Electrical Performance, Miniaturization and EMI Advantages of Very High Capacitance Density Laminates in PCBs and IC Packaging

Presented at PCB West 2011, September 29, 2011, Santa Clara, CA

Agenda

- Background on Embedded Capacitance
- Electrical Performance/EMI Data
- Capacitor Elimination Metrics
- PCB Fabrication Compatibility
- Cost Considerations
- Summary

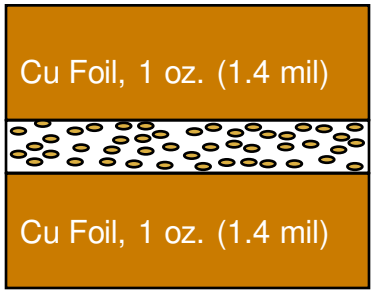
Background on Ultra-Thin Embedded Capacitance Materials

Ultra-Thin Embedded Capacitance Material

Product Description

Sheets of Cu-clad laminate
Thin, high Dk dielectric

- Ideal for high frequency decoupling
- Eliminates discrete capacitors
- Dampens plane resonances



Uses

Power-ground innerlayer (distributed capacitance) for rigid and flex PWBs and IC packages

Singulated (discrete-like) capacitors for decoupling, filtering and other functions in rigid and flex PWBs and IC packages

Ultra-Thin Embedded Capacitance Technology

Capacitance/Area = 0.885 k/t (nF/cm^2)

- Capacitance per unit area (C/A) is proportional to dielectric constant k and inversely proportional to t
- Maximize C/A by decreasing thickness (t) and increasing dielectric constant (k)

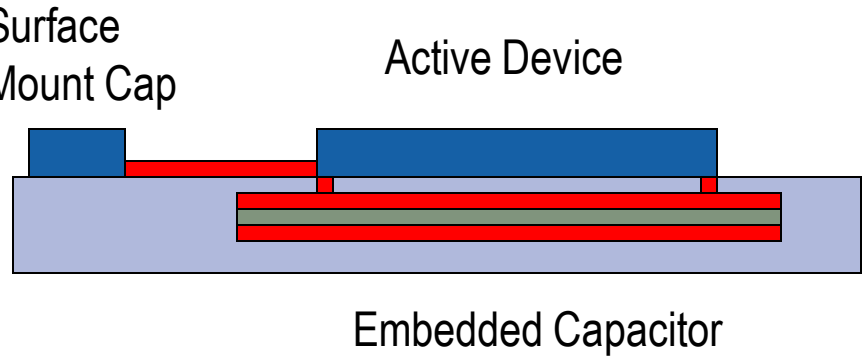
Why Embedded Capacitance?

1. Performance

- Faster charge delivery
- Effective noise dampening
- Reduced power bus noise

2. Space

- SMT caps and vias eliminated

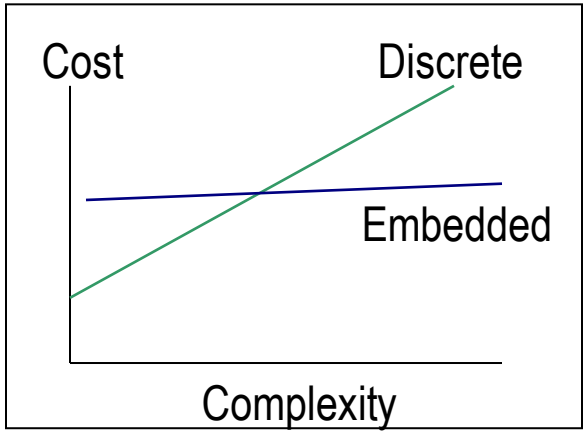


3. EMI

- Power bus noise is a leading cause of EMI

4. Cost

- Board size reduction
- Reduced assembly costs



5. Reliability

- Elimination of solder joints/vias

3M™ Embedded Capacitance Material (ECM)

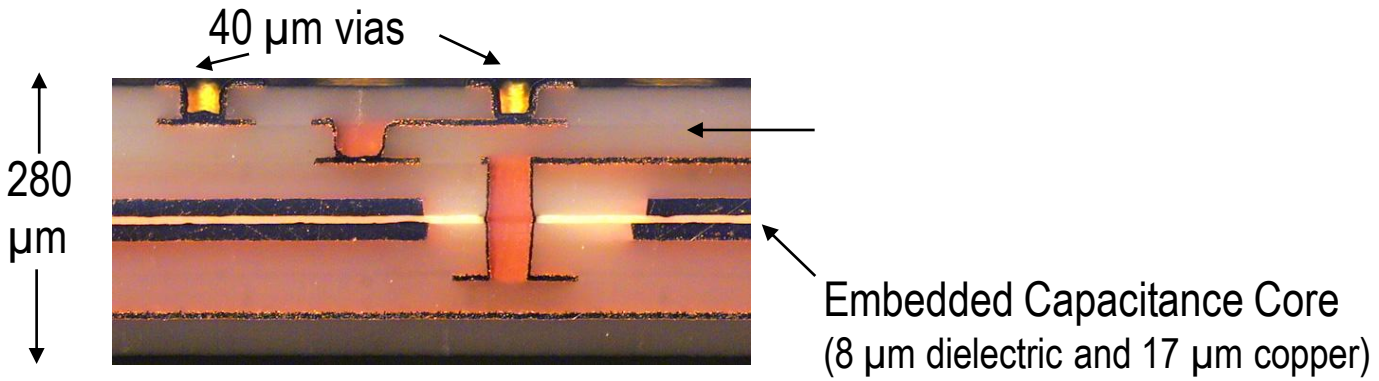
Miniaturization | Performance | Component Reduction

- **Telecom**
  Routers, Base Stations, Switches
- **Computer**
  High-end servers, Supercomputers, Storage
- **Test & Measurement**
  Automated Test Equipment
- **Military / Aerospace**
  Aircraft & Missile Avionics, Satellites
- **Chip Packaging**
  Processors, Memory Modules
- **Consumer Electronics**
  Mobile Handheld Devices, Video, MEMS Microphones

Very high C/A needed in these applications due to space constraints

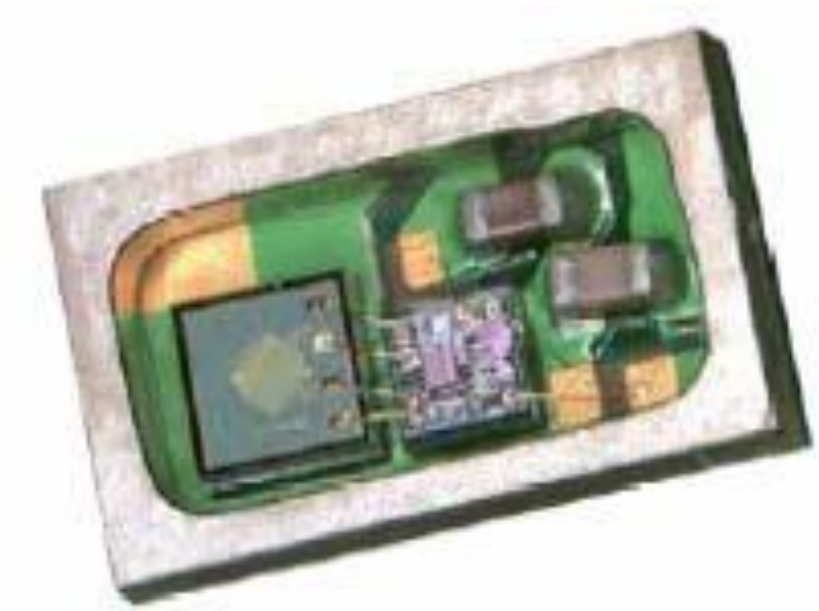
High C/A Needed IC Packaging

- Embedded Distributed Capacitance in high-speed digital IC package for high-end server

