Barriers to Implementation of High Performance Embedded Capacitance Laminates

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Outline

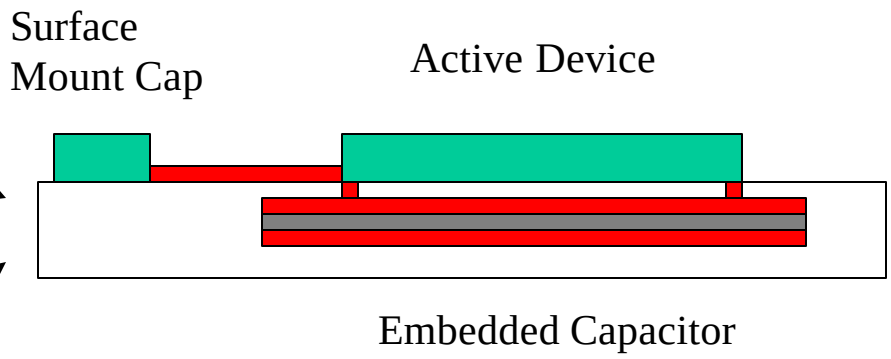
- I. Background
- II. Benefits of Embedded Distributed Capacitance
  - Electrical Performance Improvement/EMI Reduction
  - Space Reduction/Capacitor Replacement
- III. Barriers to Implementation of New Materials
  - PCB Fabrication Compatibility /Reliability
  - Sourcing Requirements/Regulatory
  - Cost
- IV. Summary

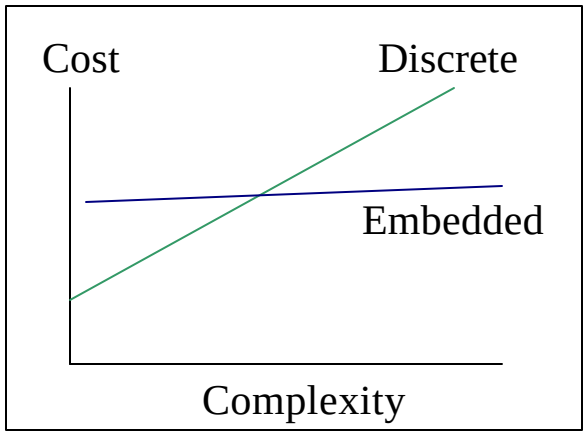
Why Embedded Capacitance?

1. Performance

2. Space

3. Cost

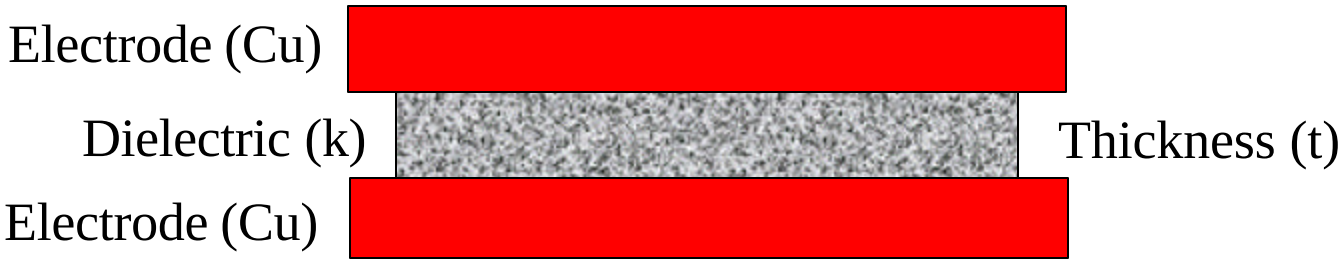




Reasons for Embedded Capacitance

Potential Benefits	Performance	Space	Cost
Faster signaling/Reduce power bus noise	Ö		
Reduce design time & redesigns	Ö		Ö
Eliminate capacitors		Ö	Ö
Reduce layer count			Ö
Enable DS to SS assembly			Ö
Reduce via count		Ö	Ö
Simplify rework			Ö
Reduce board size, thickness		Ö	
Reduce assembly time			Ö
Enable decoupling w/back-side heat sinks	Ö		
Reduce weight	Ö		
Reduce opportunities for damaged components	Ö		Ö
Improve PWB panel utilization			Ö
Reduce EMI	Ö		Ö

