INEMI Roadmap Webinar: Printed Circuit Boards (PCBs)

19 June 2025

Tarja Rapala (EIPC)
Joe Beers (Gold Circuit Electronics)

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WATCH THE WEBINAR RECORDING

YouTube: https://youtu.be/00uZwdZu-VA

Other video:
https://thor.inemi.org/webdownload//2025/Roadmap/PCB_Roadmap_061925.mp4

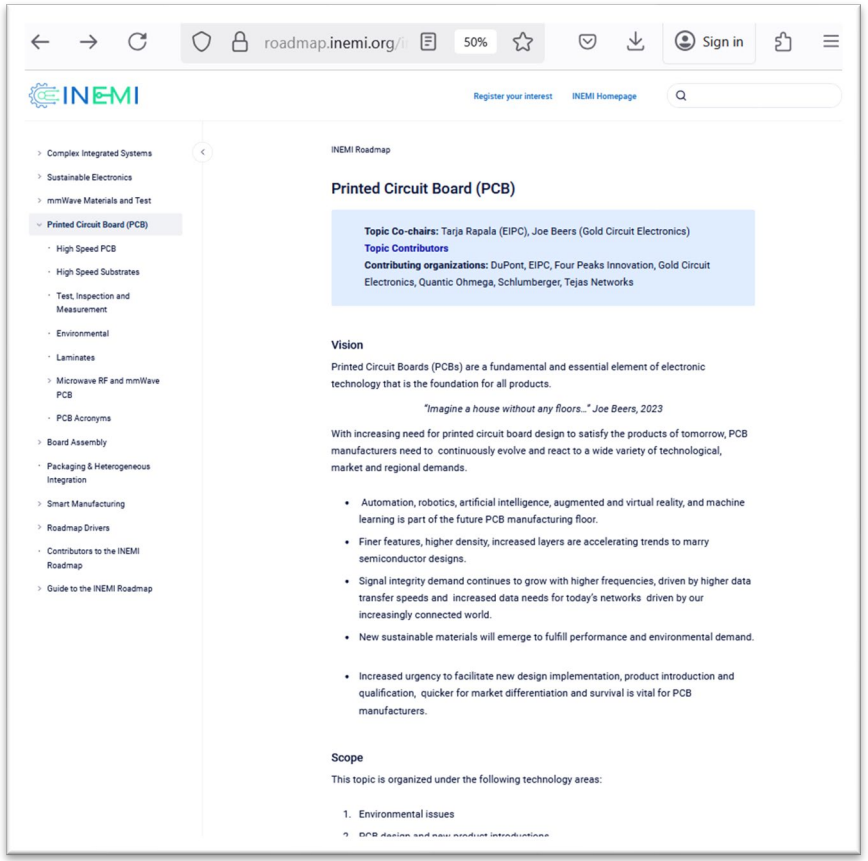
Agenda

Review of current INEMI PCB Roadmap

- Topics: High-speed PCBs; High-speed Substrates; Laminates; mmWave PCBs; Test, Inspection & Measurement; Environmental.
- Presenter: Tarja Rapala
- 40 min

Brainstorm

- Focus on future topics for the roadmap
- Moderated by Joe Beers
- 20 min



https://roadmap.inemi.org/ir/printed-circuit-board-pcb

REVIEW OF THE INEMI PCB ROADMAP

iNEMI Roadmap: Technology Scope

Focus on Manufacturing and Supply-Chain Challenges

Complex Integrated Systems

System
Level 3

Board Assembly PCB

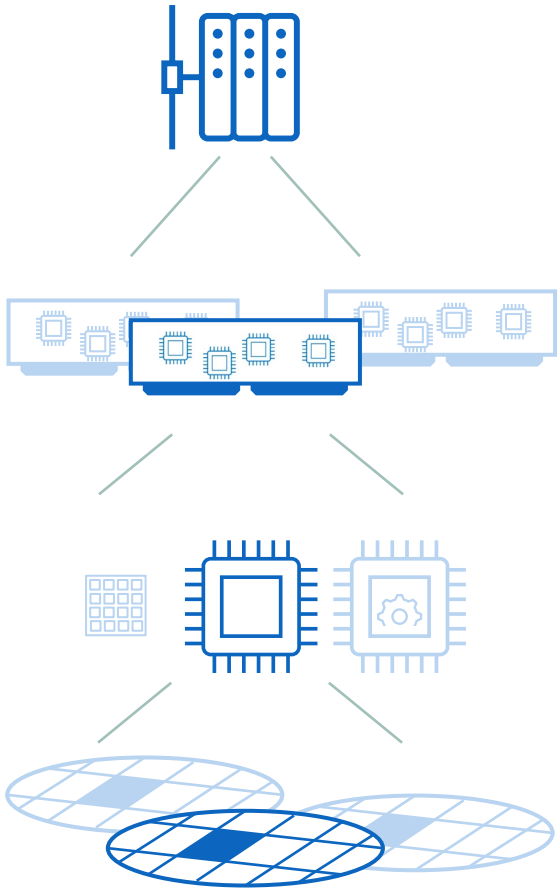
Module
Level 2

Packaging & Heterogeneous Systems

Component
Level 1

Semiconductors
mmWave materials

Die
Level 0



Cross-cutting issues

Sustainable Electronics

Smart Manufacturing

PCB Roadmap Contributors

Name	Affliation
Joe Beers (Co-chair)	Gold Circuit Electronics
Tarja Rapala (Co-chair)	EIPC
John Andresakis	Quantic Ohmega
Eric Huenger	DuPont
Ed Kelley	Four Peaks Innovation
Amba Prasad	Tejas Networks
Suriyakan Vongtragool	Schlumberger

