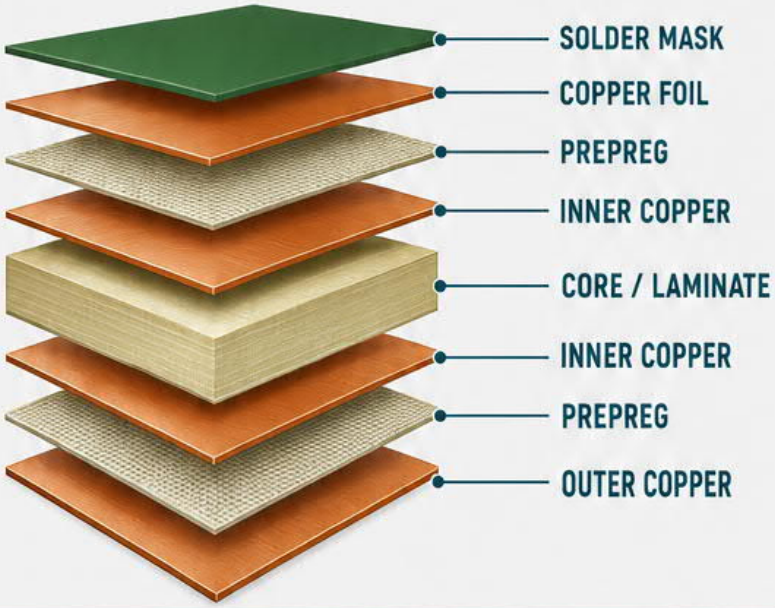
UNDERSTANDING PCB MATERIAL CHOICES

MATERIAL SYSTEM • PROPERTY SET • ENGINEERING IMPACT

The laminate system is the PCB's mechanical structure, electrical dielectric and thermal environment.



CORE / LAMINATE

fully cured copper-clad dielectric.

PREPREG

partially cured resin + glass reinforcement; final thickness depends on glass style, resin content, copper pattern and press process.

BONDPLY / BONDING FILM

specialized bonding dielectric in some RF, flex and hybrid builds.

WHAT FR-4 REALLY MEANS

- Broad family of flame-retardant glass-reinforced thermoset laminates.
- Not one resin system.
- Can include conventional, high-Tg, low-loss, halogen-free and CAF-resistant systems.

MATERIAL CHOICE INFLUENCES

- IMPEDANCE
- INSERTION LOSS
- VIA RELIABILITY
- DIMENSIONAL STABILITY
- REFLOW SURVIVAL
- MOISTURE / CAF
- THERMAL PERFORMANCE
- MANUFACTURABILITY
- COST
- AVAILABILITY

SELECT THE COMPLETE PROPERTY SET

ELECTRICAL

dielectric performance, impedance control, signal integrity.

THERMAL

heat resistance, thermal conductivity, CTE.

MECHANICAL

strength, stiffness, layer adhesion, peel performance.

ENVIRONMENTAL

moisture absorption, CAF resistance, chemical resistance.

MANUFACTURING

process compatibility, drillability, plating, yields.

SUPPLY CHAIN

availability, consistency, lead time, global support.

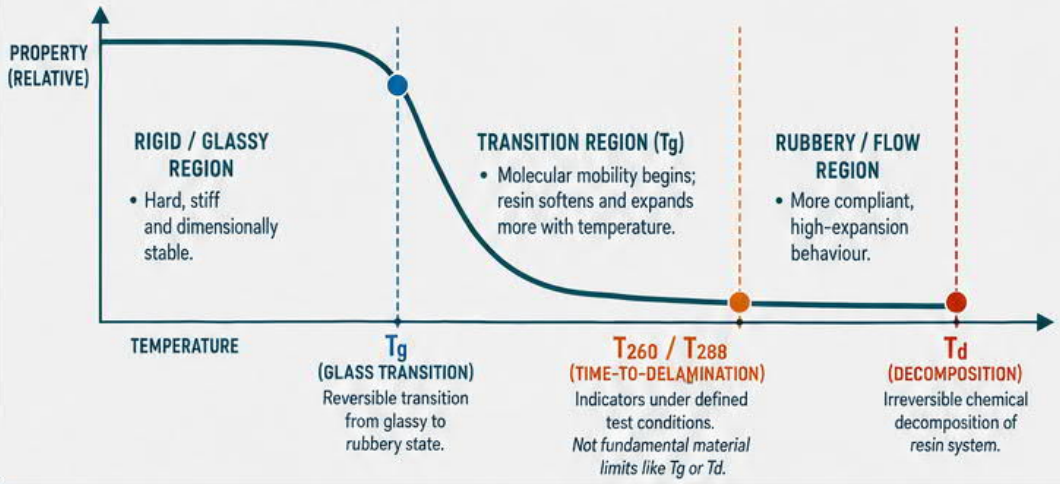
WRITING ONLY 'FR-4' CAN GIVE THE FABRICATOR TOO MUCH LATITUDE FOR A CRITICAL DESIGN.

