Hybrid PCBs for Next Generation Applications – Results of Industry Survey

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Listen to the recorded webinar

YouTube: https://youtu.be/fGqJ8fwOvhA

Other: http://thor.inemi.org/webdownload/2022/Projects/Hybrid_PCB-survey.mp4

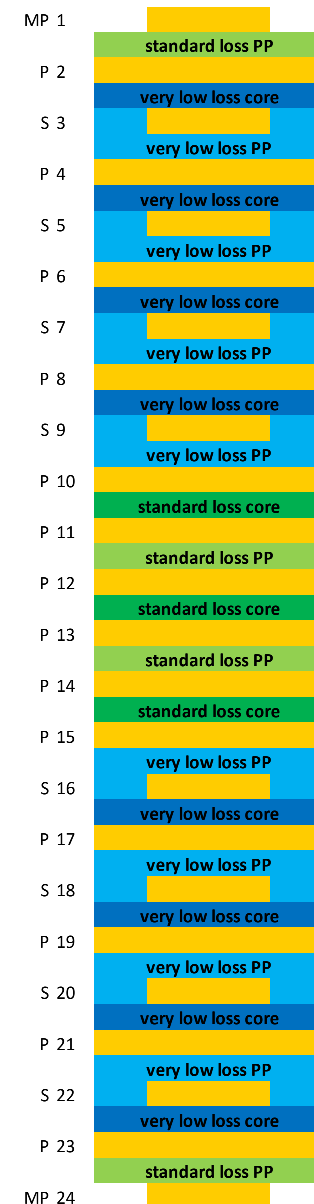
Definition of Hybrid PCB for this Survey

- Hybrid PCBs use dissimilar dielectric materials on core and/or prepreg layers to balance electrical performance and cost.
  - Lower loss materials are used on high-speed layers
  - Higher loss/low-cost materials are used on other layers

- Compatibility of the materials used is critical for ensuring PCB quality and reliability.

- This project focused on use of dissimilar thermoset materials (ex: epoxy, PPO, PPE, polyimide, etc.) and not the combination of thermoset and thermoplastic materials (ex: PTFE) nor rigid-flex PCBs.

Example hybrid PCB stack-up



Survey Background & Motivation

- The iNEMI PCB TIG identified hybrid PCB quality and reliability as a critical focus area.

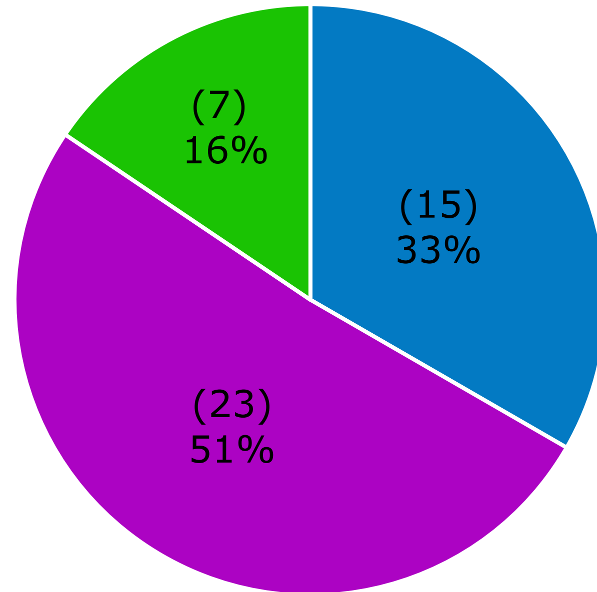
- Many material properties and manufacturing processes can influence laminate compatibility and PCB reliability. More information was needed to scope a project(s) to address this challenge.

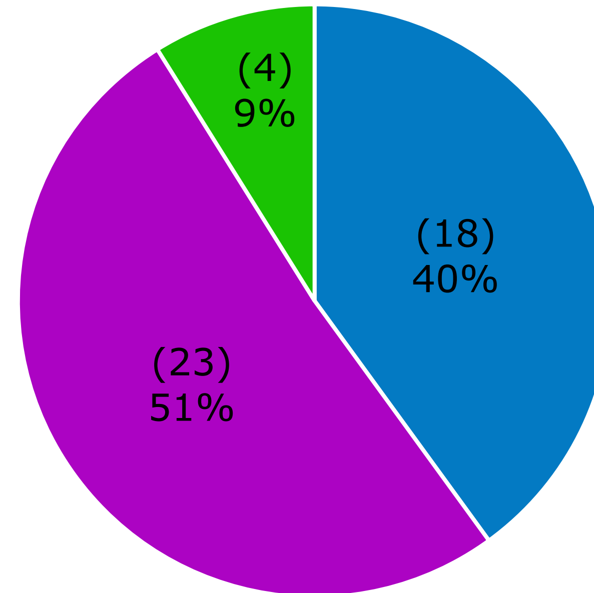
- Survey Objectives:
  - Utilize results to identify and scope an iNEMI collaborative project(s)
  - Focus on rigid, thermoset hybrid constructions
  - Collect information about hybrid PCB manufacturing and reliability/quality challenges
  - Characterize utilization of hybrid PCBs

- Survey Approach:
  - Generated using Survey Monkey
  - Polled laminate manufacturers, PCB fabricators, and OEMs
  - Anonymously compiled and analyzed data

Survey Participation by Company Type and Location

- There were 45 unique responders.
- The 45 responders represented 36 companies* located in Asia, Europe, and North America.





*Some companies had multiple responders in different locations and/or divisions

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Utilization of Hybrid PCBs

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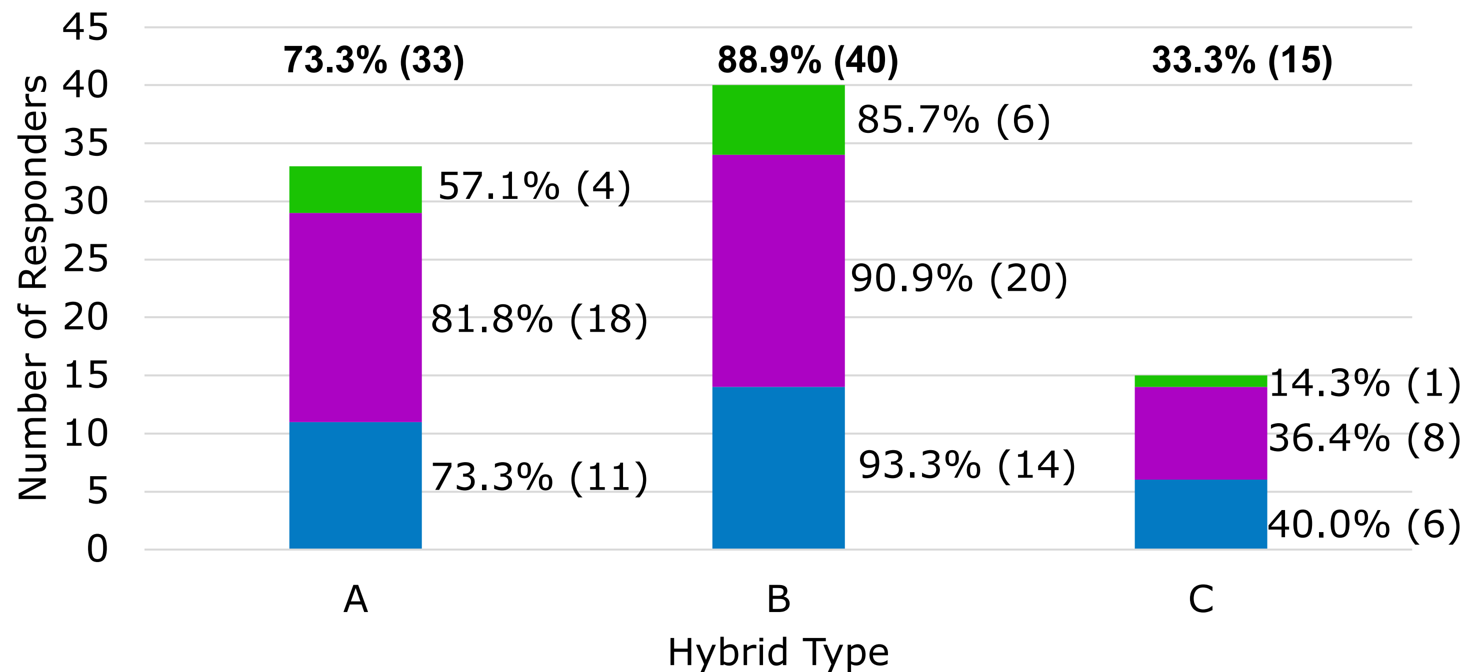
Usage of Thermoset Hybrids by Type

- 100% of responders indicated that they support/build/use hybrid PCBs.
- Type B is most commonly used.
- Types A & B are more common than C.