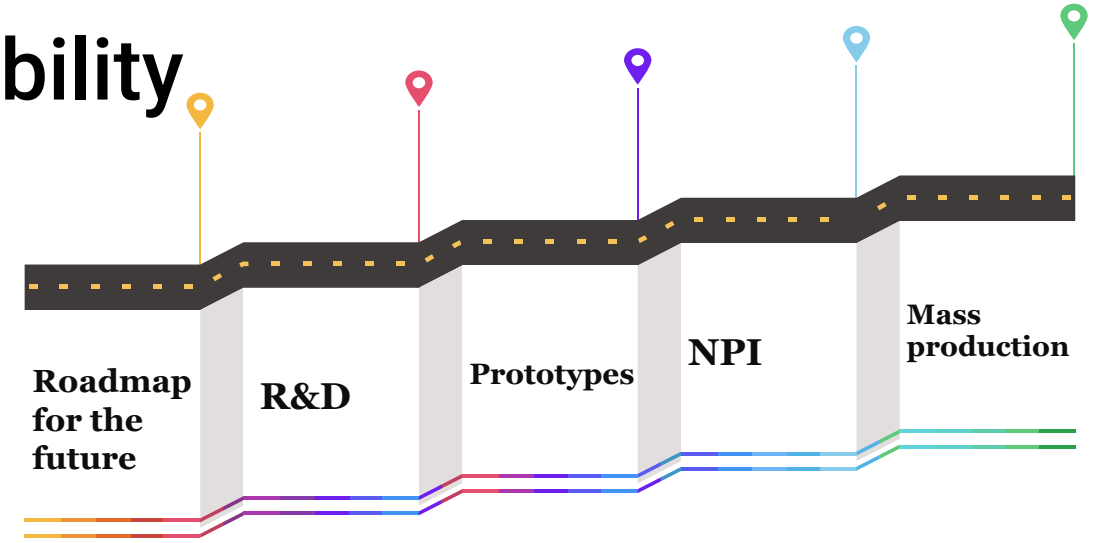
iNEMI Roadmap – Benefits Gained by Roadmap

By Tarja 19.8.2024

Creating a technology roadmap isn't just about planning for the future
It's about creating it

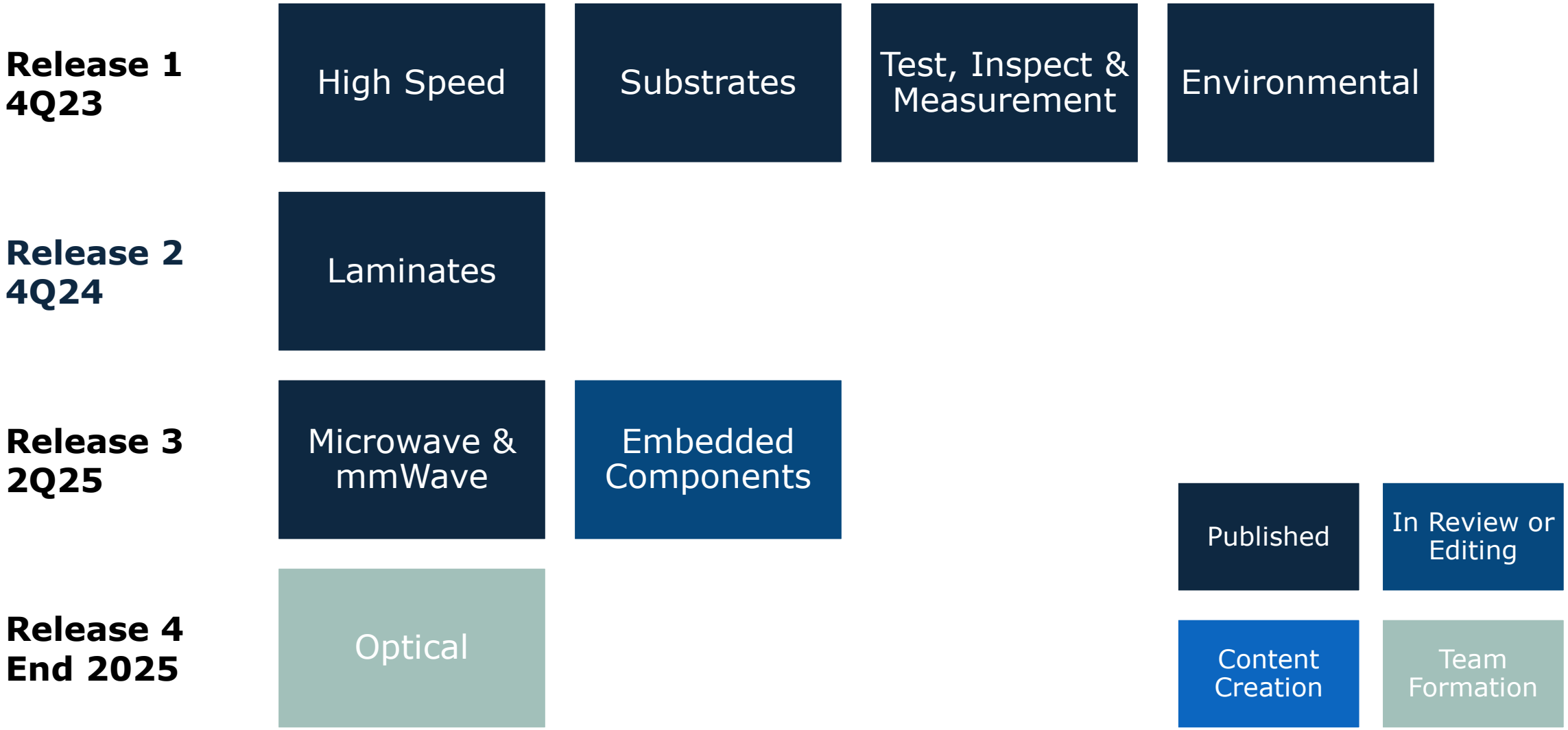
Roadmap / Design-rules / Capability

- **Road Map** Vision of where industry is going
  - (TRL: 1 to4 Research)
- **Design Rules** What designers can do to ensure manufacturability
  - (TRL: 5 to 7 development)
- **Capability** What the factory can produce today
  - (TRL: 8 to 9 deployment)

