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Evaluation Technology of Practical Electric Properties for High Frequency Materials

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Printed Wiring Board Materials Business Sector

Hitachi Chemical Co., Ltd.
Trend of high-Speed & high-frequency applications

**Frequency band**
- **RF/Wireless (Mobile, ITS, Wireless-LAN/Access, etc)**
  - VICS (2.45 GHz)
  - GPS (1.5 GHz)
  - PDC:2G (1.5 GHz)
  - W-CDMA:3G (2 GHz)
  - ITS (5.8 GHz)
  - ACC (24/60/76~79 GHz)
  - HSPA: 3.5G (2 GHz)
  - Core2 Duo (2.66 GHz)
  - Pentium IV/D (3.6 GHz)
  - Pentium IV (1.4~2.5 GHz)
  - Pentium III (0.45~1.3 GHz)
  - Pentium II (233~450 MHz)
  - Pentium (66~233 MHz)
  - PCI(33 Mbps/ch, Parallel)
  - PCI-Express (2.5 Gbps/ch, Serial)
  - PCI-Express-H (5 Gbps/ch, Serial)
  - PCIE-Ex.-H (5 Gbps/ch, Serial)
  - CPU (5 Gbps)

**Transmission speed**
- **CPU** (10 Gbps (Optical/Electronic Interconnection?))
- **Backplane**
- **High-speed digital (Server, Router, HPC, etc) / High-layer**
- **TACS/PDC:1G (800 MHz)
- IMT-Advanced:4G (3~5 GHz?)**
- **VICS** (2.45 GHz)
- **GPS (1.5 GHz)**
- **AHS (5.8 GHz)**
- **HSPA: 3.5G (2 GHz)**
- **Core2 Duo (2.66 GHz)**
- **Pentium IV/D (3.6 GHz)**
- **Pentium IV (1.4~2.5 GHz)**
- **Pentium III (0.45~1.3 GHz)**
- **Pentium II (233~450 MHz)**
- **Pentium (66~233 MHz)**
- **PCI(33 Mbps/ch, Parallel)**
- **PCI-Express (2.5 Gbps/ch, Serial)**
- **PCI-Express-H (5 Gbps/ch, Serial)**
- **PCIE-Ex.-H (5 Gbps/ch, Serial)**
- **CPU (5 Gbps)**

**Trend of high-Speed & high-frequency applications**

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Hitachi Chemical's evaluation technology

Hitachi Chemical can satisfy various evaluation requirements

Dielectric properties of materials

- Parallel Plate Capacitance
- Cavity Resonator Perturbation
- Split Post Dielectric Resonator
- Whispering-Gallery Mode

Frequency [GHz]

Practical electrical properties of PCB

- Strip Line Resonator
- SPP
- Strip Line
- Microstrip Line

Dk/Df, Attenuation
Transmission loss (=ATT) + Environmental test

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### Evaluation methods of dielectric properties

<table>
<thead>
<tr>
<th>Subject</th>
<th>Material</th>
<th>PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Cavity Resonator Perturbation</td>
<td>Strip Line Resonator</td>
</tr>
<tr>
<td></td>
<td>Split Post Dielectric Resonator</td>
<td></td>
</tr>
<tr>
<td>Freq.</td>
<td>1 ~ 20 GHz</td>
<td>50 ~ 100 GHz</td>
</tr>
<tr>
<td></td>
<td>w/o conductor</td>
<td>1 ~ 30 GHz</td>
</tr>
<tr>
<td>Sample form</td>
<td>w/o conductor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stick</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness : ~ 1 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Width: 1~2 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Length: 80 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>w/o conductor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sheet / board</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness : ~ 0.5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Width : 10 ~ 130 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>w/o conductor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness : ~ 2 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diameter : 30 ~ 60 mm</td>
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</tr>
<tr>
<td></td>
<td>w/o conductor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strip line</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thickness : ≥1.0mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Characteristic impedance: 50 Ω</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>JIS C-2565</td>
<td>Under planning</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>IPC-TM-650 2.5.5.5.1 JPCA-TM001-2007</td>
</tr>
</tbody>
</table>

- Various methods exist to evaluate dielectric properties of materials and PCBs.
- Usable frequency band and sample form are different.
PCB materials have anisotropy because of difference of Dk between resin and glass cloth.

