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Low Transmission Loss Multi-layer Material for High-Speed & High-Frequency Applications

MCL-FX-2 / FX-3

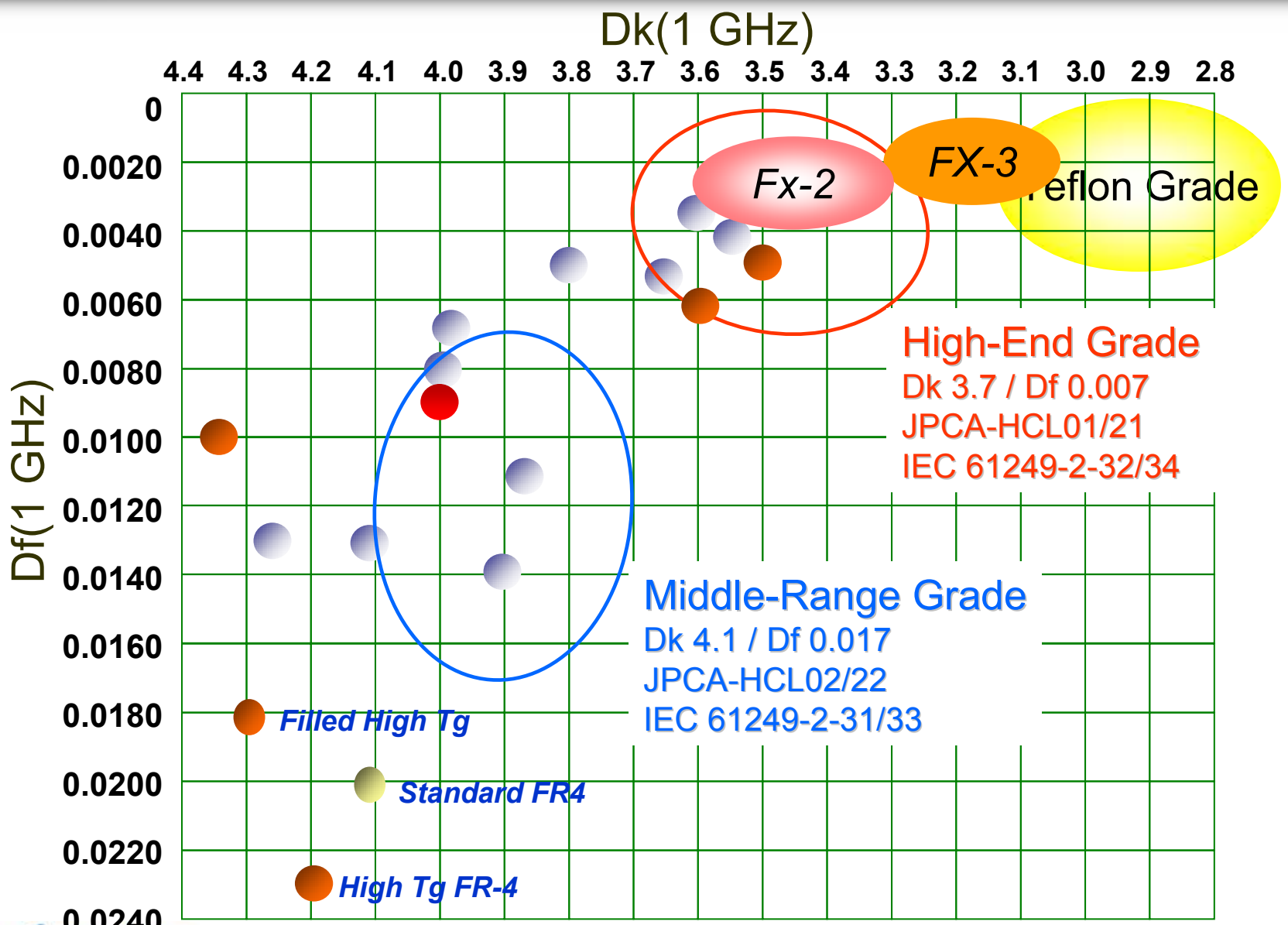
Hikari Murai, Yasuyuki Mizuno, Hiroshi Shimizu, Takahiro Tanabe, Ken Ikeda and Tetsuro Irino

Telecommunication Materials Development center
Tsukuba Research Laboratory
Printed Wiring Board Material R&D Dept.
Printed Wiring Board Materials Business Sector
Hitachi Chemical Co., Ltd.

Roadmap of Infrastructure-Communication Network

Field	Application	Properties (Functions)	Required Properties of Base Materials
General High-Frequency	Servers Routers	Transmission Rate: 1.5 Gbps⇒3 Gbps 30Layers ⇒ 40 Layers Narrow Pitch, Symmetrical Packaging Reflow Temp: 260 °C	Dk:4.0, Df:<0.010 Level Lead-Free applicable
High-End	Super Computers Giga bit Router Base Station:Back panel	Transmission Rate: 5 Gbps⇒10 Gbps 30Layers ⇒ 50 Layers Reflow Temp: 260 °C	Dk:3.5, Df:<0.005 Level Heat Resistance for Lead Free
	RF modules for Mobile Handset Devices (PA, Filter ,etc)	Halogen Free Materials applied Frequency: 1.5 GHz ⇒ 3 GHz 4Layers ⇒ 6Layers, Higher Density Reflow Temp: 260 °C Halogen Free requirement	Dk:<3.7, Df:<0.007 Level High Thickness Accuracy Laser drill process ability Heat Resistance(Lead Free) Halogen free material
	Antenna of Base Station Phase Shifters, Anti crash rader on automotive and etc	Frequency: 1.5 GHz ⇒ 3 GHz From Teflon & PPE boards to Lower Cost Materials Frequency: 24 GHz ⇒ 76 GHz	Dk:<3.5, Df:<0.003 Level Lower Process Cost Drift of electric property on water absorption

Property map of high frequency materials

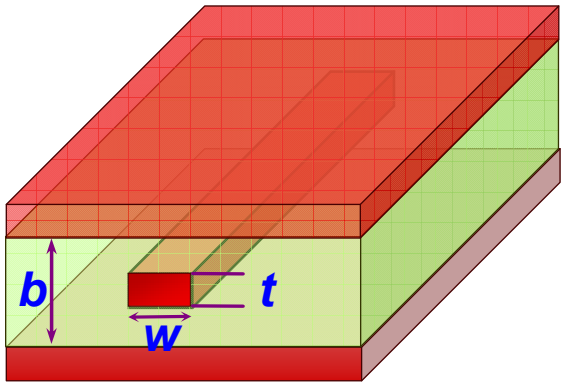


※ JPCA TM001/IPC TM650 2.5.5.5.1

Requirement of Material for High-Frequency PWBs

Important issue in high-frequency circuits → Reducing transmission loss

Stripline



b : Dielectric layer thickness
w : Conductor width
t : Conductor thickness

● Transmission loss(*a*) = Conductor loss(*ac*) + Dielectric loss(*ad*)

$$ad = 27.3 \times \frac{f}{c} \times \sqrt{Dk} \times Df$$

Dk : dielectric constant, *Df* : Dissipation factor, *f* : Frequency, *c* : Light velocity