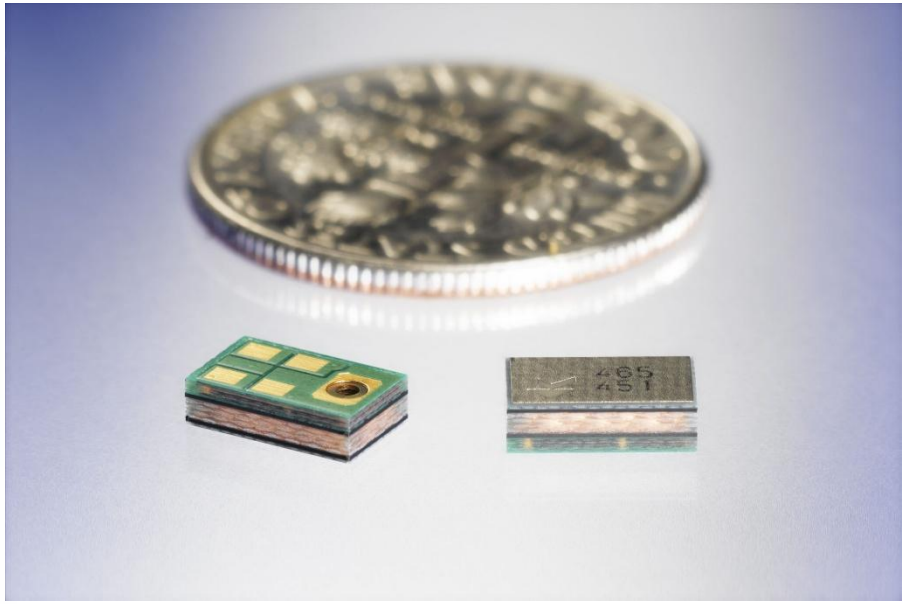


Eight Layer Package (42.5 mm X 42.5 mm) with 10 nF/in^2 ECM in middle

High C/A Needed in MEMS Module



Early design with 2 SMT caps (lid removed)



Later design with 3M™ Embedded Capacitance Material (ECM) replacing SMT caps

Electrical Performance Data in High-Speed Digital Boards

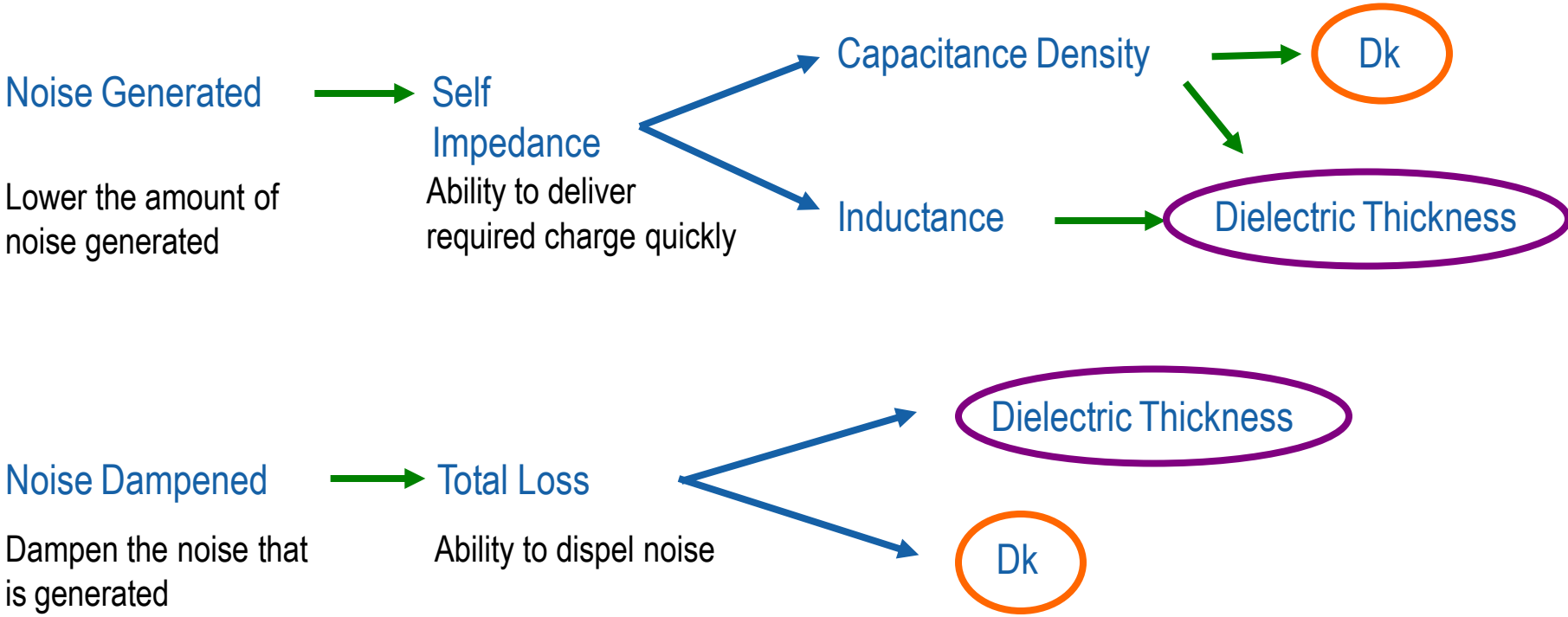
The Need for Electrical Performance

- High-speed digital electronics require **low impedance power distribution**, driven by trends in silicon
  - Lower voltages
  - Higher frequencies
  - Higher currents

$$\frac{\downarrow \text{Voltage}}{\uparrow \text{Current}} = \downarrow \text{Impedance}$$

