European Core Technologies for future connectivity systems and components

Call/Topic: H2020 ICT-42-2020

Grant Agreement Number: 956830

Draft report

"Pre-release" of D3.3 Initial COREnect industry roadmap

Deliverable type:	draft report
WP number and title:	WP3 (Roadmap and recommendations)
Dissemination level:	Public
Due date:	30.06.2021
Contributing partners:	TUD, 5G IA, AENEAS, BOSCH, CEA, EAB, IFAG, IIIV, IMEC, NXP, ST

Disclaimer

This is a snippet of the draft version of the COREnect deliverable D3.3. The authors do not accept any liability for the contents of the current document. The views and information do not necessarily represent those of the COREnect project and its consortium members. The owners do not claim any form of ownership of the presented material of information. This document does not reflect the opinion of any single COREnect partner or any of the organizations with which the experts are affiliated. The COREnect project and its consortium members are not liable for any consequence stemming from the reuse of this publication.

Table of contents

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

1. Document scope and objective

This document is a "pre-release" of the envisioned COREnect report D3.3 (Initial COREnect industry roadmap). This pre-release highlights some aspects which are currently included in the draft version of D3.3. As the draft version of D3.3 is still under construction and not reviewed nor approved by the COREnect consortium, this pre-release has no ambition to be complete nor to represent the overall view of the COREnect consortium, its experts and/or its stakeholders. The first complete version of D3.3 will be released to the European Commission within the July-September 2021 timeframe.

2. Strategic roadmap: challenges and approach

Considering the full value chain, COREnect's main objective is to:

Develop a high-level strategic roadmap of core technologies for future connectivity systems and components, targeting the next generation European telecommunications networks and service (5G and beyond).

This roadmap proposal is being developed while considering the following factors:

- **The end goal of this industrial strategy is to support the Europe's twin transitions towards a green and digital future:** enable our society to embrace digitalization in a sustainable way (from cost and power efficiency point of view) is a key societal challenge.
- **The necessity to strengthen Europe's strategy to differentiate and lead in its most important value chains while enabling the European ecosystem to adapt to a profound on-going value chain transformation:** it is mandatory to continue to innovate on "more than Moore" technologies to maintain Europe leading role on key verticals. Today, advanced connectivity solution does not necessarily need chips processed in ≤ 5 nm node, but they will do so in the future. Moreover, the European ecosystem must also adapt to the value chain transformation induced by digitalization which requires to develop the relevant skills and technologies.
- **Aim for a realistic strategy keeping in mind that available economical resources are limited**: connectivity systems require a broad range of technologies which cannot be completely mastered by a single geographic area. This implies to clearly define key priorities in agreement with existing strengths.
- **The societal impact of the COVID19 pandemic:** the current pandemic has underlined the importance of connectivity infrastructure in the resilience of our society.
- **The COVID19 pandemic impact on key technologies supply chain and importance to secure Europe's sovereignty** (which does not mean autarky): the current supply chain issue underlines the importance of cooperation with like-minded partners to support open, fair and rules-based trade to reduce strategic dependencies.
- **The geopolitical trade tension between the US and China:** the export regulation on US technologies has contributed to disruptions in the current supply chains. Moreover, Europe's current dependency on US technologies hampers Europe to act independently and take strong standpoints on business-related sovereignty topics.
- **The objective of the Europe Commission to enable Europe to produce 20% of the world's semiconductors by 2030 to meet future semiconductor industry demand:** to secure European sovereignty, manufacturing of semiconductor in Europe should reflect the size of its domestic market and the strength of its industrial players on key verticals.

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

- **The necessity to reduce Europe's dependence to US on EDA solutions, software and IP required to develop future connectivity systems:** the increased trade tension between the US and China highlighted Europe's vulnerability to US technology; it indicated alarming sovereignty issues on connectivity technologies if extraterritorial rules are applied to European semiconductor actors.
- **The necessity to bridge the current gap on advanced processor design to secure Europe's industrial strategy and digital sovereignty:** advanced computing is key to support the digitalization of our society. Today, Europe highly relies on US advanced computing technologies. This causes a critical dependency and might impact Europe's key ambition for open, ethical, trustworthy, and explainable AI and computing.
- **The European Commission's objective to enable a fabrication plant to produce leading edge technology (at least 2 nm), both on its own or through selected partnerships to ensure security of supply, in the next 10 to 15 years:** due to the importance of leading-edge semiconductor technologies to manufacture advanced computing chips, Europe has a role to play to enable a more diverse and consequently resilient supply chain to reduce its critical dependencies, while remaining open.

Keeping in mind the previous context and objectives, we first propose a synthesis of the current position of Europe on the connectivity market to identify opportunities and gaps. We will then propose a global industry roadmap strategy which will be finally derived in concrete actions proposed by COREnect's expert groups.

2.1. Major challenges and opportunities related to future European connectivity systems and components

To identify Europe's major challenges or opportunities concerning connectivity technology, we start the discussion by a review of Europe's position in the overall value chain. As illustrated in Figure 1, Europe still holds a good share in materials and tools to produce electronic components. Europe's production share is, however, lower at levels such as electronic equipment, electronic boards, and electronic components.

