

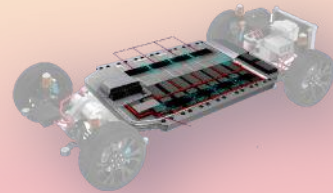
***Overconstrains? Underconstrains?
Selecting Materials for***

Automotive Designs

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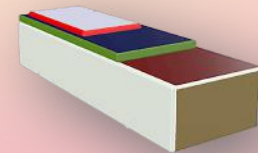
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Where High-Speed Automotive Designs Heading Today?



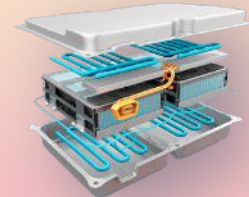
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Why Material matters in PCB Design?



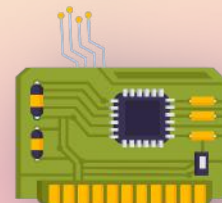
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Summary



Foreword

In automotive design, choosing the right materials is crucial.

Go too far one way, and you overcomplicate things—
to far the other, and you risk performance and safety.

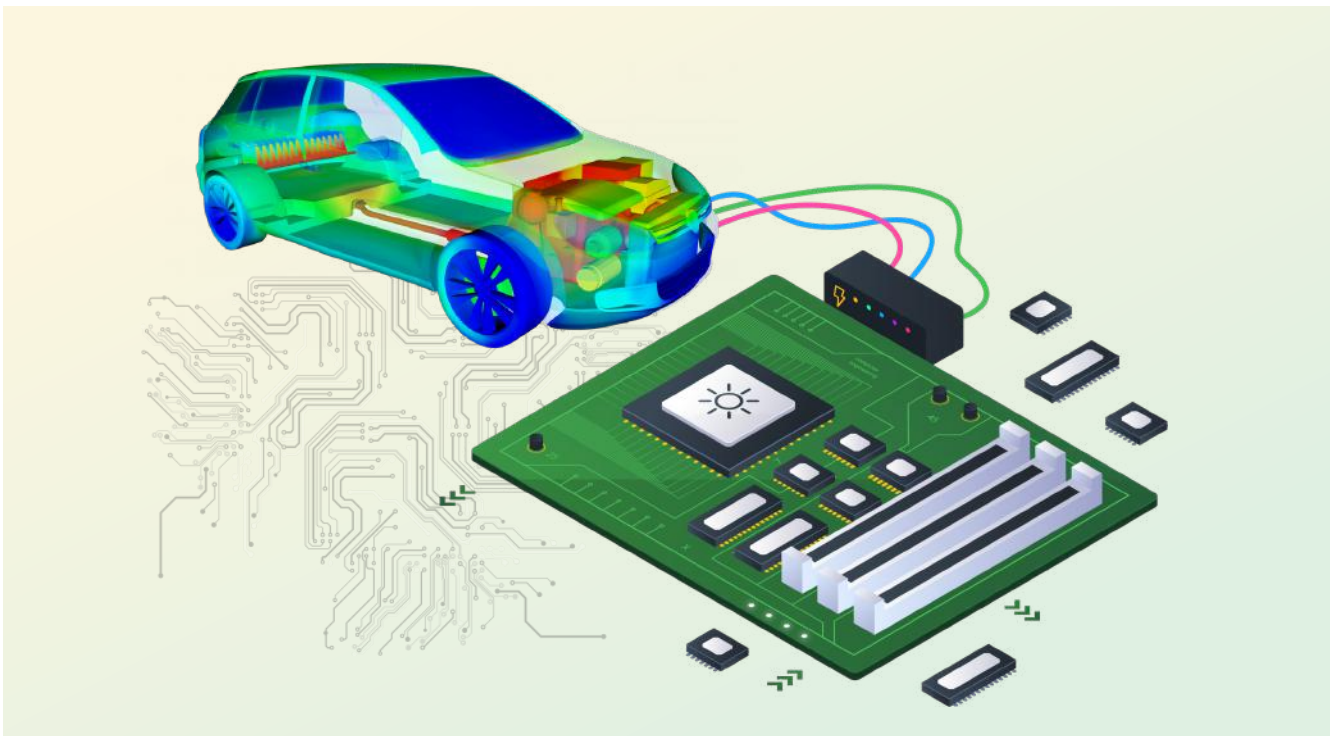
It's a fine line between over constraining your project with overly complex materials and under constraining it by compromising on quality and safety.

This eBook is your guide to navigating these decisions, helping you find materials that strike the perfect balance.

With practical insights and expert advice, you'll be equipped to make choices that enhance your designs without adding unnecessary complexity.

As you explore these pages, remember that this is just the beginning.

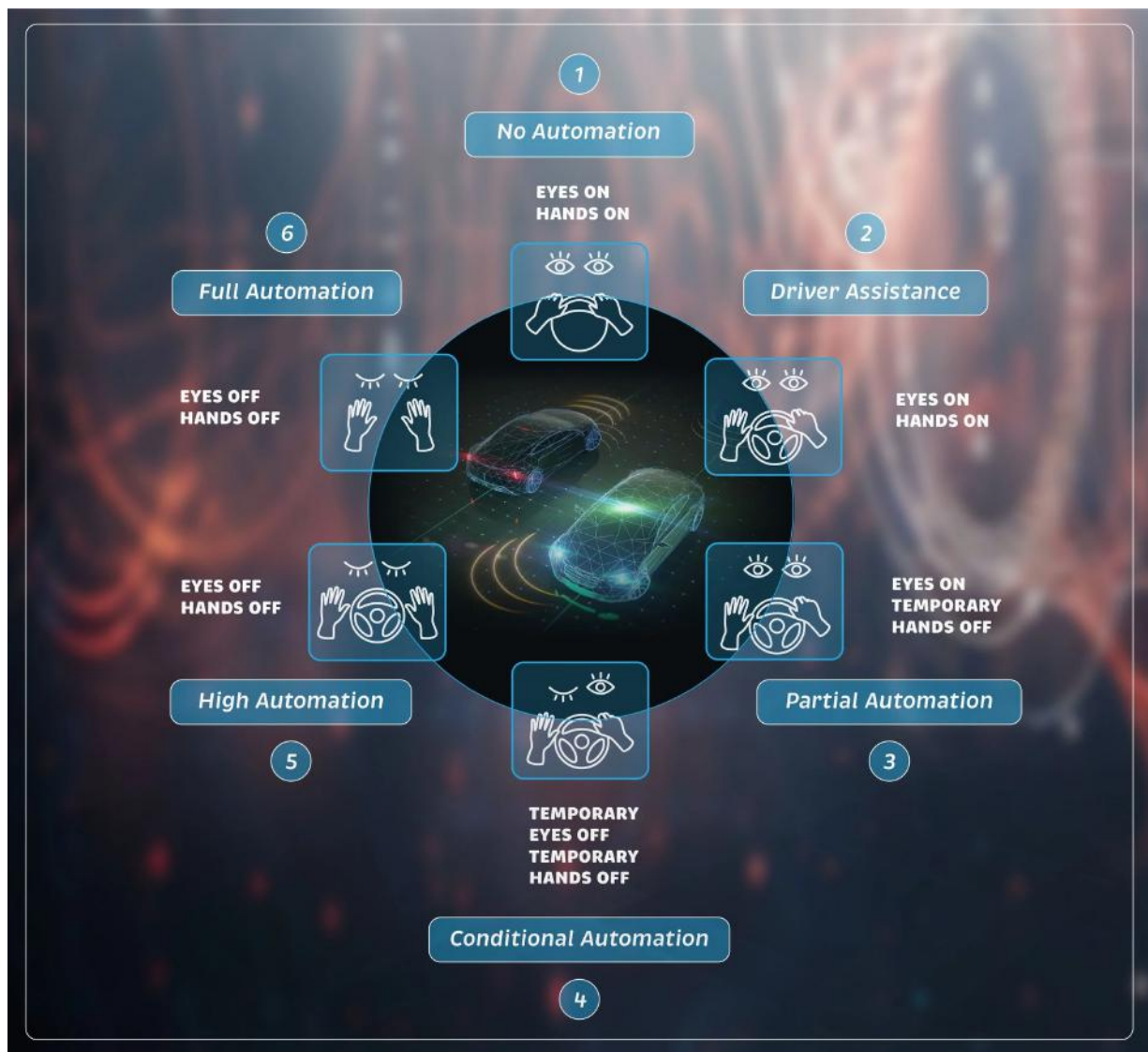
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1. Where High-Speed Automotive Designs Heading Today?