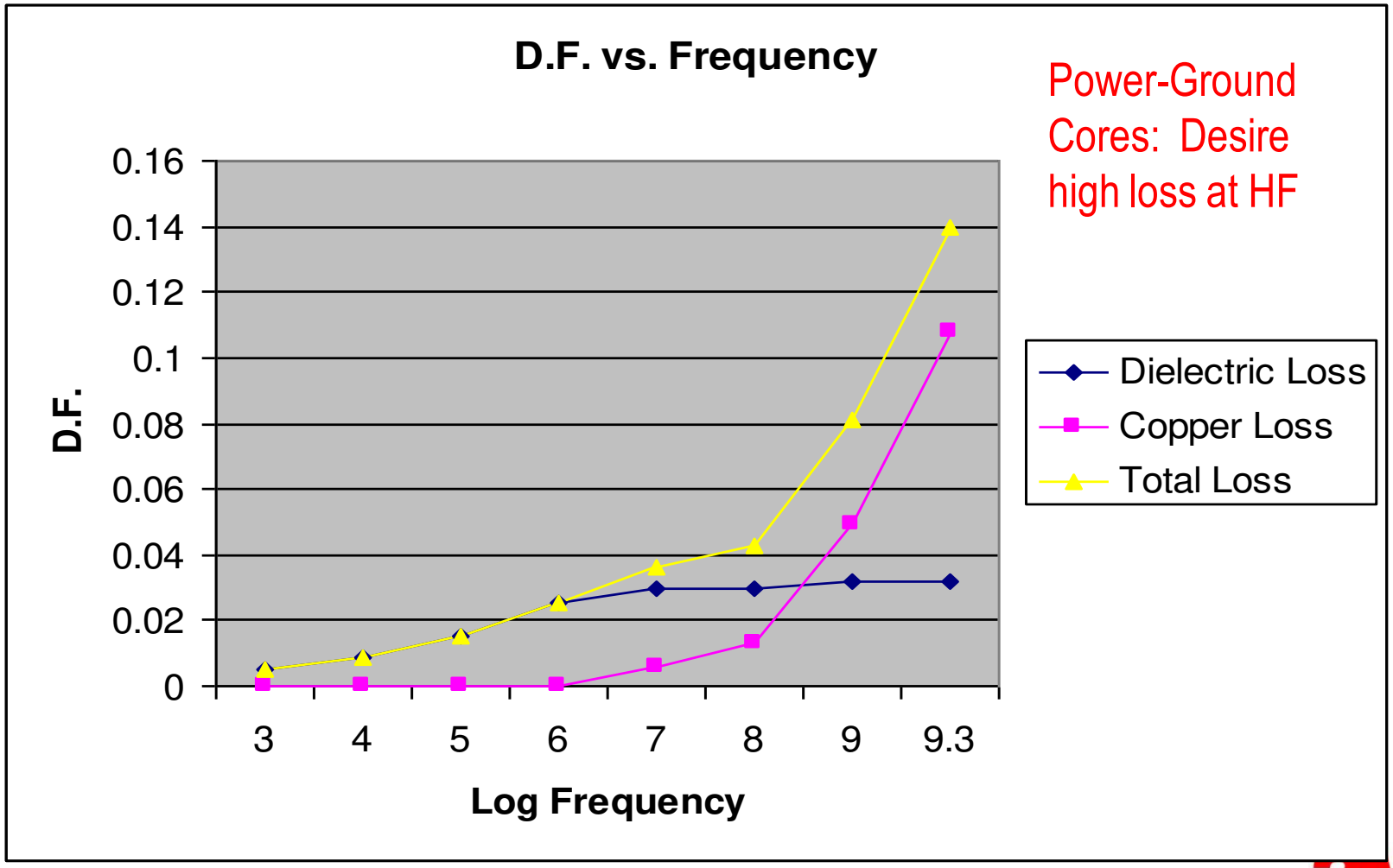
- Very high C/A ECM is a very simple and effective way to lower the impedance of the power distribution system, even on small boards, modules and chip packages
  - Lowers voltage ripple
  - Dampens board resonances
  - Reduces EMI
  - Eliminates decoupling capacitors

Key Factors for High Frequency Decoupling



Performance is driven by dielectric thickness and dielectric constant; thinner dielectrics and higher dielectric constants mean higher loss, higher capacitance and lower inductance.

Total Loss vs. Frequency (3M™ Embedded Capacitance Material (ECM)



Power-Ground Cores: Desire high loss at HF

Cu losses dominates at frequencies >150 MHz

3M™ Embedded Capacitance Material (ECM) Key Properties

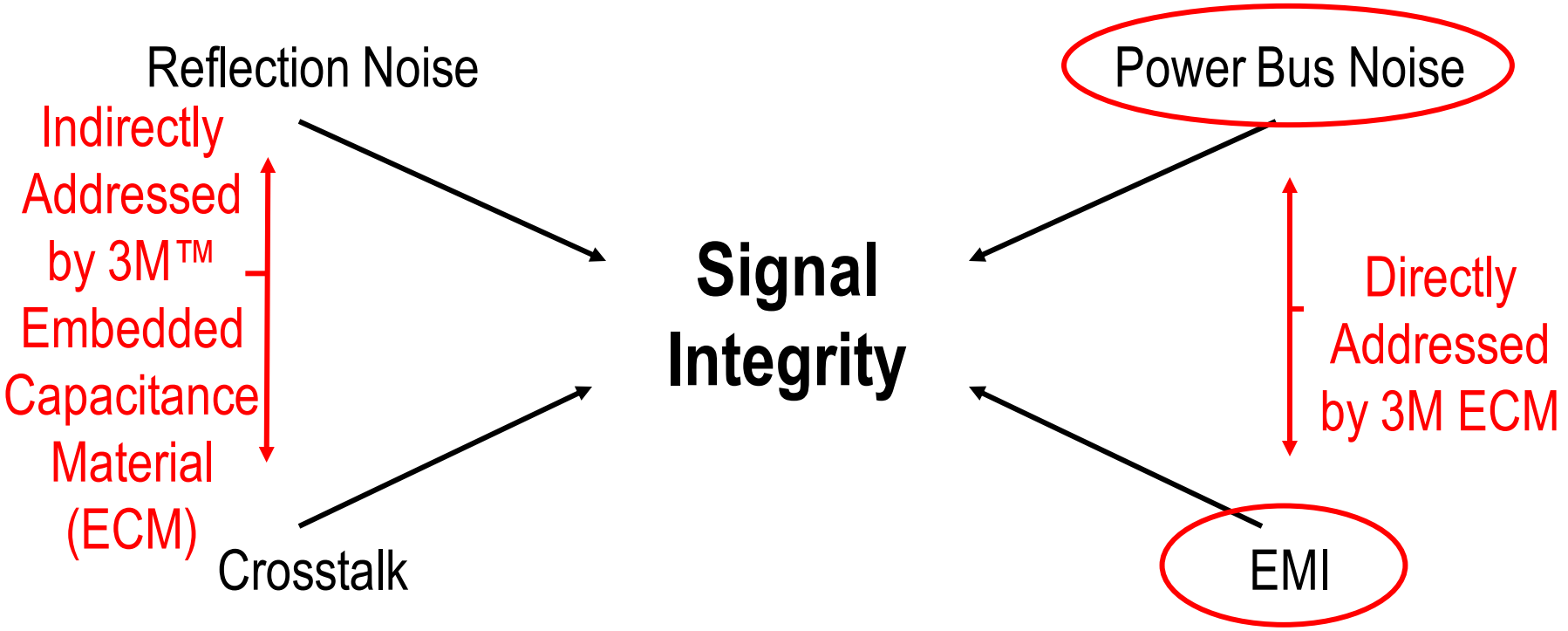
	C0614	C1012	C2006
Capacitance per Area	6.4 nF/in^2 (1.0 nF/cm^2)	10 nF/in^2 (1.55 nF/cm^2)	20 nF/in^2 (2.3-6.2 nF/cm^2)
Dk	16	22	22
Dielectric Thickness	0.55 mil (14 µm)	0.47 mil (12 µm)	0.24 mil (6 µm)
Dielectric loss @ 1GHz	0.03	0.03	0.03
Resin system	Epoxy, ceramic filler	Epoxy, ceramic filler	Epoxy, ceramic filler
TCC	Meets X7R	Meets X7R	Meets X7R
Dielectric Strength	~3300 V/mil (130 V/um)	~3000 V/mil (118 V/um)	~3000 V/mil (118 V/um)
Breakdown	>100V	>100V	>50V
Copper Thickness	1.4 mil (35 µm)	1.4 mil (35 µm) 0.7 mil (17 µm)	1.4 mil (35 µm)