Select a material system — not one impressive headline property.

UNDERSTANDING PCB MATERIAL CHOICES

TG • TD • CTE • MOISTURE • CAF

THERMAL BEHAVIOUR & KEY TEMPERATURES



- **Tg (GLASS TRANSITION)** Transition from rigid glassy resin to more compliant high-expansion behaviour.
- **T260 / T288** Time-to-delamination indicators under defined tests (e.g., IPC-TM-650 2.4.24 / 2.4.25).
- **Td (DECOMPOSITION)** Irreversible chemical decomposition; fundamentally different from Tg.

METHOD MATTERS

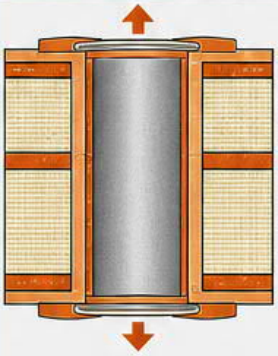
DSC (DIFFERENTIAL SCANNING CALORIMETRY)
- Detects change in heat capacity.
- Tg from midpoint of step change in Cp.

TMA (THERMOMECHANICAL ANALYSIS)
- Detects change in expansion slope.
- Tg from change in dimension vs. temperature.

DMA (DYNAMIC MECHANICAL ANALYSIS)
- Detects change in mechanical viscoelastic response.
- Tg from peak in tan δ.

Tg VALUES FROM DIFFERENT METHODS MAY DIFFER.
Always record the method and condition used.

Z-AXIS CTE & VIA RELIABILITY



PCB thickness changes with temperature due to Z-axis CTE, stretching the plated through-hole barrel.

Thick boards, high aspect ratio vias and repeated reflow increase strain and risk.

Microvia and buried interfaces also experience thermal strain.

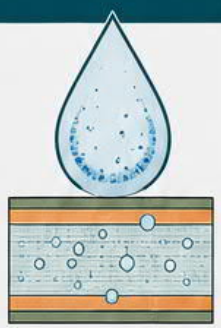
MOISTURE

Moisture is absorbed into the dielectric and affects performance.

Affects dielectric constant, dissipation, dimensions and mechanical properties.

Increases reflow / delamination risk and can reduce reliability.

Qualification must reflect storage, humidity and thermal exposure conditions.



CAF RESISTANCE

CAF is a conductive filament path between biased conductors in humid conditions.

KEY DRIVERS
- Fine conductor spacing
- Electrical voltage
- Humidity and temperature
- Contamination and ionic species
- Drilling quality and smear
- Long service life and bias duration



HIGH Tg ALONE DOES NOT PROVE LEAD-FREE OR VIA RELIABILITY.

MATERIAL SELECTION AND VIA DESIGN CANNOT BE SEPARATED.

Review Tg method, Td, T260/T288, Z-axis CTE and moisture as one thermal package.

PCB DESIGN GUIDE 07

UNDERSTANDING PCB MATERIAL CHOICES

Dk • Df • COPPER ROUGHNESS • GLASS WEAVE

Dk + DIELECTRIC THICKNESS + COPPER THICKNESS + TRACE WIDTH / SPACING + SOLDER MASK + COPPER ROUGHNESS = FINISHED TRANSMISSION-LINE BEHAVIOUR

Dk / εr

- Controls impedance, propagation delay, wavelength and geometry.
- Record frequency, test method, resin content/thickness and whether nominal, process or design Dk.

Dk values from different methods are not directly interchangeable.

Df / LOSS TANGENT

- Determines dielectric insertion loss.
- Low Df matters when channel length and frequency make dielectric loss significant.
- Ultra-low loss may add cost without benefit on short/slow interconnects.