High-speed automotive electronics integration has progressed from basic engine management systems in the **1960s** to complex networks and communication technologies supporting **Autonomous driving today**.

The evolution reflects a continuous push towards higher data transfer rates, increased functionality, and enhanced vehicle safety and performance.



2. Why Material matters in PCB Design?

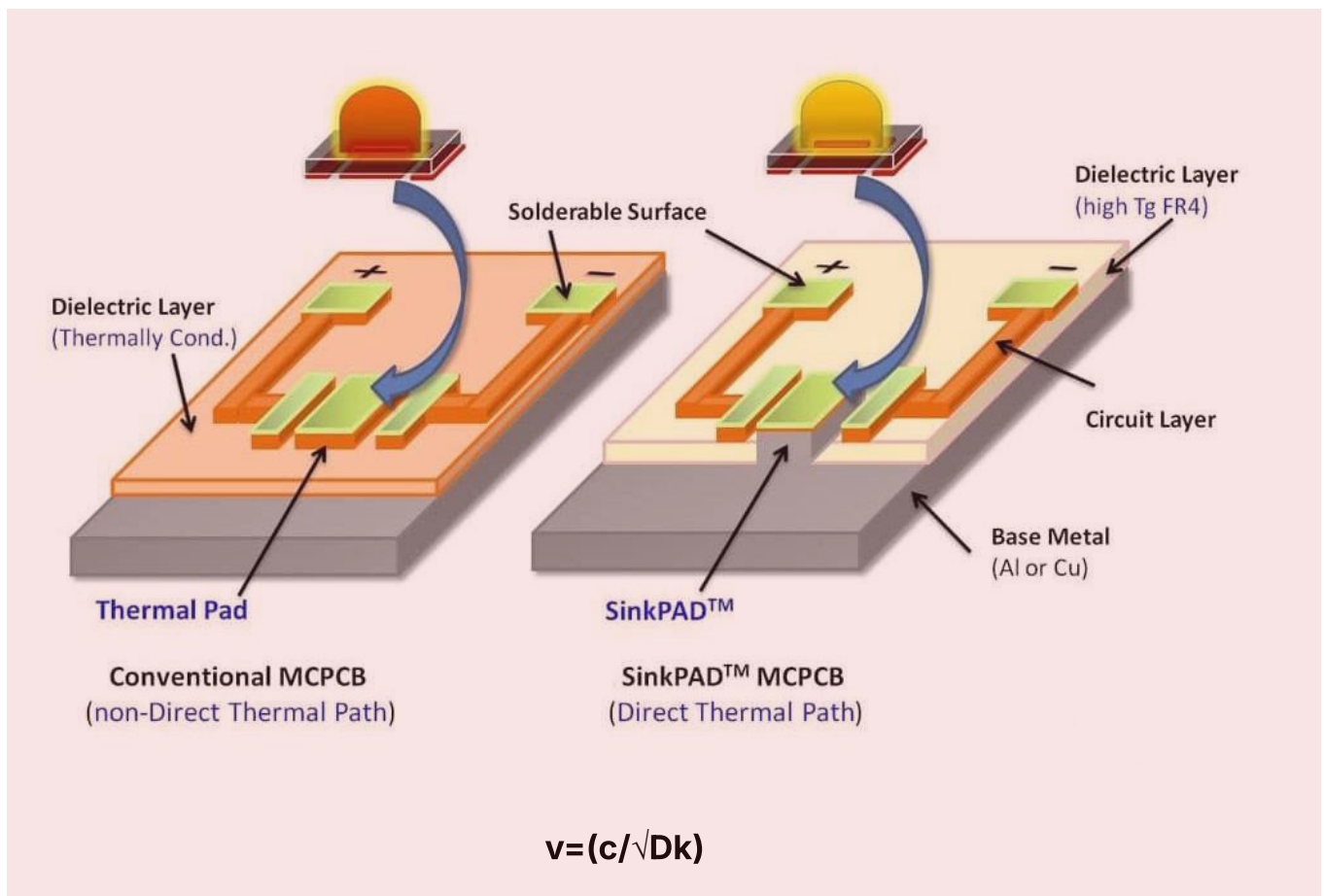
In PCB (Printed Circuit Board) design, material selection is crucial as it **directly impacts electrical performance, thermal management, and mechanical reliability.**

The choice of materials affects various performance characteristics, including signal integrity, heat dissipation, and structural durability.

Understanding these effects through specific formulas and values helps in optimizing PCB designs for demanding applications.