Power Bus Noise Reduction

- Reduce the dielectric thickness of the laminate between the power and ground planes
  - If >1.5 mils, 10 dB reduction per decade
  - If <1.5 mils, 20 dB reduction per decade
- Increase the dielectric constant of the laminate between the power and ground planes
  - If Dk <10, 7 dB reduction per decade
  - If Dk >10, 14 dB reduction per decade
- Changing from a 4 mil FR-4 power ground core to a 2 mil core will reduce power bus noise by ~4 dB
- Changing from a 4 mil FR-4 power ground core to a 0.5 mil core with Dk of ~20 will reduce power bus noise by ~20 dB

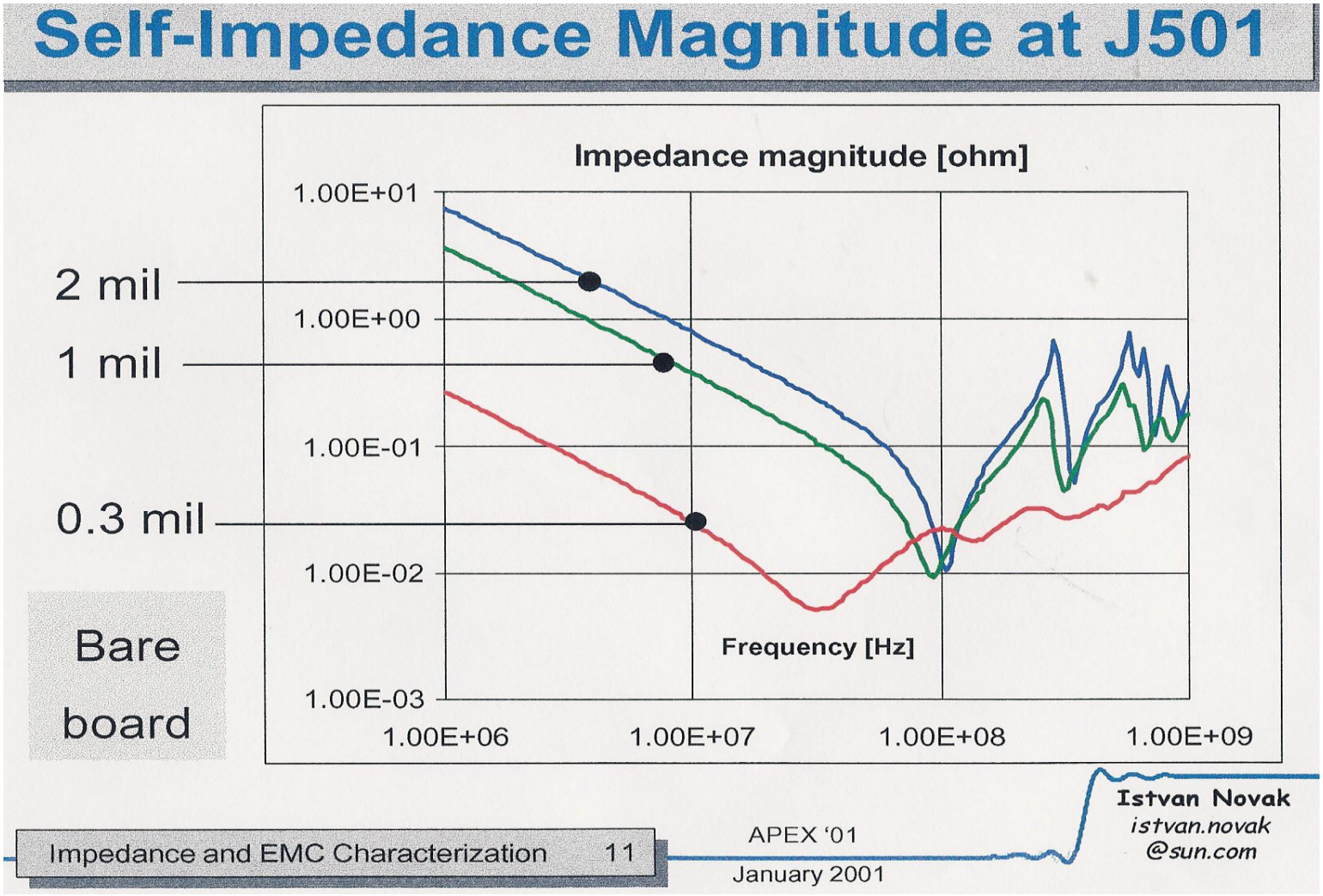
Modeling Noise on Printed Circuit Board Power Planes
John Grebenkemper, DesignCon 2004