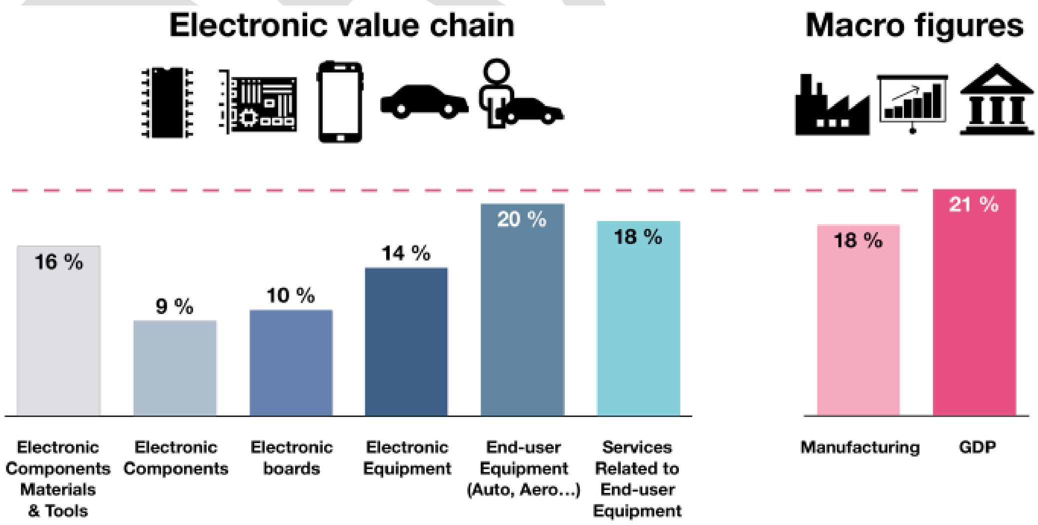

Figure 1: European share of the world production of the global electronic value chain [Dec20]

In Europe, the leading end-user segments are industrial electronics, aerospace defense and security, and automotive electronics. In the global electronics ecosystem, the leading segments are still the consumer mass markets (mobile phones, PCs). Consequently, Europe's share in the

Horizon 2020
European Union Funding
for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

world production is also highest in those segments where Europe is strongest, as illustrated Figure 2.

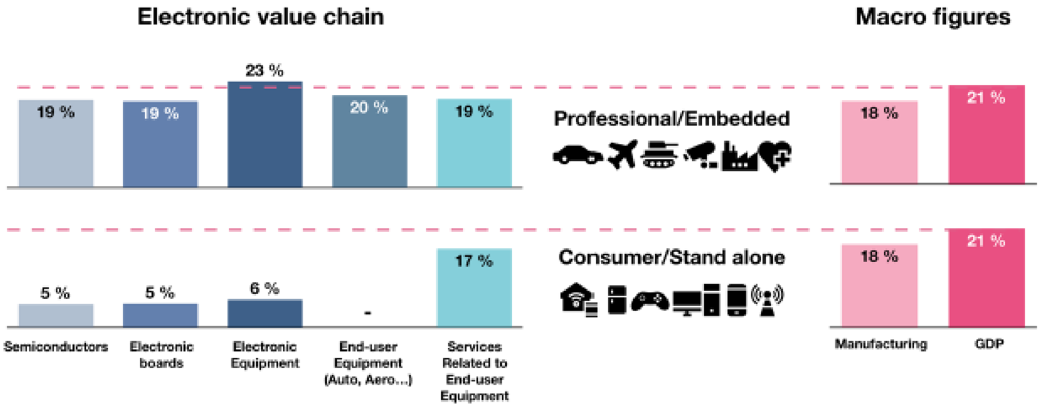

Figure 2: European share of the world production of the global focusing on professional/embedded and consumer electronic value chains [Dec20]

While Europe is just producing 9% of the overall electronic components, its market share in the professional and embedded segment is 19%. This figure is in line with Europe's GDP. Since Europe hardly addresses the consumer market, the European ecosystem requires a moderated manufacturing capacity mainly focused on mature or derivative technology. For example: automotive represents today only about 10% of the IC market and does not call for <20 nm technology. Consequently, the installed European semiconductor manufacturing capability to address Europe's key verticals is sized accordingly. As illustrated Figure 3, Europe has a strong presence on 200 mm facilities (with ST and Infineon among the top 5 leaders) which is in line with the technologies required by the European ecosystem and value chain.

(Ranked by Share of Total WW Monthly Installed Capacity)

300mm Wafers		200mm Wafers		≤150mm Wafers	
WW Share	Top 10 in Capacity	WW Share	Top 10 in Capacity	WW Share	Top 10 in Capacity
21%	Samsung	10%	TSMC	9%	CR Micro
15%	TSMC	6%	STMicro	8%	Silan
14%	Micron	6%	UMC	8%	Nuvoton
13%	SK Hynix	6%	Infineon	7%	ON Semi
11%	Kioxia/WD	6%	TI	5%	STMicro
6%	Intel	5%	SMIC	4%	TI
4%	GlobalFoundries	4%	Vanguard	3%	Rohm+Lapis
3%	UMC	4%	NXP	3%	Toshiba
2%	Powerchip	4%	ON Semi	3%	Diodes
2%	TI	3%	Toshiba	3%	TSMC

WW Share is each company's share of total industry capacity for that wafer size.
Blue bars indicate the relative amount of capacity held by each company among the top 10 leaders.
Note: Includes shares of capacity from joint ventures.
Source: IC Insights

Figure 3: Installed capacity leaders in December 2020 by wafer size [EMS21]

The situation on 300 mm wafers manufacturing is completely different. On 300 mm, there is no European actor among the top 10 players. This is directly correlated with the European position on the market since the top 300 mm manufacturing players are addressing either memory (Samsung, Micron, SK Hynix, Kioxia) or advanced logic (Samsung, TSMC, Intel). These are two

Horizon 2020
European Union Funding
for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

areas where Europe is hardly represented. As illustrated in Figure 4, the installed manufacturing capability of a given region directly correlates with the technology nodes required by the targeted markets of the associated value chain and ecosystem.