Suitable methods are utilized to evaluate anisotropic dielectric properties and practical electric properties of materials depending on frequency band and application of materials.
Strip Line Resonator

Vector Network Analyzer

SMA Connector

IN

OUT

Sample

Conductor (Copper)

Ground

Dielectric Material

Signal Line

Dielectric Material

Ground

Pile up

Fixure

IN OUT

SMA Connector

Sample

Conductor (Copper)

Ground

Dielectric Material

Signal Line

Dielectric Material

Ground

Periodic resonance frequencies

Transmission curve, $S_{21}$

Calculation $\Rightarrow$ Dk

Calculation $\Rightarrow$ Attenuation, Df

(Original conversion method)

• Frequency domain method
• Capable of measuring properties of thermal drift and moisture absorption drift
Dielectric properties (vs. frequency)

< Measurement conditions >
/ Method: Strip Line Resonator by Vector Network Analyzer/JPCA TM001/IPC-TM-650_2.5.5.5.1
/ Temperature & humidity: 25 °C/ 60 %RH
/ Laminate thickness: 0.8 mm (signal-ground distance: 0.8 mm), copper foil: 18 μm
/ Line width: 1 mm

Good stability of dielectric properties in wide frequency bands
Dielectric properties (vs. moisture absorption)

< Measurement conditions >
/ Method: Strip Line Resonator by Vector Network Analyzer/JPCA TM001/IPC-TM-650 2.5.5.5.1
/ Moisture treatment condition: PCT(121°C/0.22 MPa)-1~5 h
/ Temperature : 25 °C
/ Laminate thickness: 1.6 mm (signal-ground distance: 0.8 mm), copper foil:18 μm
/ Line width: 1 mm

Stable Dk & Df against PCT treatment compared with FR-4
**Dielectric properties (vs. temperature)**

*< Measurement conditions >*

/ Method: Strip Line Resonator by Vector Network Analyzer/JPCA TM001/IPC-TM-650 2.5.5.5.1
/ Temperature: -30~90°C
/ Laminate thickness: 1.6 mm (signal-ground distance: 0.8 mm), copper foil: 18 µm
/ Line width: 1 mm

![Graph showing dielectric properties vs. temperature](image)

Good stability of dielectric properties against temperature
### Test vehicle / SMASPP2z

<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency</th>
<th>FX-2</th>
<th>HE-679G</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Resin rich, PF</td>
<td>Resin poor, LP</td>
</tr>
<tr>
<td>Dk</td>
<td>1 GHz</td>
<td>3.12</td>
<td>3.48</td>
</tr>
<tr>
<td></td>
<td>3 GHz</td>
<td>3.11</td>
<td>3.47</td>
</tr>
<tr>
<td></td>
<td>10 GHz</td>
<td>3.09</td>
<td>3.45</td>
</tr>
<tr>
<td></td>
<td>20 GHz</td>
<td>3.09</td>
<td>3.44</td>
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<tr>
<td>Df</td>
<td>1 GHz</td>
<td>0.0050</td>
<td>0.0054</td>
</tr>
<tr>
<td></td>
<td>3 GHz</td>
<td>0.0053</td>
<td>0.0058</td>
</tr>
<tr>
<td></td>
<td>10 GHz</td>
<td>0.0053</td>
<td>0.0062</td>
</tr>
<tr>
<td></td>
<td>20 GHz</td>
<td>0.0064</td>
<td>0.0074</td>
</tr>
</tbody>
</table>

- Hitachi Chemical is certificated as an evaluator of SPP
- SPP assessment is useful to accelerate R&D of materials because we can know performance of materials including influence of copper foils
**Measurement system**

![Measurement system diagram](image)

- VNA
- Multiplier
- Coaxial cables
- Multiplier
- Horn Antenna
- Waveguide to coax transitions
- Dielectric waveguides
- Sample disk
- Wave absorber

**Resonance wave form**

![Resonance wave form graph](image)

**Dielectric properties (at 60 GHz)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Dk</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE-679G</td>
<td>4.16</td>
<td>0.0096</td>
</tr>
<tr>
<td>LZ-71G</td>
<td>3.68</td>
<td>0.0069</td>
</tr>
<tr>
<td>FX-2</td>
<td>3.52</td>
<td>0.0039</td>
</tr>
<tr>
<td>E-700G(R)</td>
<td>4.61</td>
<td>0.0101</td>
</tr>
<tr>
<td>E-800G(L)</td>
<td>3.91</td>
<td>0.0078</td>
</tr>
</tbody>
</table>