Four Factors Impacting Signal Integrity

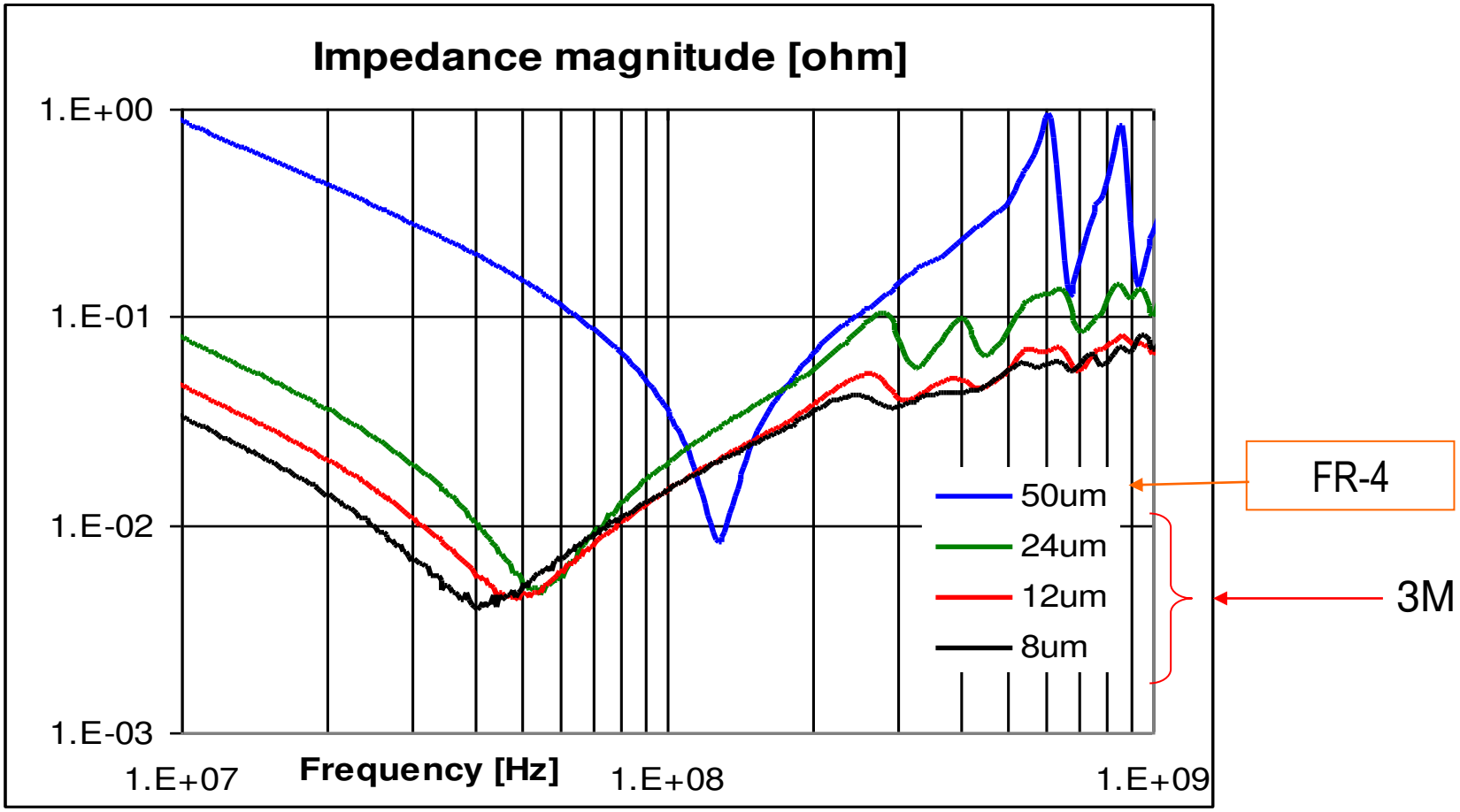


Signal Integrity, Power Integrity and EMI are all interrelated

Impedance Comparison



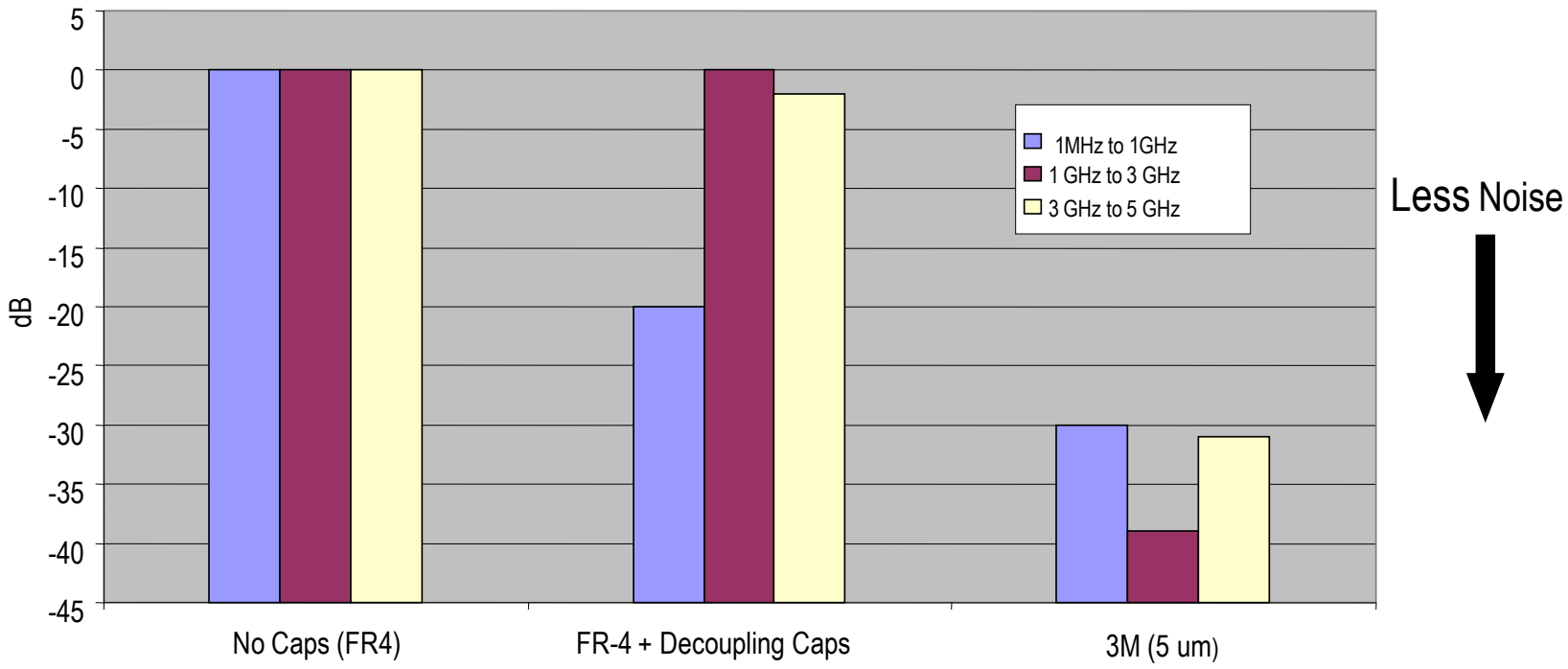
Self-Impedance Comparison



Courtesy of Sun Microsystems

Lower impedance across all frequencies with thinner /high Dk dielectric materials

Power Bus Noise on Test Vehicle (EDC TV1)

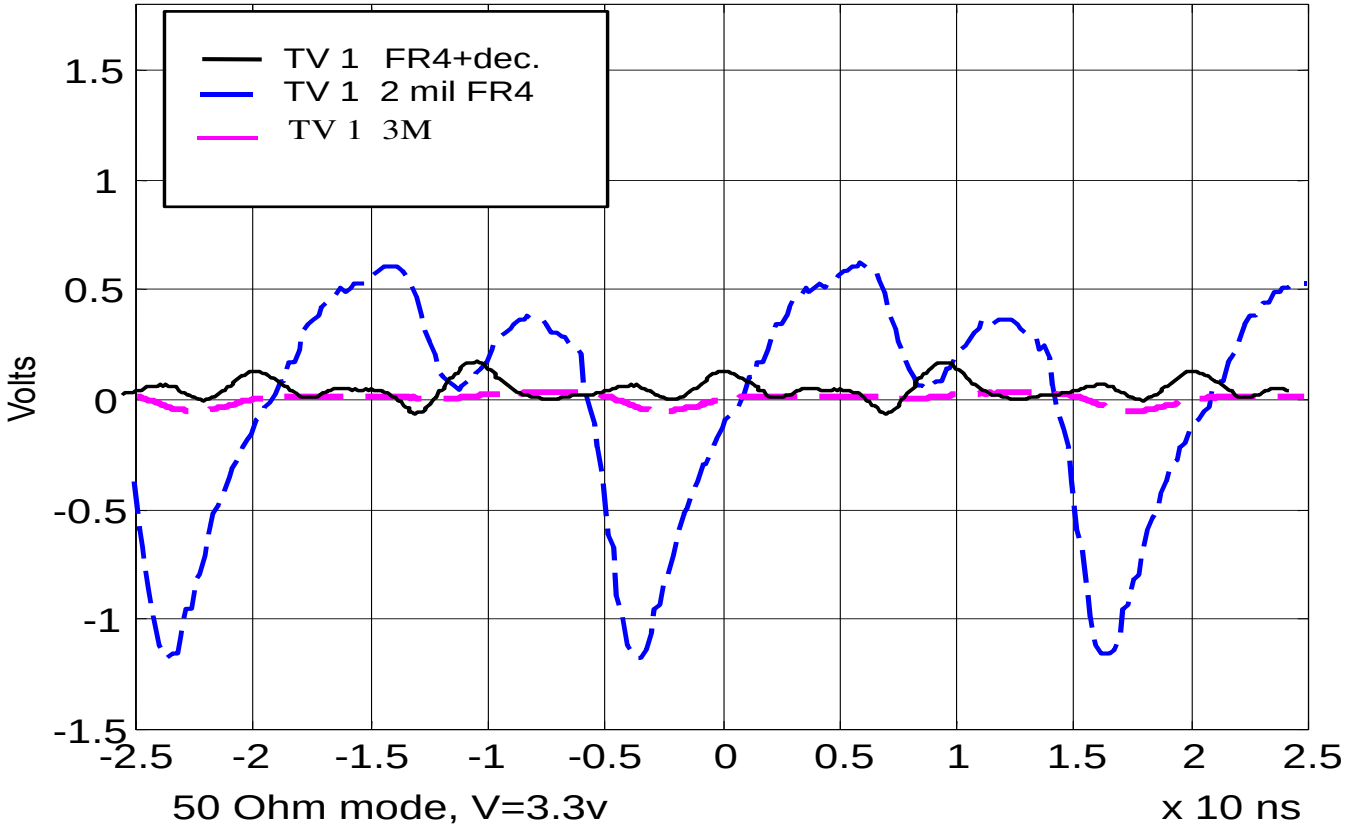


- Traditional decoupling capacitors are not effective at frequencies above 250 MHz
- 3M has excellent performance to 5 GHz (and beyond)