Use of Ultra-thin (<25 um) Power-Ground Cores for Embedded Distributed Capacitance



- **Capacitance per unit area (C/A) is proportional to k and inversely proportional to t**
- **Vary C/A by varying thickness (t) or dielectric constant (k)**

3M™ Embedded Capacitor Material Properties

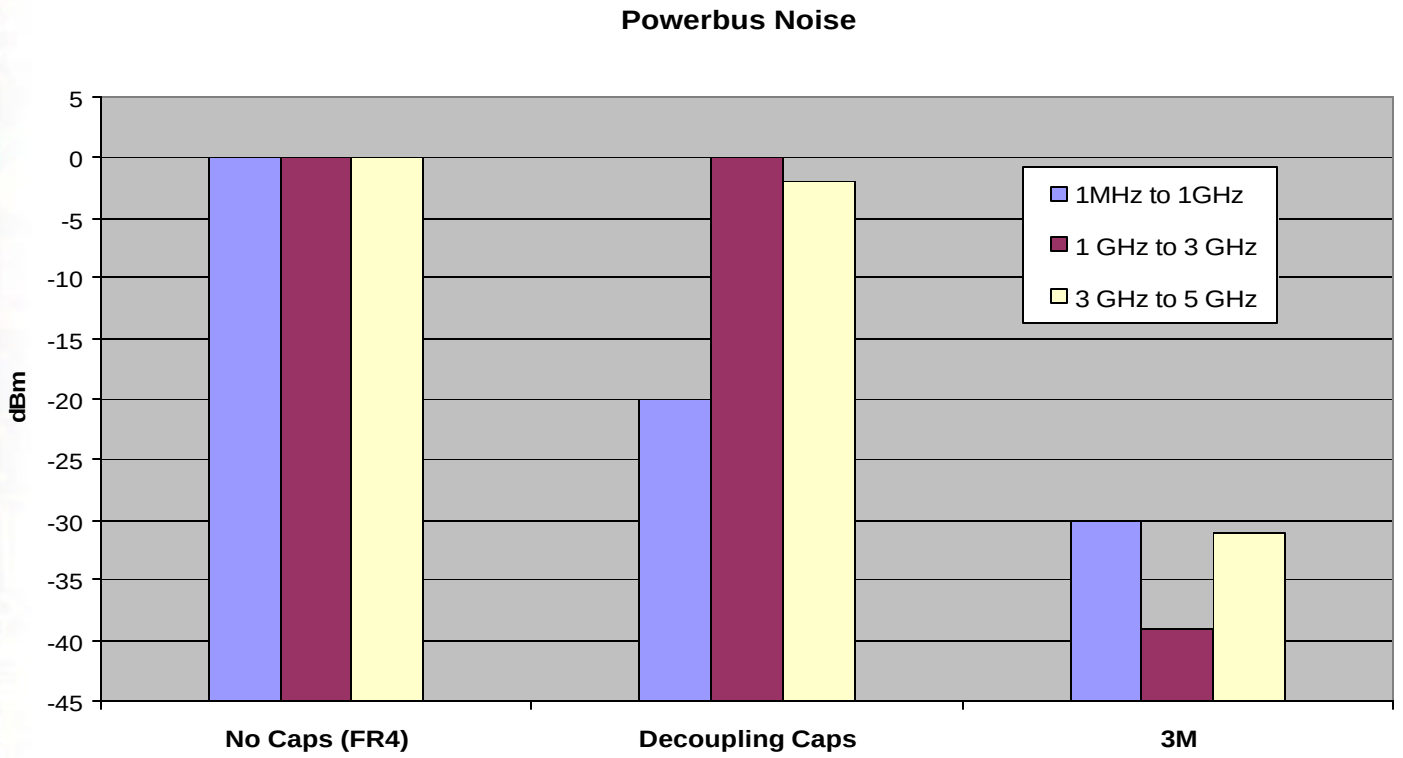
Attribute	Value
Capacitance /area	5.7 nF/in^2
Dielectric Constant	16
Freq., Voltage, Temperature	Meets X7R
Dielectric Strength	~130V/um (~3300V/mil)
Breakdown Voltage	>100V, 250V*
Dielectric Thickness	16 um (0.6 mil)
Copper Thickness	35 um (1.4 mil)
UL Flammability Rating/RTI	94V-0/130C