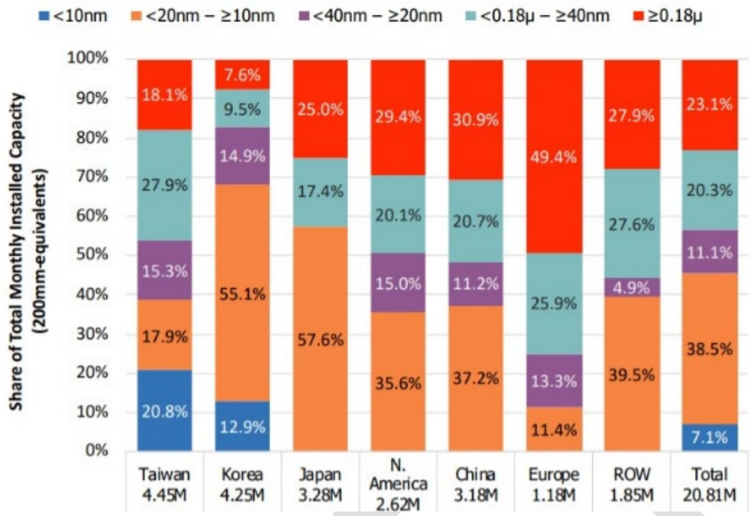

Figure 4: Monthly installed capacity for each geographic region in December 2020 [Nen21]. “ROW” means “rest of the world”.

China, Japan, US, and Korea have most of their installed capacity for technology ranging from >10 nm to < 20 nm, which serves their memory production. On the other hand, 75% of Europe’s installed capacity supports > 40 nm (50% for technologies > 180 nm) which serves its key verticals (automotive, industrial, health, …). Taiwan has a more balanced situation because TSMC’s foundry business model clearly focusses on the most advanced nodes. TSMC’s 1Q21 revenue, depicted in Figure 5, shows that the smaller nodes are driven by the smartphone and HPC business.

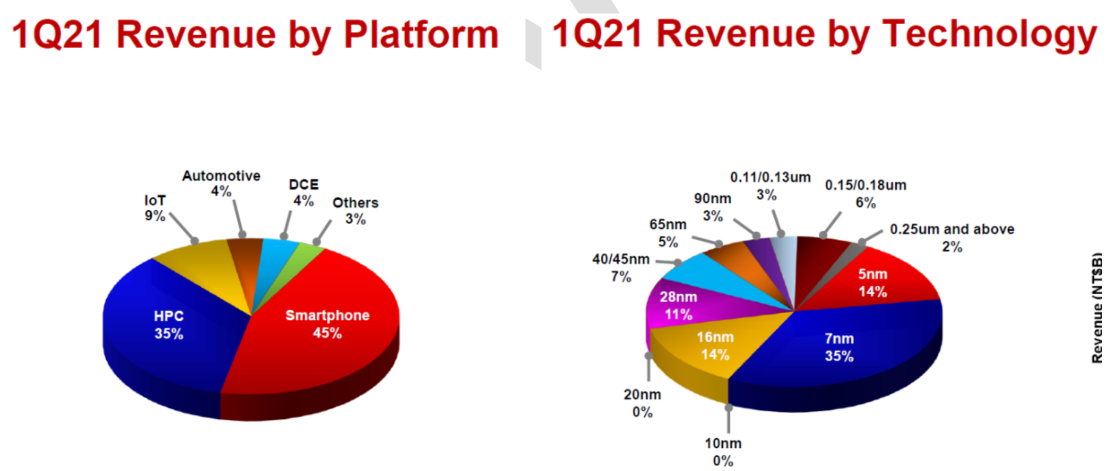

Figure 5: TSMC’s 1Q21 revenue split per application and technology [TSM21]

We can also note that, while 7 nm and 5 nm represent 20% of TSMC’s capacity, they generate ~50% of the revenue. This point is the foundation of TSMC’s high-end foundry business positioning: by maintaining its leadership on advanced nodes and being the first to deliver volume manufacturing, it captures most part of the market value. This enables them to support the high CAPEX required to develop the next nodes and install the necessary capacity (TSMC’s

Horizon 2020
European Union Funding
for Research & Innovation
This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 956830.

CAPEX in 2021 is set to 30 B$). Consequently, even a company able to offer equivalent technology and spending large CAPEX (such as SAMSUNG) is today a distant contender. From pure manufacturing side, the entry barrier is high and at short term, it may prove difficult for anyone to dispute the leadership of TSMC. Moreover, even if Europe had today the manufacturing capability of 7 nm technology, the number of European customers for this technology would be limited. This point is illustrated in Figure 6 by reviewing TSMC's key customers in 7 nm and 5 nm technology.