Data from NCMS Embedded Decoupling Capacitance Project Report - 12/00

Power Bus Noise

(Time Domain = 50 MHz

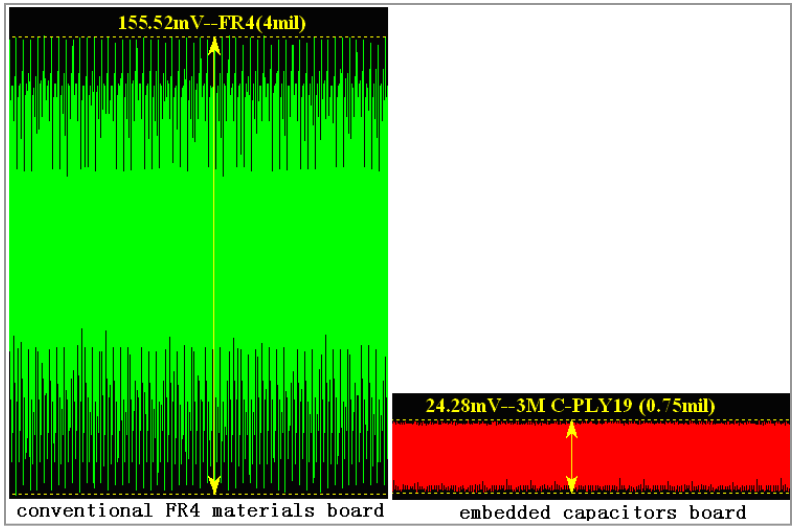


Data from NCMS Embedded Decoupling Capacitance Project Report - 12/00

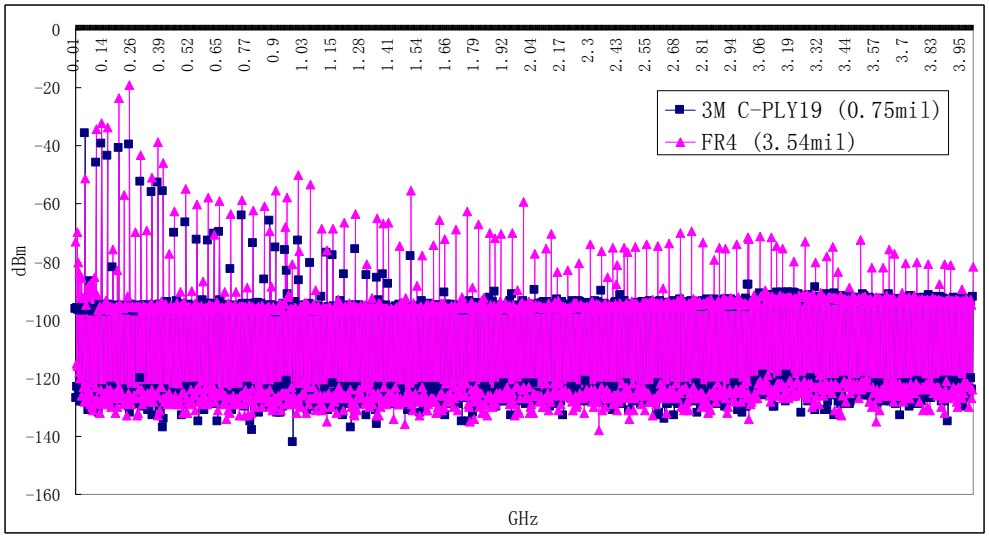
Power Bus Noise (UMR)

Power-Ground Core Material	Nominal Capacitance (nF)	Peak-to-Peak Voltage (mV)
FR-4 (with 33 discrete SMT caps)	330	214
BC2000™ (50 µm)	3	1,740
3M™ Embedded Capacitance Material (5 µm)	107	89

Comparison of Power Bus Noise on 6-Layer Board



Power ripple noise comparison in time domain

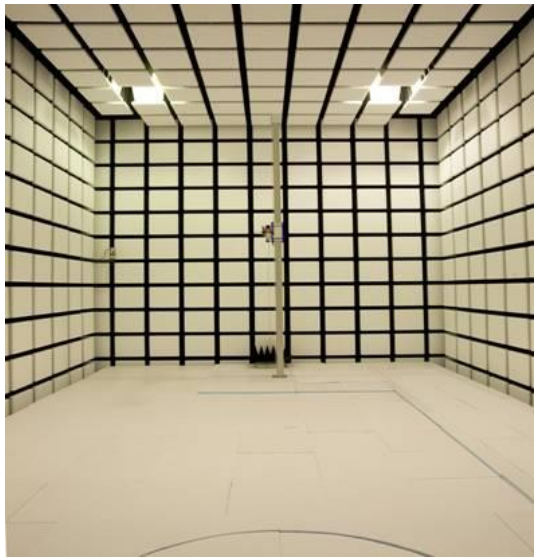


Power noise frequency spectrum comparison

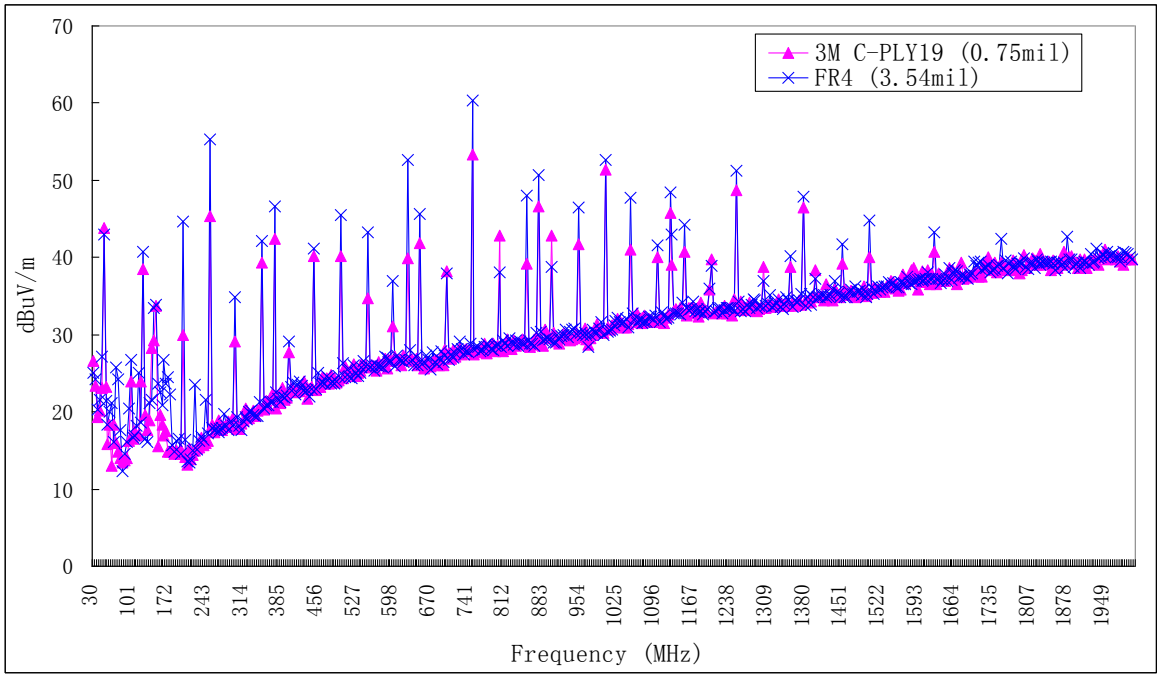
- Power noise ripple of FR4 board is much higher than the 3M™ Embedded Capacitance Material (ECM) board (156 mV vs. 24 mV)
- ECM board shows superiority over FR4 on noise reduction in entire bandwidth (10MHz-4GHz)
- ECM board noise close to white noise of Spectrum Analyzer in higher frequency over 1.5GHz
- Very promising for ECM to improve power supply quality, digital /analog interference in board and board level EMI

