Improve Power Delivery and Reduce Noise with Embedded Capacitance
Typical PDN
Why consider it
Types of Embedded Capacitance
Space
Target Impedance/ Low Inductance
Materials
In a PCB
Electrical Performance
Case Studies
PDN in a Multi-Layer PCB

- Capacitor interconnects;
- Individual capacitor values and packaging forms;
- Number of capacitors needed;
- Capacitor placement;
- PCB stack-up;
- Power/ground plane pair geometry;
- Segmentation and isolation

Courtesy of Dr. Jun Fan, MST
Device Switching And Noise Current

IC driver

VCC

charge

IC load

Z0, vp

shoot-through current

logic 0→1

GND

Vnoise

IC 2

IC driver

GND

GND

VCC

IC load

RS

logic 1→0

discharge

VCC

shoot-through current

EMI

I/O line or cable

Current drawn from power

I_{Probe3}, mA

0

20

40

60

80

0

2

4

6

8

10

time, nsec

Why Embedded Capacitance and Thin Dielectrics?

- Better PDN (Power Delivery Network)
- Lower profile
- More design space
- Low inductance
- Low impedance
- Reduced noise
- Thickness reduction
- Can remove most 0.1\(\mu\)f and 0.01 \(\mu\)f decoupling capacitors
- Weight reduction
- Higher reliability
- In some designs better thermal transfer
Background / Motivation

Ultra-Thin Laminate Market Growth

Key Event

1. Of the companies in the survey 30% of their PCB’s are using Embedded Capacitance

2. In 2015 and beyond the expectation are that this will more than double
FaradFlex® Applications

- Routers
- Servers (Cloud computing)
- SSD storage
- Super computers
- Military
- Aerospace
- Drones
- Organic Capacitor chip
  Diplexers, RF Filters
- Medical
- IC testers
- Modules
- MEMS Microphones
  (Size 2.5mmx3.5mm)
- Automotive
Automotive Applications

Vehicle communication with each other and surrounding infrastructure traffic information like accidents, traffic jams, incoming emergency vehicles, and weather information, among other things

- Electronic Toll Collection
- Cooperative Adaptive Cruise Control
- Intersection Collision Avoidance
- Approaching Emergency Vehicle Warning
- Automatic Vehicle Safety Inspection
- Transit or Emergency Vehicle Signal Priority
- Electronic Parking Payments
- Commercial Vehicle Clearance
- In-Vehicle Display of Road Signs and Billboards
- Traffic Data Collection
- Rail Intersection Warning
Sensors and Controls for **Intelligent Operating**

- LIDAR
- Radar
- Thermal
- Ultrasonic
- Sonar
- Camera
- Air Bag Sensors
- GPS
- Night Vision
Microphone Substrates

courtesy of Yole
Types of Embedded Capacitance

Planar Layers in PCB

Use this in an existing stack up of layers in the PCB

Pros
- Easy
- Addresses many issues with PCB design and power delivery
- Same or lower cost
- More reliable

Cons
- Limited capacitance currently available

Discrete in PCB cavity

Leave a cavity open in the PCB and then place the capacitor and solder in place and then fill the cavity

Pros
- Full values of capacitance available

Cons
- Manufacturing and design difficulty
- Costly
- Less reliable
What is a Planar Capacitor?

Conductive plane pair with dielectric separation

Upper conductor

S

d

Lower conductor

Dielectric material: $\varepsilon_r$

1. Polymer film and resin combination (Dupont and Oak-Mitsui)
2. Unsupported resin filled with high Dk or other types of particles (3M and Oak-Mitsui)

$C = \frac{K D_k S}{d}$

- $C$ = Capacitance (Farads)
- $S$ = Area of plates
- $D_k$ = Dielectric constant of material between plates
- $K$ = Constant
- $d$ = Thickness between plates
Component density is reaching its limit

High capacitance and capacitance uniformity are key

Source: Richard Ulrich University of Arkansas
8 Layer HDI Design

With Decoupling Caps

Without Decoupling Caps

With shared planar embedded capacitance

Courtesy of Gary Ferrari, FTG
14 Layer Design

With Decoupling Caps

Without Decoupling Caps

With shared planar embedded capacitance

Courtesy of Gary Ferrari, FTG
Discrete Capacitors on a Distributed Capacitor Plane

Courtesy of Gary Ferrari, FTG
Two Approaches to Embedded Capacitance

**Solution**

**High speed computing boards**
Servers, Routers, Switches, computers

Power distribution improvement

**Module boards**
Microphones, Cell phones, sensors, filters, tablets, controls

Miniaturization / HDI

**Ultra-Thin substrate**
for use as embedded capacitor

25 to 8 micron Polymer Dielectric

[Copper Foil]