● Propagation delay time $Td = \dfrac{\sqrt{Dk}}{c}$

● Characteristic impedance $Zo = \dfrac{60}{\sqrt{Dk}} \ln\left(\dfrac{4b}{0.67\pi(0.8w + t)}\right)$

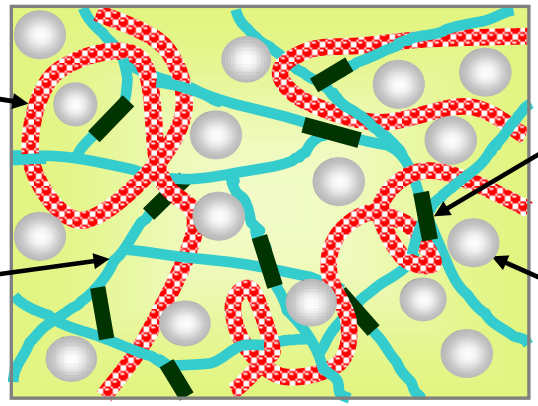
< Solution for Requirement >

/ Reduction of ad → Low Dk & Df Resin Technology
(Excellent dielectric properties & Stable Dk &Df for the wide range of frequency, temperature, humidity, …..)

/ Reduction of ac → Original Profile-Free Conductor
(High adhesion technology for very low surface roughness foil)

Development Concept of New Resin System

< Structure model of cured new resin >



Low Dk & Low Df
Thermosetting resin system
(Low-polar cross-linking design)

- Low Dk / Low Df
- Stable Dk & Df vs. Temperature & Humidity
- High heat resistance
- Good insulation reliability
- Low water absorption

Semi-IPN structure resin
by Original polymer alloy technology

Low Df Inorganic filler

Filler/Resin Interface Control

- Low Df
- Low CTE

Non-polar & Rigid
Liner polymer

- Low Dk / Low Df
- High Tg
- Low water absorption
- High heat resistance

Novel high performance material

General Properties of New Material

Item	Condition	Unit	FX-2	PTFE/E-Glass substrate	Conventional FR-4
Dielectric Constant (Dk)	1 GHz*	-	3.50 - 3.55	2.65 - 2.70	4.10 - 4.20
	1 GHz**	-	3.40 - 3.45	2.60 - 2.65	4.00 - 4.10
	3 GHz**	-	3.40 - 3.45	2.60 - 2.65	3.95 - 4.05
Dissipation factor (Df)	1 GHz*	-	0.0014 - 0.0018	0.0005 - 0.0010	0.0160 - 0.0180
	1 GHz**	-	0.0024 - 0.0028	0.0024 - 0.0028	0.0180 - 0.0200
	3 GHz**	-	0.0034 - 0.0038	0.0030 - 0.0034	0.0200 - 0.0220
Copper peel strength (18 μm)	Standard (Rz: 5-7 μm)	kN/m	0.7 - 0.9	1.3 - 1.4	1.4 - 1.6
	VLP (Rz: 3-4 μm)		0.6 - 0.7	-	-
	PF (Rz: 1 μm)		0.7 - 0.8	-	-
Glass transition temperature (Tg)	TMA	°C	175 - 185	20 - 25	120 - 130
CTE	xy	ppm/°C	14 - 15	17	14 - 17
	z1		48 - 55	100 - 110	50 - 70
	z2		100 - 130	290 - 320	240 - 310
Heat resistance (T-288)	IPC-TM-650 2.4.24.1	min	> 60	-	< 3
Heat resistance	PCT*** -3 h	-	Good	Good	NG
(288 °C/20 s dipping)	PCT*** -5 h	-	Good	Good	NG
Water absorption	PCT*** -5 h	%	0.20 - 0.30	0.01 - 0.02	1.0 - 1.2
CAF restraining property****	-	h	> 1000	-	> 1000
Flammability	UL-94	-	V-0	V-0	V-0

* IPC-TM-650 2.5.5.9: Capacitance method with RF Impedance/Material Analyzer (25 °C)

** JPCA-TM001 A test method for copper-clad laminates for printed wiring boards dielectric constanat and dissipation factor.
IPC-TM-650 2.5.5.5.1: Triplate-line resonator method with Network Analyzer (25 °C)

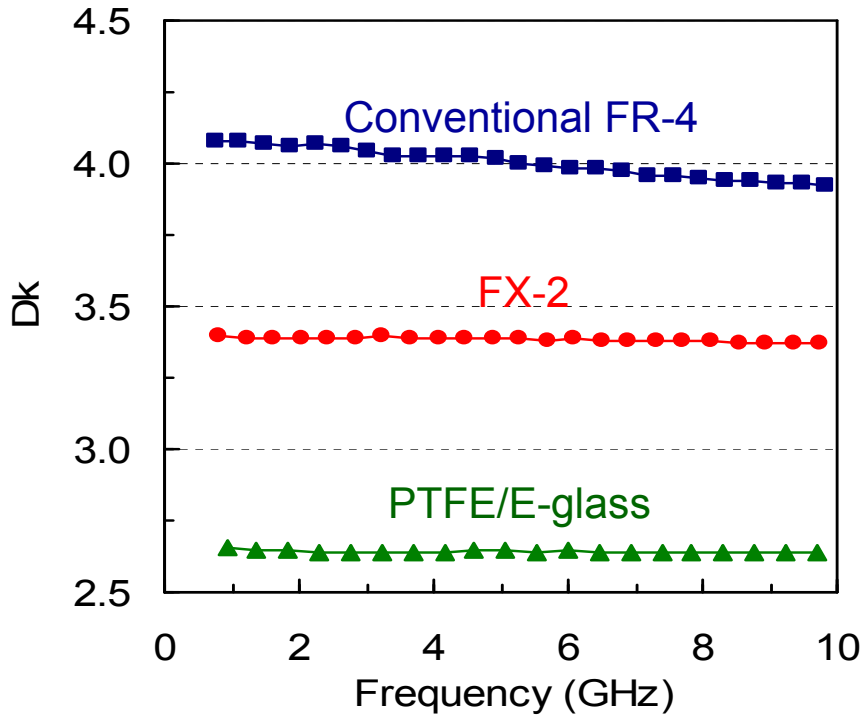
*** Moisture treatment condition: PCT (121°C/0.22 MPa)