Dielectric properties can be measured in millimeter wave band.
Evaluation of PCB (SL)

Measurement of Strip line

Test board (up to 20 GHz)

Test board (up to 40 GHz)

VNA

Coaxial cable

Connector

Test board

VNA

Probe station

Test board
Transmission loss of Strip line

<Measurement condition>
/ Structure: strip line
/ Equipment: VNA
/ Calibration: TRL

Capable of evaluating strip line up to approximately 40 GHz
Evaluation of PCB (MSL)

- Evaluation system for semi-microwave ~ milliwave properties

- TEG PWB for evaluation (microstrip line structure)
Transmission properties

Transmission loss (1 ~ 90GHz, S21@MSL)

< Measurement conditions >
/ Structure: microstrip line
/ Temperature & humidity: 25℃/40%RH
/ Characteristic impedance: 50 Ω
/ Calibration: TRL
/ Dimension parameters
  • Line width(w): 0.2 ~ 0.22 mm
  • Dielectric thickness(b): 0.1 ~ 0.13 mm
  • Copper thickness(t): 18 μm
  • Line length: 10 mm & 20 mm
  • Surface treatment of copper: Ni(4 μm)/Au(0.5 μm) plating

Copper foil (15 μm) + Ni(4 μm) / Au(0.5 μm)
High frequency materials have good stability of transmission loss against temperature.
Influence of heat-processing

Effective Dk can be calculated from phase

Drift of Effective Dk can be evaluated in millimeter wave band

- Line width ($w$): 0.2 ~ 0.22 mm
- Dielectric thickness ($b$): 0.1 ~ 0.13 mm
- Copper thickness ($t$): 18 μm
- Line length: 10 mm & 20 mm
- Surface treatment of copper: Ni(4 μm)/Au(0.5 μm) plating

Phase (vs. frequency)

Frequency (GHz)

Drift

$\Delta D_{\text{eff}}$ (calculated from $\Delta$phase)

Processing time (hr)
Drift property of transmission loss and Dk (MSL)

Influence of humidity absorption

- Transmission loss (dB/cm@76.5GHz) vs. Processing time (hr/C-85/85)
- S11 (dB) vs. Frequency (GHz)
- ΔDk (Calculated from Δf) vs. Processing time (hr/C-85/85)
Simulation technology

- 3D EM field solver (Ansys HFSS)
- Circuit simulator (Agilent ADS)

/ Guessing of electrical performance, combination of structures, and the most suitable materials

/ Designing of measurement terminals for evaluation of transmission properties to W-band, 100 GHz

/ Guessing of dielectric drift properties, $\Delta\varepsilon$, by fitting calculated resonance properties, $S_{11}$, to measured $S_{11}$
Reliability of FX-2 (update)
IST result after Pb-free

Layer count : 24 layers  
PCB thickness : 3.1 mm  
Test temp.: 150°C +/- 3°C in 3 minutes  
Criteria of failure: more than 10% change of resistance

<table>
<thead>
<tr>
<th>Drill hole size</th>
<th>Pre-conditioning</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.010”</td>
<td>AS IS</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td></td>
<td>4X (260°C)</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td></td>
<td>6X (260°C)</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td>0.0135”</td>
<td>AS IS</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td></td>
<td>4X (260°C)</td>
<td>&gt; 1,000</td>
</tr>
<tr>
<td></td>
<td>6X (260°C)</td>
<td>&gt; 1,000</td>
</tr>
</tbody>
</table>

$n = 6pnl$

Good through-hole connection reliability
CAF evaluation of high layer count board

/ Total thickness: 4.1 mm (28 layer board)
/ Wall-Wall Spacing: 0.40 mm, 0.50 mm, about 2,000 holes
/ Precondition: 85°C/85%RH/120 h + Reflow 260°C X 10 times
/ Measurement condition: 85°C/85%RH DC100 V
/ The measurement of insulation resistance in chamber

Hitachi Chemical original pattern
Results of CAF evaluation

Measurement condition: 85°C/85%RH DC100V,
The measurement of insulation resistance in chamber

Wall-Wall Spacing: 0.4 mm

Wall-Wall Spacing: 0.5 mm

Good CAF restraining property
Transmission loss of modified FX-2

<Measurement condition>
/ Structure: Strip line
/ Equipment: VNA
/ Calibration: TRL