**Hi-Dk RCF**
for use as embedded capacitor

16 to 2 micron Polymer Dielectric with Hi-Dk Filler
FaradFlex® greatly reduces power buss noise and eliminates the need for many decoupling capacitors.
FaradFlex® Compared to Traditional Material

- FaradFlex® is ½ to 1/6 the thickness compared to the typical “thinnest” laminate using glass cloth reinforcement.
- FaradFlex® increases thermal transfer from the PCB due to the ultra thin power-ground substrate.
- Dielectric withstanding voltage is typically 10 times better with FaradFlex® than the traditional FR-4 laminates and similar materials.
Power Distribution Network Simulations
Resonance/Noise/EMI
Why *FaradFlex®* Can Reduce EMI

1. Can minimize loop area \( (E_r = 1.316 \times 10^{-14} \times I \times f^2 \times S/r) \)

2. Can minimize power bus noise

3. Can minimize resonance

4. Can minimize propagation to the edge
   (Related to Transfer Impedance (S21))

\[ E : \text{Electric Field Strength} \]
\[ I : \text{Normal Mode Current} \]
\[ f : \text{Frequency} \]
\[ S : \text{Loop Area} \]
\[ r : \text{Distance} \]
## Standard Dk Products

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test Method</th>
<th>MC24M</th>
<th>MC12M</th>
<th>MC8M</th>
<th>MC25L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Thickness, μm</td>
<td>IPC or others</td>
<td>22</td>
<td>12</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>Cp @ 1 MHz, nF/in² (pF/cm²)</td>
<td>Nominal</td>
<td>1.2 (180)</td>
<td>1.9 (300)</td>
<td>3.1 (480)</td>
<td>1.0 (130)</td>
</tr>
<tr>
<td>Dk (Dielectric Constant) @ 1 MHz/1 GHz</td>
<td>IPCTM-650 2.5.5.2</td>
<td>4.4/3.5</td>
<td>4.4/3.5</td>
<td>4.4/3.5</td>
<td>3.9/3.8</td>
</tr>
<tr>
<td>Df (Loss Tangent) @1 MHz/1 GHz</td>
<td>IPCTM-650 2.5.5.2</td>
<td>0.015/0.016</td>
<td>0.015/0.020</td>
<td>0.016/0.021</td>
<td>*0.004/0.005</td>
</tr>
<tr>
<td>Peel Strength, lbs/ linear in.</td>
<td>IPCTM-650 2.5.5.2</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Dielectric Strength, kV/ mil</td>
<td>IPCTM-650 2.4.9</td>
<td>&gt;7</td>
<td>&gt;7</td>
<td>&gt;5</td>
<td>&gt;7</td>
</tr>
<tr>
<td>Tensile Strength, MPa (kpsi)</td>
<td>ASTM D-882A</td>
<td>219 (31.8)</td>
<td>194 (28.2)</td>
<td>126 (18.3)</td>
<td>227 (32.9)</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>ASTM D-882A</td>
<td>36.0</td>
<td>13.5</td>
<td>8.5</td>
<td>47.0</td>
</tr>
<tr>
<td>CTE, ppm/°C, x-y (40-200 °C), TMA</td>
<td>TMA</td>
<td>24</td>
<td>23</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>Tg, °C</td>
<td>DMA</td>
<td>183</td>
<td>187</td>
<td>188</td>
<td>161</td>
</tr>
<tr>
<td>Dielectric Withstanding Voltage</td>
<td>IPCTM-650 2.5.7.2</td>
<td>PASS (500V)</td>
<td>PASS (500V)</td>
<td>PASS (500V)</td>
<td>PASS (500V)</td>
</tr>
<tr>
<td>(Hi-Pot test)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Stress (20 Sec Float @288°C),</td>
<td>--</td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Times</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH8, 85°C/85% RH/ dc bias</td>
<td>1000 hr</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>Flammability/Temp Rating</td>
<td>UL</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
</tr>
<tr>
<td>PWB Processing</td>
<td>--</td>
<td>Both sides</td>
<td>Both sides</td>
<td>Both sides</td>
<td>Both sides</td>
</tr>
</tbody>
</table>

Note: This chart provides typical values for FaradFlex products.