Option A:
2 different dielectric material cores, only 1 dielectric material prepreg

Option B:
2 different dielectric material cores, 2 different dielectric material prepregs

Option C:
3 or more different dielectric materials

Location of different materials is for example purposes only

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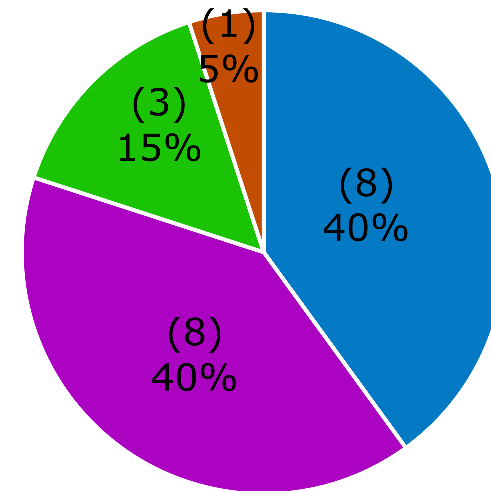
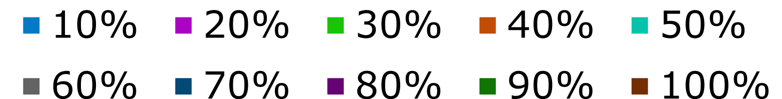
Percentage of Builds that Use a Hybrid Stack-up at PCB Fabricators

- Most of the fabricators polled responded that 10% or 20% of their production uses a hybrid stack-up.
- Other fabricators stated that 30% or 40% of production uses a hybrid stack-up.
- No fabricators responded that more than 40% of production uses a hybrid stack-up.

Percentage of Total Builds that Use a Hybrid Stack-up





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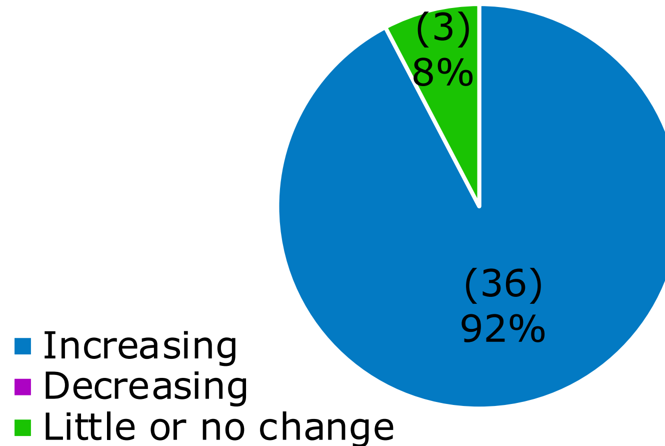
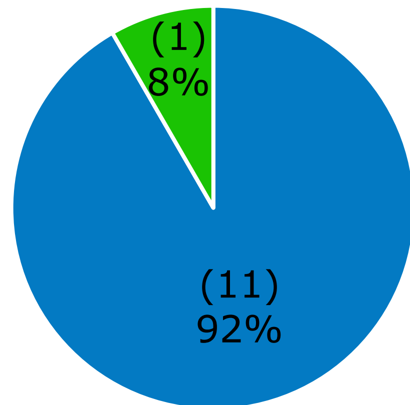
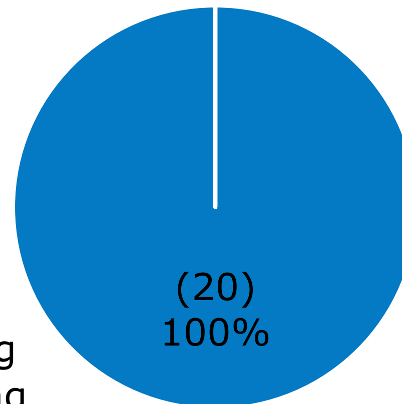
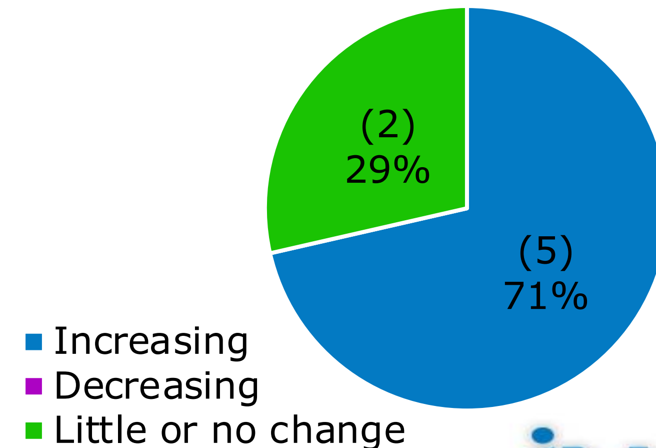
Usage Change in the Last 5 Years

- Utilization of hybrid PCBs in the last 5 years has increased as compared to prior years.









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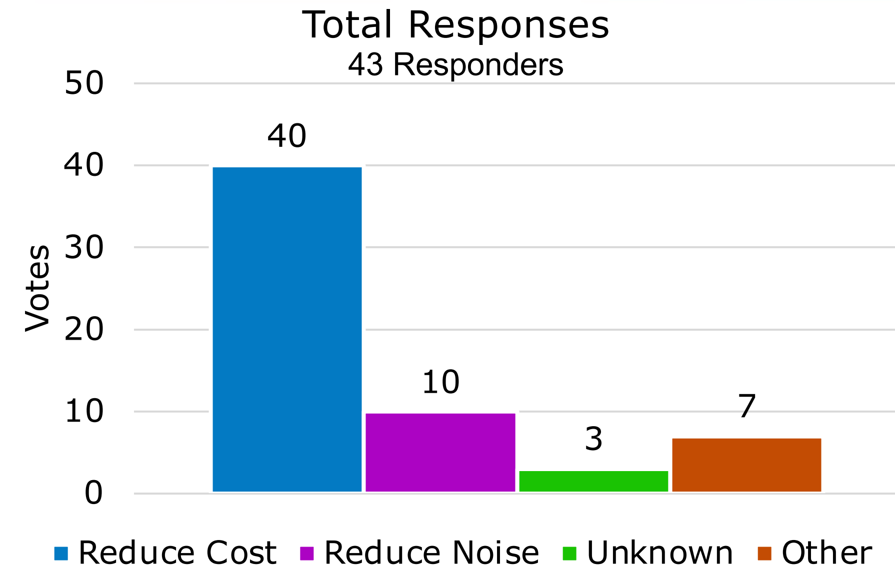
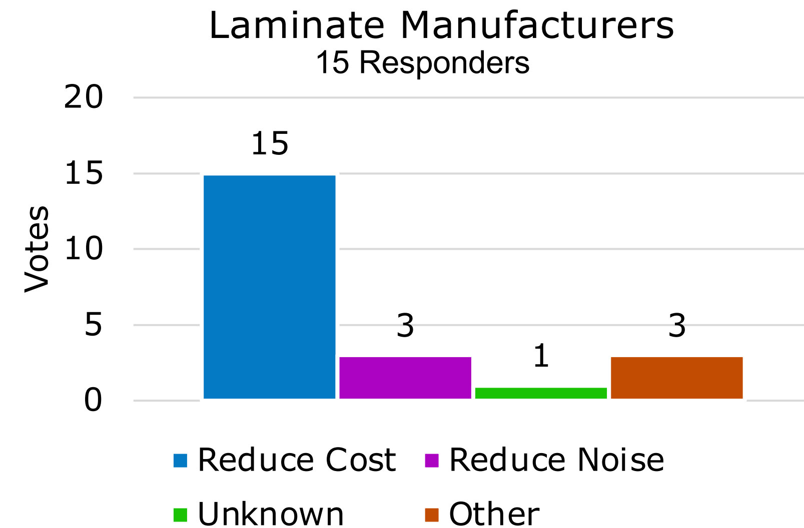
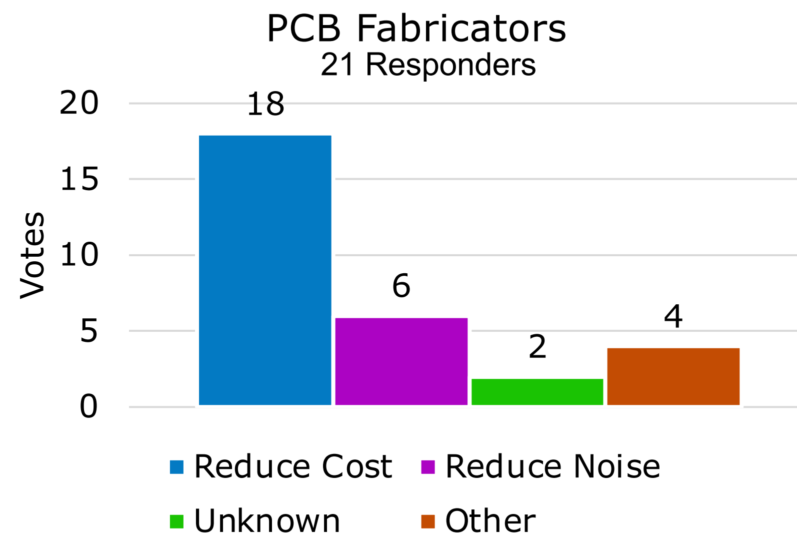
Reasons for Using Hybrid PCBs

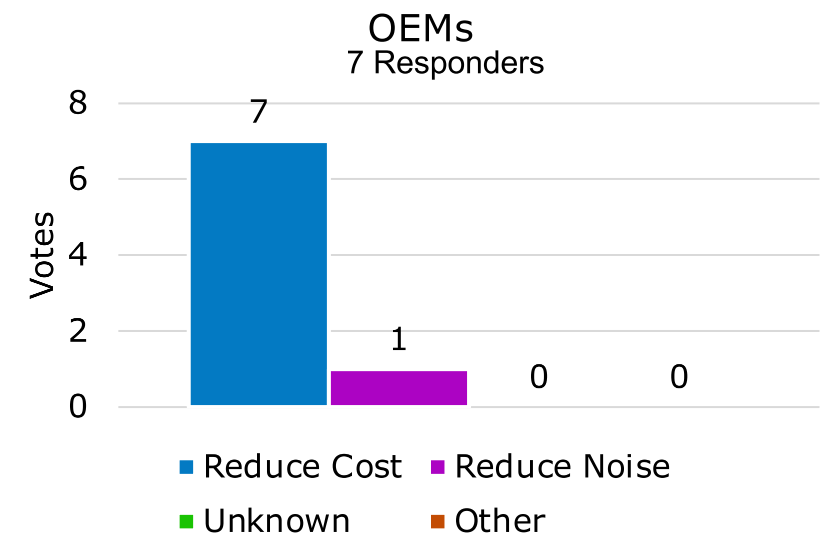
- The primary driving factor for using hybrids is to reduce cost while maintaining performance on critical layers.