1. Impact on Signal Integrity

Dielectric Properties:

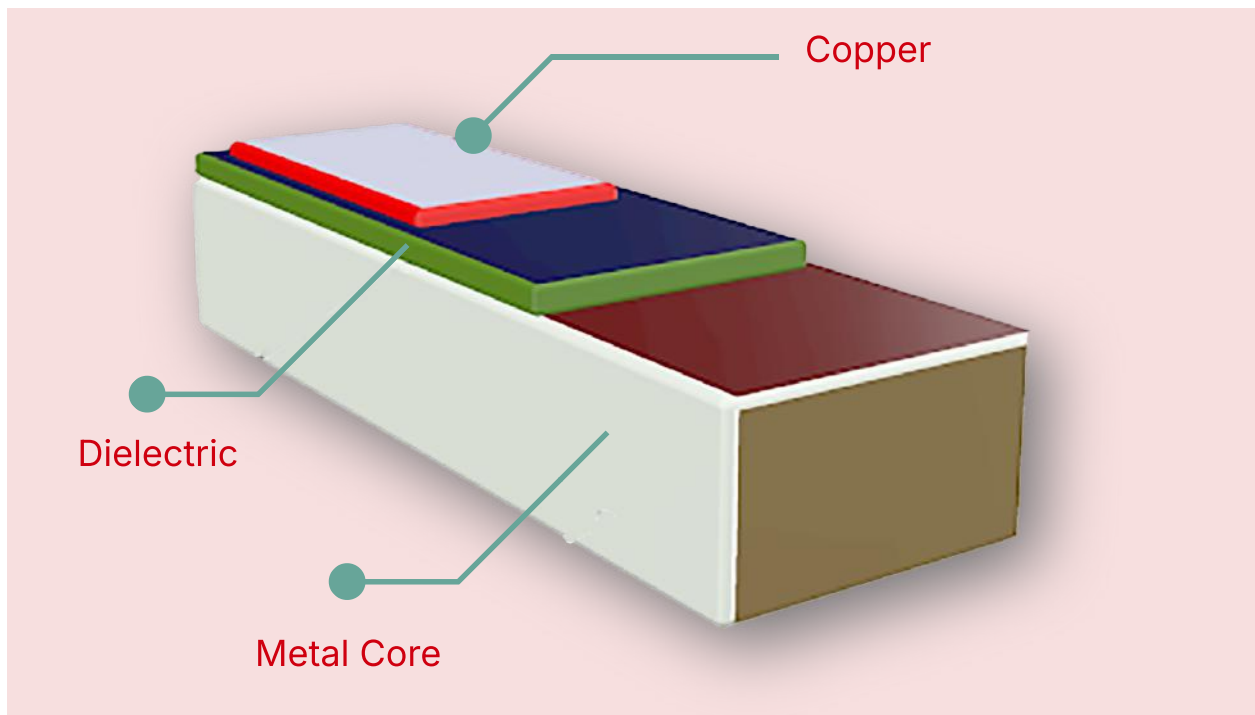


Dielectric Constant (Dk):

The dielectric constant Dk of a PCB material affects signal propagation speed.

Lower Dk values reduce signal delay and dispersion.

For high-speed designs, materials with Dk values ranging from 2.2 to 3.5 are often used.



For example, FR-4 typically has a Dk around 4.5, whereas advanced materials like Rogers 4350B have a Dk of about 3.66.

Signal Propagation Speed (v): The speed of signal propagation in a material is given by:

Where,

C - speed of light in a vacuum (approximately 3×10^8)

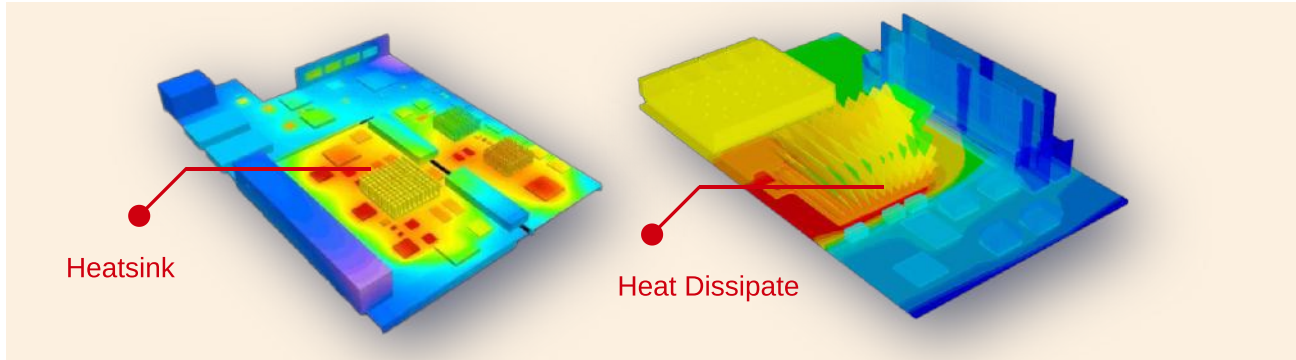
Lower Dk results in faster signal propagation

Loss Tangent (Df): The loss tangent Df quantifies dielectric losses. For high-frequency applications, materials with Df values less than 0.01 are preferred to minimize attenuation.

For instance, FR-4 has a Df of about 0.02, whereas materials like Rogers RO4000 series have Df values around 0.0035.

2. Thermal Management

Thermal Conductivity:



Heat Dissipation:

The thermal conductivity 'k' of PCB materials affects heat transfer efficiency. Materials with high thermal conductivity, such as those with metal cores, are preferred.

Typical values are:

FR-4: $k \approx 0.3 \text{ W/m} \cdot \text{K}$
Aluminum Core PCB: $k \approx 200 \text{ W/m} \cdot \text{K}$

Heat Transfer Rate (Q): The heat transfer rate through a material is given by:

where

$$Q = \frac{k \cdot A \cdot \Delta T}{d}$$

A is the Area,

ΔT is the temperature difference, and

d is the material thickness.

Thermal Expansion:

The Coefficient of Thermal Expansion (CTE) affects how the PCB expands with temperature changes. Lower CTE values, such as around 5 ppm/°C, reduce the risk of mechanical stress and failure.

3. Mechanical Strength and Reliability

Mechanical Properties:

Tensile Strength:

The tensile strength σ_t indicates the maximum stress a material can withstand before failure.

High-strength materials typically have tensile strengths of,

FR-4: $\sigma_t \approx 100\text{--}150$ MPa

Ceramic-Filled Epoxies: $\sigma_t \approx 250$ MPa

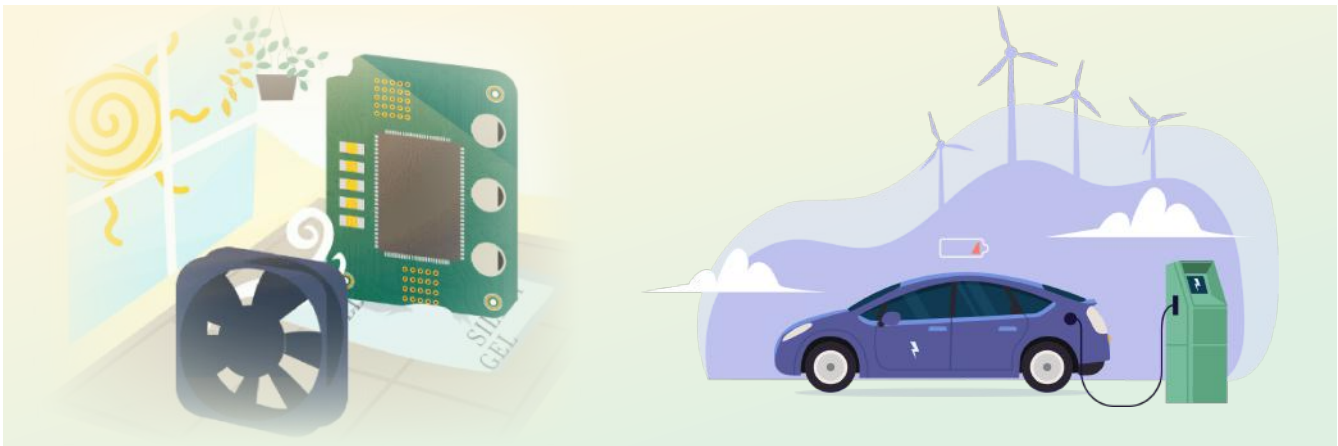
Flexural Modulus:

The flexural modulus E_f measures a material thickness,

FR-4: $E_f \approx 20\text{--}25$ GPa

Polyimide: $E_f \approx 50$ GPa

Environmental Resistance:



Moisture Absorption: The moisture absorption rate affects dielectric properties.