*Low loss material*
## High Dk Products

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test Method</th>
<th>MC12TM</th>
<th>MC8TM</th>
<th>MC8T</th>
<th>MC25ST</th>
<th>MC25LD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Thickness, μm</td>
<td>IPC or others</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>C&lt;sub&gt;p&lt;/sub&gt; @1 MHz, nF/in&lt;sup&gt;2&lt;/sup&gt; (pF/cm&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>Nominal</td>
<td>4.2 (650)</td>
<td>7.1 (1100)</td>
<td>22 (3400)</td>
<td>4.3 (660)</td>
<td>2.1 (320)</td>
</tr>
<tr>
<td>Dk (Dielectric Constant) @ 1 MHz/1 GHz</td>
<td>IPC TM-650 2.5.5.2</td>
<td>10.0/9.5</td>
<td>10.5/10.0</td>
<td>30.0/25.0</td>
<td>18.5/18.0</td>
<td>8.3/7.8</td>
</tr>
<tr>
<td>Df (Loss Tangent) @ 1 MHz/1 GHz</td>
<td>IPC TM-650 2.5.5.2</td>
<td>0.015/0.020</td>
<td>0.020/0.021</td>
<td>0.025/0.031</td>
<td>0.004/0.008</td>
<td><em>0.0027/0.0032</em></td>
</tr>
<tr>
<td>Peel Strength, lbs/linear in.</td>
<td>IPC TM-650 2.5.5.2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Dielectric Strength, kV/mil</td>
<td>IPC TM-650 2.4.9</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tensile Strength, MPa (kpsi)</td>
<td>ASTM D-882A</td>
<td>153 (22.2)</td>
<td>127 (18.4)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>ASTM D-882A</td>
<td>31.4</td>
<td>14</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CTE, ppm/°C, x-y (40-200 °C), TMA</td>
<td>TMA</td>
<td>28</td>
<td>22</td>
<td>17 (a1) 42 (a2)</td>
<td>32 (a1) 97 (a2)</td>
<td>55</td>
</tr>
<tr>
<td>Tg, °C</td>
<td>DMA</td>
<td>189</td>
<td>191</td>
<td>191</td>
<td>160</td>
<td>215</td>
</tr>
<tr>
<td>Dielectric Withstanding Voltage (Hi-Pot test)</td>
<td>IPC TM-650 2.5.7.2</td>
<td>PASS (500V)</td>
<td>PASS (250V)</td>
<td>PASS (100V)</td>
<td>PASS (100V)</td>
<td>PASS (100V)</td>
</tr>
<tr>
<td>Thermal Stress (20 Sec Float @288 °C), Times</td>
<td>-</td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>&gt;6</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>THB, 85 °C/85% RH/ dc bias</td>
<td>1000hr</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>Flammability/Temp Rating</td>
<td>UL</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
<td>V0 130°C</td>
</tr>
<tr>
<td>PWB Processing</td>
<td>-</td>
<td>Both sides</td>
<td>Both sides</td>
<td>Sequential</td>
<td>Sequential</td>
<td>Sequential</td>
</tr>
</tbody>
</table>

*Note: This chart provides typical values for FaradFlex products.
*Low loss material*
## Solutions for Modules, Packages and RF

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unit</th>
<th>MC12LD</th>
<th>MC8TM</th>
<th>MC5TM</th>
<th>MC12ST</th>
<th>MC16T</th>
<th>MC8T</th>
<th>MC3TS</th>
<th>MC2TS</th>
<th>MC3TA</th>
<th>MC8TD 2 BC</th>
<th>MC2TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Thickness</td>
<td>μm</td>
<td>12</td>
<td>8</td>
<td>5</td>
<td>12</td>
<td>16</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Capacitance @1 KHz</td>
<td>nF/n²</td>
<td>4.2</td>
<td>7</td>
<td>8.5</td>
<td>11</td>
<td>11</td>
<td>22</td>
<td>35</td>
<td>40</td>
<td>40</td>
<td>44</td>
<td>50</td>
</tr>
<tr>
<td>Dk (Dielectric Constant) @1 KHz</td>
<td></td>
<td>7.4</td>
<td>10.5</td>
<td>9.5</td>
<td>25.1</td>
<td>30</td>
<td>24</td>
<td>18</td>
<td>18</td>
<td>22</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Df (Loss Tangent) @1 KHz</td>
<td></td>
<td><strong>0.002</strong></td>
<td>0.020</td>
<td>0.023</td>
<td>0.005</td>
<td>0.030</td>
<td>0.020</td>
<td>0.020</td>
<td>0.030</td>
<td>TBD</td>
<td>0.030</td>
<td>TBD</td>
</tr>
<tr>
<td>Breakdown Voltage &gt;than</td>
<td></td>
<td>150</td>
<td>1000</td>
<td>1000</td>
<td>180</td>
<td>500</td>
<td>250</td>
<td>150</td>
<td>50</td>
<td>100</td>
<td>250</td>
<td>50</td>
</tr>
<tr>
<td>Peel Strength</td>
<td>kN/m</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Thermal Stress @288°C x 20 Sec Float x 6 Times</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>TBD</td>
<td>Pass</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Tg (DMA0 *reference only)</td>
<td>°C</td>
<td>170</td>
<td>191</td>
<td>191</td>
<td>170</td>
<td>191</td>
<td>191</td>
<td>191</td>
<td>191</td>
<td>TBD</td>
<td>191</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Note: This chart provides typical values for FaradFlex® products.