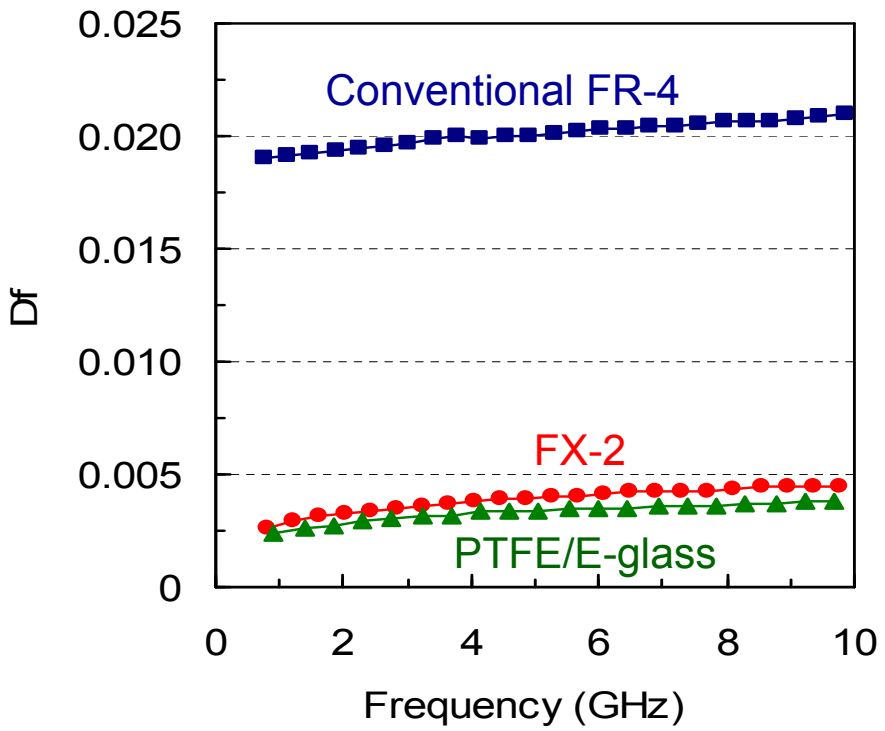
**** TH/TH wall thickness: 0.3 mm, Condition: 85°C/85%RH, 100 V dc applied

Dielectric Properties (vs. Frequency)

< Measurement Conditions >

/ Method:Triplate-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
/ Signal Conductor Line Width: 1 mm



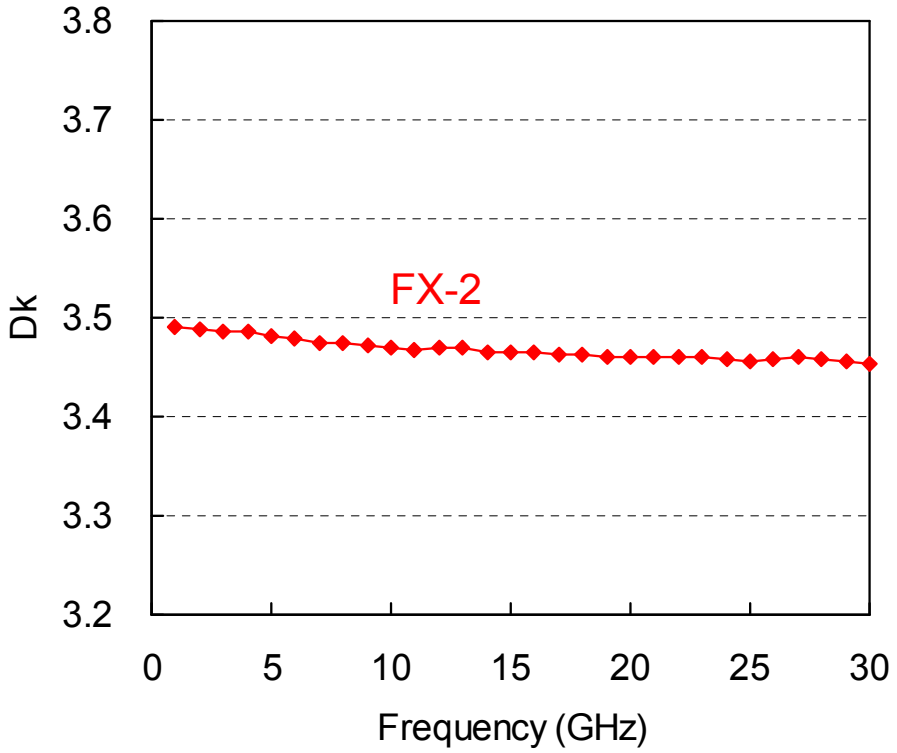


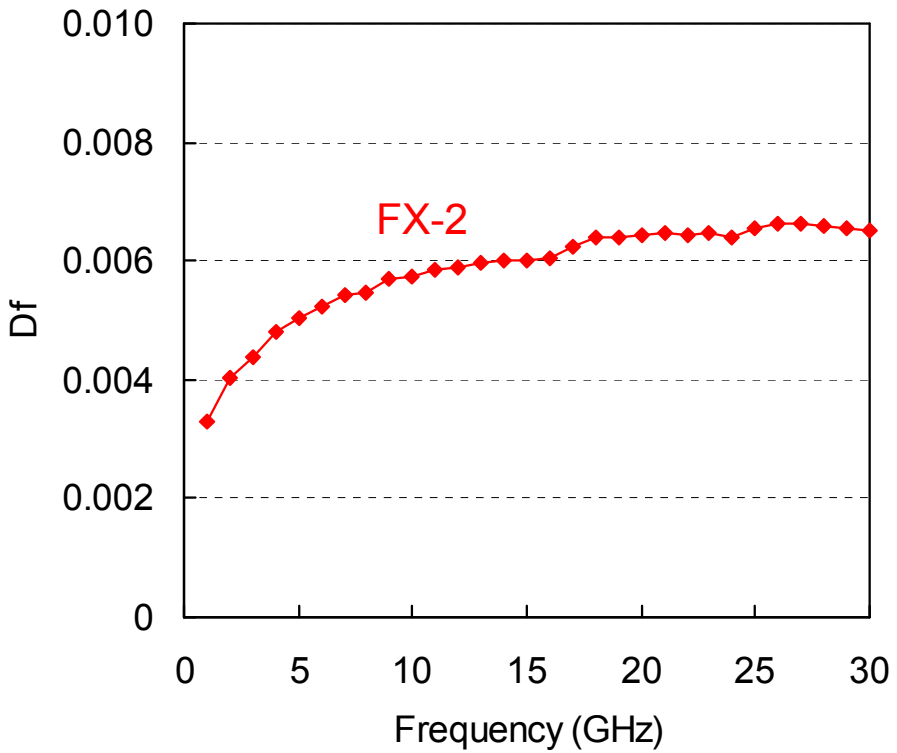
Excellent stability of dielectric properties in wide frequency bands

Dielectric Properties (vs. Frequency 1 to 30GHz)