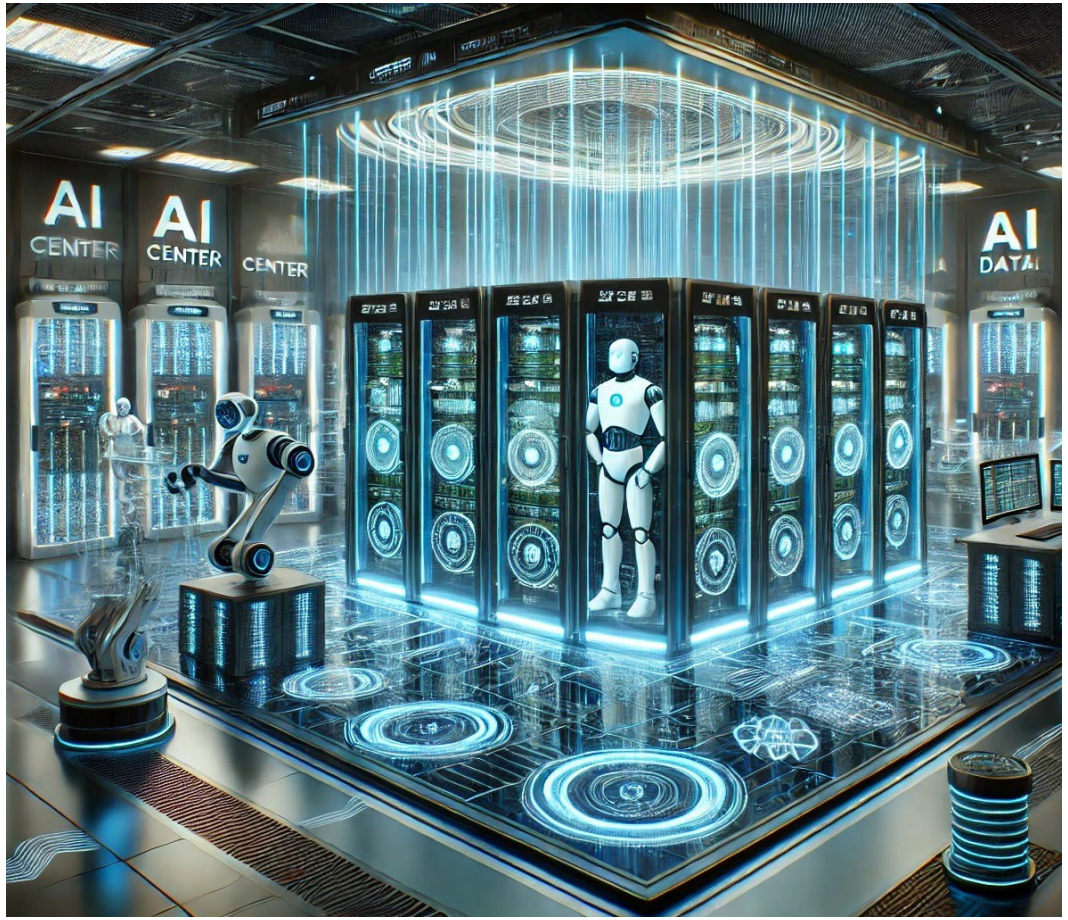


Feature	Roadmap	Design Rules	Capability
Purpose	Future strategy	Guidelines for design	Current manufacturable limits
Focus	Long-term trends	Practical constraints	Present state of production
Scope	Industry or company-level	Company and product specific	Factory-specific
Timeframe	3-10+ years ahead	Defined by existing processes	As of today
Example	Predicts <10 µm trace/space in 5 years	Requires ≥50 µm trace width	Can currently produce 30 µm trace width

PCB Roadmap Contents



Sample Application Requirements: AI Data Center



AI server (Universal Baseboard - UBB) and GPU module board

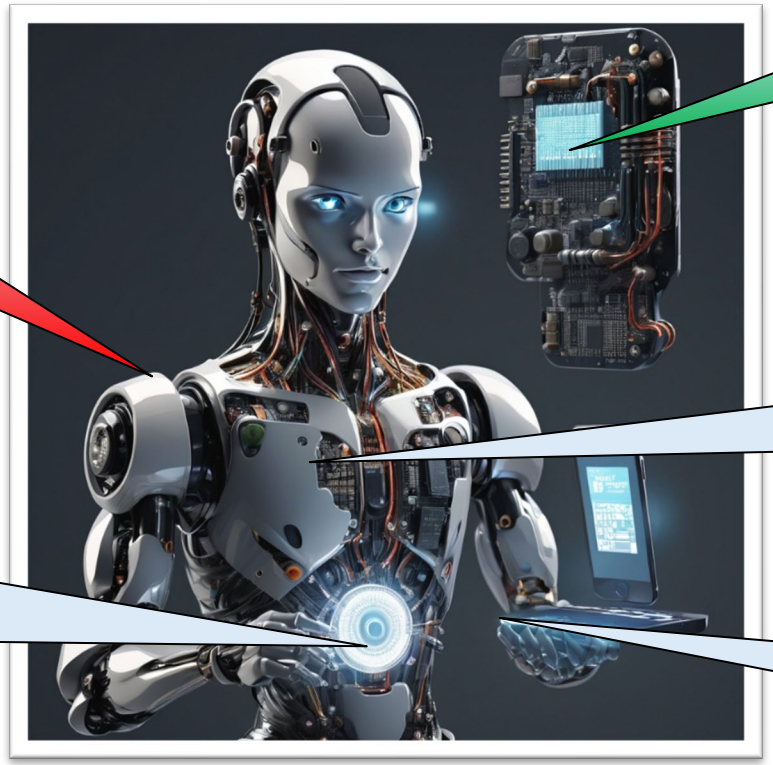
- Speed rate 112 Gbps →224 Gbps, requires M8 or M9 grade laminate material
- Ultra low-latency, high-bandwidth data transfer
- Build-up board with HDI layers → multiple pressing cycles
- Hybrid PCBs -Optical
- Good thermal conductivity as bonus
- Recyclable & Eco-Friendly Hardware → Sustainable server and cooling solutions

Industry Drivers

End-Device Trends

Hotter
Greater power transfers, higher operating temperatures

Greener
Factory operations with a smaller ecological footprint



Faster
Higher throughputs, higher frequencies, greater bandwidths

Cheaper
Lower cost point forgiven functionality and performance

Smaller
Finer lines, micro-vias, thinner dielectrics

Driving complexity in PCB features

PCB Roadmap Contents

Release 1 4Q23	High Speed	Substrates	Test, Inspect & Measurement	Environmental
Release 2 4Q24	Laminates			
Release 3 2Q25	Microwave & mmWave	Embedded Components		
Release 4 End 2025	Optical			

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In Review or Editing

Content Creation

Team Formation

High-Speed PCBs: Drivers and Needs [1/2]