*Low loss material

Higher Dk/ Thinner/ Higher Capacitance
First Type of Embedded Capacitance Laminate

Laminate constructed with:
- Copper
- Epoxy or other type resin bonded to a high performance polymer film

Includes these products:
MC24M, MC12M, MC8M, MC25L

Characteristics
- Most cost effective
- Best processability
- Longest in history
- Highest reliability
Second Type of Embedded Capacitance Laminate

Laminate constructed with:
- Copper
- Unsupported epoxy resin with barium titanate or other particles dispersed in the resin

Includes these products:
MC16T, MC25ST, MC25LD

Characteristics
- Most costly laminate
- Highest Dk
- Lowest reliability
- Least processability
- Highest Capacitance
Third Type of Embedded Capacitance Laminate

Laminate constructed with:

- Copper
- Supported epoxy resin and polymer film composite, barium titanate particles or other material dispersed

Includes these products:
MC12TM, MC8TM

Characteristics

- Mid to more costly laminate
- Very High Dk
- High reliability
- High level of processability
- Very high capacitance
- High withstanding voltage
Ultra-Thin substrate for use as power distribution layer

Construction of ultra-thin substrate

- Copper foil
- Dielectric layer using film 8 to 24 um
- Copper foil
Typical PCB Design and Stack - Up
Replace existing power/ground layers with FaradFlex® for use as power distribution layer

10 layer stackup with 2 power-ground layers at L2/L3 and L8/L9 (using FaradFlex® in the power-ground allows for embedded capacitance)
Stack-Up Example (2)

PCB 6 layer construction

PCB 4 layer construction

PCB 3 layer construction

FARADFLEX

PREPREG

COPPER
26 layer board was fabricated using MEGTRON6 and *FaradFlex*

MC24M 2/2 in the center layers
MC24M1/1 in the outer 2 layers

Core: MEGTRON6 1078 RTF x 2ply core H/H oz
Prepreg: MEGTRON6 1035KD + 1078KF 2 ply
Between center FF–FF, MEGTRON6 1035KD 2ply
PCB Fabrication/Processing
<table>
<thead>
<tr>
<th>Standard Etching for MC8TM</th>
<th>Sequential Etching for MC8T, MC12ST, MC25LD, MC12LD</th>
</tr>
</thead>
<tbody>
<tr>
<td>To etch both sides of the thin core material at the same time</td>
<td>To etch one side of the thin core material, laminate into a subpart, then etch the second side</td>
</tr>
</tbody>
</table>

**Standard Etching for MC8TM**

**Step 1**
- Cu foil (35μm)

**Step 2**
- Ethching on both side

**Sequential Etching for MC8T, MC12ST, MC25LD, MC12LD**

**Step 1**
- Cu foil (18μm)

**Step 2**
- DES process on one side

**Step 3**
- Laminate that side into a subpart
- Part of core/board prepreg

**Step 4**
- Image and etch the second side

Oak-Mitsui Technologies LLC Confidential July 18, 2016
Reliability
<table>
<thead>
<tr>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>6x Through Hole Solder Shock</td>
<td>PASS</td>
</tr>
<tr>
<td>6x Blind Via Solder Shock</td>
<td>PASS</td>
</tr>
<tr>
<td>Dielectric Thickness per Cross Section within +/-10%</td>
<td>PASS</td>
</tr>
<tr>
<td>T-288 (&gt;20min)</td>
<td>PASS</td>
</tr>
<tr>
<td>IST Testing (500 cycles)</td>
<td>PASS</td>
</tr>
<tr>
<td>Core Level Hi-Pot Testing 100 Cores (100V/sec; 500Vmax)</td>
<td>PASS</td>
</tr>
<tr>
<td>Finished Circuit Level Hi-Pot 50 circuits (100V/sec; 500Vmax)</td>
<td>PASS</td>
</tr>
</tbody>
</table>

Courtesy of Sanmina-SCI
Improved Impedance/Inductance
Bare Board Impedance Measurement

MEASURE $S_21$ BY DIRECT STIMULUS INJECTION INTO THE COPPER PLANES

4 LAYER TEST BOARD CROSS SECTION VIEW

Courtesy of Oracle
Discrete capacitors of 0.1µF have a resonance frequency of about 15 MHz. Discrete capacitors of 0.01µF have a resonance frequency of about 40 MHz.