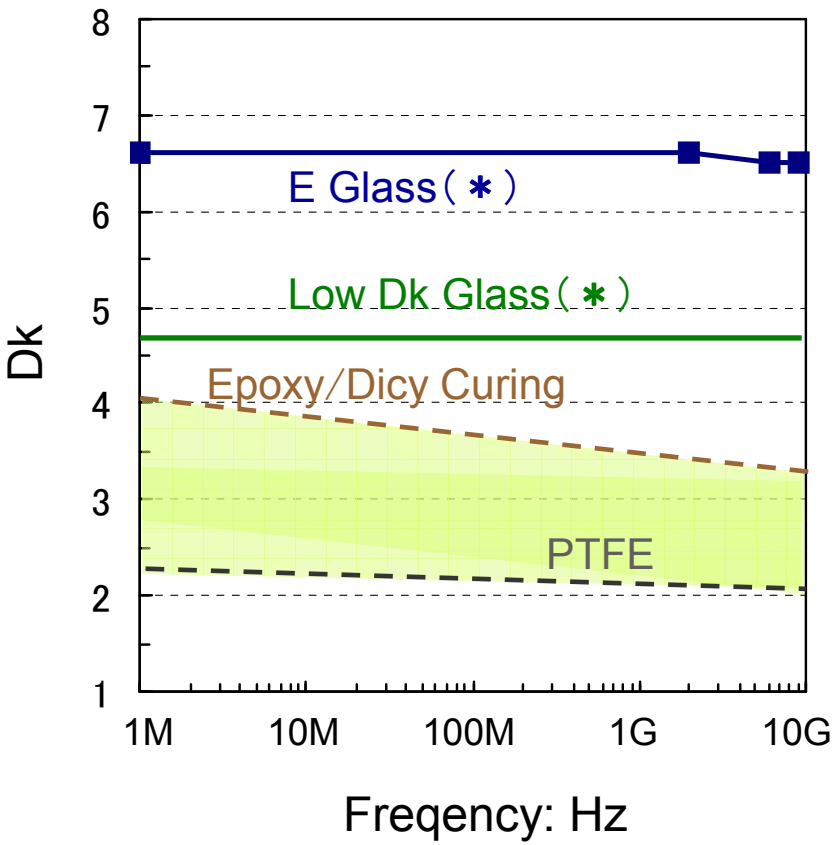
< Measurement Conditions >

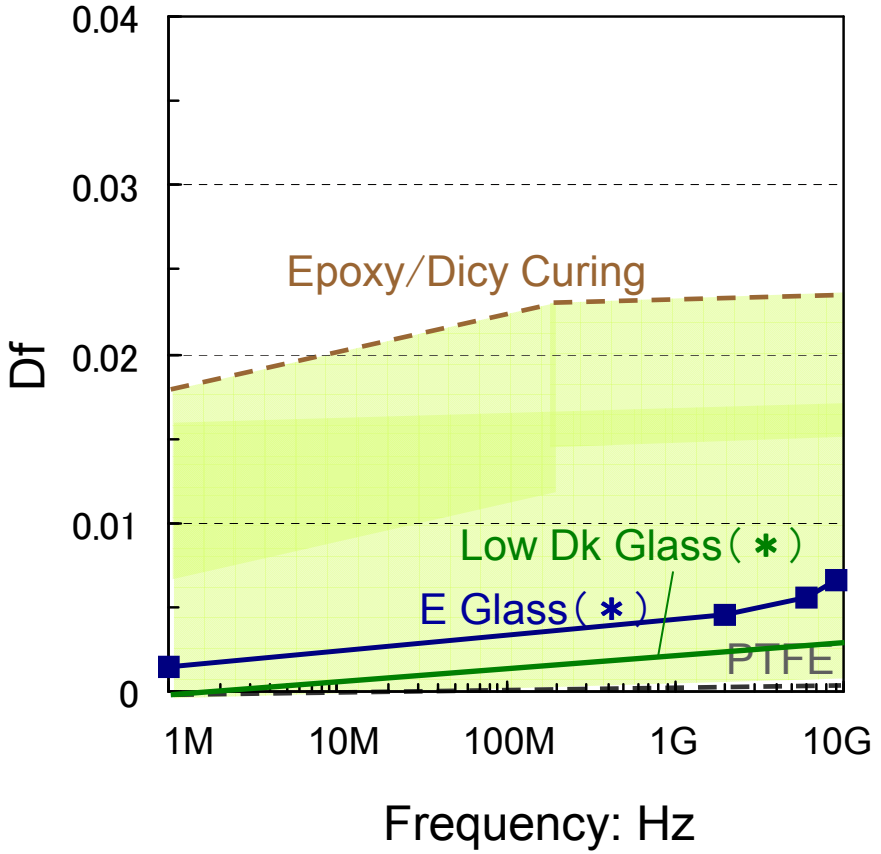
/ Method:Triplate-Line Resonator by Vector Network Analyzer/JPCA TM001/IPC-TM-650_2.5.5.5.1
/ Temperature & Humidity: 25 °C/ 60 %RH
/ Laminate Thickness: 0.8 mm(Signal-Ground Distance: 0.8 mm), Copper foil:18 μm
/ Signal Conductor Line Width: 1 mm