* In development

Benefits of Embedded Distributed Capacitance

Electrical Performance and EMI Reduction

Power Bus Noise on Test Vehicle



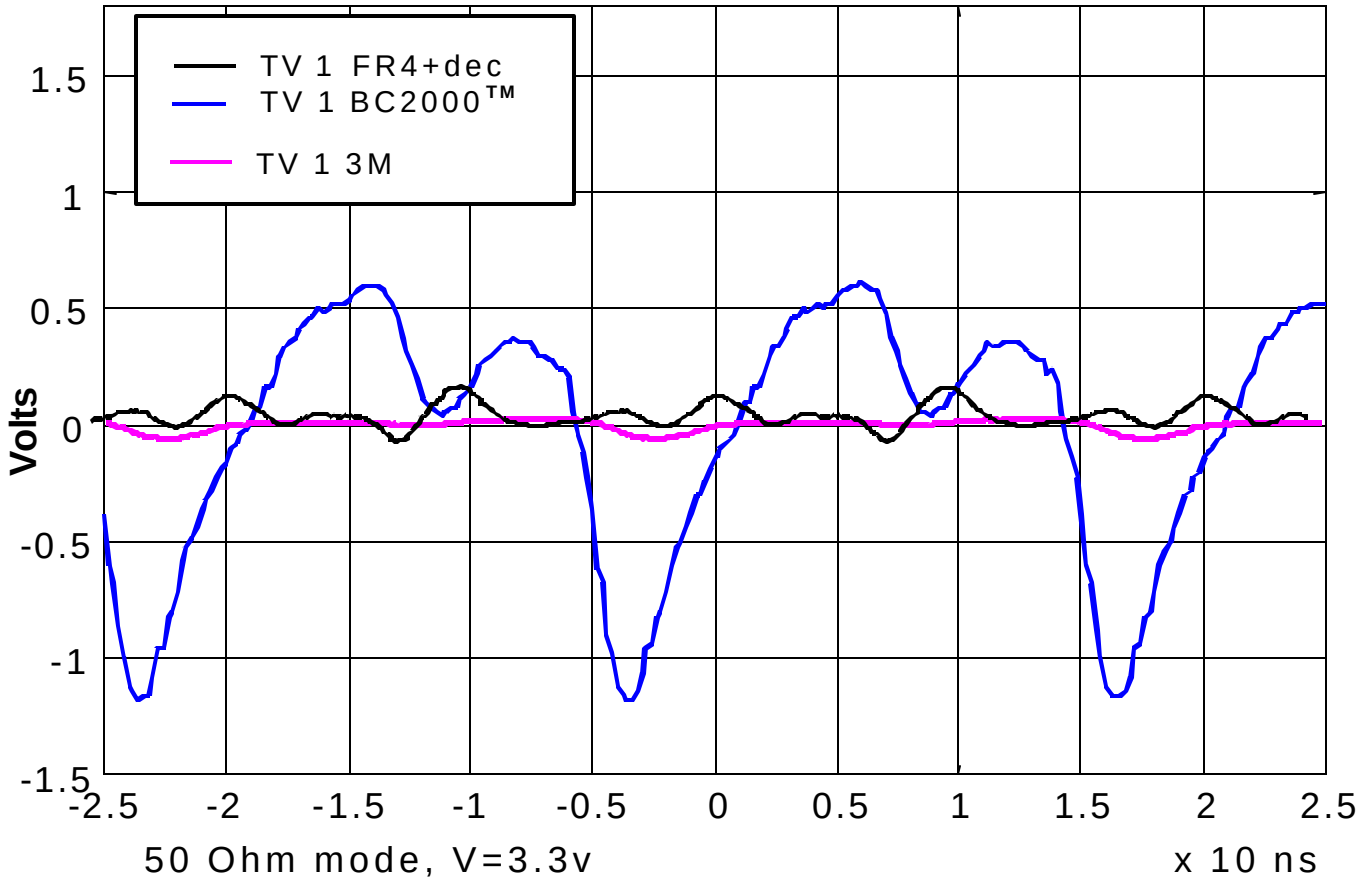
Less Noise

- **Traditional decoupling capacitors are not effective at frequencies above 1 GHz**
- **3M ultra-thin material has excellent performance to 5 GHz**