- Laminate and PCB fabricators highlighted a few other drivers:
  - Improve reliability by using lower CTE laminate on critical layers
  - Reduce reliance on low Dk glass
  - Reduce heavy copper (2 oz) fill risk by using standard loss materials









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Challenges in Manufacturing Hybrid PCBs

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Ranking of Manufacturing Challenges

- Respondents from all three company types were asked to rank 10 options from most to least challenging
- There was high variability in responses as evidenced by ranking range for each challenge

- Tier 1 Challenges: Determining material compatibility and managing warpage
- Tier 2 Challenges: Optimizing lamination/drill/desmear parameters, predicting or optimizing scale factors, and preventing delam
- Tier 3 Challenges: PTH reliability, optimizing hole metallization/plating, meeting CAF requirements

		Determining Material Compatibility	Optimizing Scale Factors	Optimizing Lamination Parameters	Optimizing Drill Parameters	Optimizing Desmear Parameters	Optimizing Hole Metallization	Managing Warpage	Preventing Delam	PTH Reliability	Meeting CAF Requirements
Total Responses 41 responders	Average Rank	4.0	5.3	4.8	5.1	5.5	6.8	4.5	5.4	6.3	7.2
	Min	1	1	1	1	1	1	1	2	1	1
	Max	9	10	10	10	10	10	10	9	10	10
Laminate Manufacturers 13 responders	Average Rank	3.5	6.6	4.0	4.1	5.2	7.2	6.5	5.3	4.8	7.9
	Min	1	1	1	1	2	1	1	2	1	2
	Max	8	10	9	8	10	10	10	9	9	10
PCB Fabricators 21 responders	Average Rank	4.4	4.5	5.3	5.5	5.7	6.1	3.9	5.6	6.9	7.0
	Min	1	1	1	2	1	1	1	2	2	1
	Max	9	9	9	10	10	10	10	9	10	10
OEMs 7 responders	Average Rank	4.0	5.3	4.7	6.0	5.3	7.9	2.9	5.1	7.4	6.4
	Min	1	3	1	3	2	4	1	2	2	3
	Max	9	7	10	8	9	10	7	9	10	10

1 = most difficult challenge (red), 10 = least difficult challenge (green)

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Open Comments Regarding Challenges with Hybrid PCBs

Question: Please list/describe any specific challenges that warrant further industry collaboration to investigate.

- Laminate manufacturer highlights
  - Defining material compatibility for use in a hybrid stack-up
  - Understanding CTE of resin and how to minimize impact of mismatch on thermal robustness
  - Defining a method to accurately assess desmear rates of laminate materials
  - Understanding how material position in the stack-up influences warpage and delamination
  - Improving supply chain collaboration (ex: some end users do not understand the difficulties in hybrid design)
- PCB fabricator highlights
  - Determining material compatibility for use in a hybrid stack-up
  - Characterizing the effect of material location in stack-up (including asymmetry)
  - Understanding PCB reliability with different CTE materials in stack-up
  - Improving warpage prediction and control
  - Improving designer understanding of hybrid cross-section requirements to minimize reliability and warpage concerns
  - Using of laminates from different suppliers in same stack-up
- OEM highlights
  - Understanding impact of laminate material CTE and Tg mismatch in stack-up
  - Managing warpage of asymmetric hybrid stack-ups
  - Characterizing hybrid stack-up impact on layer-to-layer registration
  - Not sure there are issues that need collaborative projects

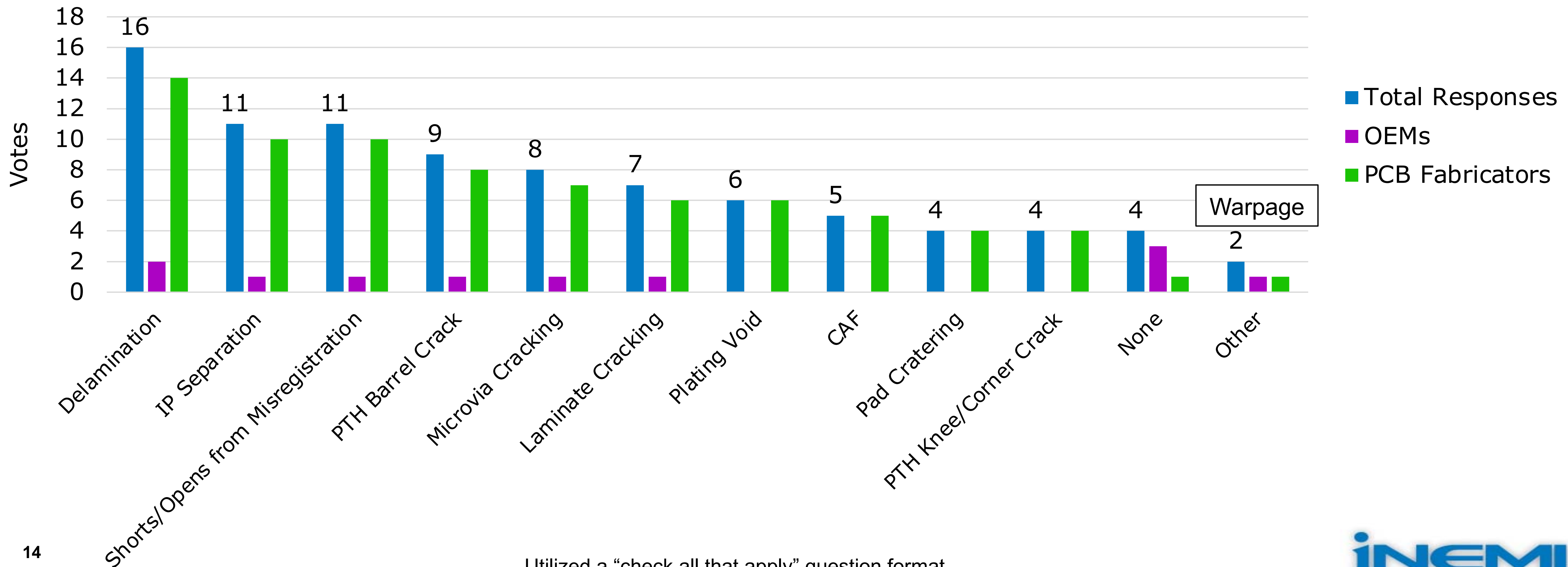
Manufacturing Parameters that are More Critical for Hybrid PCBs

PCB fabricators were asked what manufacturing factors or parameters are more critical during lamination, drill, desmear, and hole metallization for hybrid stack-ups as compared to pure stack-ups.

- Lamination
  - Rate of heat rise, peak temp, time at peak temp, and pressure must be carefully considered for hybrid PCBs
  - Parameters are selected by comparing resin flow window, minimum melt viscosity, gel time, and thermal stability of the materials
  - Lower loss laminates typically have a narrower processing window than higher loss laminates so the requirements of the lower loss material are the priority and adjustments may need to be made to accommodate the higher loss material
- Drill
  - Drill bit type, chip load, speed, feed rate, hit count, and number of pecks must be carefully considered for hybrid PCBs
  - Parameters are selected based on material filler type/content, hardness, and Tg as well as input from laminate manufacturer
  - Parameters may be based on the material that is more difficult to drill (usually lower loss material) and adjustments are made from there
- Desmear
  - Use of type of desmear (chemical and/or plasma) and treatment duration must be carefully considered for hybrid PCBs
  - Parameters are selected based on material filler, material compatibility with chemical desmear, etch rate (weight loss)
  - Parameters may be based on the material that is more difficult to clean (usually lower loss material) and adjustments are made from there
- Hole metallization
  - Overall response was that plating is not more challenging for hybrid vs. pure PCBs
  - It is important to properly optimize drill and desmear properties to ensure adhesion of copper to hole wall
  - Need to ensure compatibility of resins with plating chemistries

What Failure Modes Are More Common in Hybrid PCBs?

- Delamination, IP separation, and misregistration were rated as the more common failure modes for hybrid PCBs.
- Both of the "other" responses sited warpage as a failure mode.
- PCB fabricators indicated more failure modes for hybrid PCBs than OEMs.