Resin / Glass Fabric Effect of Dk/Df



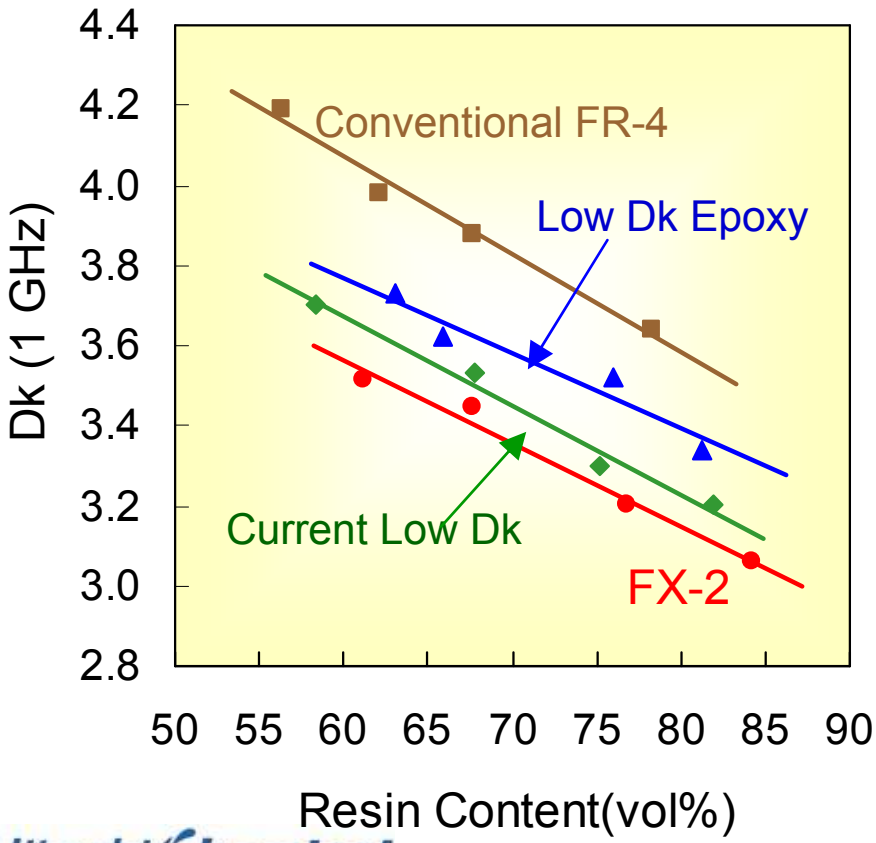


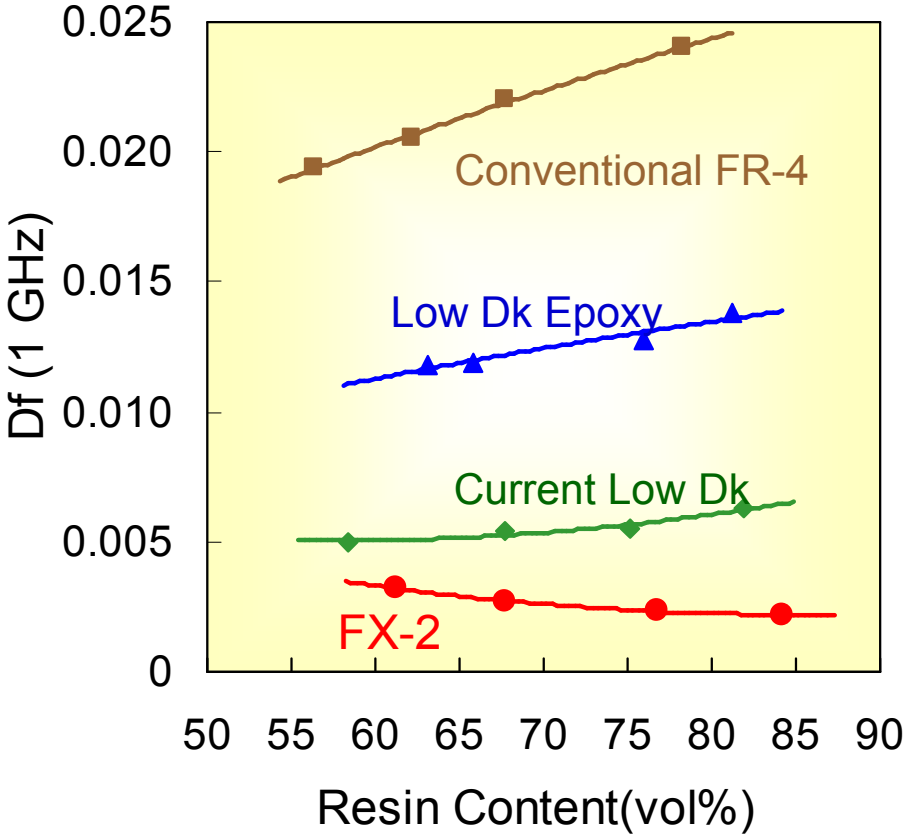
＊）Glass Fabric Data by suppler

Dk & Df of new material

Relationship between Dk&Df and resin content of laminates

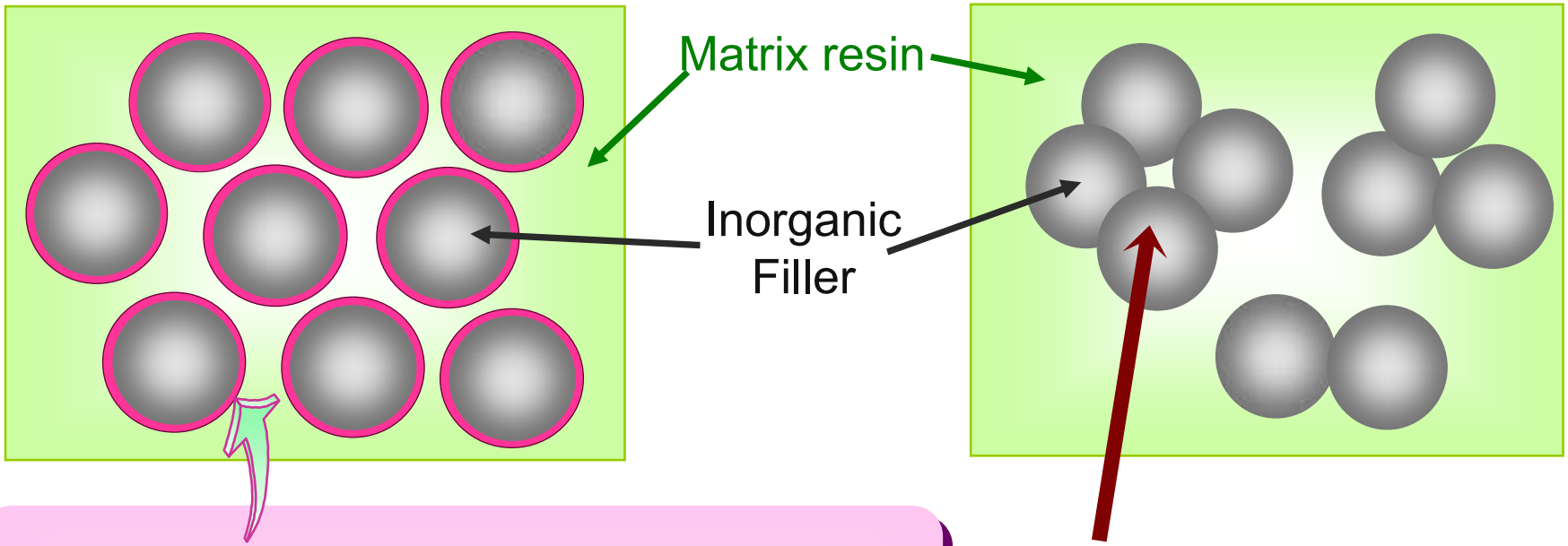
< Measurement Conditions >
/ Method : Triplate-Line Resonator by Vector Network Analyzer (JPCA tm001/IPC-TM-650_2.5.5.5.1)
/ Temperature & Humidity : 25 ℃/ 60 %RH
/ Laminate Thickness : 1.6 mm (Signal/Ground: 800 μm apart), Copper foil : 18 μm
/ Signal Conductor Line Width : 1 mm (Zo: ca. 50 Ω)





Filler/Resin-Composite Technology(1)

Interface Control between Filler and Resin (FICS)