For instance, FR-4 may absorb up to 0.1% moisture, which can impact performance.

Low moisture absorption materials like high-grade ceramics are preferred for critical applications.

4. Cost and Manufacturing Considerations

Material Costs: High-performance materials such as those with advanced dielectric properties or metal cores can be more expensive.

Cost considerations often balance with the need for performance and reliability.

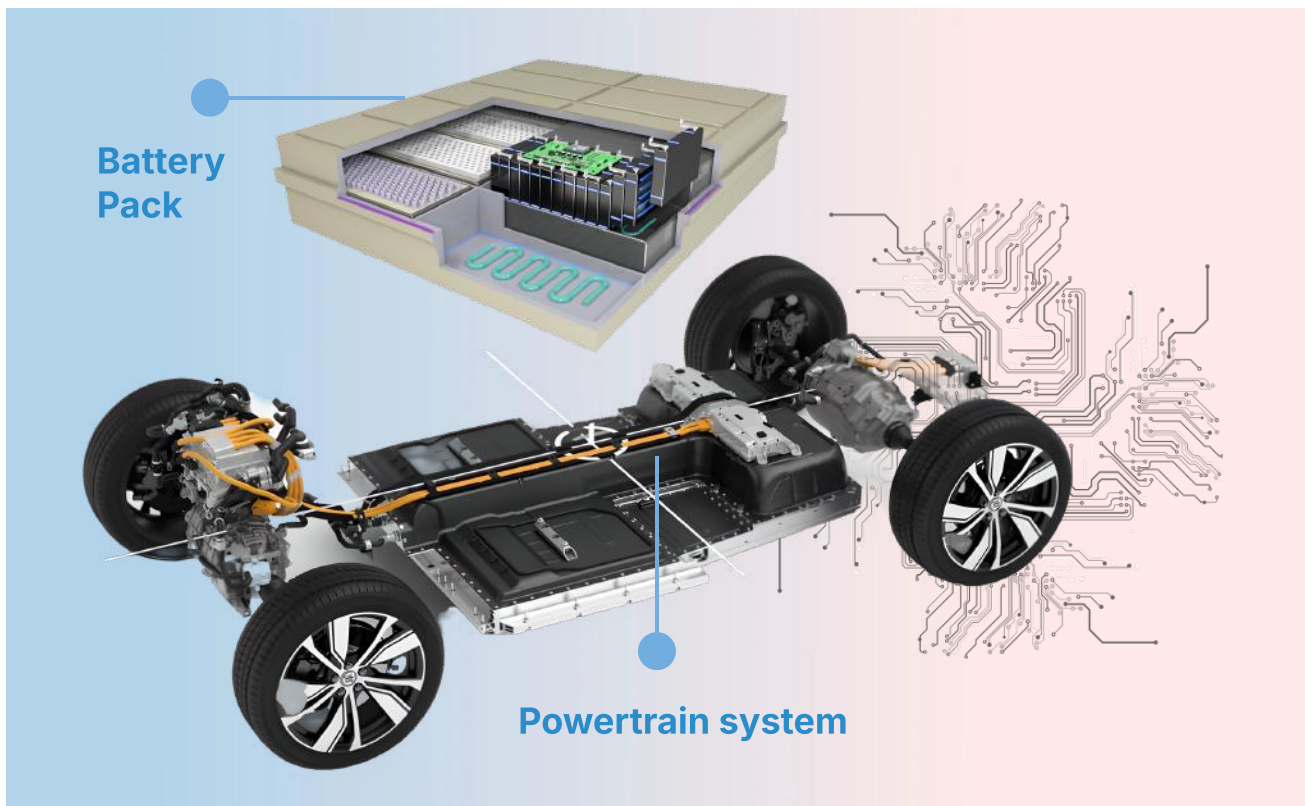
Manufacturability:

Processing Compatibility: Materials like FR-4 are easy to process and handle, while high-frequency materials might require specialized handling. For example, PTFE-based materials often need more careful handling due to their sensitivity to processing conditions.

5. Compliance and Standards

Regulatory Compliance: Compliance with industry standards ensures that materials meet safety, performance, and environmental requirements. For automotive or aerospace applications, materials must adhere to standards such as IPC-6012 for PCB fabrication.

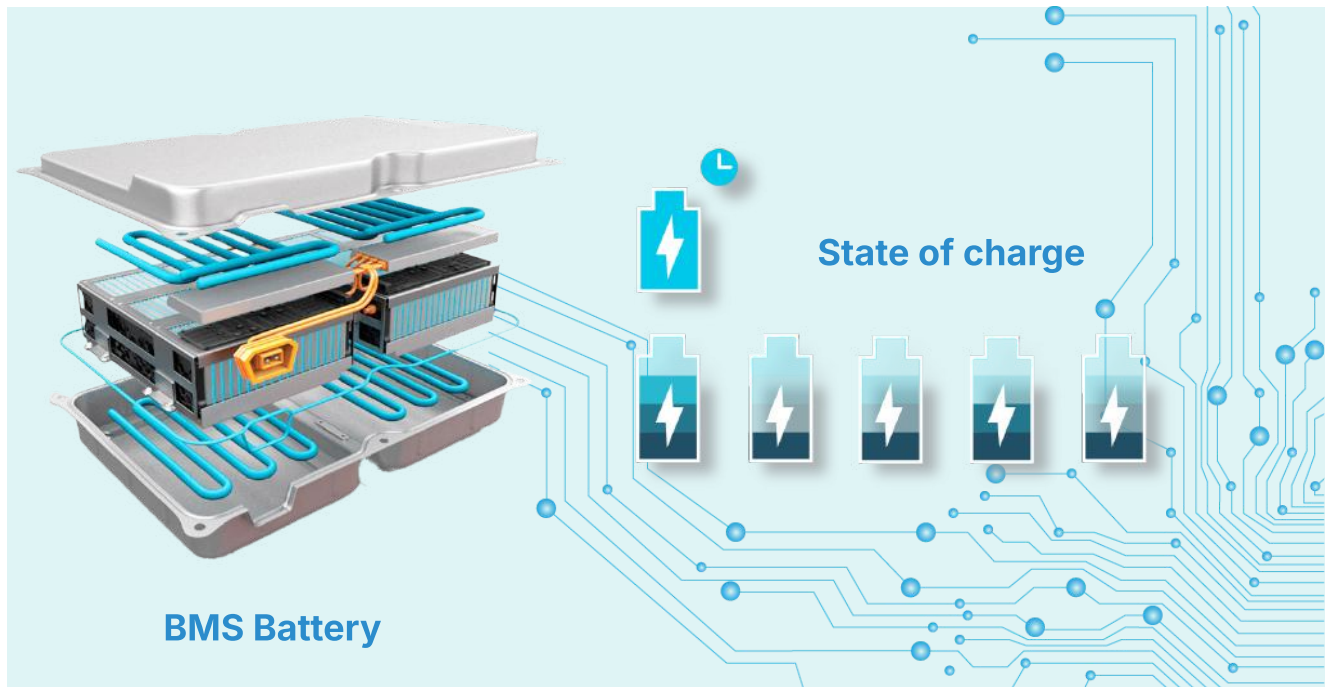
3. Material Selection for Electric Vehicle- Battery Management System(BMS)