Utilized a "check all that apply" question format

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Determining Compatibility of Materials to be Used in a Hybrid Stack-up

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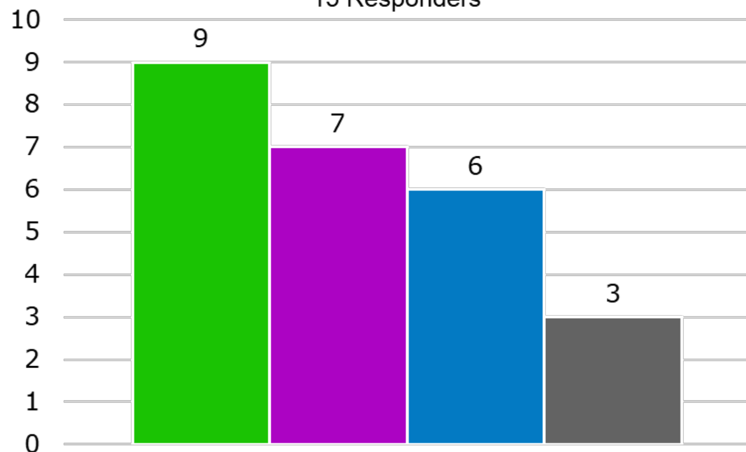
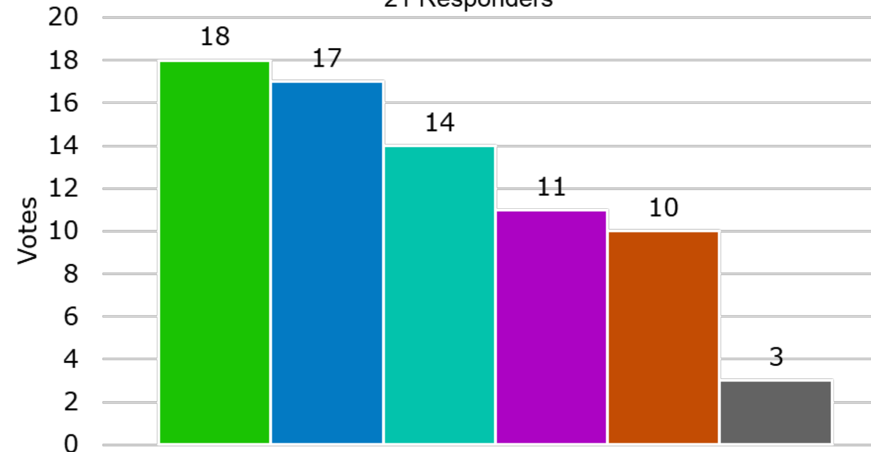
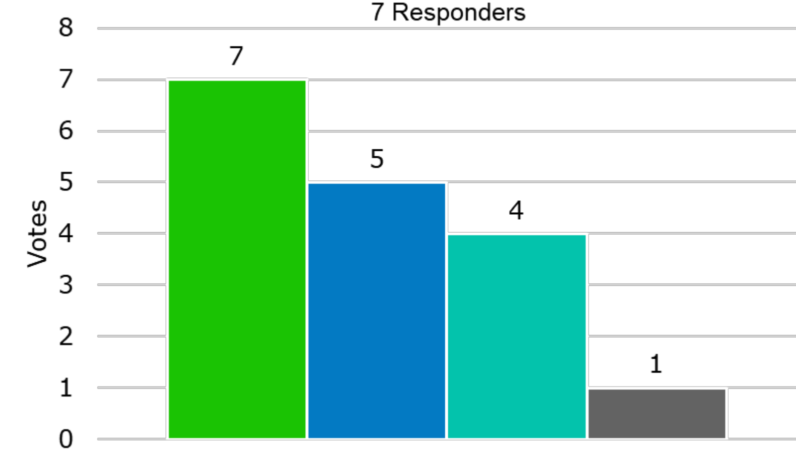
How is it Determined if Two Laminate Materials are Compatible?

- Conducting trial builds is the most common approach for determining laminate compatibility.
- "Other" comments provided:
  - Comparison of CTE, especially above Tg
  - Analysis of resin melt viscosity and flow window
  - Review process guideline provided by laminate manufacturers
  - Consideration of copper foil and oxide treatment compatibility
  - UL recognition







Material Properties Most Critical to Consider

Question (to laminate manufacturers only): Please select the top 4 material properties from the list below that are most critical to consider when evaluating if two different dielectric materials are compatible for a hybrid stack-up.

Property	**Number of Votes***
Desmear Rate	7
Rheological Properties (minimum melt viscosity, resin flow temperature, get time, etc.)	7
Z-axis CTE	7
Resin Chemical Compatibility	6
Cure Time, Kinetics, and Temperature	4
Glass Transition Temperature	4
X/Y axis CTE	3
Flame Retardant Type	2
Propensity for Water Absorption	2
Required Rate of Heat Rise during Lamination	2
Filler Type and Content	1
Storage Modulus and Loss Modulus	1
Thermal Decomposition Temperature	1
Other	1
Volatile Content	0

*13 Responders

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How Similar Do Key Material Properties Need to Be for Materials to Be Compatible for Use in a Hybrid Stack-up?

Laminate manufacturers were asked how similar the CTE, desmear rate, & rheological properties of materials needed to be for the materials to be compatible for use in a hybrid stack-up.

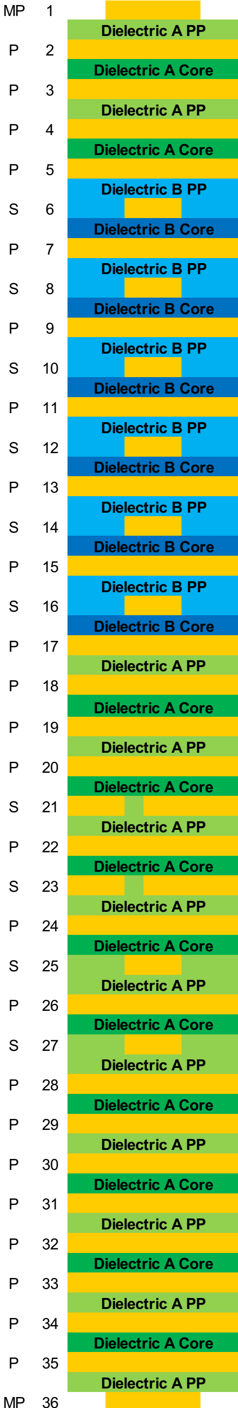
- Responders indicated that ideally these properties should be as close as is possible
- Thresholds for an acceptable amount of difference between materials varied greatly among responders

- CTE
  - No consensus on how different the CTE can be
  - Responses ranged from 5-50% allowable difference between materials
  - Other factors (modulus and bond strength) may influence how much CTE mismatch can be tolerated

- Desmear Rate
  - Responses ranged from 1-20% allowable difference between materials
  - Materials used in the stack-up must be compatible with the desmear type (plasma or chemical) used
  - Risk is over etching one material which reduces dielectric spacing and can increase risk of CAF

- Rheological properties
  - Responses ranged from 2-30% allowable difference between materials
  - Minimum melt viscosity should be within ~10 C
  - Need to compare of rheology curve to ensure overlap of resin flow window

Use of Asymmetrical Resin Hybrid PCBs

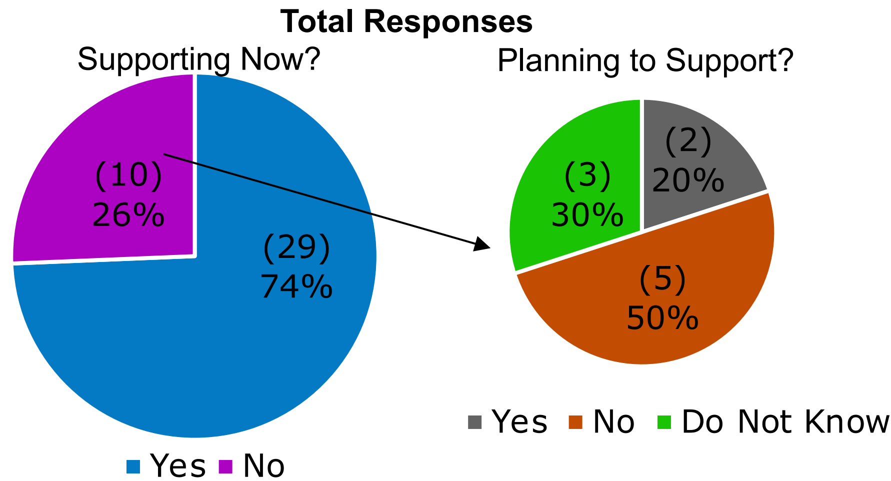


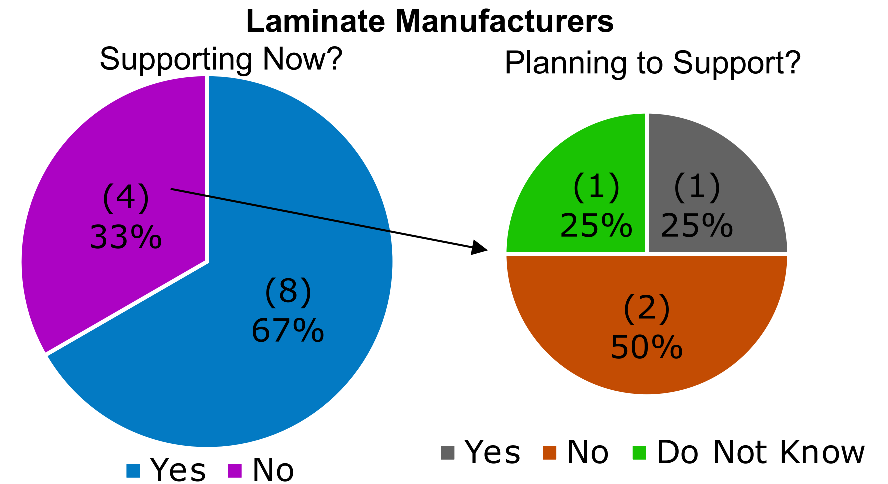
Dielectric B layers are not centered in the design cross-section