Higher frequencies	2023: 400Gbps [internet switch] 112 Gbps [data center]	Increasing complexity needed in line card stack-ups	2023: High layer count 26-32 layers
	2026: 800Gbps [internet switch] 224 Gbps [data center]		2026: High layer count 36-52 layers
	2028/2033: 1.2-1.6 Tbps [internet switch[224-448 [data center]		2028/2033: High layer count with complex HDI build-ups 8+n+8 layers

High-Speed PCBs: Drivers and Needs [2/2]

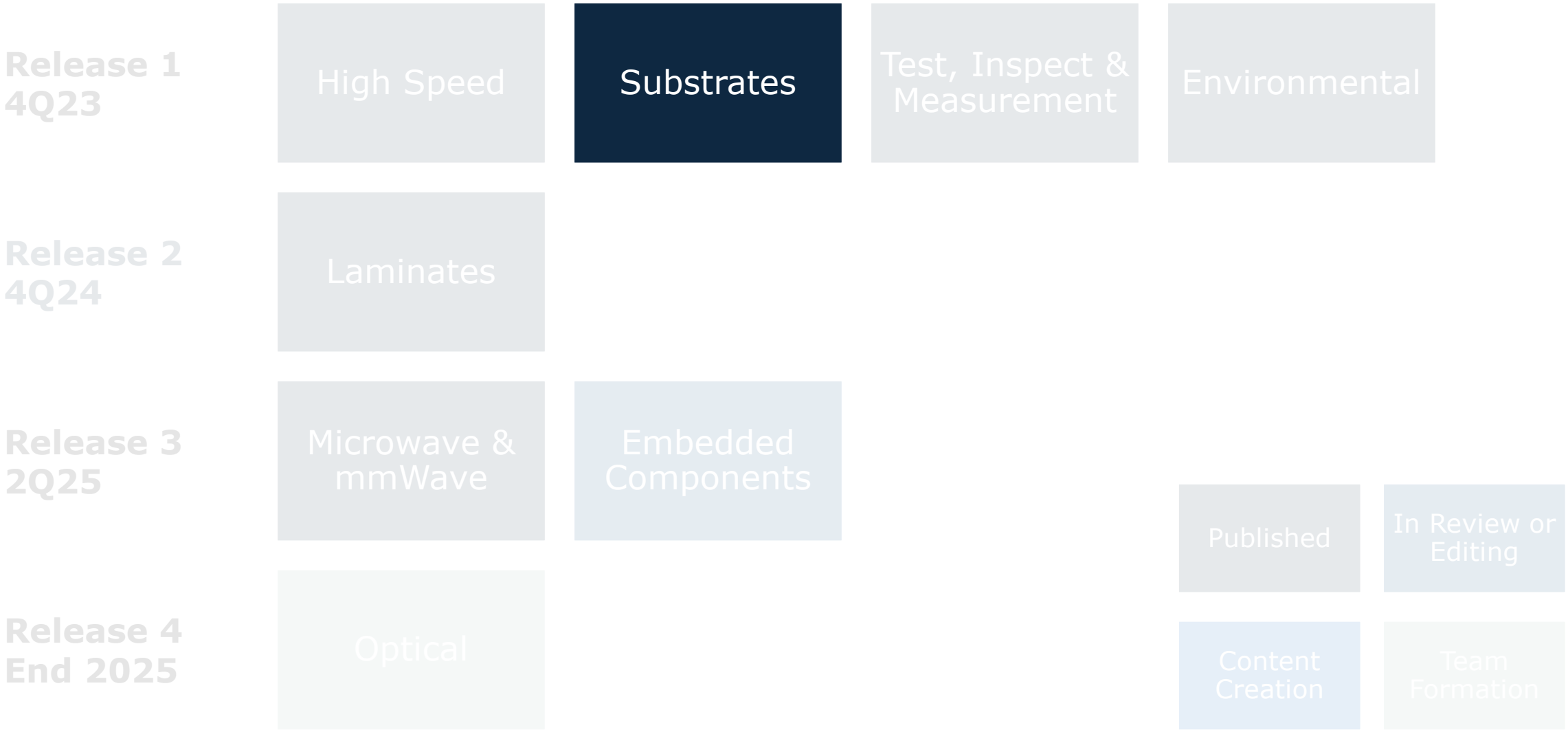
Reduced pin pitch	2023: Thinner line cards: 0.6 mm Smartphones: 0.35 mm	Backplanes/ mid-plane architecture evolution	2023: Up to 60 layers; impedance tolerance at 8%
	2026: Thinner line cards: 0.5 mm Smartphones: 0.30 mm		2026/2028: Thinner traces; more complex connectors/press fit; tighter impedance (5%) and physical tolerances
	2028/2033: Thinner line cards: <0.5 mm Smartphones: <0.30 mm		2033: Backplane functionality moves from passive to active

High-Speed PCBs: Solutions

In-table color key	Range of Technology Readiness Levels	Description
2	TRL: 1 to 4	Levels involving **research**
6	TRL: 5 to 7	Levels involving **development**
9	TRL: 8 to 9	Levels involving **deployment**

		EXPECTED TRL LEVEL			
TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2023)**	**3 YEARS (2026)**	**5 YEARS (2028)**	**10 YEARS (2033)**
Frequency drivers	Material libraries (including new high-frequency materials such as Teflon) from PCB fabricators, simulation tools and processes for high frequencies at 800Gb/s	7	8	9	9
	… 1.2-1.6Tb/s	4	6	8	9
	… 1.6Tb/s and above	3	4	5	8
Layer count	Drill size of 8 mils to attain multilayers technologies to be attained by necessary investment for capacity	6	7	8	9
	New and extended regional manufacturing facilities	4	5	6	8

PCB Roadmap Contents



High-Speed Substrate (IC and Ultra HDI): Drivers and Needs [1/2]

High-complexity architecture	2023:	16-layer any-layer board
	2026:	Any-layer board with increased layer count and reduced build-up layer thickness
	2028/2033:	Increased layer count with alternate constructions and more capable processes

Process evolution for smaller feature sizes and reliability	2023:	SAP process with process parameter control Clean room environment
	2026:	SAP process with optimized process parameter control Investment for automation and clean room manufacturing
	2028/2033:	Fully additive process with optimized process control Investment for automation and clean room manufacturing

High-Speed Substrate (IC and Ultra HDI): Drivers and Needs [2/2]

Materials for high-speed connectivity

2023:

Cu: HVLP2 & HVLP3/low etch oxide

Glass: Low Dk, 1027 spread glass

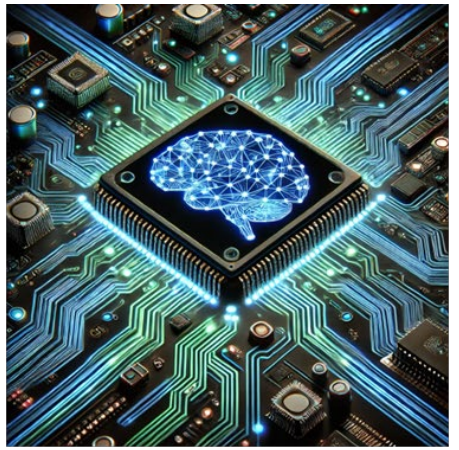
2026:

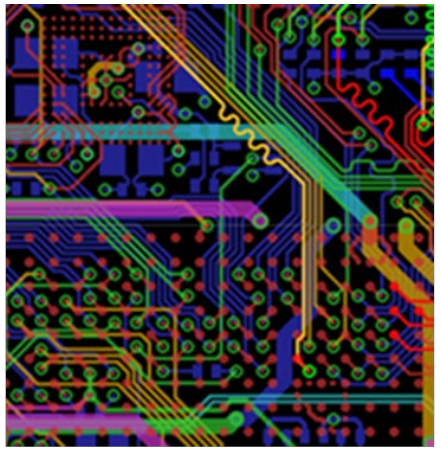
Cu: HVLP3 & HVLP4/no etch oxide

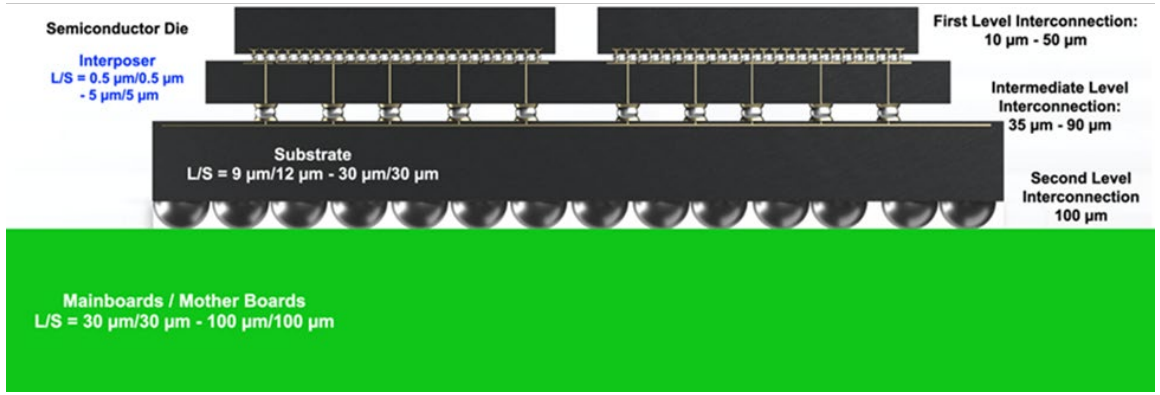
Glass: Lower Dk, 1017 spread glass

2028/2033:

Thinner spread glass (1010, 1000)







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TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2023)**	**3 YEARS (2026)**	**5 YEARS (2028)**	**10 YEARS (2033)**
Architectures	New manufacturing technologies for embedded solutions (optical modules) and thinner materials	6	7	8	9
	Smaller feature sizes: finer lines and spacings, smaller through holes, tighter aspect ratios	6	7	8	9
	Increased use of modularity for dense boards	5	6	7	8
Dielectric (IC and HDI)	Use non-reinforced layers adapted from IC substrate approaches	7	8	8	9
	New lower-loss dielectrics – multiple resin systems being developed, choice depends on frequency, performance, cost, etc.	6	7	8	9

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Test, Inspect & Measurement: Drivers & Needs [1/2]

Improved electrical testability	2023:	Continuity testing with impedance, volumetric control of conductor
	2026:	More involved, 100% continuity testing. Impedance, volumetric control of conductor
	2028/2033:	Able to address more complexity
Control and automation	2023:	Adaptive control with some dynamics in place
	2026:	Dynamic control capability
	2028/2033:	Full automation with factory AI

Test, Inspect & Measurement: Drivers & Needs [2/2]

Traceability

2023:

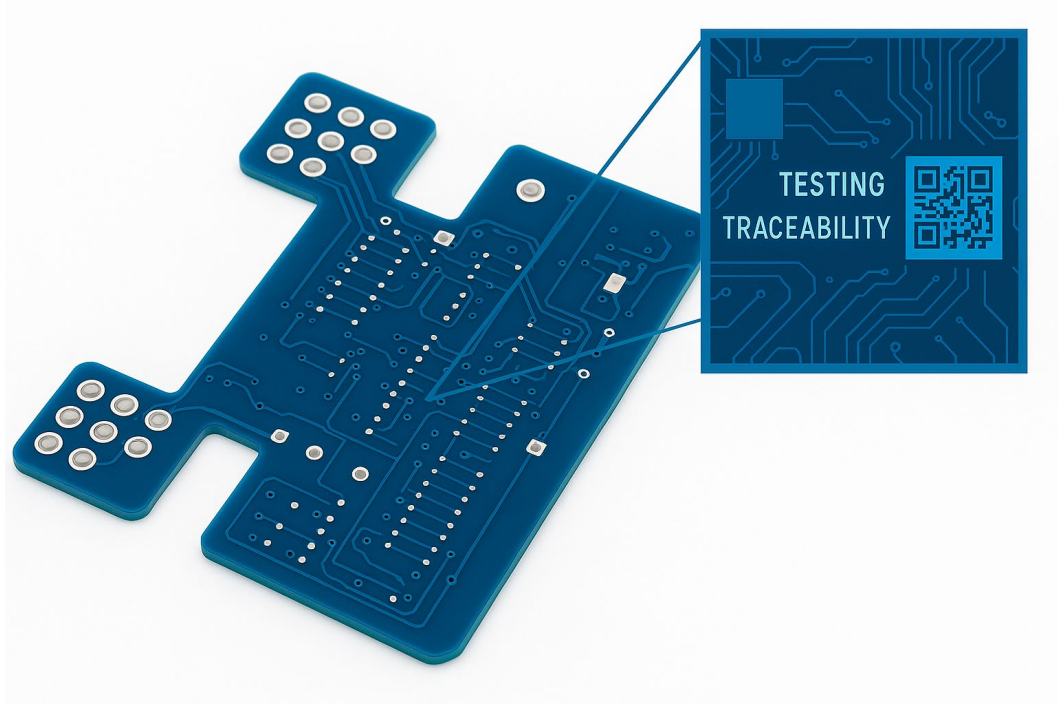
Lot/batch code traceability

2026:

Individual board bar code traceability, smaller and more precise

2028/2033:

Individual board bar code traceability embedded inside the board e.g. RFID



Test, Inspect & Measurement: Solutions

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TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2023)**	**3 YEARS (2026)**	**5 YEARS (2028)**	**10 YEARS (2033)**
[Equipment] Electrical Testability	Existing machine development (software and mechanics)	6	8	9	9
	More comprehensive testing with software and hardware upgrades	5	6	8	9
	New testing machine development (e.g., non-contact, etc.) for smaller dimensions, finer pitch, speed, data handling…	5	5	6	8
[Equipment] Measurability	Increase in-process automated measurement and feedback for control of machine and chemical parameters (close-loop, realtime)	5	5	6	8
	Improve ML to reduce variation and optimize process	4	5	6	8
	AI utilized to optimize machine control and data handling	3	4	5	6

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Environmental: Drivers & Needs [1/2]

Products' environmental profiles	2023/2026: Some early availability of information technology (IT) tools/platforms/regulatory watch. Regionally-driven only.	Resource management at end-of-live	2023/2026: Industrial mitigation of electronics disposal: Limited corporate programs, and company initiatives/targets.
	2028/2033: Globally-driven initiatives and harmonized		2028/2033: Maturation and deployment

Environmental: Drivers & Needs [2/2]

Energy reduction in manufacturing

2023:

Quantification of energy usage in manufacturing

2026/2028:

Alternative methods for lower-energy manufacturing, with a focus on plating and lamination

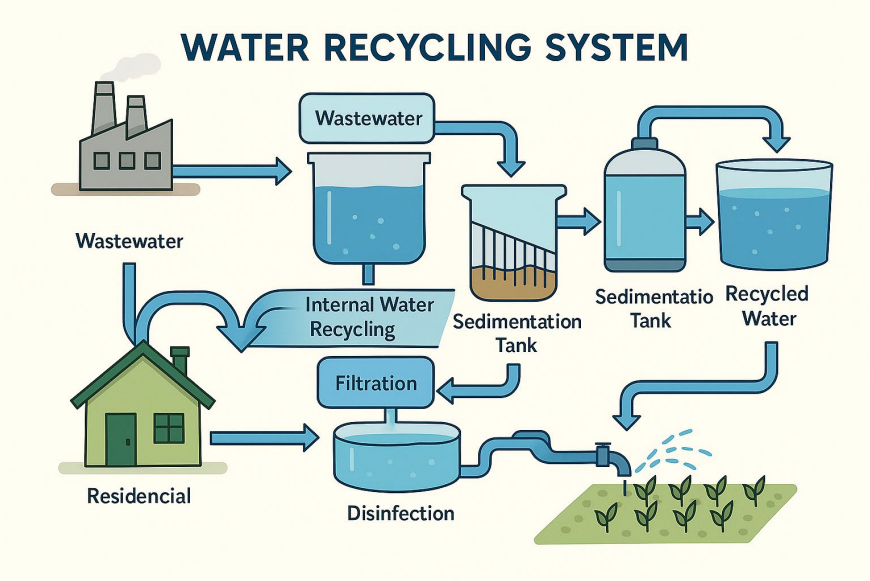
2033:

Move to 3D/additive manufacturing techniques

Water usage in manufacturing

2023 to 2033:

Reduction in waste-water outflows and improvement in the energy efficiency of waste-water treatment



Environmental: Solutions

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		EXPECTED TRL LEVEL			
TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2023)**	**3 YEARS (2026)**	**5 YEARS (2028)**	**10 YEARS (2033)**
Product environment	Compliance and innovation are coincident with regulatory introduction	6	7	8	9
Supply chain (e.g, verification of entire supply chain, qualification)	Emergence of fully traceable product certification throughout the supply chain	5	6	7	8
Resource management (e.g., energy, water, air, waste (circuitry, boards, landfill, chemical, etc.)	Factory-level deployment of retrofitted and new equipment that meets regulatory needs	5	6	7	8
	Focused collection and review of ongoing and future profiles from PCB manufacturing and suppliers to implement measurement and develop a	6	8	8	9

PCB Roadmap Contents

Laminates: Drivers & Needs [1/2]

Build-up miniaturization (reduced pitch size)	2023: 200 um (core) 95 um (build-up)	Reduced CTE	2023: 6 ppm/K (xy) 30 ppm/K (z)
	2026: 190 um (core) 80 um (build-up)		2026: 4 ppm/K (xy) 15 ppm/K (z)
	2028: 170 um (core) 70 um (build-up)		2028: 3 ppm/K (xy) 15 ppm/K (z)
	2033: 150 um (core) 50 um (build-up)		2033: 3 ppm/K (xy) 15 ppm/K (z)

Laminates: Drivers & Needs [2/2]

Speed performance: Lower Df for the substrate	2023: Df = 0.01-0.009	Processes to support smaller interconnect sizes	2023: *For handheld devices:* maintain hole quality in preparation and drilling
	2026: Df = 0.006		2026: *For handheld and large format devices:* maintain hole quality in preparation and drilling
	2028/2033: Df < 0.003		2028/2033: Introduce homogenous materials (e.g., resin-coated Cu foil) to enable further reductions in interconnect size