A **Battery Management System (BMS)** is an integral part of modern battery-powered systems, especially in electric vehicles (EVs).

The BMS continuously monitors key parameters of each cell in the battery pack, including **voltage, current, temperature, and state of charge (SOC)**.

This data helps in understanding the health and status of the battery.



To ensure all cells in the **battery pack are at the same voltage level**, the BMS balances the charge across the cells.

This prevents overcharging or deep discharging of individual cells, which can lead to premature failure or reduced battery capacity.

The BMS estimates important battery states like **state of charge (SOC), state of health (SOH), and state of power (SOP)**.

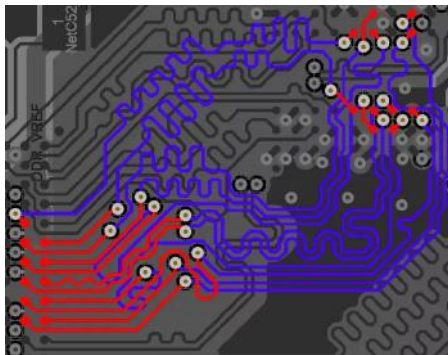
These estimates help in predicting the range of an EV, scheduling maintenance, and ensuring optimal performance.

a) Importance of Material Selection

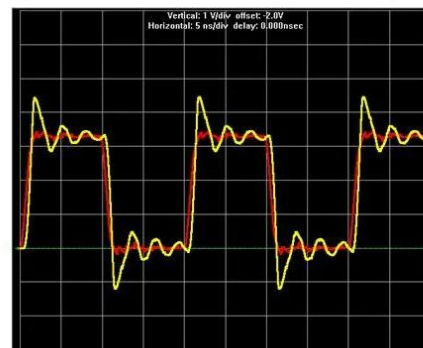
High-Speed Communication:

- The materials used in the PCB must have appropriate **electrical properties**, such as **low** dielectric constant (Dk) and low dissipation factor (Df), to ensure minimal signal loss and distortion.
- Poor material selection can lead to signal integrity issues, causing errors in communication and data processing.

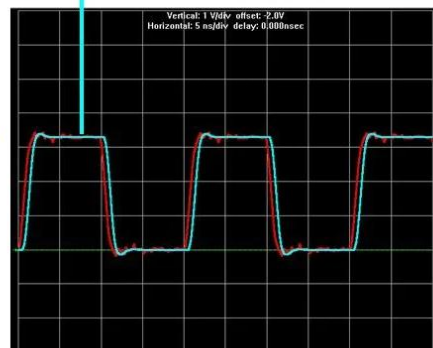
High Speed Signal



3 inch long PCB Trace

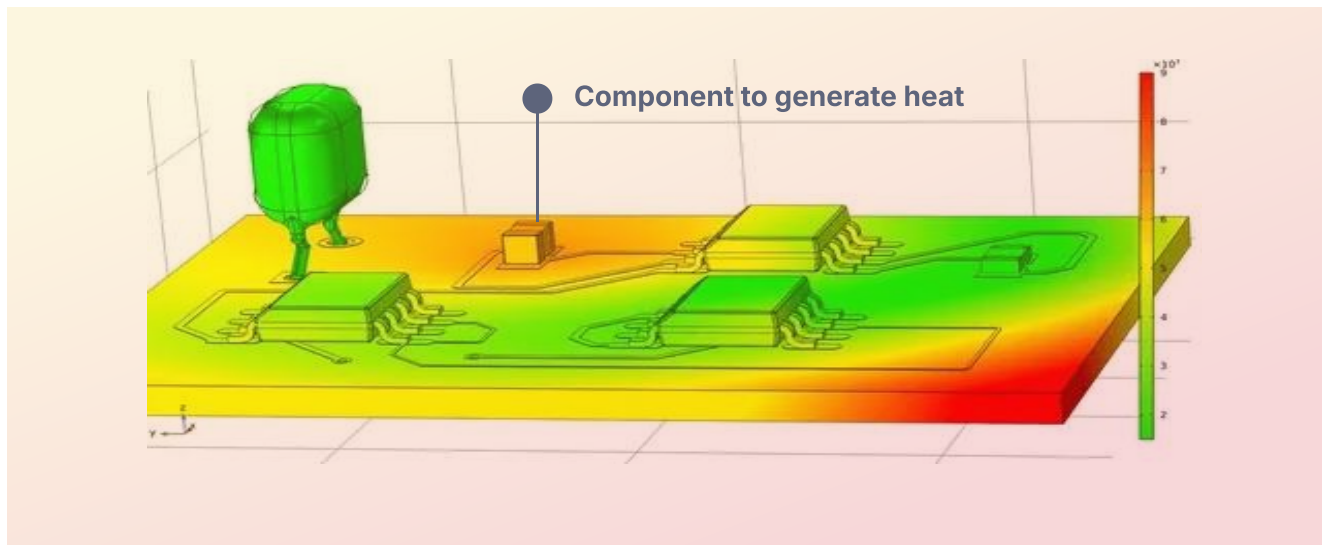


3 inch long PCB Trace
Series termination (~40 Ohms)



Heat Dissipation:

- BMS components, especially in high-power applications like electric vehicles, generate significant heat.
- The PCB material must have high thermal conductivity to dissipate this heat effectively.
- Inadequate thermal management can lead to overheating, component failure, and reduced system reliability.