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

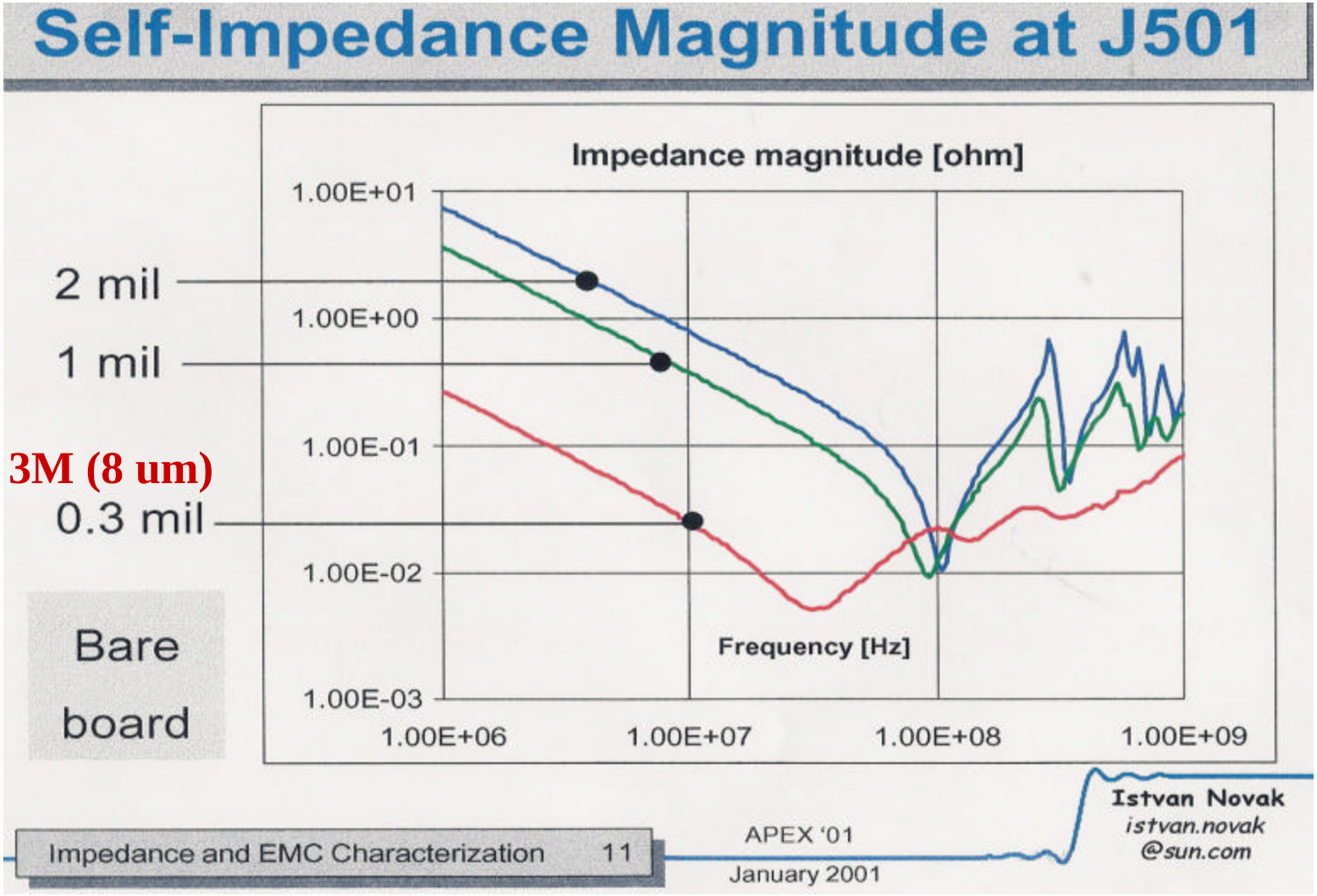
Power Bus Noise

Power-Ground Core Material	Nominal Capacitance (nF)	Peak-to-Peak Voltage (mV)
FR-4 (with 33 discrete SMT caps)	330	214
BC2000™ (50 um)	3	1,740 (did not function)
3M Embedded Capacitance Material (5 um)	107	89