Optimize Df where the channel and frequency justify the added cost.

COPPER FOIL & ROUGHNESS

ED
Electrodeposited (Smoother)

ROLLED ANNEALED
(Rougher)

REVERSE-TREATED / LOW-PROFILE / VERY-LOW-PROFILE
(Smoother)

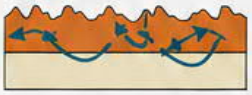
SKIN-CURRENT PATH

SMOOTHER COPPER



Lower scattering — lower loss

ROUGHER COPPER

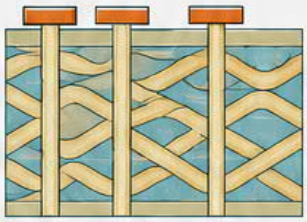


More scattering — higher loss

Low-Df resin with very rough copper can surrender part of the expected loss benefit.

GLASS WEAVE & RESIN CONTENT

Differential traces sampling different glass/resin regions can create skew and local impedance variation.



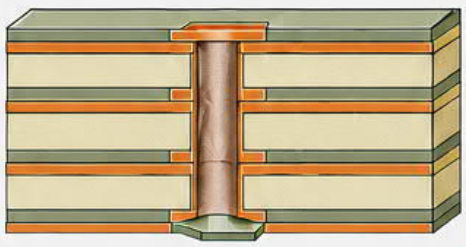
Uneven sampling → skew & local impedance variation

MITIGATION

- Use spreads to average out glass/resin.
- Route with slight angle instead of perfectly parallel.
- Use wider geometry or more spacing.
- Allow skew margin in the design.

MODEL THE REAL STACK-UP

- **FINISHED DIELECTRIC THICKNESS** — Use actual measured or controlled values.
- **ACTUAL GLASS STYLES** — Include weave and spread characteristics.
- **COPPER / ETCH GEOMETRY** — Use real foil type, plating and etch profile.
- **DESIGN Dk** — Use Dk at frequency with process thickness.
- **ROUGHNESS MODEL** — Use appropriate roughness for copper foils.
- **FREQUENCY DEPENDENCE** — Account for Dk and loss vs. frequency.



CONTROLLED IMPEDANCE IS A PROPERTY OF THE FINISHED TRANSMISSION LINE — NOT THE LAMINATE ALONE.

Know the materials. Model reality. Build with confidence.

UNDERSTANDING PCB MATERIAL CHOICES

MATERIAL FAMILIES • SPECIAL CONSTRUCTIONS • THERMAL PATHS

MATERIAL TIER MATRIX

STANDARD FR-4	General digital, control and power applications. Cost and availability dominate.
HIGH-Tg / THERMALLY ROBUST FR-4	Lead-free, multilayer and industrial environments. Thermal reliability dominates.
IMPROVED / MID-LOSS	Moderate high-speed digital. Cost-effective loss reduction.
LOW / VERY-LOW-LOSS	Fast SerDes and long channels. Loss budget justifies premium.
RF / MICROWAVE SPECIALTY	Controlled Dk/Df and frequency stability for RF and microwave circuits.
POLYIMIDE	High-temperature, aerospace and flex / rigid-flex applications. Processing, moisture and cost require review.

SPECIAL REQUIREMENTS

HALOGEN-FREE

Does not automatically mean lower loss or higher reliability. Changing system affects Tg, CTE, drilling, moisture and CAF performance.

LEAD-FREE COMPATIBILITY

Requires Td, T260 / T288, CTE, moisture, construction and reflow-cycle review—not Tg alone.

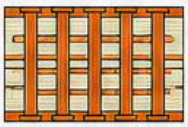
THERMAL ARCHITECTURES

THICK COPPER PLANES



Increase copper weight on power / ground planes to reduce thermal resistance.

THERMAL VIA ARRAYS



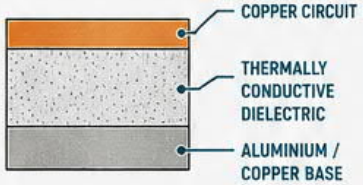
Place dense via arrays under heat sources to transfer heat to inner planes or backs.