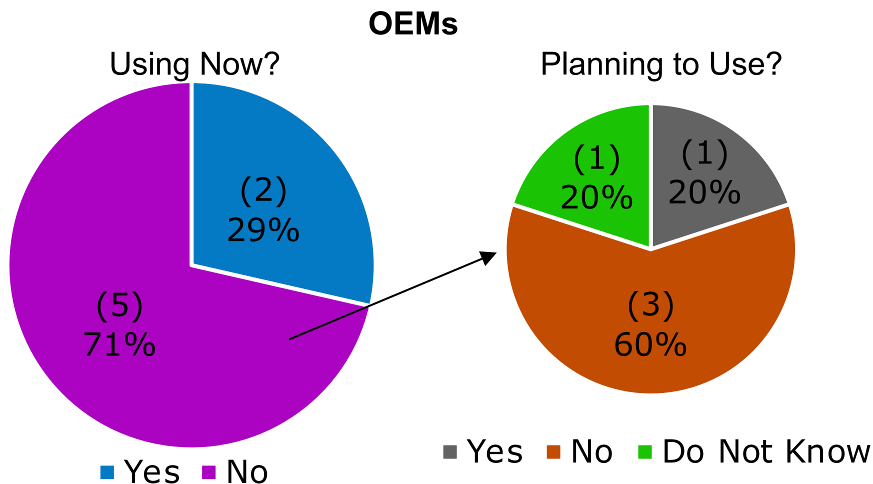
Location of different materials is for example purposes only

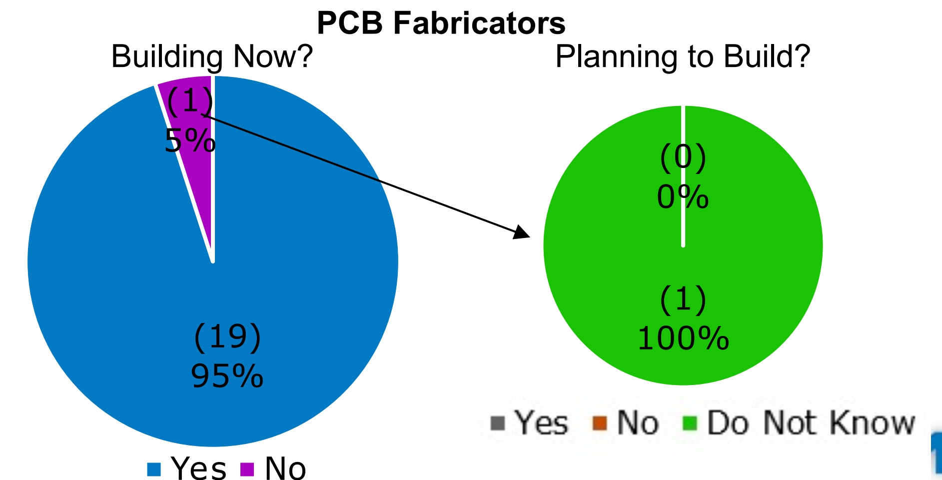
Utilization of Asymmetrical Hybrid Stack-ups

- Many laminate manufacturers and nearly all PCB fabricators build PCBs with asymmetrical hybrid stack-ups.
- The majority OEMs polled do not use or design PCBs with asymmetrical hybrid stack-ups.



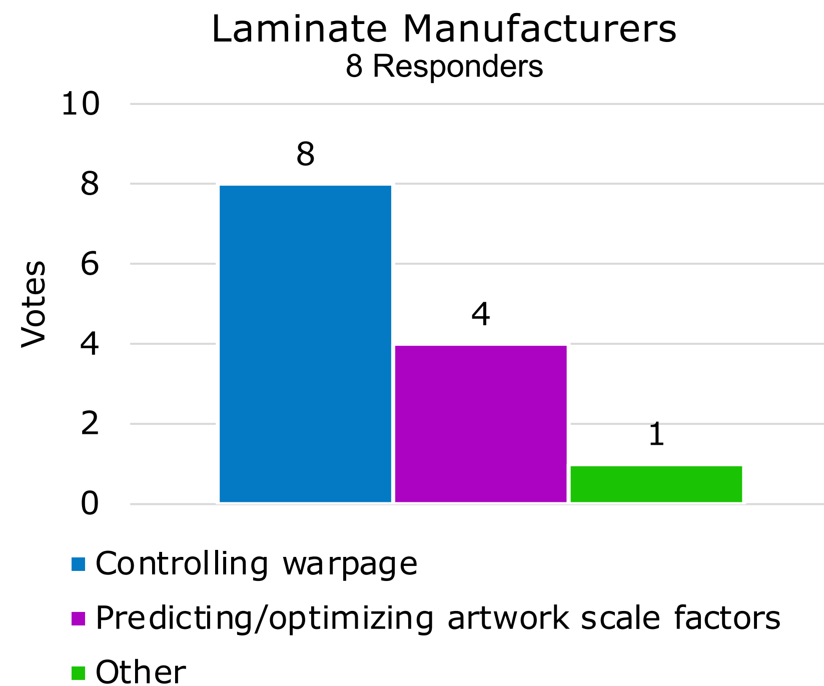


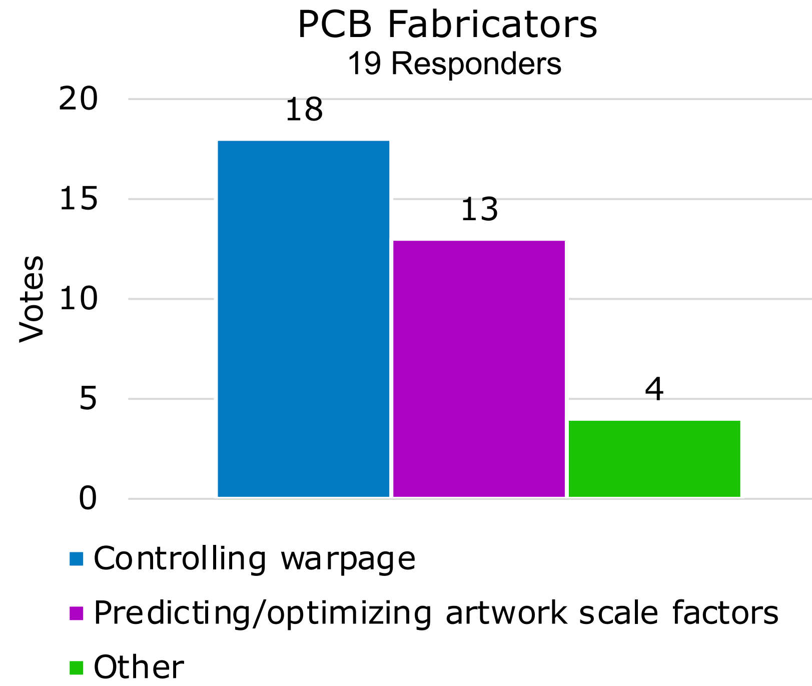


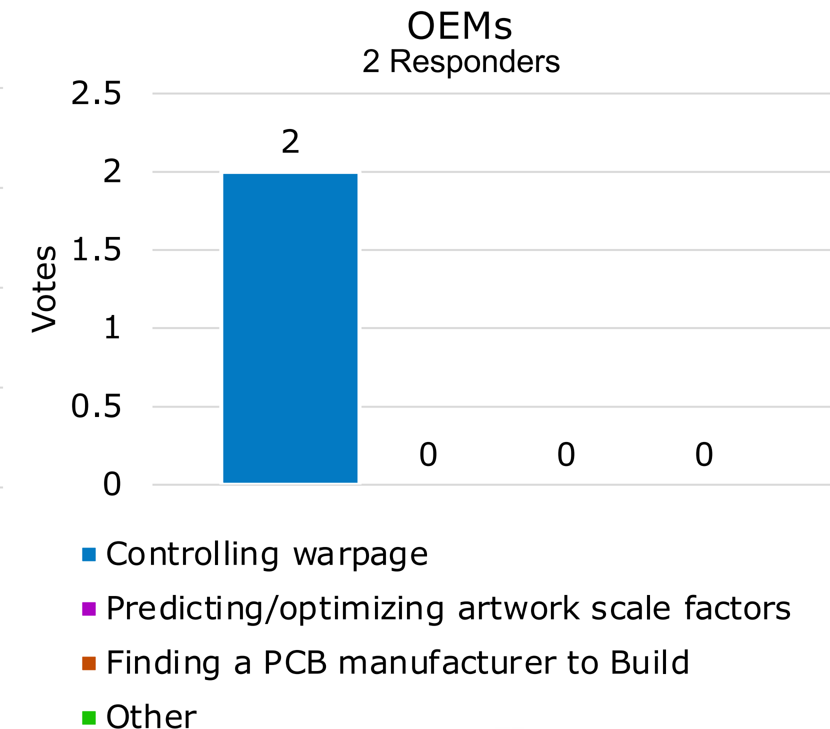


Challenges in Manufacturing Asymmetrical Hybrid PCBs

- Nearly all responders indicated that controlling warpage is a challenge.
- Most PCB fabricators also indicated that optimizing scaling factors is challenge while not all laminate manufacturers and OEMs were aware of the extent of this concern.
- Other challenges cited include: PTH reliability, preventing delamination, educating customers, optimizing the lamination cycle, and selecting dielectric thickness to offset warpage caused by asymmetry