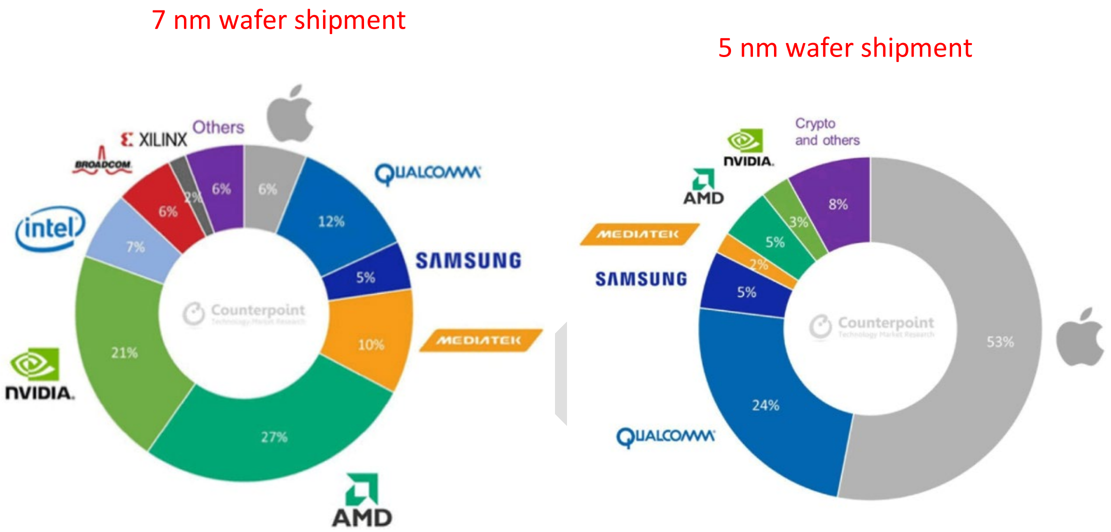

Figure 6: TSMC 7 nm and 5 nm shipments breakdown by customer [Haa21]

While Huawei used to be TSMC's second largest customer just after Apple, the US expert restrictions have reshaped the landscape. Today, all TSMC key customers for 7 nm and 5 nm technologies are US fabless companies. The only exceptions are Samsung and MediaTek. It illustrates a key weakness of the European ecosystem. Since there are currently no large European fabless or system companies requiring high volumes of extremely scaled semiconductor technologies (< 7 nm node), the current industrial drive to develop such manufacturing capabilities shows to be rather limited. Moreover, given that China and US are today leading in strategic topics such as AI, they are not expected to own the required manufacturing capability. As such, they are as dependent on the Taiwanese semiconductor technology as Europe.

However, the lack of <20 nm node manufacturing capability in Europe does not mean that Europe refrains from this topic. Europe's strong position on semiconductor manufacturing equipment enables Europe to play a strategic role on the value chain. ASML is a good example since it is today the sole source of EUV lithographic scanner on the market. Figure 7 shows the EUV shipment forecast by customer and learns how leading foundries such as TSMC, Samsung and Intel are relying today on ASML (and consequently on European technology).

Horizon 2020 European Union Funding for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

Company	EUV shipments (unit)					
	2018	2019	2020	2021E	2022E	2023E
TSMC	**7**	**16**	**18**	**28**	**31**	**33**
Samsung	**3**	**5**	**8**	**9**	**14**	**15**
Intel	**4**	**3**	**3**	**2**	**3**	**5**
GlobalFoundries	1	0	0	0	0	0
Hynix	1	1	1	1	1	1
Micron	0	0	0	1	1	1
SMIC	0	0	0	0	0	0
Others	2	1	1	0	0	0
Total EUV shipments	**18**	**26**	**31**	**41**	**50**	**55**
EUV ASP (EUR mn)	**105**	**109**	**145**	**145**	**153**	**163**

Source: Mizuho Securities Equity Research Estimates

Figure 7: EUV shipment forecast by customer [Fas2]

The recent US export restriction prevented Chinese companies to access to <14nm nodes by preventing US vendors (such Applied Material, KLA, ...) and foundries to sell their US-technology based products. This provides interesting perspectives concerning the position that Europe can adopt to safeguard its sovereignty and access to key technologies related to the connectivity topic.

Consequently, even if Europe does not own today the complete connectivity value chain, it still has a leading position on key topics. These topics include semiconductor manufacturing equipment, manufacturing of differentiated technologies, leading position on the wireless infrastructure market, …. This enables Europe to play a leading role on future connectivity technology development and secure its sovereignty by strengthening its partnership with other countries.

Moreover, from pure manufacturing point of view, the importance of leading-edge technology nodes versus legacy ones has to be put into perspective. Figure 8 shows that the capacity in leading edge technology nodes will grow in the coming 3 years while the legacy nodes will still represent a significant portion of the overall capacity.