### PCB Electrical Performance

#### Significant Reduction of Impedance

<table>
<thead>
<tr>
<th>Product</th>
<th>nF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZBC2000</td>
<td>16</td>
</tr>
<tr>
<td>ZBC1000</td>
<td>32</td>
</tr>
<tr>
<td>MC24M</td>
<td>40</td>
</tr>
<tr>
<td>MC8M</td>
<td>124</td>
</tr>
<tr>
<td>MC12TM</td>
<td>180</td>
</tr>
<tr>
<td>MC16T</td>
<td>440</td>
</tr>
</tbody>
</table>

**Panel Size:** 50 in²  
80% Retained Cu

Thinner Dielectrics and Higher DK = Lower Impedance

Resonant Frequency

Dk Effect
Resonances occur above 200 MHz

Panel Size = 50 in²
80% Retained Cu

<table>
<thead>
<tr>
<th>Product</th>
<th>nF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZBC2000</td>
<td>16</td>
</tr>
<tr>
<td>ZBC1000</td>
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</tr>
<tr>
<td>MC24M</td>
<td>40</td>
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</tr>
<tr>
<td>MC12TM</td>
<td>180</td>
</tr>
<tr>
<td>MC16T</td>
<td>440</td>
</tr>
</tbody>
</table>
PCB Electrical Performance (Up to 25 GHz)

18”x18” Z11 Simulated

Freq [GHz]

ZMag [Ohm]

Curves:
- FR4
- MTL C
- MC25L
- MC8M
- MC8TM
- MC12M
- MC12TM
- MC24M
- ZBC2000

MTL C 18”x18” Z11 Simulated

PCB Electrical Performance (Up to 25 GHz)
Power/Ground Plane Simulation

- Utilize EMIStream/PIStream
  - Developed by NEC
  - Based on PEEC method with Spice Simulation
- Input PCB Layout in Design File (xxx.dsn)
  - Output provided by standard PCB layout tools (Mentor Graphics, Cadence, Zuken, etc.)
- Select thickness, Dk and Cu thickness of P/G planes
- Select frequency range
- Can add/remove discrete decoupling capacitors

Partial Element Equivalent Circuit Model for Power/GND Plane Pair
PI Simulation with EMIStream

Conditions: 18 Layer, Size (7.5” x 9.5”), 3.3V Plane, 1 – 1000 MHz (1 MHz Step), 1 oz. Cu, Core 24 mil thickness

Normal Core (24 mil) with 580 De-Caps
Normal Core (24 mil) without De-Caps
FaradFlex® (MC24M: 1 mil) without De-Caps

Spectrum Chart of plane resonance

Courtesy of NEC & TOYOTech
For RF Applications
High DK and/or Low Df

Fig. 1. Low dielectric loss (DF) FaradFlex, “ST” & “LD” series for RF module

Main application:
→ WiMAX FEM: LPF, BPF, Diplexer
→ WiFi RF module

Fig. 1. Low dielectric loss (DF) FaradFlex, “ST” & “LD” series for RF module
Dk & DF vs Frequency (1 GHz – 10 GHz)

Fig. Dk and DF vs frequency at GHz of FaradFlex materials
Electrical Benefits
Reduced Jitter/Improved “Eye”
Using FaradFlex
MC24M
MC12TM
or MC8TM

Courtesy of Samtec and Teraspeed
PDS Impedance Profile
0402 Capacitors with 4 mil Deep Planes
Various Plane Thicknesses on 6” x 6” PCB

Reduction in dielectric thickness decrease impedance, but also lowers resonance frequency.

Reduction in dielectric thickness increases magnitude of peaks.

Increase in material Er lowers resonance frequency.

Courtesy of Samtec and Teraspeed
SerDes Filtering Comparison

PowerPoser™ SerDes Filtering

Xili filtering

Courtesy of Samtec and Teraspeed
Courtesy of Samtec and Teraspeed

Design uses all Xilinx mandated linear power supplies and ferrite filter networks for MGT SerDes.
Xilinx Filter Network with SMPS Performance @ 3.125 Gbps

Courtesy of Samtec and Teraspeed

Without Power Poser
Using FaradFlex MC12TM as the key layer in the Interposer
### PCB Construction of Reference Board

<table>
<thead>
<tr>
<th>No</th>
<th>Layer</th>
<th>Thickness [mm]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Signal</td>
<td>0.057</td>
<td>Include Plating</td>
</tr>
<tr>
<td></td>
<td>prepreg</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gnd (Plane)</td>
<td>0.032</td>
<td></td>
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<tr>
<td></td>
<td>core</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Signal</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td></td>
<td>prepreg</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td></td>
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<td></td>
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<td>5</td>
<td>Vdd (Plane)</td>
<td>0.032</td>
<td></td>
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<tr>
<td></td>
<td>core</td>
<td>0.15</td>
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<tr>
<td>6</td>
<td>Signal</td>
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<td>prepreg</td>
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<tr>
<td>7</td>
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<td>core</td>
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<td></td>
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<td>8</td>
<td>Signal</td>
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<tr>
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<td>prepreg</td>
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<td>Signal</td>
<td>0.032</td>
<td></td>
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<td>core</td>
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<tr>
<td>10</td>
<td>Vdd (Plane)</td>
<td>0.032</td>
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<tr>
<td>11</td>
<td>Gnd (Plane)</td>
<td>0.032</td>
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<tr>
<td></td>
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<tr>
<td>12</td>
<td>Signal</td>
<td>0.032</td>
<td></td>
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<tr>
<td></td>
<td>core</td>
<td>0.15</td>
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<tr>
<td>13</td>
<td>Gnd (Plane)</td>
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<td></td>
</tr>
<tr>
<td>14</td>
<td>Signal</td>
<td>0.057</td>
<td>Include Plating</td>
</tr>
</tbody>
</table>