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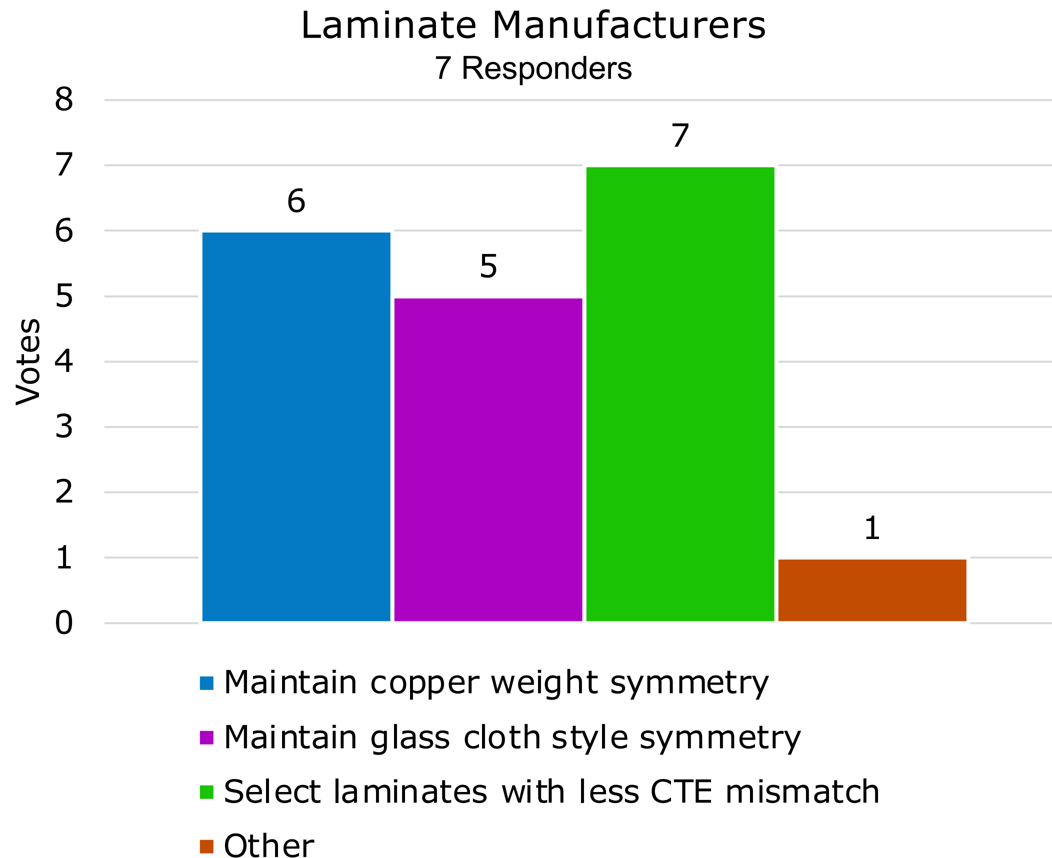
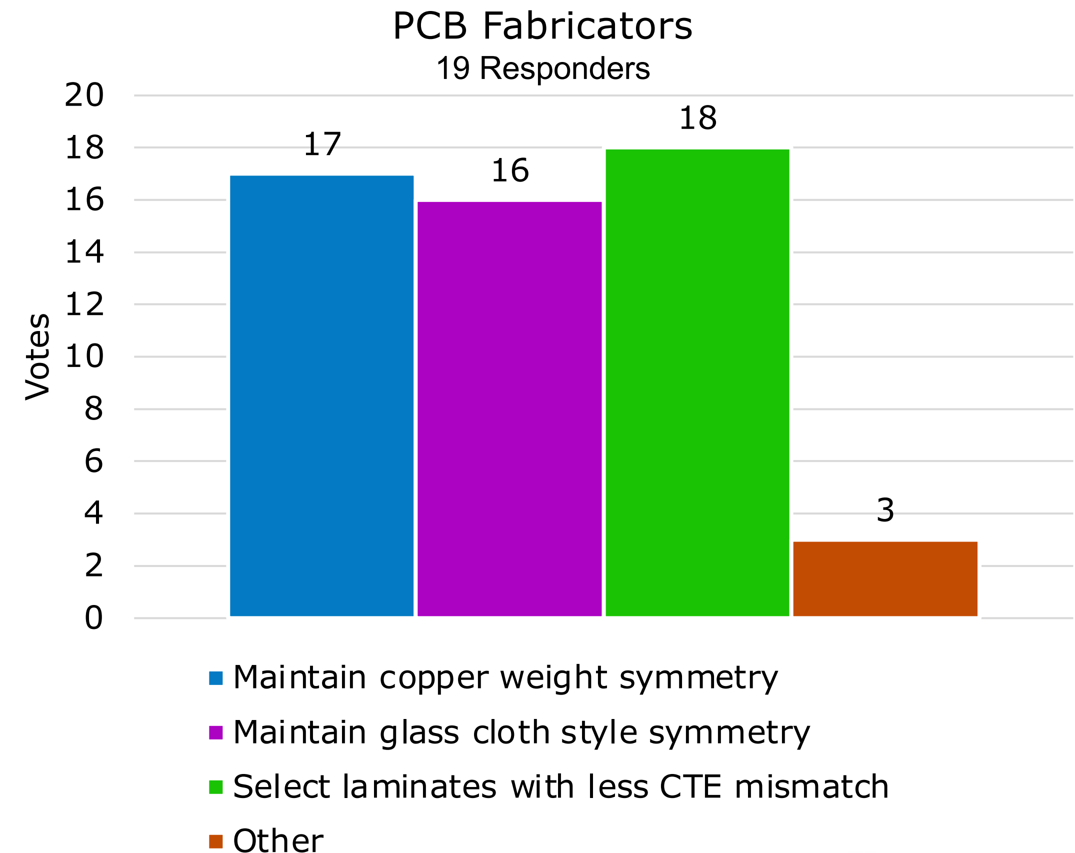
Recommendations When Using Asymmetric Hybrid PCBs

- Responders indicated that it is helpful to 1) select materials with less CTE mismatch, 2) maintain copper weight symmetry 3) maintain glass style symmetry when designing or manufacturing asymmetrical hybrid PCBs.
- Other recommendations included: counterbalancing dielectric thickness and copper weight to compensate for warpage, maintaining prepreg resin content symmetry, and avoiding asymmetry when possible.





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Laminate Materials from Different Manufacturers in the Same Stack-up

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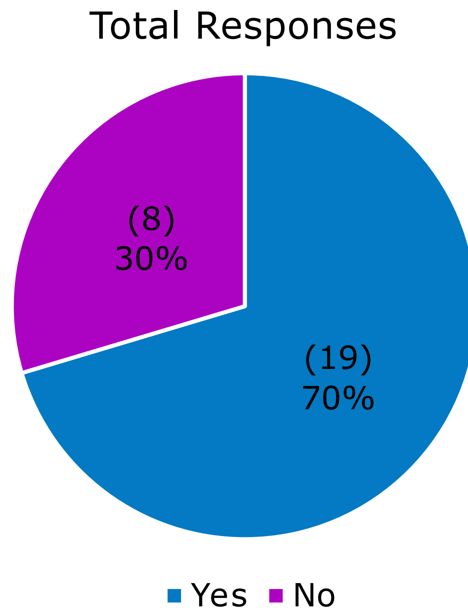
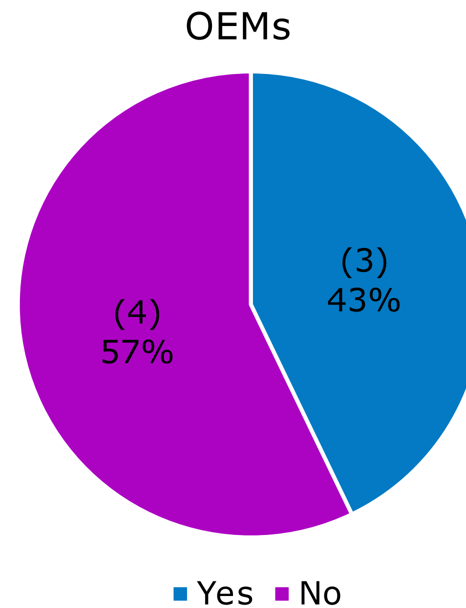
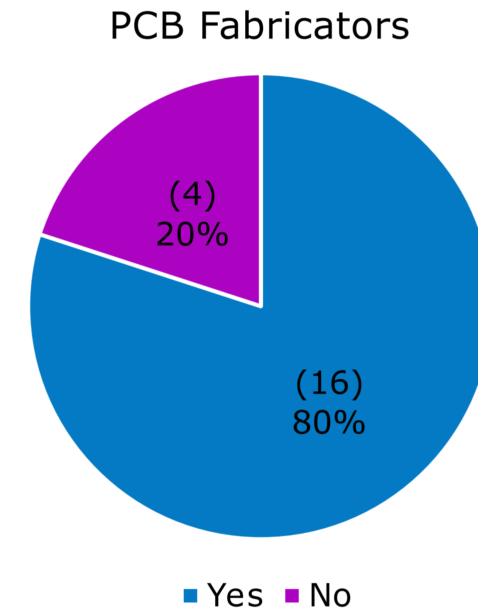
Use Materials from Different Manufacturers in a Stack-up

- Use materials from different manufacturers is not uncommon among PCB fabricators.
- OEMs were split on whether they allowed use of materials from different manufacturers.
- OEMs that use materials from different manufacturers in a stack-up cited the following reasons:
  1. Cost (all 3 responders)
  2. Electrical performance requirements (2 of the 3 responders)
  3. Reliability concerns (1 of the 3 responders)







Impact of Using Materials from Different Manufacturers on PCB Manufacturing

- There are not new manufacturing challenges as compared to hybrids with materials from the same laminate manufacturer, but more work will be required to determine if the materials are compatible and to optimize processes.
  - DOEs, trial runs, scout lots are required to determine parameters for lamination, drilling, and desmear
  - More internal qualification and reliability testing is typically required
- If properties are not compatible, manufacturing may need to be done in subassemblies as much as is possible, increasing lead time and cost.
- Obtaining troubleshooting support from laminate manufacturers becomes more difficult.
- UL certification testing may not already be conducted.
- Several fabricators stated that using different laminate manufactures is supported but is not recommended.