Optimization of filler / resin-interface

→ **High Dispersion & Excellent adhesion**

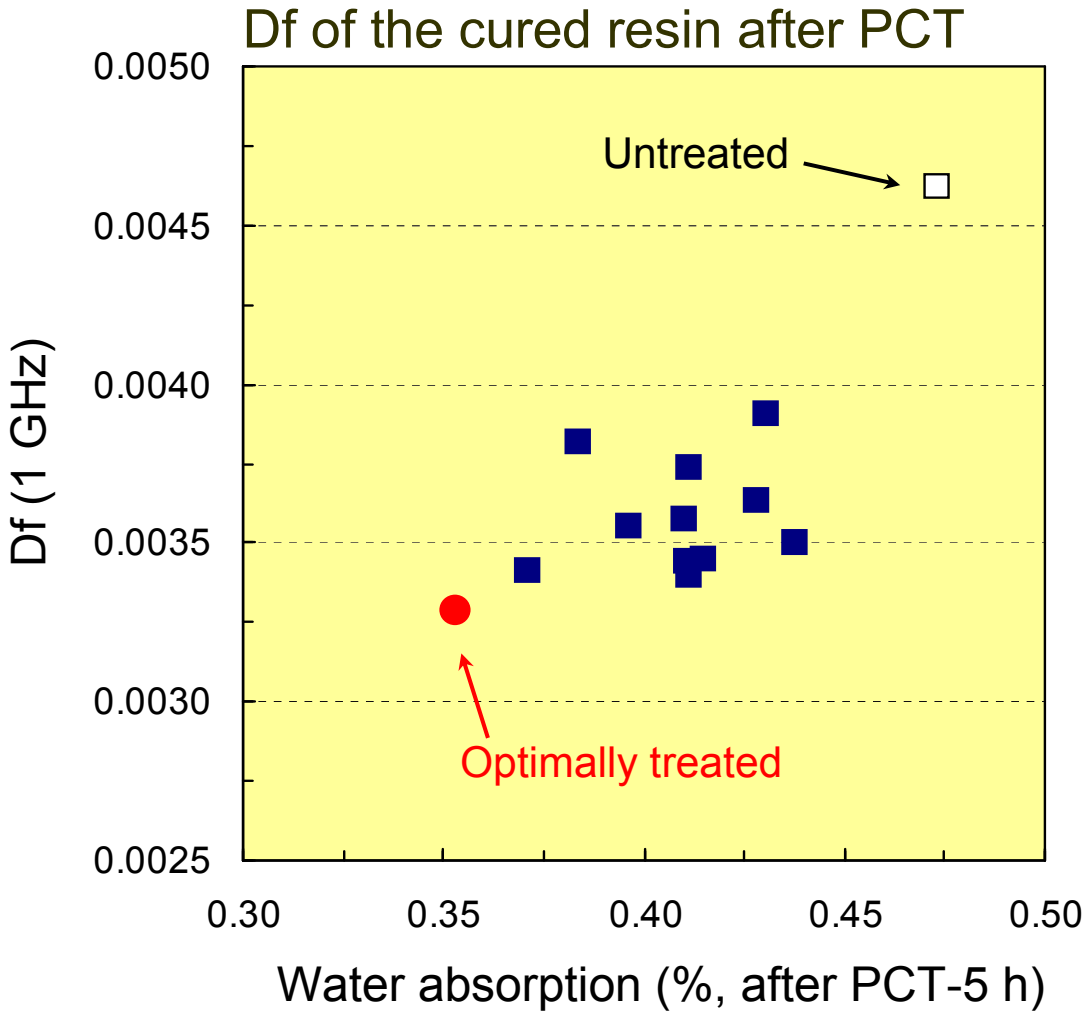
/ Low water absorption
/ Excellent heat resistance
/ Excellent electric insulation and CAF restraining property

Aggregation

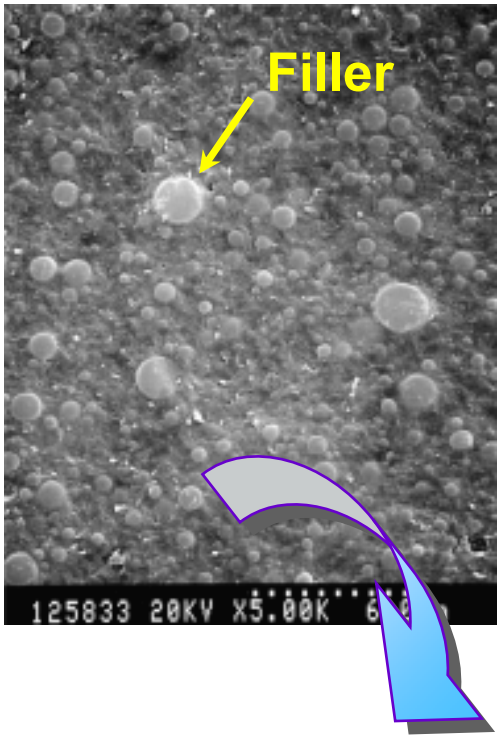
/ Increase in water absorption
/ Poor heat resistance
/ Poor electric insulation and CAF restraining property

Filler/Resin-Composite Technology(2)

Effect by Optimal Interface Control on Df of the Cured Resin



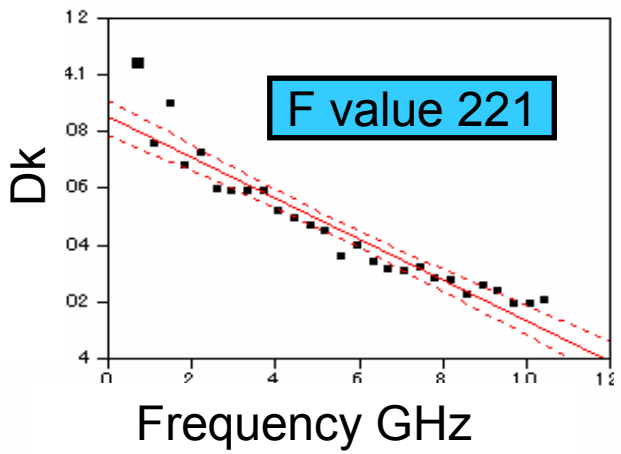
< Cross section of cured resin >

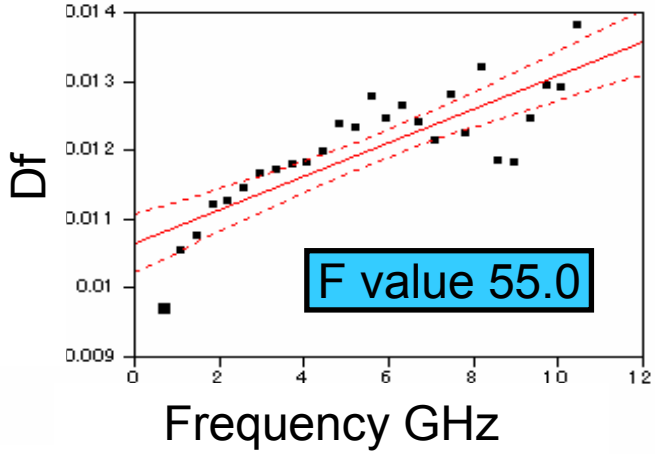


Excellent dispersion & adhesion

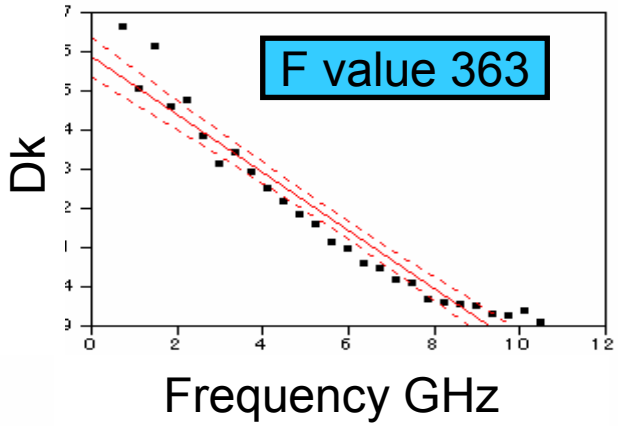
Dk, Df Deviation Analysis (- Filler size impact)