Laminates: Solutions

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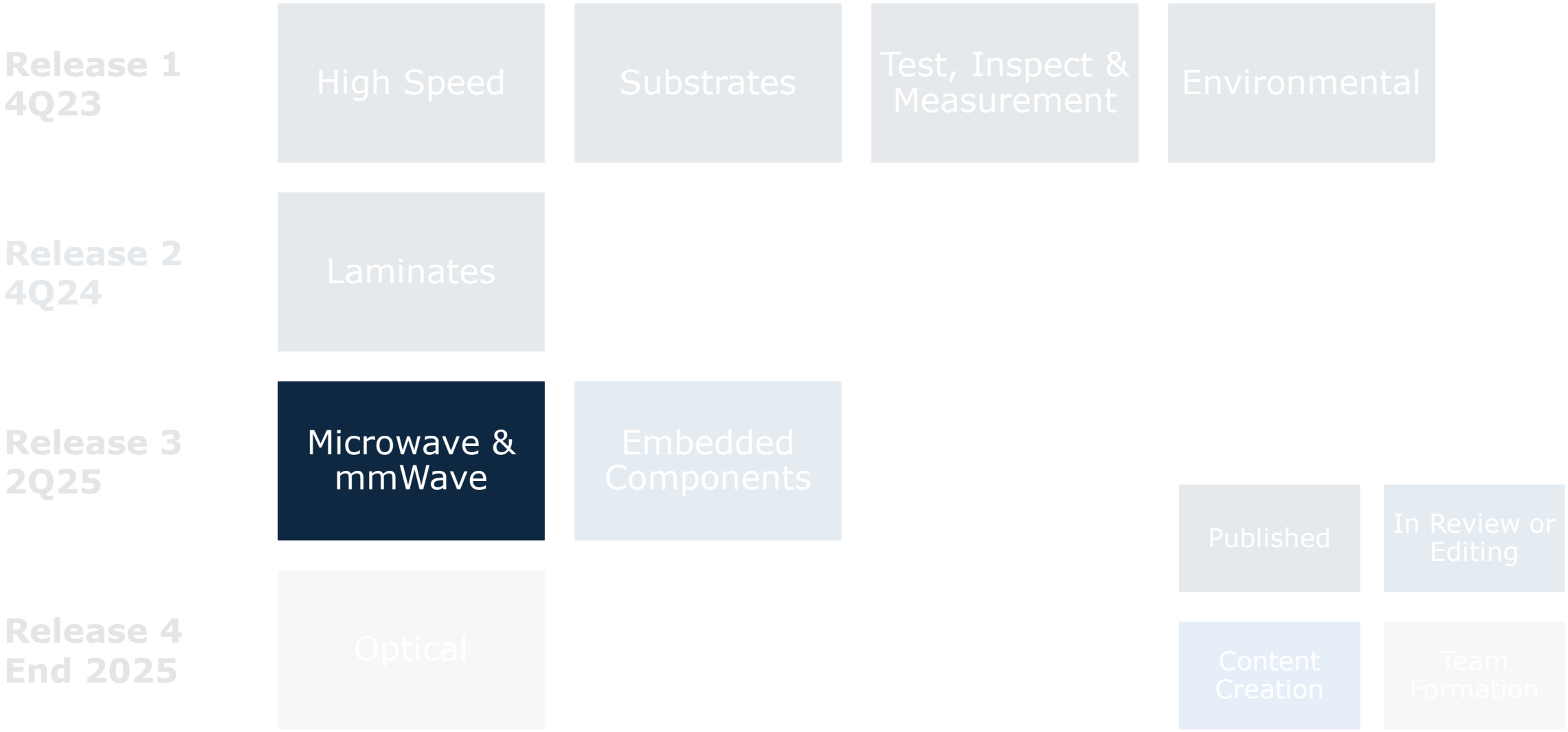
		EXPECTED TRL LEVEL*			
TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2025)**	**3 YEARS (2028)**	**5 YEARS (2030)**	**10 YEARS (2035)**
Build-up processes for miniaturization (pitch, line width, etc., hole size, thickness, aspect ratio)	Stay current with state of art equipment	7	8	9	9
	Invest in semi-additive solutions and processes (i.e., Cu deposition on dielectric coating with Pd)	6	7	8	8
	Continue development and deployment of high aspect ratio (AR) drilling and laser ablation, plating	7	8	9	9

PCB Roadmap Contents



Microwave & mmWave PCBs : Drivers & Needs [1/2]

Increasing frequency	2023: ADAS: 25+77GHz Wireless: 30 GHz	Low-loss materials	2023: Dielectric: Df<0.030, low moisture absorption Cu foil: Low surface roughness and insertion loss, with, e.g., HVLP2 & HVLP3/low etch oxide
	2026: ADAS: 25+77GHz Wireless: 56 GHz		Dielectric: Df<0.010 Cu foil: HVLP3-HVLP4/no etch oxide
	2028/2033: ADAS: 25+77GHz Wireless: 80 GHz		2028/2033: Dielectric: Df<0.002 Cu: HVLP4 & HVLP5/no etch oxide, with good chemical adhesion

Microwave & mmWave PCBs : Drivers & Needs [2/2]

Improved thermal management

2023:

Higher operational temperature → Better heat transmission for dielectric materials