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

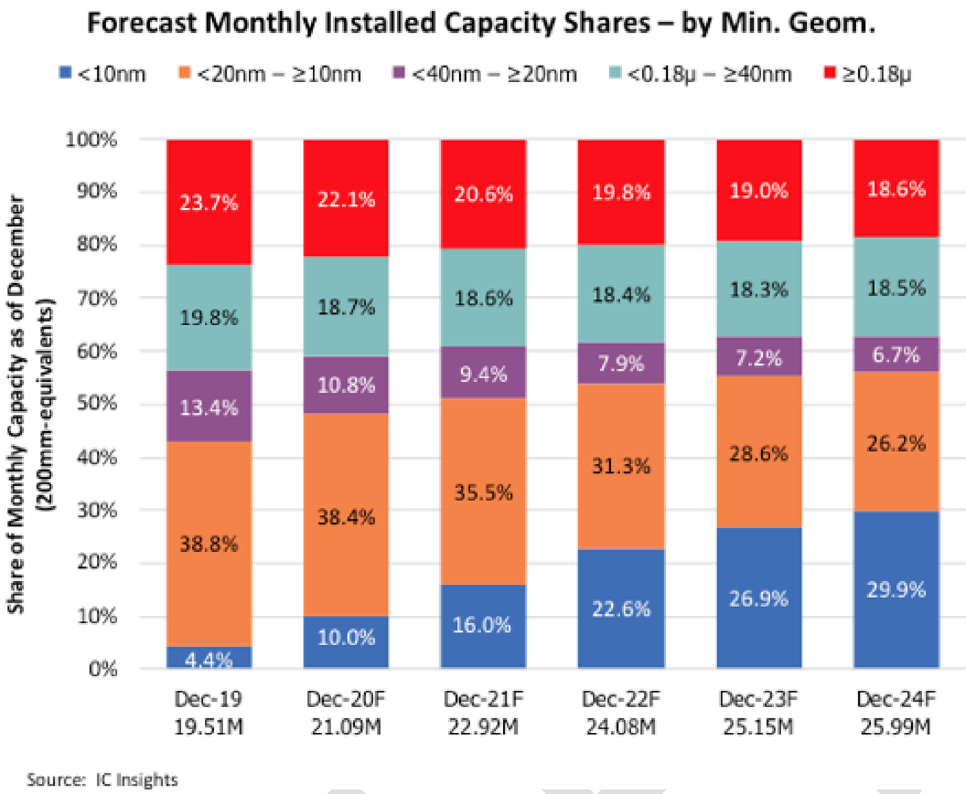

Figure 8: Wafer Capacity by Feature Size Shows [ICi20]

The growing trend of leading-edge technology capacity is mainly driven by consumer products such as smartphones. As illustrated in Figure 9, leading-edge technologies are used in 89 % of the smartphone's application processor or modem, whereas only 5 % of the RF and connectivity part implement such technologies. Consequently, in the smartphone market, leading edge nodes represent 27% of the overall chip area (~7.5M 12 inches wafer count/year) while legacy nodes are addressing the remaining 73% (~47M 8 inches wafer count/year).

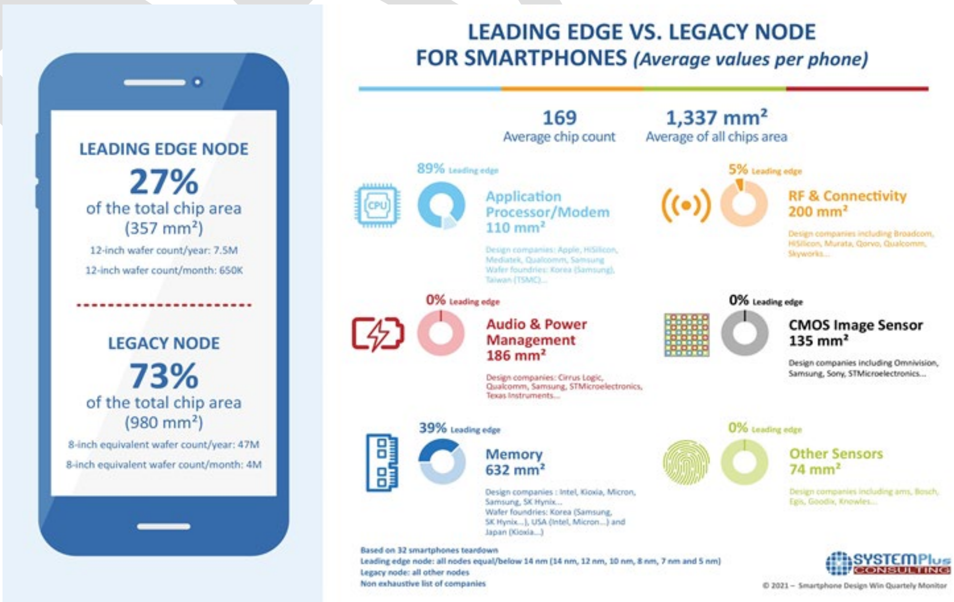

Figure 9: Leading edge versus legacy technology nodes used in smartphones [Sys21]

Given this persisting strong demand, the legacy technology node market will remain very active in the foreseeable future. The associated 200 mm installed capacity is expected to increase to

Horizon 2020
European Union Funding
for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

record levels from 2020 to 2024, beating the last records seen in 2006 and 2007 (as illustrated Figure 10). Moreover, European legacy technology node players are also transitioning to 300 mm fabs to increase even further installed capacity. Infineon's new 300 mm Fab in Villach in Austria, STMicroelectronics' new 300 mm fabs in Agrate in Italy, Bosch's new 300 mm facility in Dresden in Germany and STMicroelectronics' 300 fab extension in Crolles in France are good examples of such actions.