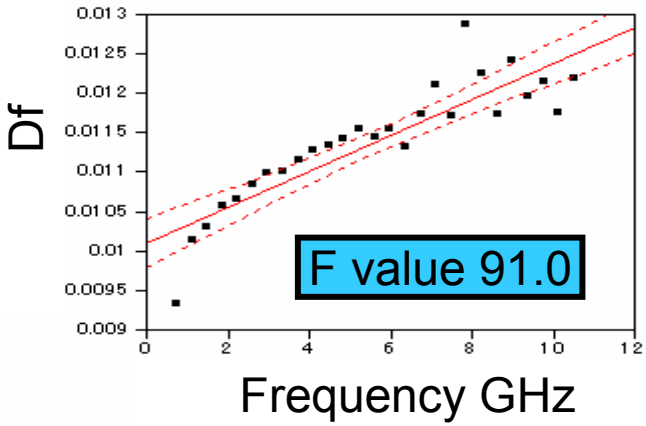
Conventional Filler used





Smaller particle filler used

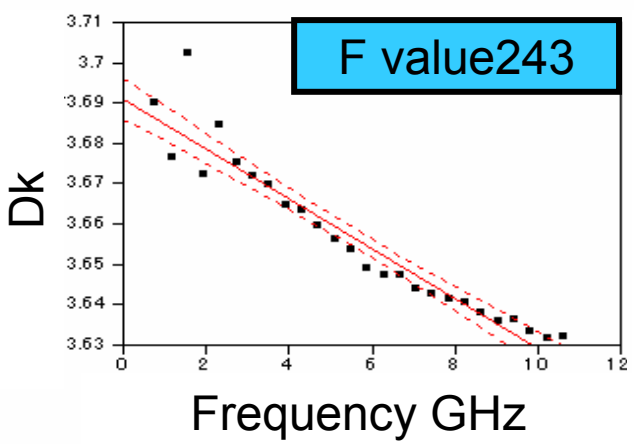


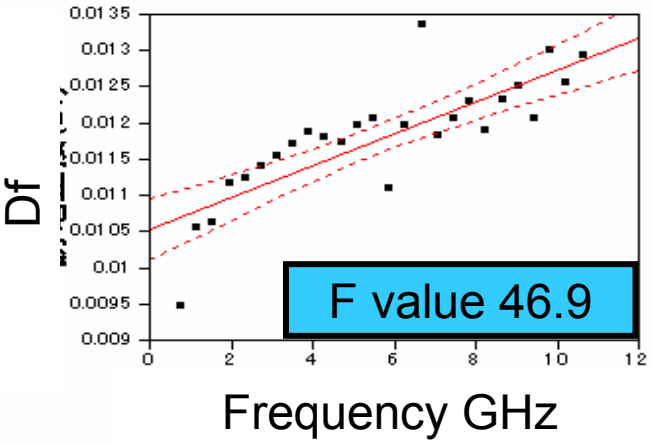


Dk Standard Dev. of small filler is 22% lower than that of conventional
Df Standard Dev. of small filler is 18% lower than that of conventional

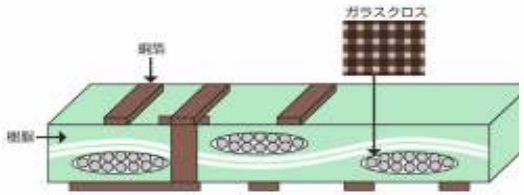
Dk, Df Deviation Analysis
(- Fiber wave Impact: #1078 vs. #1080)

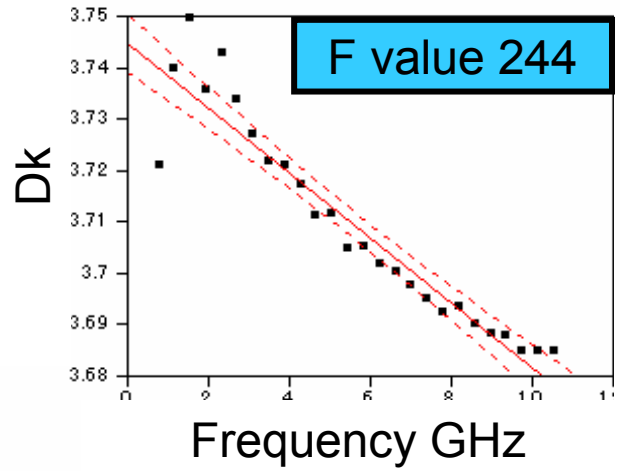
Conventional Glass
(#1080×13ply
RC:57.9%)

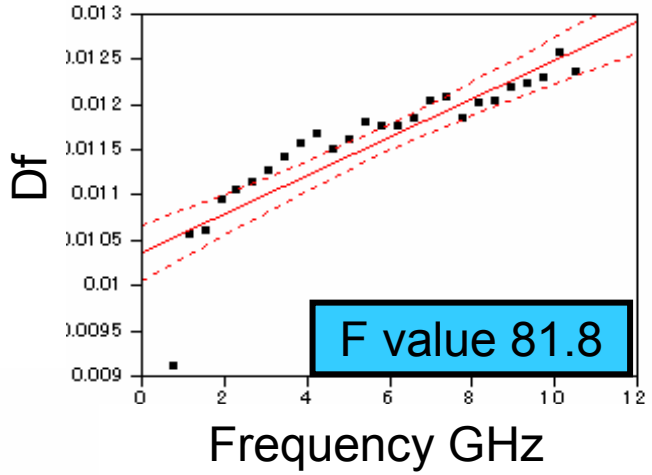




Spread out Glass
(#1078×13ply
RC:55.5%)



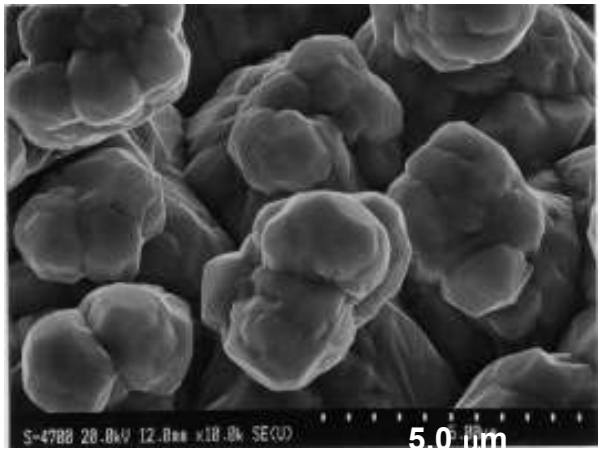




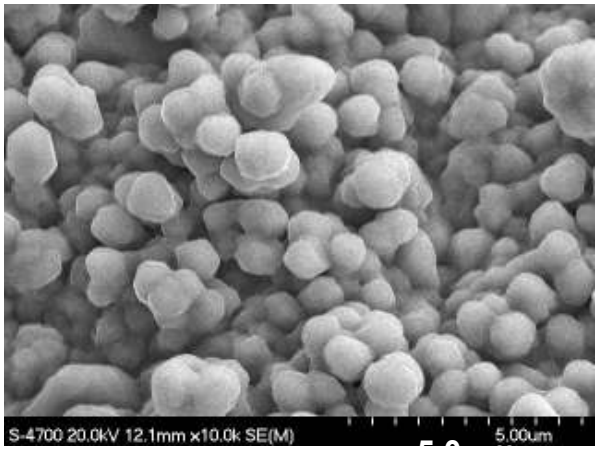
Dk standard Dev. Of 1078 is equivalent to that of 1080
Df Standard Dev. of 1078 is 24% lower than that of 1080

