi as separate functional units.
- **USB 3.0** can be used as an easy-to-use, high-speed interface
- **Spartan UltraScale+** from 10 k up to 52 k logic cells in the A529 package looks like best solution
- Based on this, the **FPGA function node** is created, complete with USB bridges, 168-pin connectors, and all other necessary components
- HMI, Internet, and related security functions are handled by the connected IPC/PC/Raspberry Pi system and its powerful operating system
- Some of the many possible uses were demonstrated—**the possibilities are endless!**

Summary

- The Spartan UltraScale+ board and design service for FPGA and Raspi will offer at the website together with existing Artix and Kintex UltraScale+ boards (www.ultrasom.eu and www.avt-ilmenau.de)



UltraSOM-Boards available on www.ultrasom.eu

Thanks for your attention

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