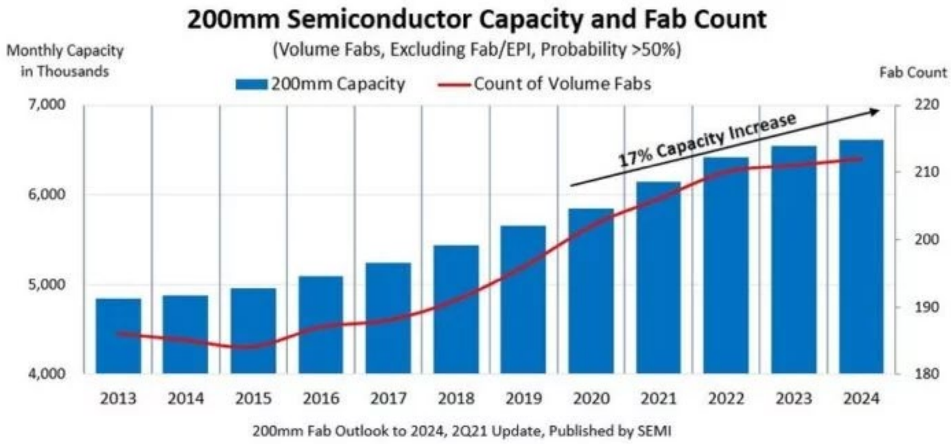

Figure 10: 200 mm semiconductor capacity and count of fabs [Fas21]

Put more simply, there is no opposition to be made between leading edge and legacy technology nodes. Strengthening key partnerships within Europa may secure the technology access and the European sovereignty. Still, not owning the complete technology portfolio does not prevent Europe to capture a significant part of the semiconductor manufacturing chain. Europe's developed technologies and associated installed capacity might, however, remain closely linked to the needs of Europe's key verticals and the European overall position in the value chain. Having such technology and processing capacity, however, is likely to stimulate existing and to initiate new ecosystems in Europe.

2.2. Proposed Industry Roadmap Strategy: How should Europe address future connectivity technologies with a value-chain approach?

The European challenges and opportunities on connectivity technology to support its strategic agenda are as follows:

Opportunities:

- Strong position on wireless and wireline infrastructure markets
- Strategic link between core semiconductor technology capability and key verticals (automotive, industrial, space and defense, …)
- Combining those two assets makes Europe a strong contender to take a leading role towards 6G and beyond, while covering the entire value chain

Challenges:

- Digitalization modifies the European value chain, in which Europe risks to reduce its technological sovereignty. The rise of AI, for example, is likely to increase our dependency on US technologies.
- Geopolitical tension and trade restrictions imposes an increased risk of disruption of the European supply chain. It is key for Europe to mitigate this risk through a more diverse and resilient supply chain.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

With financial resources being limited, COREnect is proposing an industry roadmap with a 10- to 15-year timeline. This roadmap addresses different timeframes with a changing focus in terms of strategic investments, markets, and technological development.

<u>**Short term (2 years from now):**</u>

- **Strengthen areas where Europe is leading (BiCMOS, III-V, RF, analog, ...) to secure its position and gain market share to ensure Europe to play a leading role for 6G:** Europe needs to continue to innovate on differentiated technologies where it leads today to secure its leadership. Transitioning from 200 mm to 300 mm fab manufacturing differentiated technologies is a key industrial challenge.
- **Secure access to <7 nm CMOS technology:** Digitalization requires the know how to design dedicated advanced computing chips. Europe needs to secure both the design capability as well as the access to a diverse and trustworthy supply chain.
- **Strengthen the education on IC design (both in analog/RF and digital):** To enable an appropriate pool of experts able to address European industrial players’ needs but also make Europe an appealing place to invest.

<u>**Mid-term (5 years from now):**</u>

- **Strongly support module integration technologies (both design and fabrication) to combine components from a wide range of technologies (advanced digital and memory chips, but also legacy CMOS, FD-SOI, SOI, BiCMOS, III-V, photonics, sensors):** such approach will enable Europe to capture a higher portion of the value chain by delivering systems instead of components. Moreover, it may also allow viable solutions in markets that are not big enough to support development cost required by smallest CMOS nodes. Instead, functionality could be implemented with multiple modularly designed chips in legacy technologies. This can enable defense industry to produce entirely in Europe exploring available production technologies even leading-edge nodes are not available.
- **Enable Europe to lead on future connectivity standardization actions while moving higher in the value chain:** Leveraging its current strength, Europe can play a leading role in the definition of 6G. Core technologies developed in Europe should also enable to develop more complex connectivity solutions (smart sensors enriched by AI features, more integrated 6G RF solutions, …) and then capture more value.
- **Strengthen European position on EDA, IP & software:** Creating an open and more diverse ecosystem is key to ensure a resilient supply chain and enable Europe to mitigate sovereignty risks.
- **Enable smartly positioned European fabless ecosystem:** To play a role in advanced computing chips (or modules) and to mitigate Europe’s current dependency, a strong European fabless ecosystem is a mandatory starting point.