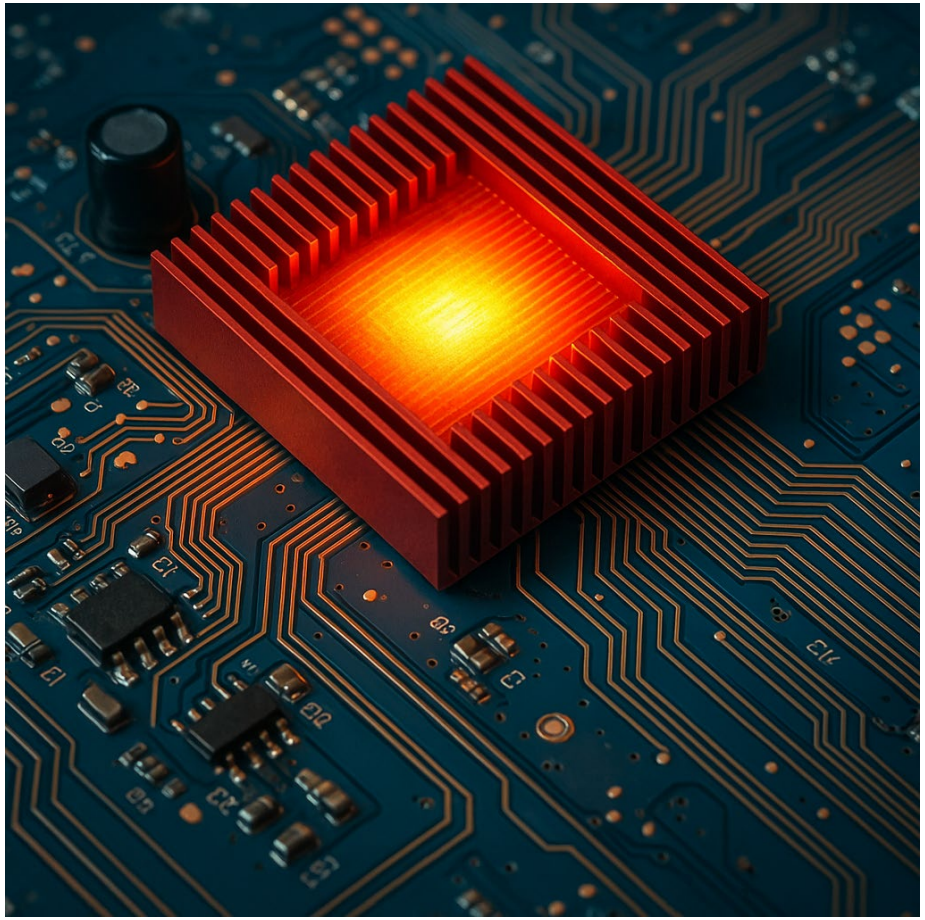
>1W/mK with low Dk

2026:

>2W/mK with low Dk

2028/2033:

>10W/mK and low Dk



Microwave & mmWave PCBs: Solutions

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TECHNOLOGY ISSUE	**POTENTIAL SOLUTIONS**	**TODAY (2025)**	**3 YEARS (2028)**	**5 YEARS (2030)**	**10 YEARS (2035)**
Frequency Drivers	[See solutions in Materials and Process Accuracy and Variations below]				
Styles of mmWave Circuits	Hybrid stack-ups to limit high frequency challenges to limited layers	6	6	7	8
	Additive manufacturing of structures, both dielectrics and metals	5	7	8	9
	3D-printed structures, both dielectrics and metals	4	6	7	8
Thermal	Resin-coated Cu with HDI layers	7	8	9	9

Conclusions and Key Takeaways

Market-Driven Solutions

- PCB technology is driven by the application requirements of all major business sectors, including AI, automotive, telecommunications, aerospace, and industrial electronics

→ Align technology innovation with industry needs

Challenges & Gaps

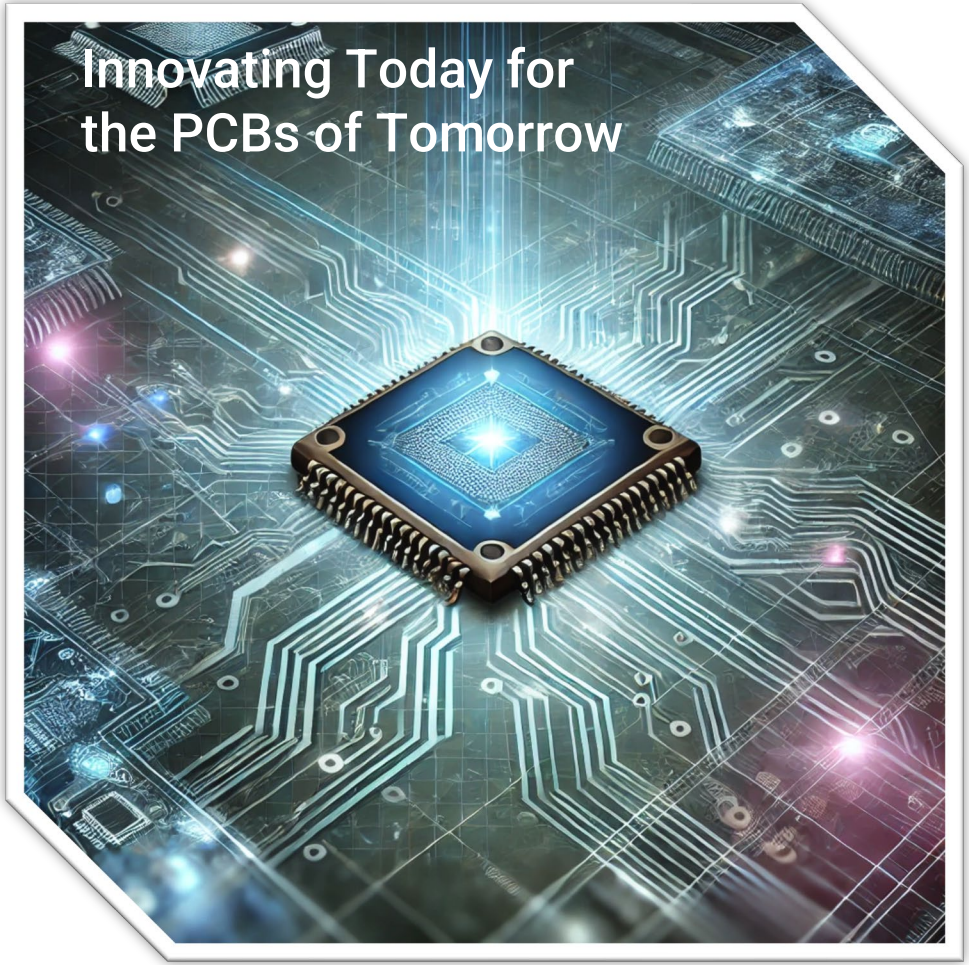
- Balancing electrical performance, reliability, and sustainability
- Miniaturization & integration requirements → New innovations

→ Strengthen partnerships for supply chain security

Supply Chain & Future Roadmap

- Strong collaboration among OEMs, fabricators, and suppliers
- Focus on new, high-reliability materials for diverse applications
- Eco-friendly & recyclable solutions for sustainability

→ Stay updated on industry regulations and sustainability trends



What's Next: Optical PCBs

Many applications involve increasing integration of optical functionality into PCBs.

Target:

- Roadmap optical waveguides and embedded optical functions, optical interconnects and the need to support optical engines and devices.
- Both single-mode 1310nm and multimode 850nm technologies considered.

Status:

- Currently recruiting contributors.
- Contributors do not need to be part of an INEMI member organization.

Expected scope of contributions:

- One-hour calls, held weekly.
- Minimal off-line work.

Contact fmullany@inemi.org if you or a colleague might be interested.

WHERE TO FIND MORE INFORMATION

Website
- iNEMI Project information
- iNEMI upcoming events
- iNEMI Roadmap

Social
- iNEMI TV on YouTube
- Follow iNEMI on LinkedIn

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