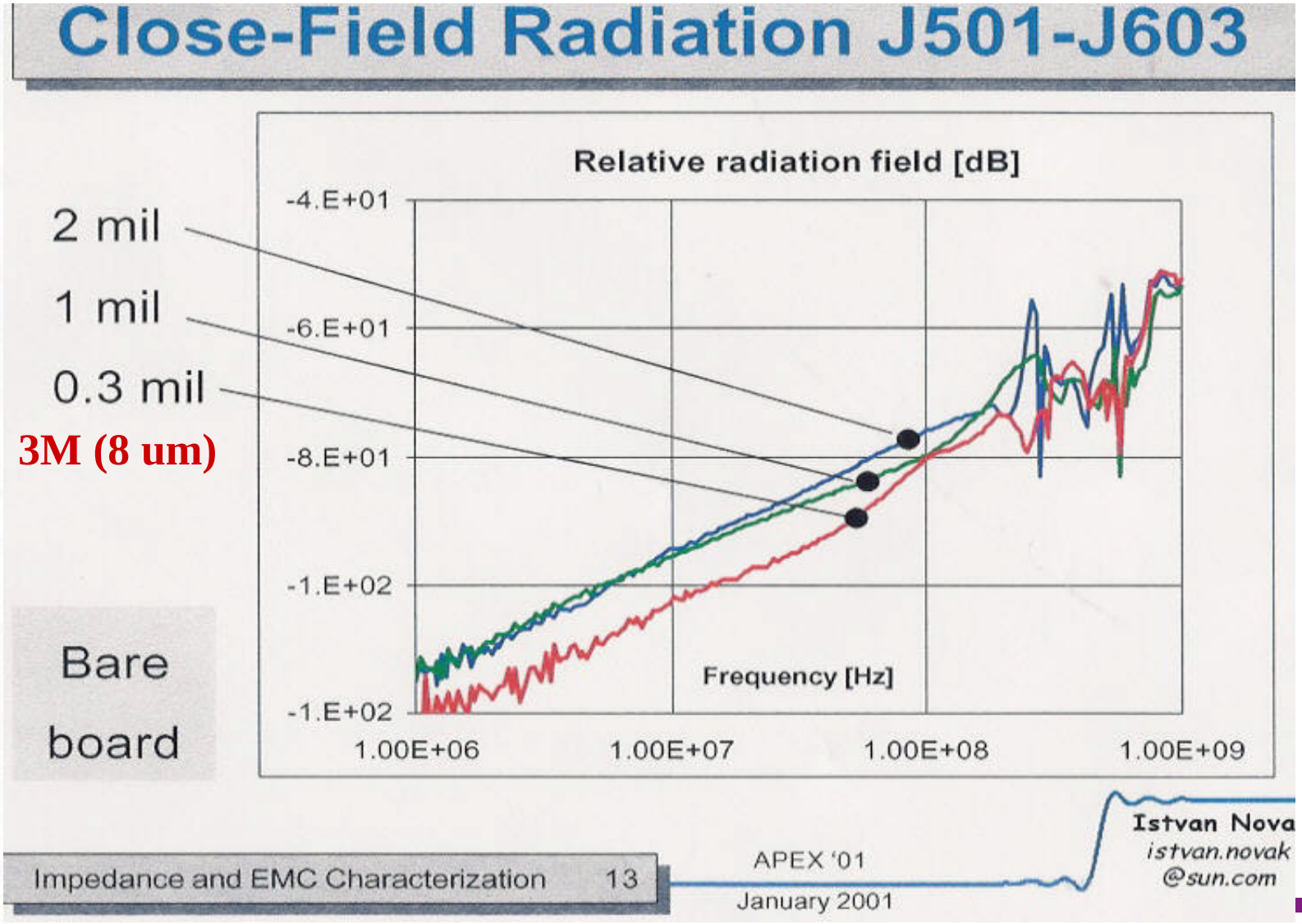
3M material only had one-third the capacitance but cut the noise by more than one-half!