<u>**Long term (10 to 15 years from now):**</u>

- **Make Europe the IC design champion:** Europe must become the global IC design champion to ensure its position in connectivity system manufacturing and to preserve their claimed value chain share.
- **Enable the establishment of <7 nm CMOS manufacturing in Europe** (not excluding partnership with non-European players) **to support the created domestic market.**

3. First draft of strategic industry-relevant R&I roadmaps

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 956830.

Based on initially identified COREnect end-to-end system view together with value chain consideration, COREnect organizes three COREnect Expert Groups to address the industry roadmaps in three strategic focus areas**:**

- Expert Group #1 Compute and Store
- Expert Group #2 Connect and Communicate
- Expert Group #3 Sense and Power

Today, the expert groups consist of 96 experts from industry, SME's, research institute, universities, and associations. 61 experts are consortium members and 35 experts are from outside the consortium. COREnect continuously seeks to optimize the expert group's composition via open calls (https://www.corenect.eu/news/call-for-experts) to obtain an optimal scientific, organizational, and social balance. For each expert group, a Chair and Vice-Chair have been selected by the COREnect consortium with the responsibility to coordinate these groups. As a result of several public workshops and focused meetings and brainstorm discussions, the experts aligned their views on Europe's major challenges and opportunities. Combining their specialist knowledge, COREnect benefits from broad insights into crucial fields that require our attention and, thus, address the upcoming challenges in Europe regarding 5G and beyond. Altogether, capturing and crystallizing the discussions, the three expert groups are cooperatively developing the COREnect industry roadmap.

Although each Expert Group is focusing on a defined strategic area, one can find many overlapping topics within this holistic approach. Security and energy efficiency are cross-cutting design considerations in the COREnect technical vision and inherently the common work of Expert Groups. Therefore, the sphere of ***Energy Efficient, Green Communication Electronics*** will be equally covered in the chapters dedicated to the expert groups. Therein, advanced computation and sustainable fabrication are going to be examined from the perspective of the device itself (EG1), the transceivers (EG2), as well as from the sensors and power management (EG3) point of view.

Regarding 5G/6G application areas, security and trustworthiness are focus for several stakeholders. Therefore, technologies to cope with untrusted third-party IP (EG1), telecommunication hardware and software (EG2) and failure detection and security technologies (EG3) are contributing to the question of how to derive ***Electronics for Trustworthy Communication*** in 6G and beyond. Regarding the technical aspects of the European sovereignty and its ecosystem, the key question is investigated whether a whole European value chain including the tools and knowledge is feasible, required, and how it can be realized.

Third, an integrated approach of ***Future Core-Technologies and Integration*** throughout all three expert group chapters is going to highlight the areas in packaging, materials, semiconductor, production, and assembly that can bring the Europe forward towards a more inclusive and carbon-neutral society. For instance, multi-chip modules (MCM) and the integration of memory chiplets (EG1), semiconductor trade-offs for wireless and wireline transceivers (EG2), or heterogeneous integration and the semiconductor processing technology landscape (EG3) and its opportunities for Europe are being reflected on in each chapter. Social inclusion with new user interfaces, knowledge, education and job generation, and the general orientation towards megatrends (e.g. demographic change, global warming) will equally play a role, guiding the proposed strategies towards a common goal.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

The specific objections of the Expert Groups *Compute and Store* (EG1), *Connect and Communicate* (EG2), as well as *Sense and Power* (EG3) are described in the following subsections.

3.1. EG1: compute and store

For 5G and beyond, ever more performant digital computing platforms and components will be required. However, Europe is becoming increasingly dependent on outside companies supply for these components and systems. This makes the European supply chain highly susceptible to disruptions such as trade wars. Expert Group 1 (EG1) therefore investigates the role of computing and storage solutions for Europe's 5G and 6G sovereignty.

EG1 identifies key technologies that enable Europe to build trustworthy and competitive systems for communication (terminals and the RAN) and different applications (IoT, personal devices and personal mobile robotics). The focus will be on programmable computing platforms and the included storage components under the consideration of different operating constraints and the need to support legacy software.

This expert group identifies system requirements for the RAN and the UE use cases. From these requirements EG1 derives the form needed to fulfill the specific functions at each layer of the computing platform from the bottom-up. At the bottom there are the process technologies that are used to physically realization. Modern computing platform contain at least one, more often multiple, cores whose software interface is defined by the instruction set architecture (ISA). For different situations, such as infrastructure equipment or edge devices, different ISAs may be used. EG1 also analyzes the European position in memory and storage and how it can be improved. The challenge of integrating multiple heterogenous cores, memories, accelerators (c.f. EG3) and intellectual property (IP) blocks in a Multiprocessor system on a chip (MPSOC) is investigated. Finally, EG1 proposes an operating system framework which is based on the principles of modularity and microkernel.

3.2. EG2: connect and communicate

6G wireless communication will make use of frequency bands from 5G and its predecessors but in addition use extra bands. A clear extension of the spectrum beyond 5G is the use of carrier frequencies above 100 GHz, which we address here as THz communication. Here, the D-band (110-170 GHz) will be used initially. In a later phase, even higher frequencies can be addressed (e.g. the first standardization efforts have resulted in IEEE 802.15.3d, which targets the spectrum 253–322 GHz, which is the higher part of the G-band). However, a lot of communication in 6G, if not the majority, will happen below 100 GHz, using existing frequency bands or gaps in the microwave and mm-wave spectrum. In this section, we refer to the microwave frequency region as the region of carrier frequencies roughly below 20 GHz, whereas we call the mm-wave region the frequency band above 20 GHz up to 100 GHz. Above 100 GHz we address the spectrum as the sub-THz band.