HIGHER-CONDUCTIVITY DIELECTRIC



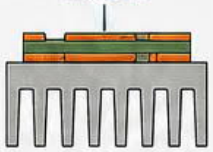
Use materials with higher thermal conductivity dielectrics to lower junction-to-ambient path.

METAL-CORE / IMS



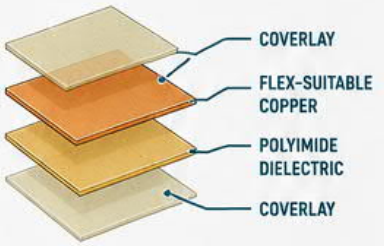
Insulated Metal Substrate (IMS) provides direct heat spread into a metal base.

EXTERNAL HEATSINK / CHASSIS



Interface to heatsink or chassis for maximum thermal dissipation.

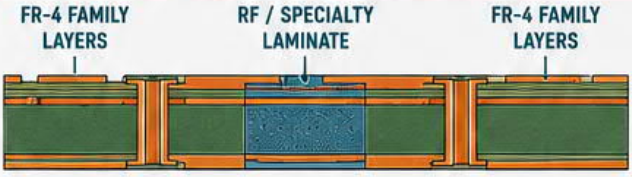
FLEX & RIGID-FLEX



- Use polyimide dielectric and flex-suitable copper.
- Respect minimum bend radius.
- Control copper grain direction for reliability.

Rigid-flex must be designed as a manufacturing stack-up from the beginning.

HYBRID CONSTRUCTION



BENEFITS

- Premium material used only where needed.
- Balance performance and cost.

RISKS

- Mismatched CTE
- Resin flow differences
- Dk transitions
- Drilling and plating challenges
- Bow / twist risk

TWO INDIVIDUALLY PROVEN MATERIALS DO NOT AUTOMATICALLY FORM A PROVEN HYBRID MULTILAYER.

Select materials that match the electrical, thermal and environmental objectives—not just the cost target.

UNDERSTANDING PCB MATERIAL CHOICES

SELECT BY APPLICATION • AVAILABILITY • SUBSTITUTION CONTROL

LOW-SPEED CONTROL / POWER	SHORT MODERATE-SPEED DIGITAL	PCIe / FAST SerDes	LONG BACKPLANE / NETWORKING	RF / MICROWAVE	DEFENCE / AEROSPACE	POWER / LED
Robust standard FR-4 often sufficient.	High-Tg or improved-loss FR-4 may be sufficient.	Channel-loss analysis drives the material class.	Low or very-low-loss material often justified.	Controlled Dk/Df, frequency and temperature stability.	Contractual specification, traceability, environment and via reliability.	Complete thermal path may drive IMS or high-k system.

HIGH-SPEED DIGITAL

CALCULATE TOTAL CHANNEL LOSS
Include connectors, vias, transitions and packages.

LONGEST ROUTE & FREQUENCY CONTENT
Use the worst-case path and actual spectrum.

MODEL Df & FOIL ROUGHNESS
Include dielectric loss, copper roughness and plane effects.

CHECK Dk & VIA RELIABILITY
Confirm dielectric constant, via structure and return path integrity.

SELECT LOWEST-COST MATERIAL WITH ADEQUATE MARGIN
Balance performance, cost and availability.

Protocol name alone does not dictate one material.

RF FRONT END

CONTROL KEY PARAMETERS
Control Dk, Df, tolerance, thermal coefficient, finished thickness and foil.

MINIMIZE VARIATION
Tight control of dielectric and copper properties reduces mismatch and loss.

ADDRESS PIM IF RELEVANT
Material, surface smoothness and plating quality all influence PIM.

TIGHTLY CONTROL SUBSTITUTIONS
Only within a validated equivalence envelope.

USE REPRESENTATIVE RF STRUCTURES
Measure on structures that reflect the real design.

AVAILABILITY MATTERS

STOCKED MATERIALS
Use commonly stocked cores, prepregs and foil where possible.

REGIONAL AVAILABILITY
Confirm availability in your region and across the supply chain.

AUTHORIZED SOURCE
Sourced through approved distributors or direct partners.

LEAD TIME / MOQ
Validate realistic lead time and minimum order quantities.

CERTIFICATES & TRACEABILITY
Demand MTRs, lot traceability and certificates of conformity.