Total thickness: 2.368 mm ± 0.2 mm

(Courtesy of NEC System Technology, Inc. & NEC Information Technology, Inc.)
Distant Place Magnetic Field Measurement

- Antenna direction is Horizontal (Horizontal Polarized Wave Measurement)
- Antenna direction is Vertical (Vertical Polarized Wave Measurement)

(Source: Noise Laboratory)
Comparison Between Reference Board with Caps and FaradFlex® without Caps

![Comparison Between Reference Board with Caps and FaradFlex® without Caps](image-url)
NCR-TERADATA Case Study
Board Stack-Up

Current Stackup

Total Copper:
Power – 3oz
GND – 3 oz

Emb Capacitance Stackup

Total Copper:
Power – 3oz
GND – 5 oz

781 0.1\mu F decoupling capacitors
Capacitance Measurement

<table>
<thead>
<tr>
<th>Plane Pair</th>
<th>FR-4 (nF)</th>
<th>MC24M (nF)</th>
<th>MC12M (nF)</th>
<th>MC12TM (nF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5V/GND</td>
<td>76.1 (75.8)</td>
<td>179.5 (179.0)</td>
<td>286.7 (266)</td>
<td>487 (478)</td>
</tr>
<tr>
<td>3.3V/GND</td>
<td>21.2 (21.2)</td>
<td>323.8 (321.3)</td>
<td>551 (541)</td>
<td>1148 (1082)</td>
</tr>
</tbody>
</table>

*From LCR Meter*

*Extracted from VNA*

Note: 1.5V plane is split resulting in smaller capacitor area.

Replaces 78.1 μF of capacitance on standard board (781 capacitors of 0.1 μF)

(Courtesy of Univ. of Missouri at Rolla)
The embedded capacitance materials replaces 781 capacitors of 0.1 μF on the standard FR-4 board.
The embedded capacitance materials replaces 781 capacitors of 0.1 μF on the standard FR-4 board.
Harris Case Study
The Embedded Passive Journey

IPC/APEX – April 2, 2008
Authors:
Bill Devenish – Harris Corp., Mechanical Advanced Development (MAD)
Andrew Palczewski – Harris Corp., PCB Technologist
Passive Discrete Components

Used with the permission of Harris Corporation
## Component Cost

<table>
<thead>
<tr>
<th></th>
<th>Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part Cost</strong></td>
<td></td>
</tr>
<tr>
<td><strong>CAPACITORS</strong></td>
<td>$1.19</td>
</tr>
<tr>
<td><strong>RESISTORS</strong></td>
<td>$9.77</td>
</tr>
<tr>
<td><strong>Cost of Quality</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Component</strong></td>
<td><strong>Body</strong></td>
</tr>
<tr>
<td><strong>CAPACITORS</strong></td>
<td>$4.04</td>
</tr>
<tr>
<td></td>
<td>0603</td>
</tr>
<tr>
<td></td>
<td>0402</td>
</tr>
<tr>
<td><strong>RESISTORS</strong></td>
<td>$11.06</td>
</tr>
<tr>
<td></td>
<td>0201</td>
</tr>
<tr>
<td></td>
<td>0402</td>
</tr>
<tr>
<td><strong>Assembly Cost</strong></td>
<td>$11.82</td>
</tr>
<tr>
<td><strong>Total Parts</strong></td>
<td>591</td>
</tr>
</tbody>
</table>
Reduce PCB Size

*FaradFlex®* embedded capacitance and embedded resistance shrinks PCB Size

### Original panelization - 16 up

- **Size**
  - Panel 18.0” x 24.0”
  - Array 5.6” x 5.524”
  - Part 4.54” x 2.15”
- **Panel Yield**
  - 8 Arrays of 2 Parts
  - 16 Parts Total
  - 57.3% Material Utilization
- **Matrix**
  - On panel 2 x 4
  - Origin X3.35 YD.802
  - On Array 1 x 2
- **Spacing**
  - On panel 0.1” x 0.1”
  - On Array 0.1” x 0.1”
- **Panel Borders**
  - Left 3.35” Right 3.35”
  - Top 0.802” Bottom 0.802”