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

Impedance Comparison



Radiated Emissions Comparison

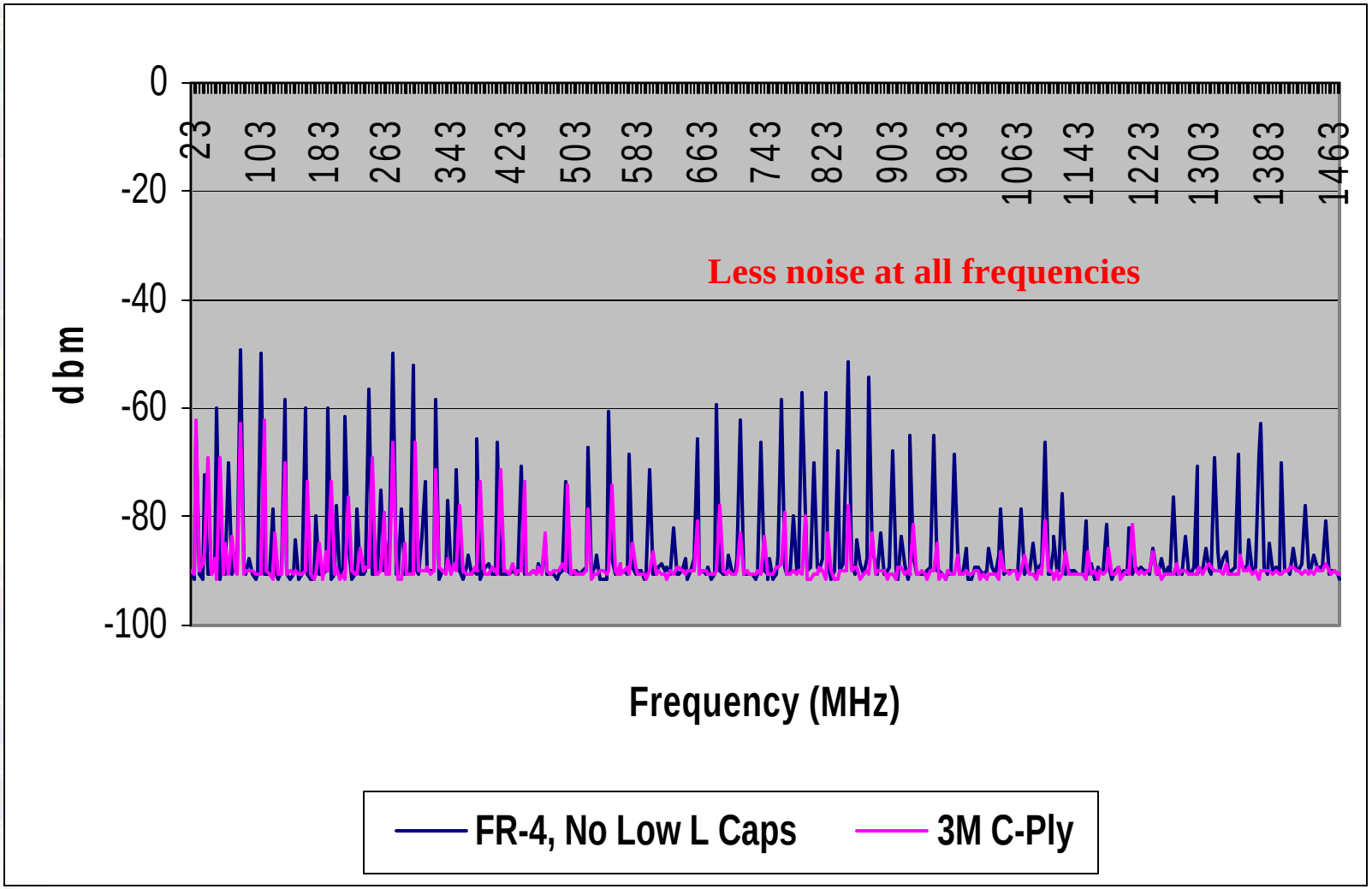


Embedded Capacitor Test Board

(Courtesy of Hewlett Packard)