Designing transceivers that use carrier frequencies in the sub-THz band is challenging for the active devices. Whereas CMOS downscaling has enabled a massive deployment of CMOS in microwave and mm-wave and high-speed wireline applications, the speed of a single transistor, expressed in terms of the maximum frequency oscillation f_{MAX}, at which power gain has dropped to 0 dB, is more or less saturating to a value below 400 GHz for downscaling beyond the 28 nm generation. This means, for example, that in the D-band (roughly at one third of this 400 GHz)

Horizon 2020 European Union Funding for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

the maximum power gain per stage is less than 3, but it is always lower due to losses in passive components. Further downscaling of CMOS does not boost f_{MAX} anymore, it only leads to a reduction of the size of digital standard cells, still giving a performance improvement for digital signal processing but not anymore for analog signal processing at high frequencies.

Higher f_{MAX} values than the best values for CMOS can be obtained with silicon bipolar transistors, which can be combined with CMOS in a BiCMOS process. Even higher f_{MAX} values are obtained with high-mobility III-V materials such as InP. Such material even has the advantage over silicon that it can still operate at higher voltages, such that InP is better suited for power generation in the sub-THz region.

With an f_{MAX} value for CMOS of almost 400 GHz, CMOS can be used for wireless transceiver design from the low-GHz range up to the D-band, as evidenced both by prototypes described in publications and by products. Only for the generation of power, CMOS falls short, both for cellular applications in the low-GHz range and for the D-band. The consequence is that for transceiver design, except for the power amplifier, technology choice is more based on economical or strategic considerations than on performance.

For the roadmap discussion, EG2 divides the field of "connect and communicate" into the following 4 domains:

- Radio access networks (RAN)
- Consumer grade connectivity
- Industrial grade connectivity
- Datacenters

3.3. EG3: sense and power

In addition to computing and communications core technologies, future networks require the development of supplementary core technologies that support the design of computing components (EG1) and communications components (EG2) and are essential for controlling the telecommunication and vertical value chain. With billions of sensors connected, tendency rising, there will be numerous challenges to be addressed, ranging from RF bandwidth availability, optimization of energy usage, reliability and maintenance, security of transmitted data, as well as utilization and analysis of the data collected from the sensors.

The goal of Expert Group 3 (EG3) is to identify key challenges for innovations and sovereignty in the areas of sensing and power for future network. This will encompass the following key domains to focus upon:

- Sensor Processing in 5G and beyond
- Power Management
- Core Process Technologies
- System and Component Architectures

This expert group explores the challenges and opportunities that are going to confront not only the telecommunications and microelectronics industry, but the whole value chain and society. Overall, EG3 aims to define the overall European strengths for maintaining and developing our strongholds in the domain of sensing and power. It targets to address selected weak points that are critical yet can be realistically achieved.

Horizon 2020
European Union Funding
for Research & Innovation
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.

4. Common strategic actions across the expert groups

Beyond the technical actions proposed by each expert groups, some transversal actions can be defined as key enabler to secure and strengthen proposed strategy. The actions which are beneficial to the full connectivity value chain will be defined throughout the project lifetime.

5. References

[Dec20] Decision Etudes & Conseil, "Study on the electronic ecosystem. Overview, developments and Europes's position in the world", A study prepared for the European Commission DG Communications Networks, Content & Technology, 2020, online: http://www.decision.eu/wp-content/uploads/2020/02/DECISION_Study_Electronics_Ecosystem.pdf.

[EMS21] EMS NOW, "TSMC Ranks in Top-10 For Capacity in Three Wafer Size Categories", 2021, online: https://emsnow.com/tsmc-ranks-in-top-10-for-capacity-in-three-wafer-size-categories/.

[Fas21] Frédéric Fassot, "Fabs 200 mm: vers une augmentation des capacites de 17% en 2024", vipress.net, 2021, online: https://vipress.net/fabs-200-mm-vers-une-augmentation-des-capacites-de-17-en-2024/.

[Haa21] Hilebert Haagedoom, "Apple claims half of TSMC 5nm production capacity for 2021", Counterpoint Research, 2021, online: https://www.guru3d.com/news-story/apple-claims-half-of-tsmc-5nm-production-capacity-for-2021.html.

[ICi20] IC Insights, "Wafer Capacity by Feature Size Shows Strongest Growth at <10nm", 2020, online: https://www.icinsights.com/news/bulletins/Wafer-Capacity-By-Feature-Size-Shows-Strongest-Growth-At-10nm/.

[Nen21] Daniel Nenni, "Global Wafer Capacity 2021-2025", SemiWiki.com, 2021, online: https://semiwiki.com/forum/index.php?threads/global-wafer-capacity-2021-2025.13705/.

[Sys21] SystemPlus consulting, "Leading edge vs. legacy node for smartphones", Smartphone Design Win Quartely Monitor, 2021, online: www.eetimes.com/wp-content/uploads/Infographic-Smartphone-Design-Win-Monitor-Q1-2021-surfaces_V2.jpg.

[TSM21] TSMC 2021 First Quarter Earnings Conference, April 15, 2021.

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 956830.