Microvias & Hybrid PCBs

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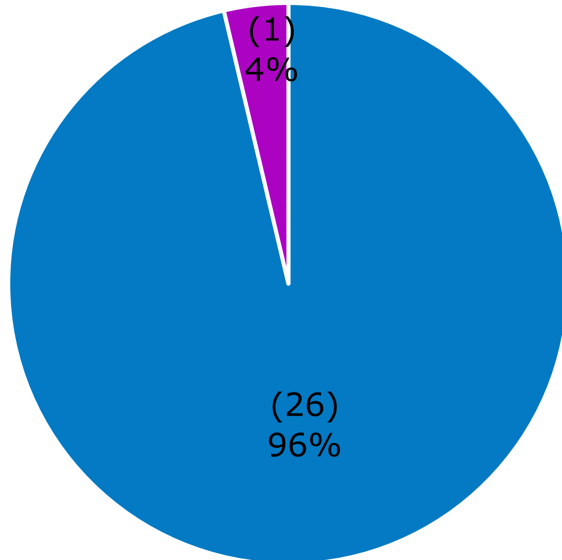
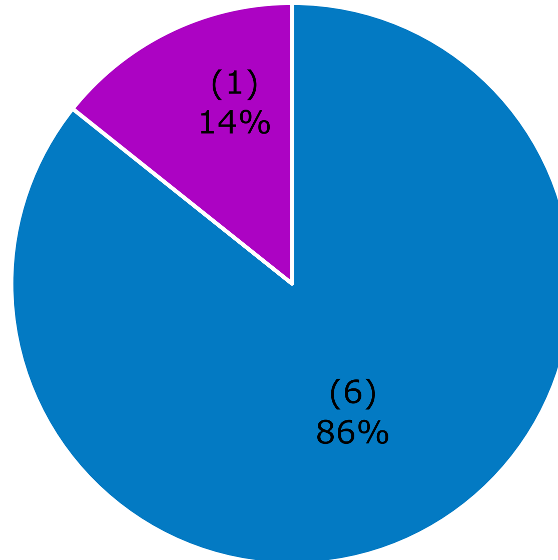
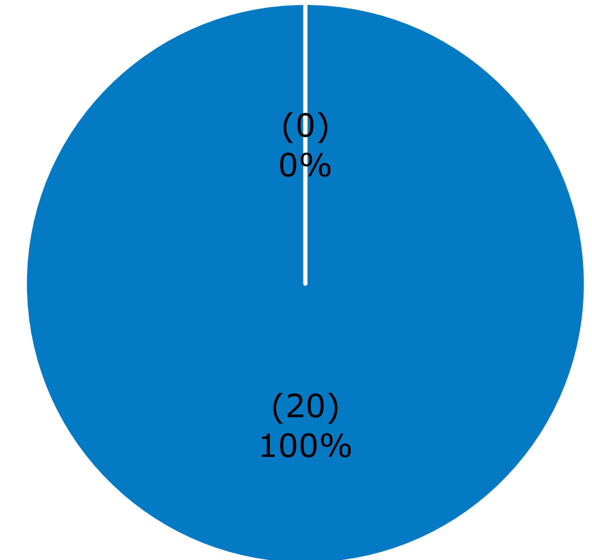
Use of Microvias in Hybrid PCBs

- Microvias are widely used in hybrid stack-ups







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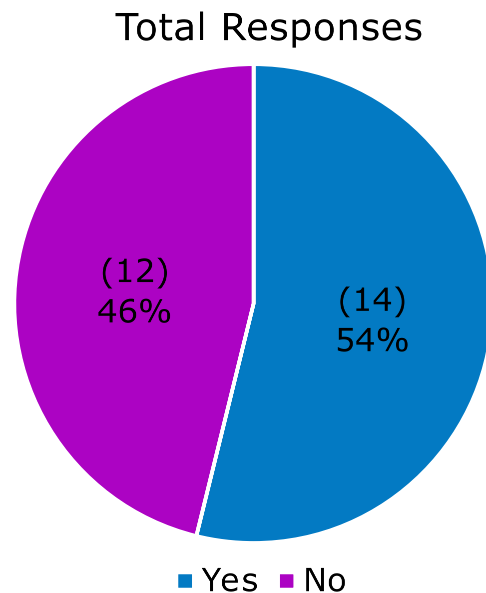
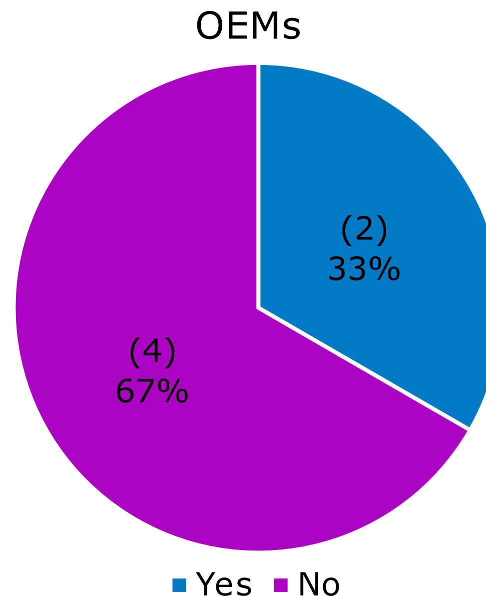
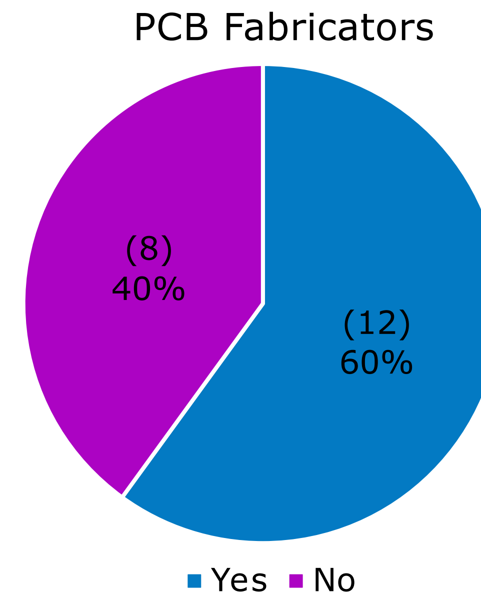
Impact of Hybrid on Microvia Design, Manufacturing, and Reliability

- The industry is split on whether having a hybrid stack-up influences microvia design, manufacturability, and reliability. PCB Fabricators more so than OEMs indicated an impact.

- Highlights of comments from responders:
  - CTE mismatch can cause microvia reliability concerns
  - Some materials, particularly high-speed materials, may not have the thermal mechanical robustness to survive multiple lamination cycles
  - Hybrid stack-ups make optimization of the scaling factor more challenging and may cause misregistration issues for stacked microvias
  - Laser parameters and desmear need to be optimized for each material to ensure microvia reliability







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Open Comments

(Results of final question asking if there was anything else the respondent wanted to share)

Summary of Open Comments

Laminate Manufacturer Highlights

- Cooperation between designers from all OEMs to minimize the possible material combinations would be useful.
- Factors that could cause stack-up imbalance (symmetry and CTE mismatch) and lead to warpage need to be considered early in design development.
- Hybrid constructions using the same resin system with different glass cloth types (E-glass and low Dk glass) can reduce some concerns with using hybrids while offering some cost savings.
- Delamination in standard loss prepregs can be a concern because the lamination process window is narrowed by using a hybrid stack-up materials. Longer curing time can address this but reduces productivity, increasing manufacturing cost.

PCB Fabricator Highlights

- It is challenging to determine if materials will be compatible based on reported properties. It is unclear how similar the materials need to be for manufacturability.
- A material selection and design guideline to help select materials that reduce risk of warpage and provide the best reliability would be helpful.
- Bond strength at the interface of different resins can be a concern. Compounds given off by some laminates will impact the curing of other laminates and can result in under-curing and delamination.
- Bow and twist requirements need to be relaxed if an asymmetrical stack-up is used. More positional tolerance is needed for non-reinforced laminates. Designers should follow IPC-2221 and IPC-2222 guidelines to minimize risk of manufacturing issues and field failures.
- The lead time, sheet size, and grain direction of different laminate materials may be different which can cause manufacturing challenges.

OEM Highlights

- Use of hybrid constructions is common.
- Each combination of materials requires UL certification which is time consuming to obtain. This process needs to be accelerated.
- It is unknown if newer ultra-low loss laminates pose a greater risk in hybrid constructions.

Conclusions & Potential Projects

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Key Takeaways

- Use of hybrid PCBs is common and increasing to achieve better electrical performance while limiting cost.
- Use of a hybrid stack-up requires process optimization especially for lamination, drill, and desmear processes. DOEs, trial runs, and scout lots are required to dial-in parameters and ensure reliability.
- Determining whether materials will be compatible and managing warpage are the biggest challenges in manufacturing hybrid PCBs.
- Material CTE, rheological properties, desmear rate, and chemical compatibility are the most critical material parameters to consider when determining if materials are compatible for use in a hybrid stack-up.
- Supply chain collaboration is critical to successfully produce reliable hybrid PCBs.
  - Designers, PCB fabricators, and laminate manufactures need to collaborate on material selection and compatibility recommendations.
  - Designers need to work with PCB fabricators to adjust cross-section and layout to minimize risk of warpage.
  - PCB and laminate manufacturers need to communicate on best balance of process parameters to accommodate all materials used in the stack-up.
  - Assembly suppliers need to be consulted about allowable warpage.
- Designers need to consider not only raw material cost but also manufacturing cost. For example, an asymmetrical cross-section may appear to save cost on paper but struggles in manufacturing may drive up PCB cost and engineering investment.