Courtesy of Huawei

Board Level 3M™ Embedded Capacitance Material (ECM) Performance Comparison – Test Result



Full Wave Darkroom

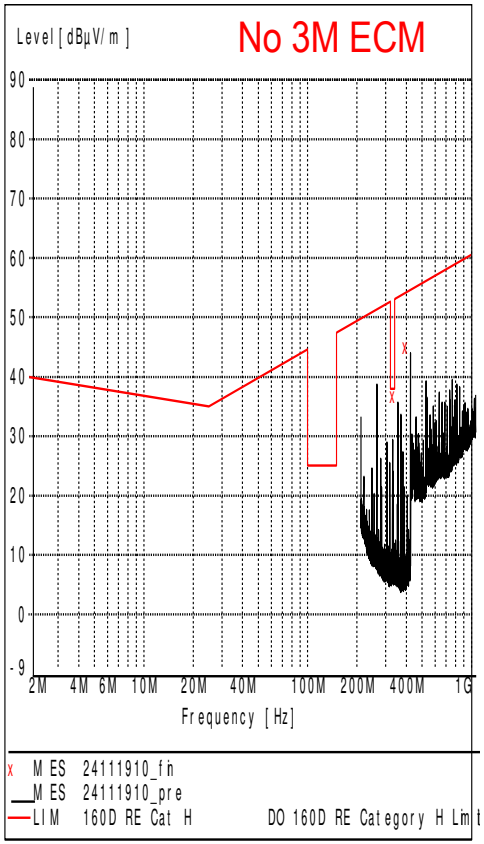


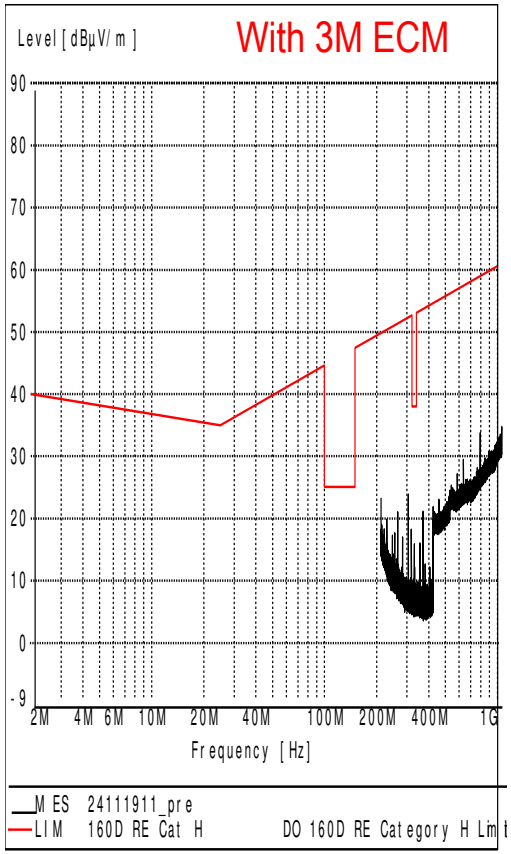
Radiated Emission Test Result （30MHz - 2GHz ）

- Radiated Emission Test in standard full wave darkwave for FR4/ECM board.
- Obvious better performance of ECM board from 30M to 2G (only tested up to 2G)

Courtesy of Huawei

EMI Reduction with use of 3M™ Embedded Capacitance Material (ECM) on Rigid Multi-layer Board in Avionics Application





Courtesy of U.S. Defense Prime Contractor

Electrical Benefits of Ultra-Thin Embedded Distributed Capacitance (Power-Ground)

- Lowers impedance of power distribution system
- Dampens board resonances
- Reduces noise on power plane
- Reduces radiated emissions
- High Dk significantly improves performance compared to same thickness with low Dk

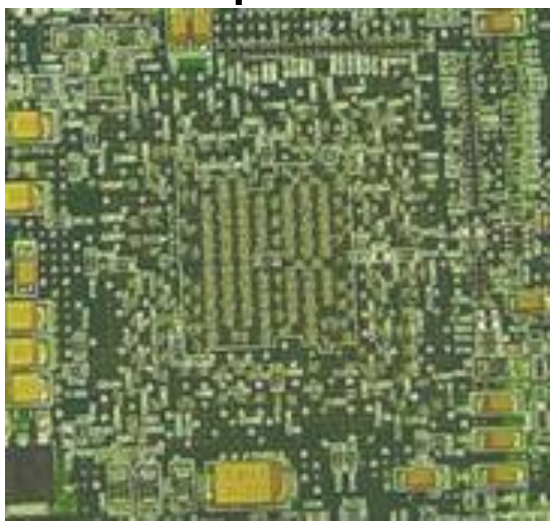
Capacitor Elimination Metrics

Examples of How Many Discrete Caps Can be Replaced per Board Area

Design	Board Layers	No. of 3M ECM Power-Ground Cores	Approx. Board Area (in^2)	Total No. of Caps Removed	Caps Removed per sq in
EDC TV1	6	1	6	33	5.5*
OEM A	12	1	35	126	3.6
OEM B	10	2	17	73	4.3
OEM C	8	2	12	57	4.6
OEM D	14	2	121	529	4.4
OEM F	14	2	~100	443	~4.4*
OEM G	20	2	~80	~660	~8.2

*100% of decoupling caps removed

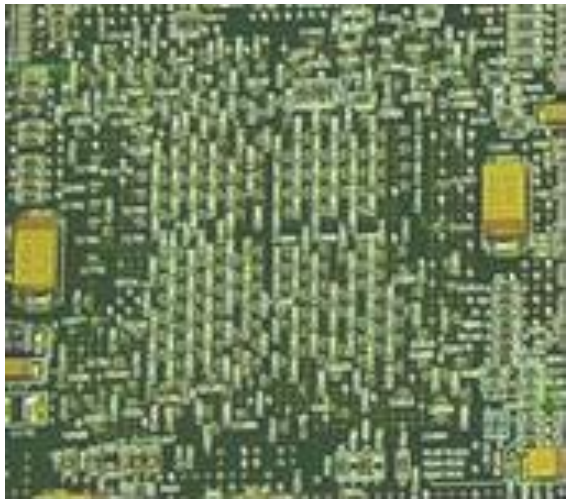
Discrete Capacitor Elimination on Telecom Board



Baseline Design (BGA1)

VS.