### Revised panelization - 40 up

- **Size**
  - Panel 18.0” x 24.0”
  - Array 8.0” x 4.42”
  - Part 3.4” x 1.61”
- **Panel Yield**
  - 10 Arrays of 4 Parts
  - 40 Parts Total
  - 81.9% Material Utilization
- **Matrix**
  - On panel 2 x 5
  - Origin XD.95 YD.75
  - On Array 2 x 2
- **Spacing**
  - On panel 0.1” x 0.1”
  - On Array 0.4” x 0.4”
- **Panel Borders**
  - Left 0.95” Right 0.95”
  - Top 0.75” Bottom 0.75”

Used with the permission of Harris Corporation
### Analysis Results:

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Embedded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board Width (inches)</td>
<td>2.5</td>
<td>2.42</td>
</tr>
<tr>
<td>Board Length (inches)</td>
<td>4.0</td>
<td>3.87</td>
</tr>
<tr>
<td>Number Up</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Number of Layers</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Panelization Efficiency</td>
<td>0.69</td>
<td>0.69</td>
</tr>
</tbody>
</table>

- **Component Cost Difference**: -11.11
- **Assembly Cost Difference**: -19.41
- **Board Price Difference**: 4.52
- **System Total Cost Difference**: -26.0

Positive values (red) indicate increases in cost when passives are embedded.

Negative values (green) indicate decreases in cost when passives are embedded.

---

**Courtesy of Harris Corp. and CALCE**
Other FaradFlex Benefits
**Lifetime Test Comparison**

*FaradFlex® Embedded Capacitors vs Surface Mount Discrete*

**150°C 650V, Raw Data**

Start Date: 8/12/14  
Start Time: 15:00

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fail Date</th>
<th>Fail Time</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC24M-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-10</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>MC24M-11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC24M-16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PCBs using discrete surface mount capacitors**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fail Date</th>
<th>Fail Time</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>100V-1</td>
<td>11/8/14</td>
<td>8:00</td>
<td>2105.00</td>
</tr>
<tr>
<td>100V-2</td>
<td>10/24/14</td>
<td>13:00</td>
<td>1750.00</td>
</tr>
<tr>
<td>100V-3</td>
<td>11/5/14</td>
<td>18:00</td>
<td>2043.00</td>
</tr>
<tr>
<td>100V-4</td>
<td>10/4/14</td>
<td>13:30</td>
<td>1270.50</td>
</tr>
<tr>
<td>100V-5</td>
<td>11/13/14</td>
<td>10:25</td>
<td>2227.42</td>
</tr>
<tr>
<td>100V-6</td>
<td>10/8/14</td>
<td>1:30</td>
<td>1354.50</td>
</tr>
<tr>
<td>100V-7</td>
<td>9/23/14</td>
<td>4:30</td>
<td>997.50</td>
</tr>
<tr>
<td>100V-8</td>
<td>9/29/14</td>
<td>2:00</td>
<td>1139.00</td>
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<tr>
<td>100V-9</td>
<td>10/21/14</td>
<td>4:00</td>
<td>1669.00</td>
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<tr>
<td>100V-10</td>
<td>10/28/14</td>
<td>0:50</td>
<td>1833.83</td>
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<td>100V-11</td>
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<td>5:45</td>
<td>1910.75</td>
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<td>100V-12</td>
<td>10/22/14</td>
<td>14:00</td>
<td>1703.00</td>
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<td>100V-13</td>
<td>10/9/14</td>
<td>21:15</td>
<td>1398.25</td>
</tr>
<tr>
<td>100V-14</td>
<td>10/23/14</td>
<td>1:45</td>
<td>1714.75</td>
</tr>
</tbody>
</table>

PCBs using *FaradFlex®* for embedded capacitance

All the *FaradFlex®* embedded capacitors and test boards are still running with no failures

**Typical Failure Mode of MLCC**

There were no 50V chip caps included

All of the discrete surface mount capacitors test boards and all the capacitors have failed.
The regression equations for the 1 mil embedded capacitance (MC24M) characteristic life and for the 100ppm failure rate, estimates at 150°C for these failure rates can be calculated for any voltage below 800V on this material.

Characteristic life (hours) = $2.062672E+06(Voltage^{-0.6891})$ Equation 1
Considering a long field history for 12V and below, the characteristic life for 12V at 150°C as 372,191.5 hours which is approximately **42.5 years**. This is **over 10x longer Lifetime than PCB’s with surface mount capacitors** at the same conditions.

100ppm failure rate (hours) = $1.404739E+06(Voltage^{-0.6891})$ Equation 2
Similarly, the 100ppm estimated failure rate (Equation (2)) would not occur until 253,473 hours, which is approximately **28.9 years**.