List of Potential Project Topics

1. **Creation of a guideline for assessing material compatibility, optimizing manufacturing processes, and summarizing design considerations.**
   - Provide guidance and education for designers and PCB fabricators
   - Include information about determining material compatibility from data (i.e., CTE, rheology, and desmear rate) provided by laminate suppliers
   - Include information for how to select and optimize lamination, drill, and desmear parameters
   - Include recommendations for design of cross-sections and layouts to minimize warpage
   - Include details about potential failure mechanisms

2. **Study on how placement of materials with dissimilar properties within the stack-up impacts warpage and reliability using simulations.**
   - Lower loss on outside layers vs. inside layers
   - Ratio of lower loss layers to higher loss layers
   - Symmetrical vs. asymmetrical
   - Placement of thermoplastic vs. thermoset materials
   - Impact of degree of CTE mismatch

3. **Study of the key drivers causing warpage in asymmetrical hybrid PCBs**
   - Identify the key factors cause warpage (design, material properties, and processing parameters)
   - Determine which factors have the biggest influence
   - Assess if processing parameters can overcome some amount of warpage

List of Potential Project Topics

4. **Evaluation of the effect of CTE mismatch on reliability**
    - Build PCBs with stack-ups composed of materials with similar and dissimilar CTEs
    - Assess warpage, registration, and PTH reliability with degrees of CTE mismatch

5. **Development of a standardized method for assessing desmear rates**
    - Understand what is lacking or challenging about current methods
    - Conduct DOE with different materials to assess desmear rates
    - Generate standardized test procedure

6. **Evaluation of the effect of desmear rate mismatch on reliability**
    - Build PCBs with stack-ups composed of materials with similar and dissimilar desmear rates
    - Assess PTH reliability and CAF risk with different degrees of desmear rate mismatch

7. **Study on the impact of hybrid stack-up on microvia reliability**
    - Evaluate hybrid stack-ups with different CTE mismatch
    - Evaluate reliability of microvias in lower loss laminate layers and higher loss laminate layers
    - Assess registration of stacked microvias

Poll

Which, if any, of these potential projects would be valuable and of interest to you and your company?

1. Creation of a guideline for assessing material compatibility, optimizing manufacturing processes, and summarizing design considerations.

2. Study on how placement of materials with dissimilar properties within the stack-up impacts warpage and reliability using simulations.

3. Study of the key drivers causing warpage in asymmetrical hybrid PCBs

4. Evaluation of the effect of CTE mismatch on reliability

5. Development of a standard method for assessing desmear rates

6. Evaluation of the effect of desmear rate mismatch on reliability

7. Study on the impact of hybrid stack-up on microvia reliability

8. None of the above

Project Team

Below is a list of the project participants that contributed to creation of the survey and analysis of results

- Sarah Czaplewski – IBM
- John Andresakis – Dupont
- Ed Kelley – Isola
- Chudy Nwachukwu – ITEQ
- Steve Ethridge – Dell
- Suixin Zhang – Isola
- Suriyankan Vongtragool – Schlumberger
- Juan Landros – Intel
- Peter Cheng – Unimicron
- Leon Lin – Unimicron
- Samgo Cai – Sytech
- Margee Shah – Ibiden
- Steve Payne – iNEMI
- Cynthia Williams – iNEMI

Thank you for listening!

Please contact Steve Payne (steve.payne@inemi.org) with any comments, suggestions, or questions, and if you are interested in participating in future iNEMI projects

Back-Up

Hybrid PCB Qualification Test Methods and Test Vehicles

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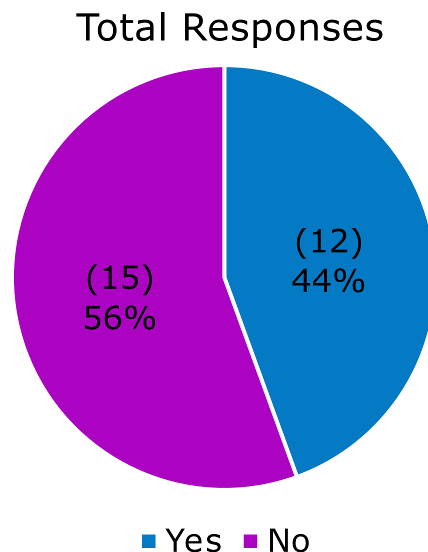
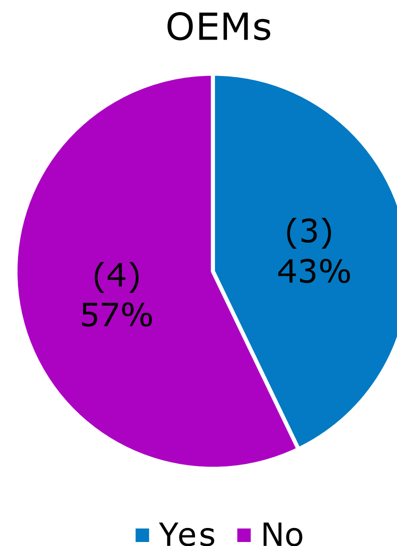
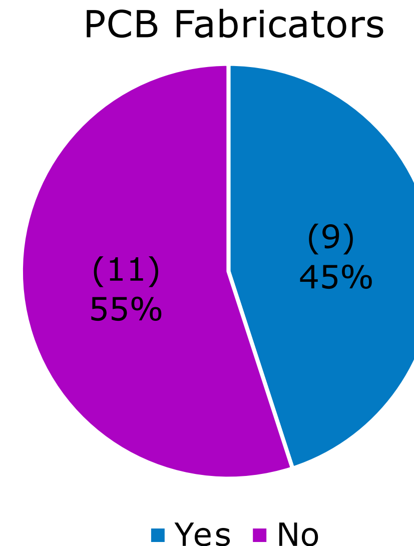
Are Different Qualification Test Methods Used for Hybrid PCBs?

- The industry is split on whether different qualification tests and test vehicles are used for hybrid PCBs. Although, slightly more responded “no”.
- OEMs generally use the same test methods and vehicles as for pure stack-ups. A few OEMs highlighted differences in PCB qualification approach for hybrid PCBs:
  - Include real boards rather than only TVs
  - Include SMT yield test vehicle to assess warpage through reflow and temperature cycling
- PCB fabricators need to conduct a more thorough internal qualification to optimize manufacturing parameters.
  - Includes reliability testing
  - Evaluation of different combinations of material placement within stack-up







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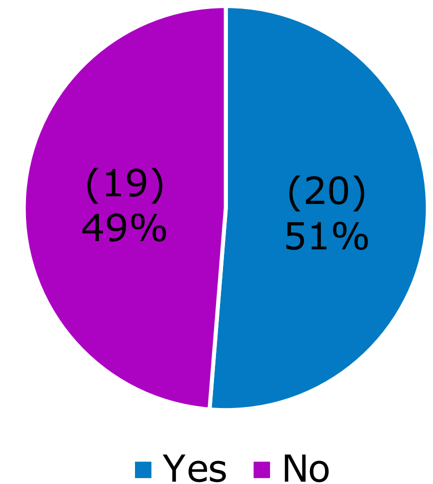
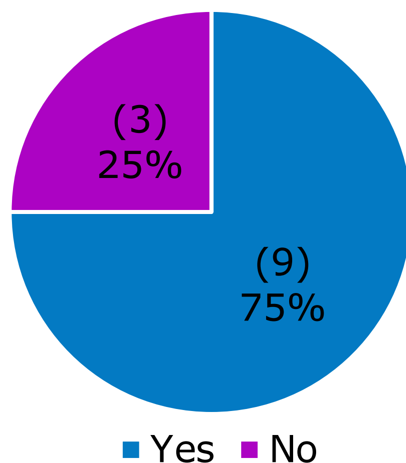
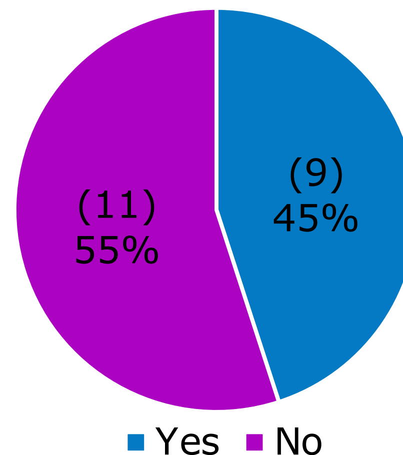
Thermoplastic & Thermoset Hybrids for Non-RF Applications

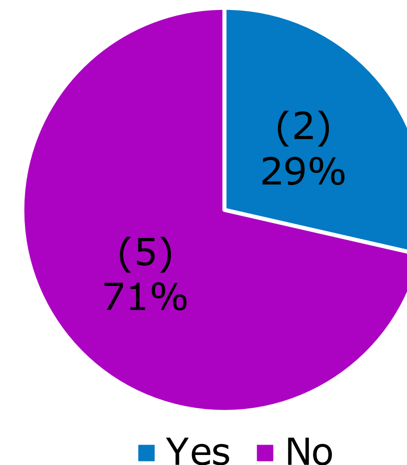
Need to hybrid thermoplastic materials with thermoset materials for non-RF applications?

- The industry is split on whether there is a need to hybrid thermoplastic and thermoset materials for non-RF applications.
- Majority of OEMs said "no" while majority of laminate manufacturers said "yes".
- For those that indicated a need, the main driver was electrical performance to support future 5G and 112+ GB/s applications.
- Thermoplastic resins have lower loss, but worse filling capability so thermoset materials are used on layers that are not critical for high speeds.









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