- **Processor daughtercard**
  - MIPS R14K processor @ 550 MHz
  - 9 Secondary cache SRAM's @ 275 MHz
- **Laminate thickness between power and ground modified**
  - 3 mil FR-4
  - 3M Embedded Capacitor Material, 0.3 mil thickness (8 um)
- **Measurements made on 1.5 volt I/O power distribution**

Power Bus Noise vs. Frequency (H.P.)



H.P. Test Board Noise Levels

3 mil FR-4 without Low L Bypass Caps	0.0 dB
3 mil FR-4 with Low L Bypass Caps	-6.8 dB
3M Embedded Capacitor Material (8 um) without Low L Bypass Caps	-13.3 dB
3M Embedded Capacitor Material (8 um) with Low L Bypass Caps	-13.9 dB

Reduction of ~13 dB with the use of ultra-thin power-ground core

Benefits of Embedded Distributed Capacitance

Space Reduction and Discrete Capacitor Replacement

Examples of Embedded Distributive Capacitance Replacing Discretes

Design	Discrete Capacitance Removed (nF)	Embedded Capacitance (nF)	Ratio of Removed to Embedded	% of Total Discrete Capacitance Removed
EDC TV1	**330** *33 x 0.01 uF*	**105**	**3.1**	**100%**
OEM A	**12,600** *126 x 0.1 uF*	**300**	**42.0**	**>75%**
OEM B	**6,310** *62 x 0.1 uF* *11 x 0.01 uF*	**210**	**30.0**	**>60%**
OEM C	**3,180** *29 x 0.1 uF* *28 x 0.01 uF*	**305**	**10.4**	**>75%**
OEM D	**52,900** *529 x 0.1 uF*	**1970**	**26.9**	**>75%**
OEM E TV	**9,900** *99 X 0.1 **uF***	**660**	**15.0**	**100%**

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 E TV	4	1	120	99	0.8*

*100% of decoupling caps removed

Barriers to Implementation

Barriers: PCB Fabrication Compatibility

PCB Processing Fabrication Using 3M ECM

- Compatible with all standard PCB fabrication (including laser ablation)
- Material handling is the most significant issue
- A sequential lamination process is recommended
  - Pattern 1st side copper
  - Laminate patterned side to prepreg to create subpart
  - Pattern 2nd side copper
- If a sequential lamination process is utilized, there are no design limitations

Barriers: PCB Fabrication Compatibility

- **Numerous fabricators in the U.S., Canada, Taiwan and Korea have successfully fabricated boards utilizing 3M Embedded Capacitor Material**
  - **Over 30 board designs have been manufactured by over 15 fabricators for over 20 different OEMs**
  - **Additional fabricators have demonstrated process capability**
- **Fabricators in Europe, Singapore, China and Hong Kong currently building prototypes**

Barriers: Reliability

- **Large amount of testing on 3M Embedded Capacitor Material to standard industry tests completed with excellent results**
- **Testing completed over an 8 year span**
  - **1996-1999 DARPA Program**
  - **1998-2000 NCMS EDC Consortia**
  - **1999-2003 NIST AEPT Consortia**
  - **2000-2004 Fabricator/OEM Testing**
  - **1996-2004 3M Internal Testing**
- **Testing done on both 8 and 16 um dielectric thickness material**

Reliability Testing on 3M 8 um Dielectric

Test	*Property*	*Result*
High Temp (125°C/25V)	Capacitance Dissipation Factor (D.F.)	No Change (1000 hrs)
Thermal Cycle (-55/125C)	Capacitance/D.F.	No Change (1000 cycles)
Thermal Shock (-40C/125C)	Capacitance	No Change (1000 cycles)
TMA (T260)	Life	>5 minutes**
***THB* (85C/85%RH/15 V)**	Life Capacitance D.F.	>1000 hrs 10-15% Increase* 0.4% to 0.9%*
ESD (2-8 kV)	Capacitance/D.F.	No change
Bend Test	Capacitance/D.F.	No change (200 cycles)
Multiple Reflow (235C; 3X)	Capacitance	No change
Solder Float (288C)	PTH Quality	Pass (MIL-PRF-31032)