Embedded Capacitance Design (BGA1)



Baseline Design (BGA2)

VS.

Embedded Capacitance Design (BGA2)

Cap Elimination Summary

- Surface mounted discrete capacitors are usually ineffective above several hundred MHz
- 3M™ Embedded Capacitance Material (ECM) can replace a large number of discrete decoupling capacitors from the board surface
- Results to-date suggest:
  - Typically ~75% of discrete decoupling capacitors can be removed
  - Typically ~4-8 decoupling caps per square inch can be removed
  - Only 1 – 10% of the amount of SMT capacitance removed is needed due to lower inductance
  - Even when large quantities of SMT caps are removed, electrical performance is still improved

PCB Compatibility

PCB Processing - 1

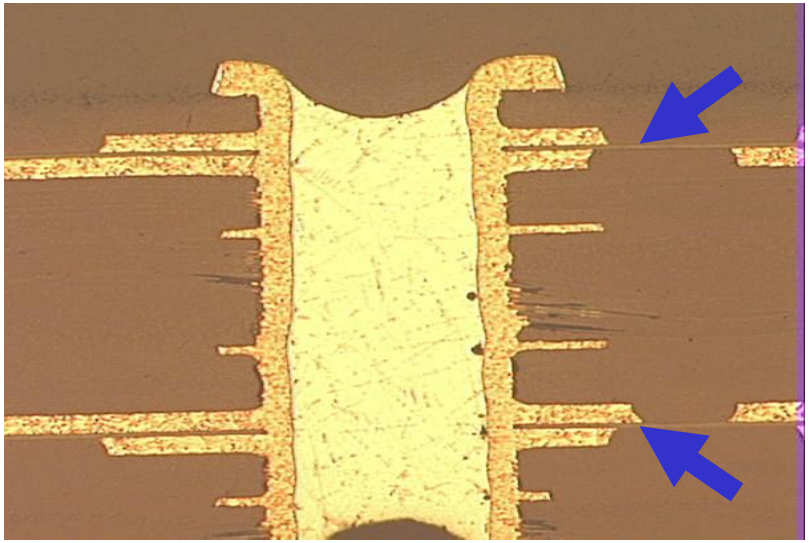
- Compatible with all standard rigid/flex PCB processing (includes laser drill, plasma de-smear and alternative oxides)
- Material handling is most significant issue
  - (compares to bare 2 ounce copper)
- A sequential lamination process is recommended
  - Pattern 1st side copper
  - Laminate patterned side to another layer of prepreg
  - Pattern 2nd side copper
- If a sequential lamination process is utilized, there are no design limitations

PCB Processing - 2

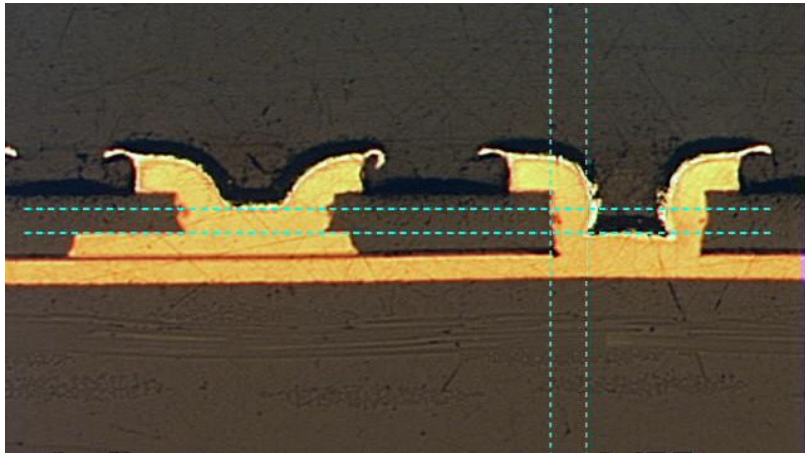
- Typically 1 to 4 cores of material are used in a board stack up (2 is the most common)
- Typical locations in stack up are middle (one core) and layers 2/3 and n-1/n-2 (2 cores)
- Compatible with all common laminate/prepreg materials
  - Low and high Tg FR-4 (Epoxy-Glass)
  - BT/Epoxy
  - Nelco 4000-13/4000-13SI
  - Isola 370 HR
  - PPO/Epoxy (Megtron/Getek®)
  - Embedded Resistor Materials
  - Polyimide Film
  - Thermount® (Polyimide)
  - Polyimide-Glass*
  - Rogers 4450 and 4003
  - Gore Microlam™ 630
  - APPE

*Prepreg materials need max cure temp of 200C for some ECM materials

PCB Fabrication Results



Two 3M™ Embedded Capacitance Material (ECM) laminate cores (8 µm) separated by an FR406 core.



Microvias in test board.

PCB Fabrication and OEM Acceptance

- Many PCB fabricators have successfully fabricated ECM in high volume commercial applications
  - Over 120 PCB fabs have used the material to-date
  - Used by PCB fabs in at least 15 countries to-date (including many in Asia)
  - Material has been used in backplanes, daughter cards, modules, IC packaging and flex circuits
  - Board layer counts from 2 to over 40
  - Boards have been built for military/aerospace, telecom, computer, handheld, IC packaging, automotive, medical, ATE market segments

UL Testing/RoHS

- UL recognition (ECM C0614)

Test	Property	Result
Laminate	Flammability	94V-0
Laminate	Solderability Limits	288ºC/30 sec
Laminate	Relative Thermal Index	130ºC
Board	Flammability	94V-0
Board	Max Operating Temp	130ºC

- RoHS compliant
- Compatible with lead free assembly
- Does not contain bromine
- Halogen-free versions available

Cost Considerations

3M™ Embedded Capacitance Material (ECM)

Cost Reducers and Adders

	Cost Reducers	Cost Adders
Board	Smaller board sizes Reduced layer counts Fewer solder joints/vias	Material costs PCB processing costs Potential lower yields
Board Assembly	Eliminated capacitors Reduced assembly costs Improved yields	
System/Design	Fewer design cycles Faster layouts Eliminated EMI measures Improved reliability, service life	Difficult to alter embedded materials

Cost Conclusions

- Bare board costs will typically increase
- System costs may increase or decrease
  - Design dependant
  - Higher component densities favor embedding
  - Boards with high panel utilization favor embedding
- The technology and supply chain infrastructures have matured greatly; the costs of embedded approaches have declined and opportunities for system cost reduction have expanded greatly compared to several years ago .

Summary

- Ultra-thin/high Dk laminate materials used for power-ground cores (distributed capacitance) offer very significant electrical performance advantages compared to standard FR-4 laminate materials
- Ultra-thin, high Dk dielectric materials also offer many other advantages over standard FR-4 power-ground core laminates
  - Thermal
  - Reliability
  - Component and Space Reduction
  - Regulatory (EMI)
  - Easier/Faster Board Design
- New, even higher C/A products can achieve excellent decoupling and low pass filtering on even extremely small products such as chip packaging , handheld products and microphones

Key Contacts

- Contact us or visit www.3Mcapacitance.com to…
  - Get samples for prototyping
  - Obtain a quote for purchasing
  - Set up a visit and/or conference call with a 3M engineer

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