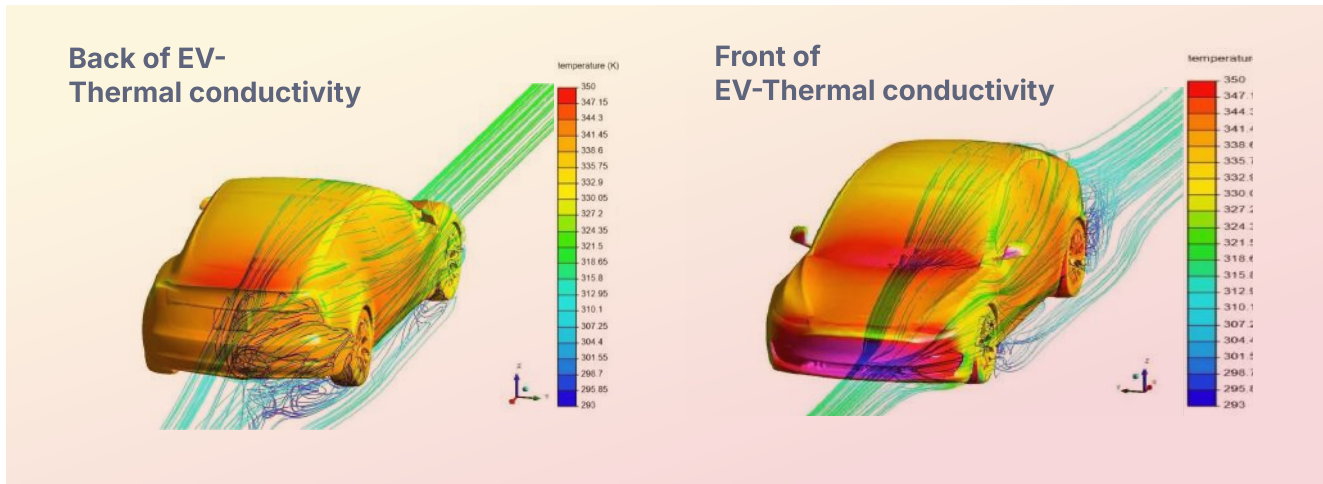


Operational Stability:

BMS units are often subjected to varying temperatures, vibrations, and mechanical stresses.

The material must be dimensionally stable and durable to maintain its integrity under these conditions.

Poor material selection can result in warping, delamination, or mechanical failure, compromising the BMS's performance.



Safety Considerations

BMS systems need to ensure proper isolation between high-voltage and low-voltage sections.

The materials used should have excellent insulating properties to prevent electrical shorts or leakage, which could lead to safety hazards.

Material Degradation:

Over time, materials can degrade due to environmental factors like moisture, temperature fluctuations, and chemical exposure.

The selected materials must be resistant to these factors to ensure long-term reliability.

Failure to choose the right materials can lead to premature aging and failure of the BMS.

Cost vs. Performance Trade-offs:

While high-performance materials may offer superior properties, they also tend to be more expensive.

Selecting the right material involves balancing performance needs with cost constraints to ensure the BMS is both effective and economically viable.

b) Laminate Material Selection for EV

Laminates are specialized materials used in PCB design to ensure reliable performance in high-frequency applications. For high-speed designs, which involve high-speed data communication and power management, choosing the right laminate is crucial for optimal performance.

PARAMETERS	PARAMETER VALUES	HIGH SPEED LAMINATES FOR BMS
Dielectric Constant	3.0 - 3.3	Low Dk reduces signal delay, essential for maintaining signal integrity.
Dissipation Factor	0.008 - 0.01	Low Df minimizes signal loss, crucial for clear data transmission.
Thermal Conductivity	0.6 - 1.0 W/m·K	High thermal conductivity prevents overheating, ensuring component reliability.
Controlled Impedance	50 - 75 Ohms (depends on specific design requirements)	Ensures consistent signal integrity by preventing reflections.
Dimensional Stability	Stable across a temperature range of -40°C to +125°C	Maintains performance by preventing warping under environmental changes.
Flexibility & Strength	High flexural strength and impact resistance	Offers durability to withstand mechanical stresses without affecting performance.
PTFE Laminates	-	Ideal for high-frequency data with minimal signal distortion.
Ceramic-Based Laminates	-	Suitable for consistent performance with minimal signal loss.
Hybrid Laminates	-	Balances thermal management, impedance control, and mechanical robustness for high-speed designs.
Overall Impact	-	Enhances signal integrity, thermal management, and mechanical durability, crucial for reliable operation.

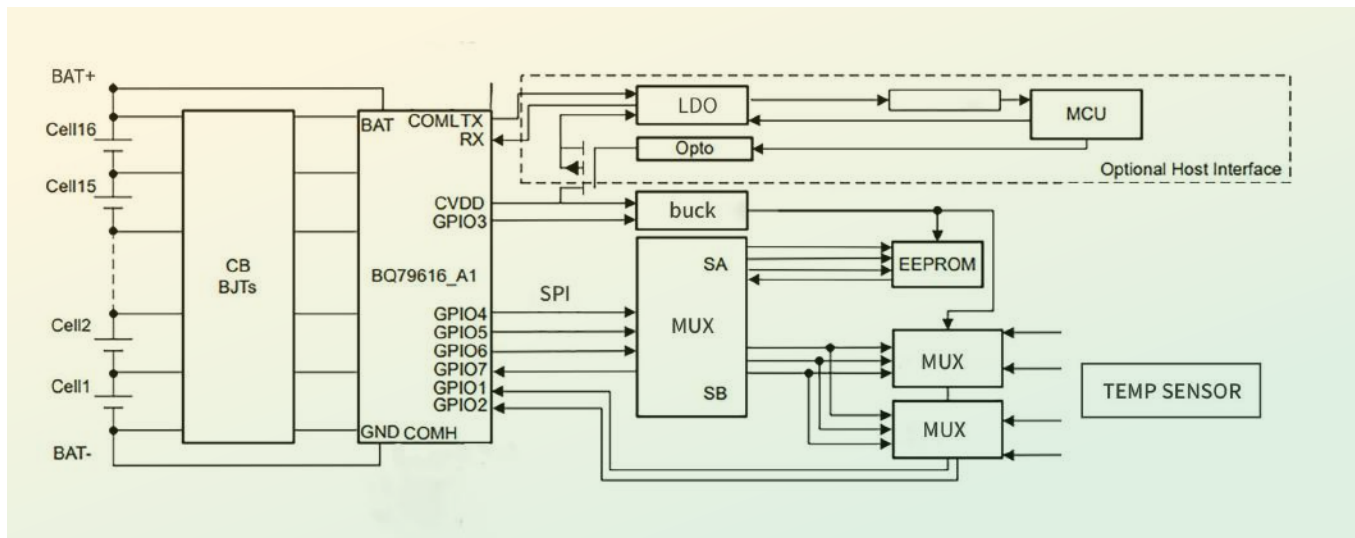
b) Methods and Testing for Material Selection

To determine that material selection is the issue or not in a high-speed section Battery Management System (BMS), several methods and tests are used.