***Returned to pre-test level after bake**

****Failure in FR-4, not ECM**

Reliability Testing on 3M 16 um Dielectric

Test	*Property*	*Result*
High Temp (125°C/50V)	Capacitance Dissipation Factor (D.F.) Insulation Resistance	No Change (1000 hrs) No Change (1000 hrs) >1000 Mohm
Thermal Cycle (-40C/125C)	Capacitance	No Change (1000 cycles)
Thermal Shock (-40C/125C)	Capacitance	No Change (1000 cycles)
TMA (T260)	Life	>5 minutes**
***THB* (85C/85%RH/9.5V)**	Life (Insulation Resistance)	>500 hrs (>200 Mohm)
Multiple Reflow (250C; 3X)	Capacitance	No change
Solder Float (288C; 10 sec)(6X)	PTH Quality	Pass (MIL-PRF-31032)
Solder Float (288C; 10 sec)(3X)	Capacitance D.F.	No Change No Change

****Failure in FR-4, not ECM**

Barriers: Sourcing/Regulatory

- **Multiple sourcing is available to PCB fabricators for ultra-thin, filled, high performance embedded capacitor laminate materials**
- **At least one of these materials can currently be manufactured in high volumes**
- **Most of these materials have UL recognition at the laminate level and many have or will have board level recognition in the near future**
- **Some of these materials are compatible with lead-free assembly**

Barriers: PCB Fabrication Sourcing

- Most of the larger North American fabricators have experience with at least one ultra-thin, filled laminate material
- Many smaller fabs who specialize in military products also have experience
- Some domestic suppliers have up to fours years of experience working with these materials
- In the past year or two, numerous offshore fabricators have begun to work with these materials

Barriers: Cost

- Use is being driven by electrical performance and space reduction needs
- Assembled board cost reduction has not and will not be a driving force in the near future for these materials
- This may change as use of these materials increases
- However, in a few cases, cost reduction is currently possible with the use of these materials

Summary

Benefits Summary - 1

- **Surface mounted discrete capacitors are ineffective at high frequencies (~500 MHz+)**
- **Low impedance and high capacitance are ideal for power supply decoupling at high frequencies**
- **Thin dielectric materials significantly dampen noise at high frequencies**
- **Lower power bus noise can result in reduced radiated emissions**

Benefits Summary - 2

- **Ultra-thin, filled laminates used for power-ground cores have the potential to remove most or all of the high frequency decoupling capacitors**
- **Surface mounted discrete capacitance can be effectively replaced by embedded capacitance with only a small fraction of the total discrete capacitance**

Barriers: PCB Compatibility/Reliability

- **Thin, loaded dielectric laminate materials have been shown to be very compatible with standard printed circuit board processing**
- **Numerous fabricators have been successful in building prototype lots and have the capability to produce boards in volume**
- **A large amount of 3M internal and independent testing has shown that thin, loaded epoxy dielectric laminates are reliable**

Barriers: Sourcing/Regulatory

- **Some ultra-thin, filled dielectric laminate can currently be manufactured in high volume**
- **Many PCB fabricators have experience with these materials**
- **Ultra-thin, filled dielectric laminate have UL recognition at both the laminate and board levels**
- **Some ultra-thin, filled dielectric laminates are compatible with lead-free assembly**

Barriers: Cost

- **Embedded distributed capacitance can be very cost-effective on many high performance designs and where space reduction is critical**
- **Cost remains a large barrier, this will change in the future as use becomes more widespread**

3M Commercialization Status

- **16 um dielectric product is available for immediate sale (<5 day lead time), has UL approval, and can be manufactured in volume**
- **Currently sampling to many OEMs and Fabricators for qualification testing**
- **Approximately 6 OEM's have internally qualified 3M Embedded Capacitor Material for use in their products; Additional qualifications in process**

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