NAMED MATERIAL VS EQUIVALENT

Dk / Df	Equivalent only if tested by the same method and at the same frequency.
Tg / Td / CTE	Glass transition, decomposition temperature and coefficient of thermal expansion.
MOISTURE / CAF	Moisture absorption characteristics and CAF performance.
FOIL PROFILE	Copper roughness profile (Ra/Rz or RTF) and treatment.
THICKNESS CONSTRUCTION	Dielectric thickness, tolerance and laminate construction (e.g., 2116/1080).
UL / ENVIRONMENTAL STATUS	UL recognition, flammability rating and RoHS/REACH/halogen status.
FABRICATION EXPERIENCE	Qualified fabricator experience with the material in similar builds.

EQUIVALENCE ENVELOPE CHECKLIST

- [ ] Compare measured Dk/Df at specified frequency.
- [ ] Verify Tg, Td and CTE match or are within envelope.
- [ ] Confirm moisture absorption and CAF performance.
- [ ] Match copper foil profile and surface treatment.
- [ ] Confirm thickness construction and tolerances.
- [ ] Verify UL rating and environmental compliance.
- [ ] Confirm successful fabrication history with the alternate material.
- [ ] Document the equivalence decision and retain data.

FOR HIGH-SPEED OR HIGH-RELIABILITY BOARDS, MATERIAL SUBSTITUTION IS AN ENGINEERING CHANGE – NOT MERELY A PURCHASING DECISION.

Choose the right material for performance, availability and risk – and document the decision.

NOVATRONIC PCB

PCB DESIGN GUIDE 07

VISUAL GUIDE • SHEET 6 OF 6

UNDERSTANDING PCB MATERIAL CHOICES

COLLABORATION • QUALIFICATION • FINAL REVIEW

PRACTICAL MATERIAL-SELECTION FLOW

1. DEFINE APPLICATION / ENVIRONMENT
2. DEFINE ELECTRICAL, THERMAL & RELIABILITY NEEDS
3. ESTABLISH BOARD / VIA ARCHITECTURE
4. SCREEN MATERIAL FAMILIES
5. SELECT FABRICATOR & CHECK STOCK
6. BUILD PROPOSED STACK-UP
7. MODEL SI / RF / THERMAL PERFORMANCE
8. QUALIFY MATERIAL + PROCESS + COUPONS
9. FREEZE APPROVED MATERIAL / SUBSTITUTION SET

MANUFACTURER DFM QUESTIONS

- Exact laminate/prepreg material system.
- Applicable IPC-4101 or customer specification.
- Core / prepreg / resin content and style.
- Finished dielectric thickness (target and range).
- Design Dk and Df: frequency and test method.
- Copper foil profile (type and roughness).
- Tg method, Td, T260 / T288 and Z-CTE.
- Moisture absorption and CAF performance.
- UL recognition (or equivalent) if required.
- Reflow, via, and HDI process qualification.
- Stock status, substitutions, certificates (COC / UL) and build history.

COMMON MISTAKES

- Selecting "FR-4" without full evaluation.
- Selecting material by Tg alone.
- Assuming lowest Df is automatically best.
- Comparing Dk values from unlike methods.
- Ignoring foil roughness and glass weave.
- Treating prepreg thickness as fixed.
- Using unrestricted "equivalent" materials.
- Choosing exotic / non-stock materials without supply plan.
- Mixing unqualified hybrid materials.
- Assuming high-Tg means lead-free safe.
- Ignoring fabricator process experience.

FINAL REVIEW

- Application environment and life defined.
- Assembly process and exposure known.
- Class / customer requirements identified.
- Board thickness, layers and copper set.
- Via architecture checked against CTE.
- Full thermal package and hot spots reviewed.
- Dk / Df appropriate for frequency range.
- Foil profile and glass weave controlled.
- Thermal path and heat spreading adequate.
- Flex / rigid-flex / hybrid aspects reviewed.
- Material availability and lead time confirmed.
- Substitution plan defined and qualified.
- Certificates, COC / traceability specified.
- Final modelling uses production stack-up.

THE BEST MATERIAL IS NOT THE ONE WITH THE HIGHEST Tg OR LOWEST Df – IT IS THE CONTROLLED SYSTEM THAT MEETS PERFORMANCE, RELIABILITY, MANUFACTURING AND SUPPLY REQUIREMENTS.

Define the risk • select the system • model the real stack-up • qualify and control production.