It would be **highly unusual** for the field environment to exceed 130°C which is the UL rated MOT (Maximum Operating Temperature) **for most FR4** and similar printed circuit board materials. It becomes very clear why field failures would be highly unusual for the 1 mil embedded capacitance( MC24M) materials.
Performance: Thermal Stability

Embedded Capacitance Core

-------------------------

FaradFlex 1.5 to 3 times better heat transfer due to thinness

Thinner dielectric provides better heat transfer to copper

Standard Core

-------------------------
### Capacitor Material vs. FR4

#### Enhanced when combined with Ohmega Material

<table>
<thead>
<tr>
<th>Properties</th>
<th>NiP/Capacitor Core</th>
<th>NiP Core FR-4 (control)</th>
<th>Remarks and Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet Resistivties (ohm/square)</td>
<td>25</td>
<td>25</td>
<td>Nominal</td>
</tr>
<tr>
<td>Material Tolerance</td>
<td>+/-5%</td>
<td>+/-5%</td>
<td></td>
</tr>
<tr>
<td>Load Life Cycling Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistor Size: 0.500&quot; X 0.050&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaded: (Δ R%) @ 150mW</td>
<td>&lt;0.9 after 3200 hrs.</td>
<td>&lt;5</td>
<td>MIL-STD-202-108I</td>
</tr>
<tr>
<td>Unloaded: (Δ R%)</td>
<td>&lt;0.74 after 3200 hrs.</td>
<td>5</td>
<td>On Cycle: 1.5 hrs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Off Cycle: 1.5 hrs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Length Of Test: 10000 hrs</td>
</tr>
<tr>
<td>Current Noise Index in dB</td>
<td>&lt;=-23</td>
<td>&lt;=-15</td>
<td>MIL-STD-202-308</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Voltage Applied: 5.6 Volts</td>
</tr>
<tr>
<td>Humidity Test (Δ R%)</td>
<td>0.5</td>
<td>0.5</td>
<td>MIL-STD-202-103A</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Temp: 40 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Relative Humidity: 95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time: 240 hrs</td>
</tr>
<tr>
<td>Characteristic (RTC) PPM/°C</td>
<td>-6.0</td>
<td>50</td>
<td>MIL-STD-202-304</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot Cycle: 25 °C, 50 °C, 75 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cold Cycle: 25 °C, 0 °C, -25 °C, -55 °C</td>
</tr>
<tr>
<td>Thermal Shock (Δ R%)</td>
<td>0.2</td>
<td>-0.5</td>
<td>MIL-STD-202-107B</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No of Cycles: 25</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Hot Cycle Temp: 125 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cold Cycle Temp: -65 °C</td>
</tr>
<tr>
<td>Solder Float (Δ R%)</td>
<td></td>
<td></td>
<td>MIL-STD-202-210D</td>
</tr>
<tr>
<td>After 1 Cycle</td>
<td>-0.4</td>
<td>0.5</td>
<td>Temp: 260 °C</td>
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<tr>
<td>After 5 cycles</td>
<td>-0.6</td>
<td>0.5</td>
<td>Immersion: 20 Second</td>
</tr>
<tr>
<td>Power Density (mW/mil²) derated at 50%</td>
<td>0.45</td>
<td>0.15</td>
<td>Step-up Power Test</td>
</tr>
</tbody>
</table>

3X better power density through resistor due to better heat conductivity of FaradFlex

Synergistic Effect!

Courtesy of Bruce Mahler of Ohmega
**Conclusion**

- **Embedded Capacitor** can improve system price/performance by
  - Reducing discrete capacitors
  - Reducing PCB size
  - Increasing functionality
  - Improving Power Distribution
  - Improving Signal integrity
- **Thinner Power Distribution Planes** are required for improved impedance performance at high frequency
- New substrates have demonstrated *excellent electrical performance* and physical properties.
- They are *compatible* with PCB processing; a truly “drop in” material.
- Materials are commercially available from many fabricators
- Substrates filled with ferroelectric particles have better performance, but result in higher cost PCBs
- **GREEN** and lead free solution
FaradFlex® ADVANTAGES

- Broadest lineup of products
- Delivery is 1 week or less in US and Asia
- Local sales and technical support in US and Asia
- Highest quality material compared with competitive materials (no foreign material)
- Best panel size flexibility for PCB Designs
- Most copper weight options
- Lowest profile copper available used ONLY on FaradFlex®
- Reliability: All panels HIPOT tested by Oak-Mitsui prior to shipment
Email:  
Robert Carter, VP of Business Development and Technology  
robert.carter@oakmitsui.com  
Eriko Yamato, FaradFlex® Marketing Manager  
eriko.yamato@oakmitsui.com  
Yuji Kageyama, President  
yuji.kageyama@mitsui-kinzoku.co.jp  

Additional information available at  
www.faradflex.com
How can FaradFlex® Optimize PDN and Reduce Noise?

Answer: “Ask Bob”