STEPS	DESCRIPTION
1. Initial Performance Testing	
Signal Integrity Testing	Check for noise, reflections, or attenuation to detect potential material issues.
Thermal Analysis	Identify hotspots and ineffective heat dissipation using thermal imaging or simulations.
Mechanical Stress Testing	Test for warping, delamination, or mechanical failure under thermal cycling or stress.
2. Analysis of Material Properties	
Dielectric Constant (Dk)	Higher Dk can cause signal delay and timing errors.
Dissipation Factor (Df)	Higher Df leads to increased signal attenuation, affecting high-speed lines.
Thermal Conductivity	Low thermal conductivity can result in poor heat dissipation and performance degradation.
3. Comparison with Industry Standards	
Benchmarking	Compare current material with industry standards (e.g., PTFE or ceramic-based laminates) to assess performance.
4. Simulation and Modeling	
Electromagnetic Simulation	Use tools to model signal propagation and detect issues like signal delay or impedance mismatches.
Thermal Simulation	Predict heat management efficiency and identify inadequacies in thermal properties.
5. Root Cause Analysis	
Cross-Sectional Analysis	Examine PCB cross-section for delamination or physical issues linked to material properties.
Failure Mode Analysis	Perform systematic analysis (e.g., FMEA) to identify and address material-related failures.
6. Testing with Alternative Materials	
Material Substitution	Build and test with alternative materials to confirm if performance improves with better-suited properties.

c) Challenges in Material Selection for the BMS

Section Focus : Interface and Power Management Section



Material Currently Used: Standard FR-4

Challenges Identified:

- Signal integrity issues due to higher Dk and Df values.
- Inadequate thermal management.
- Mechanical stress and warping.

Issues and Analysis:

Signal Integrity:

Even at the standard **SPI speed of 60 Mbps**, the quality of signal transmission is critical. FR-4 with a high dielectric constant (Dk) can cause signal delay and timing errors, leading to communication failures.

Thermal Management:

Power management sections generate heat. With **FR-4's low thermal conductivity**, hotspots can form, affecting component reliability and overall board performance.

Mechanical Durability:

Standard FR-4 may not provide sufficient mechanical stability under thermal cycling, leading to potential board warping or delamination.

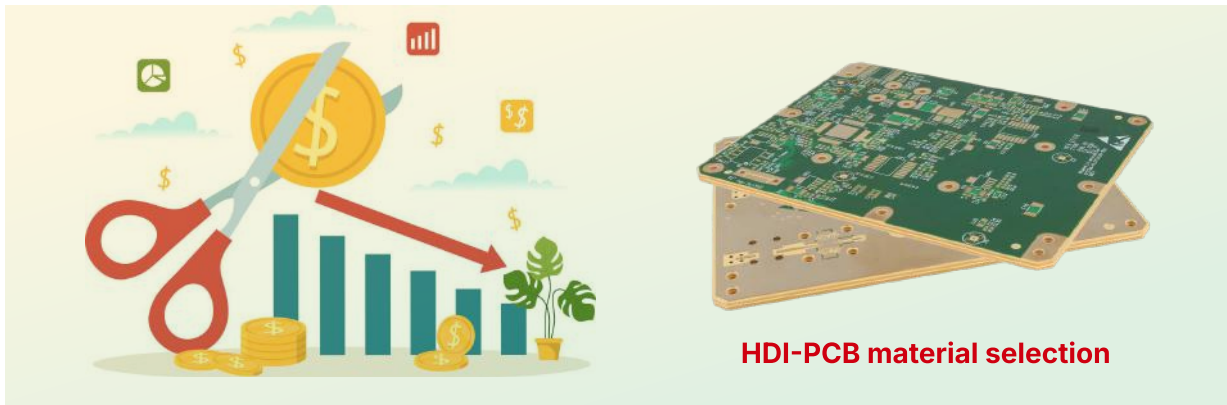
Suggested Material Improvements

PROPERTY	CURRENT VALUE	SUGGESTED VALUE	IMPACT
Dielectric Constant (Dk)	4.5	3.3	Enhanced signal integrity; reduced signal delay and distortion.
Dissipation Factor (Df)	0.02	0.008	Reduced signal loss; clearer data transmission.
Thermal Conductivity	0.3 W/m·K	0.6 W/m·K	Improved heat dissipation; reduced hotspots and better component lifespan.

Testing Results

ANALYSIS	OBSERVATION
Signal Integrity	Improved timing accuracy for SPI communications, with fewer errors and more reliable data transmission.
Thermal Performance	Decrease in hotspot formation, maintaining cooler operating temperatures with improved thermal conductivity.
Mechanical Reliability	Reduced warping and better performance under stress, especially in high-temperature environments.

Design Focused to Minimise Cost



HDI-PCB material selection

Optimize Dk Value: Choose materials with a Dk of 3.3 to balance performance and cost.

Evaluate Material Choices: Select materials with a lower Df where necessary to improve efficiency without significantly increasing costs.

Consider Cost-Effective Thermal Solutions: Use materials with better thermal conductivity but evaluate if the cost increase is justified by performance gains.