Line width: 180~200 μm
Cu thickness: 18 μm

Equal to conventional FX-2
# Road map of Hitachi high frequency PWB materials

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>High-end digital (High-speed &amp; High-layer)</strong></td>
<td>300 Mbps~1 Gbps</td>
<td>1.25~2.5 Gbps</td>
<td>3.2~6.4 Gbps</td>
<td>~10 Gbps</td>
<td>&gt;10 Gbps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission rate/Link (Backplane) (Mobile)</td>
<td>&lt;2.4 kbps</td>
<td>9.6~144 kbps</td>
<td>2 Mbps</td>
<td>3.8 Mbps</td>
<td>5.7 Mbps</td>
<td>7.2 Mbps</td>
<td>&gt;10 Mbps</td>
<td></td>
</tr>
<tr>
<td>High-end Router</td>
<td>High-end Server</td>
<td>Transport</td>
<td>Super computer</td>
<td>IC tester</td>
<td>Measuring equipment</td>
<td>BTS (Sgnl.-Pros.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dk&lt;3.8/Df&lt;0.005</strong></td>
<td><strong>Dk&lt;3.7 Df&lt;0.003</strong></td>
<td><strong>Dk&lt;3.5 Df&lt;0.002</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LX-67/LX-67Y</td>
<td>LZ-71G</td>
<td>FX-2/FX-3</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Dk:3.5/Df:0.005</td>
<td>Dk:3.6/Df:0.006</td>
<td>Dk:3.2-3.5/Df:0.0025-0.0028</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Middle ~ Low digital (High-speed &amp; High-layer)</strong></td>
<td>1.25~2.5 Gbps</td>
<td>3.8 Mbps</td>
<td>5.7 Mbps</td>
<td>7.2 Mbps</td>
<td>&gt;10 Mbps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dk&lt;4.5/Df&lt;0.025</strong></td>
<td><strong>Dk&lt;4.5/Df&lt;0.018</strong></td>
<td><strong>Dk&lt;4.0/Df&lt;0.01</strong></td>
<td><strong>Dk&lt;3.8 Df&lt;0.007</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dk:4.0/Df:0.02</td>
<td>Dk:4.5/Df:0.01</td>
<td>Dk:4.3/Df:0.018</td>
<td>Dk:4.0/Df:0.009</td>
<td>Dk:3.7/Df:0.007</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>RF/Wireless (Analog high-Freq.)</strong></td>
<td>5.7 Mbps</td>
<td>7.2 Mbps</td>
<td>&gt;10 Mbps</td>
<td></td>
<td></td>
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<tr>
<td><strong>Df&lt;0.01</strong></td>
<td><strong>Df&lt;0.005</strong></td>
<td><strong>Dk&lt;3.5 Df&lt;0.003</strong></td>
<td><strong>Dk&lt;3.2 Df&lt;0.002</strong></td>
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<tr>
<td>Antenna Sensor</td>
<td>RF-Module</td>
<td>Base station</td>
<td>Mobile devices Satellite</td>
<td></td>
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<tr>
<td>HD-67</td>
<td>LX-67F</td>
<td>FX-2/FX-3</td>
<td>FX-4</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dk:10.2/Df:0.009</td>
<td>Dk:3.7/Df:0.003</td>
<td>Dk:3.2-3.5/Df:0.0025-0.0028</td>
<td>Dk:3.2/Df:0.0025</td>
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<tr>
<td><strong>High-Freq. -PKG</strong></td>
<td>3.5 Mbps</td>
<td>5.7 Mbps</td>
<td>&gt;10 Mbps</td>
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<tr>
<td><strong>Df&lt;0.015</strong></td>
<td><strong>Df&lt;0.01</strong></td>
<td><strong>Df&lt;0.005</strong></td>
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<tr>
<td>Mobile devices RF-Module MMC-PKG OEIC-PKG</td>
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<tr>
<td>E-679FG</td>
<td>LZ-71G</td>
<td>E-800G,Falcon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dk:4.5/Df:0.014</td>
<td>Dk:3.6/Df:0.006</td>
<td>Dk:4.0/Df:0.005</td>
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<tr>
<td>AS-Z5(BU) Dk:3.1 Df:0.004</td>
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</tbody>
</table>

Dk&Df:@1GHz
1. Hitachi Chemical has various evaluation technology of dielectric properties and practical electrical properties.

2. Hitachi Chemical intend to accelerate R&D of materials for next generation through these technology and newly constructed technology.

3. We also would like to propose the combination of the most suitable materials depending on PCB structure and applications by using evaluation technology and simulation.