Design-Focused Recommendations



PTFE Laminates

Ceramic-Based Laminates

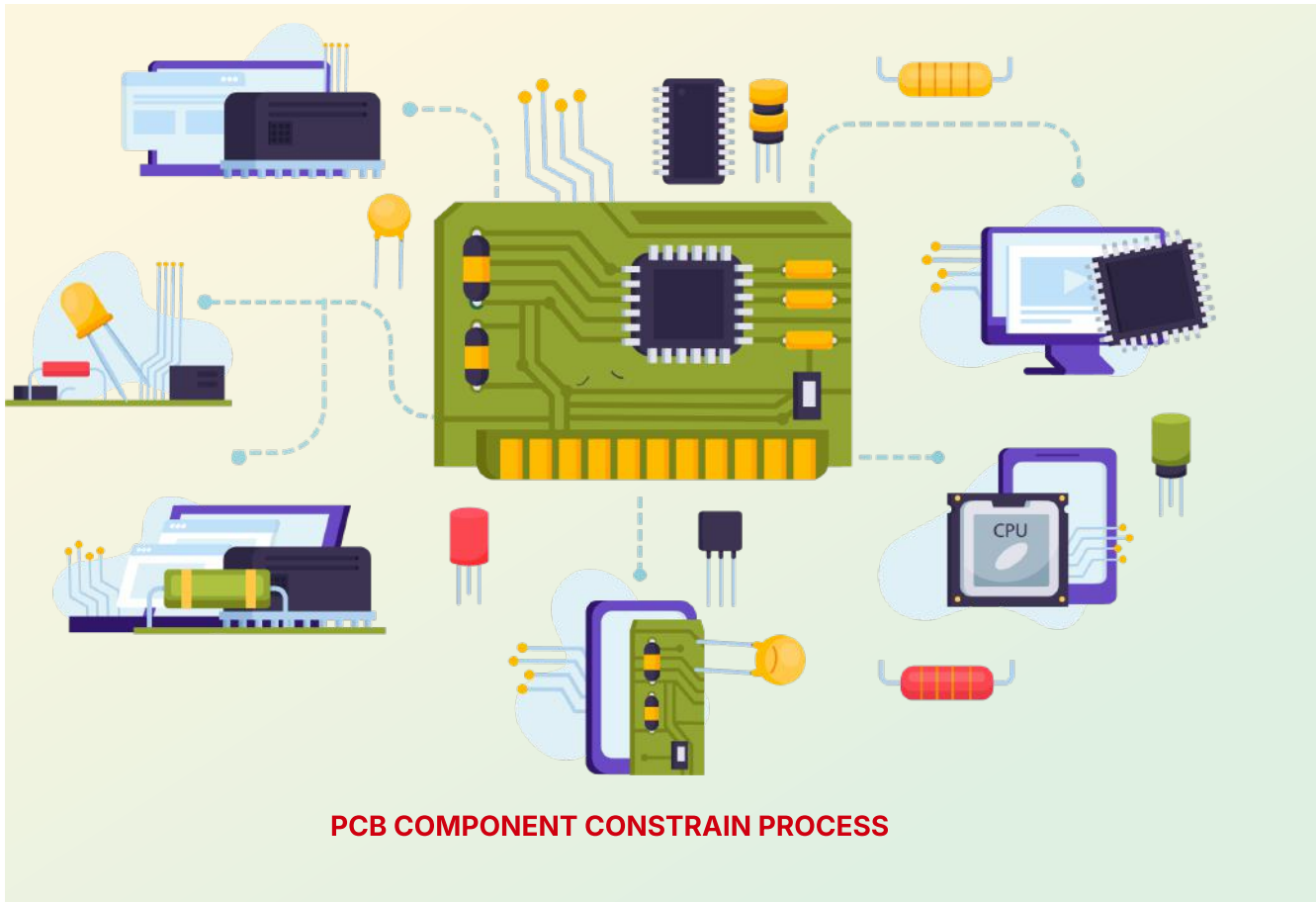
Hybrid Laminates

PTFE Laminates: Use for high-speed data integrity needs. Balance the higher cost with significant improvements in signal performance.

Ceramic-Based Laminates: Opt for these to reduce signal loss, while keeping an eye on their cost versus the benefit in high-frequency applications.

Hybrid Laminates: Incorporate for enhanced thermal management. Evaluate their cost against the long-term reliability and reduced thermal issues.

4. Material Selection Underconstrains, not Overconstrains-Here's how?



When selecting materials for PCB design, it's crucial to focus on essential performance requirements **without overcomplicating the process with excessive constraints**.

Over constraining leads to higher costs, longer development times, and potentially unnecessary complexity in manufacturing.

Key Considerations:

Performance-Driven Selection:

Prioritize materials based on critical factors such as thermal conductivity, dielectric constant, and loss tangent.

These parameters directly impact signal integrity, power management, and thermal performance.

Manufacturability:

Choose materials that are readily available and easy to work with in existing manufacturing processes. This reduces the risk of delays and ensures a smoother transition from design to production.

Cost Efficiency:



Avoid specifying high-performance materials that exceed the requirements of the application. Instead, opt for materials that provide sufficient performance at a lower cost, balancing quality with budget constraints.

Reliability and Longevity:

Consider the operating environment of the PCB. Select materials that can withstand the specific conditions the board will encounter, such as temperature fluctuations, humidity, and mechanical stress, without adding unnecessary overengineering.

Implementation Strategy:

Underconstrains Philosophy:

- Focus on "good enough" rather than "perfect."
- Identify the minimum material properties that satisfy design requirements and avoid the temptation to overengineer.
- This approach leads to more efficient designs that are easier to manufacture and cost-effective without sacrificing performance or reliability.

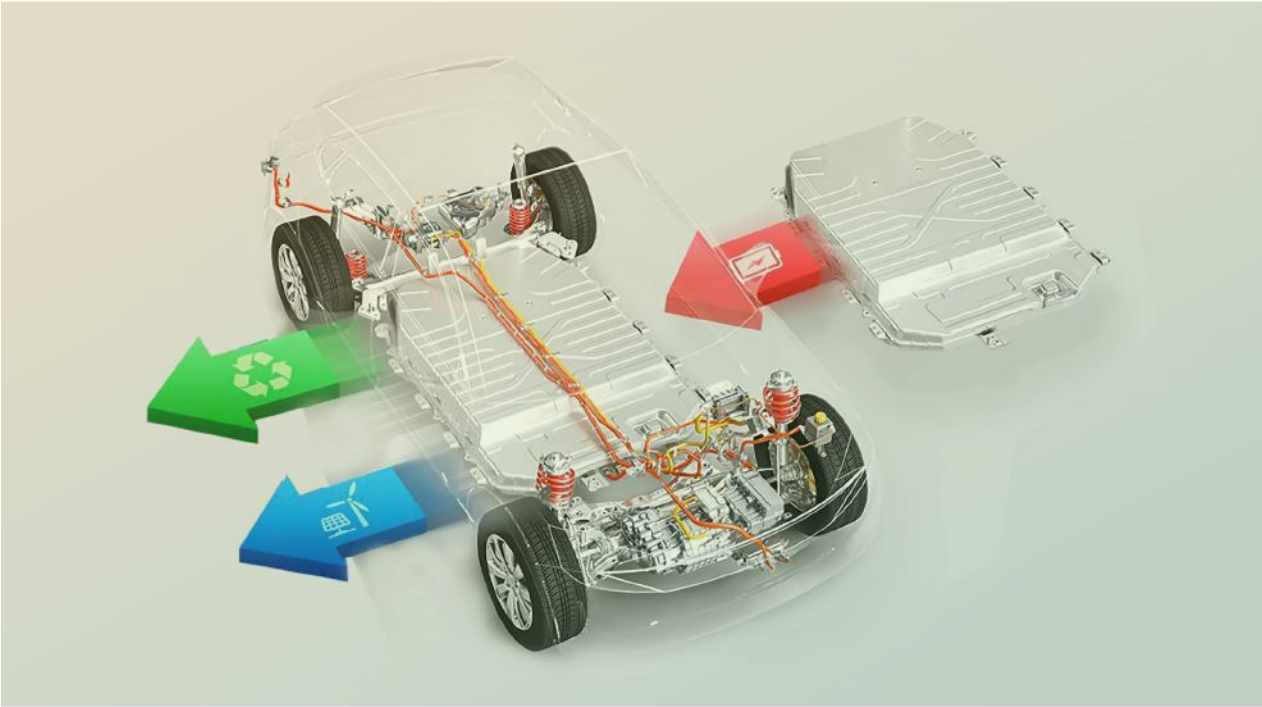
Iterative Testing

- Use prototypes and simulations to validate material choices.
- This allows for fine-tuning without overcommitting to a single material early in the design process.

Collaboration with Suppliers:

- Engage with material suppliers early to understand the full range of available options and their trade-offs.
- This helps in selecting materials that are optimal for both performance and cost.

Summary



Choosing the right materials in automotive design is a balancing act.

Go too far in one direction, and you risk overconstraining your design—making it costly and complex.

But if you underconstrain, you might compromise on performance and safety.

The key is finding the perfect balance.

You need materials that meet your design requirements, stay within budget, comply with regulations, and are easy to manufacture.

This balance is what makes your designs both innovative and practical.

Want to learn how to get this balance right?

Download our eBook, "Overconstrains? Underconstrains?"

Selecting Materials for Automotive Designs" and discover the strategies that ensure your designs succeed.

Visit our website **www.gighz.net**

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