Copper Roughness

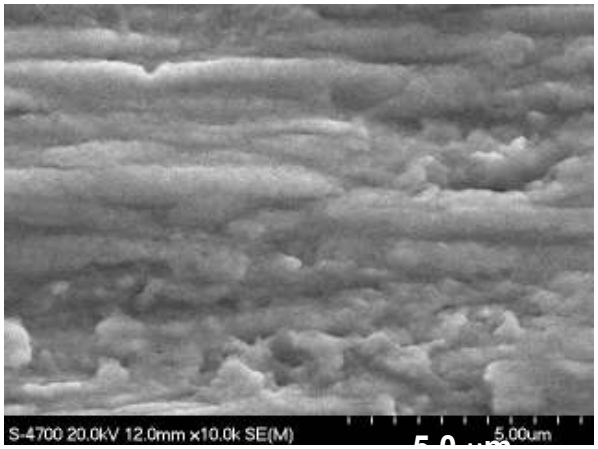
- Surface shape of matt side by SEM



Standard Rz : 6-8 μm

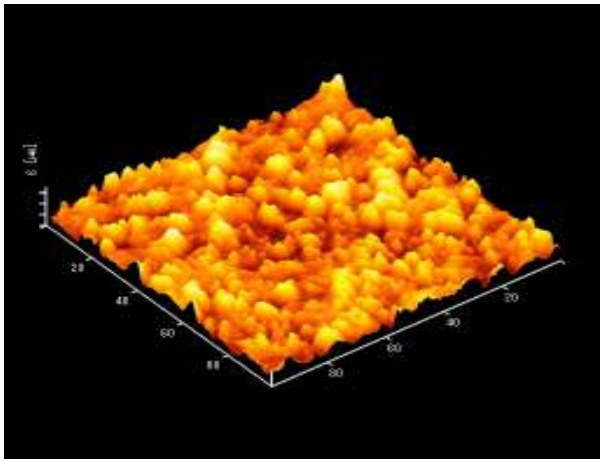


VLP Rz : 3-4 μm

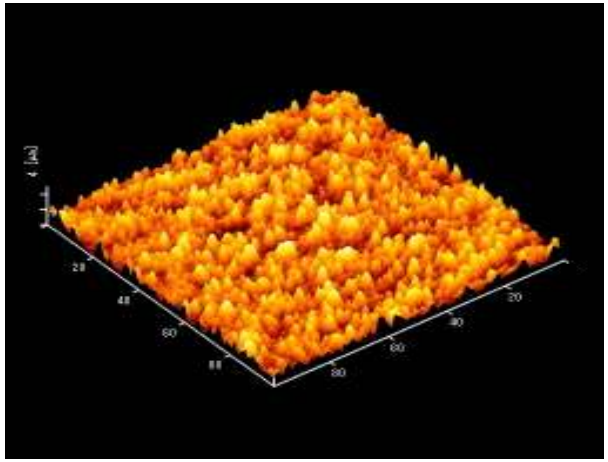


Profile-free Rz : 0.5-1.5 μm

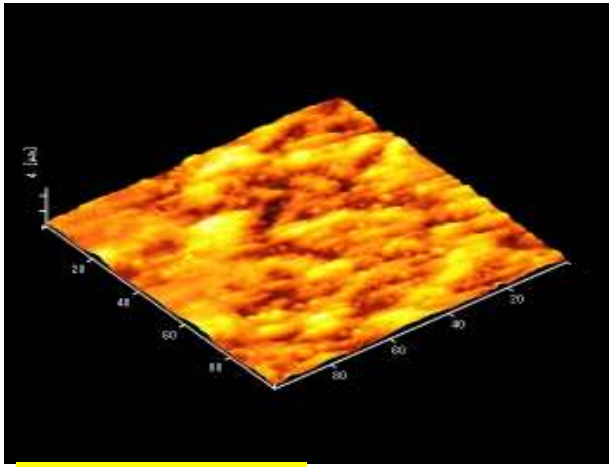
- Surface shape of matt side by AFM



Rz=7 μm



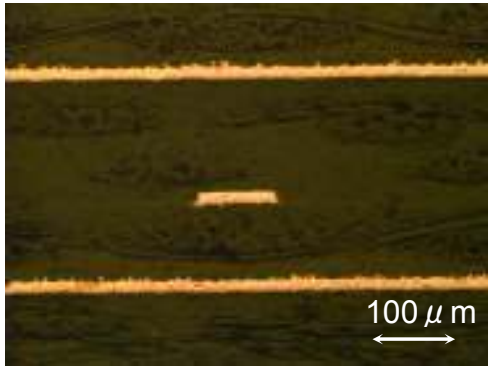
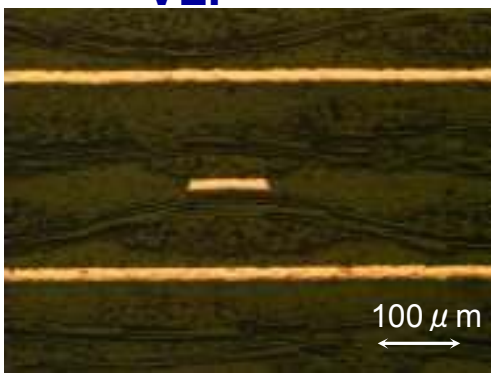
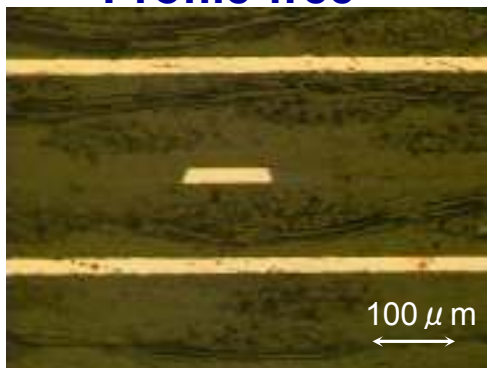
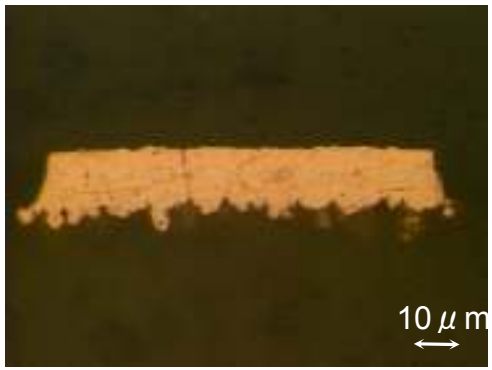
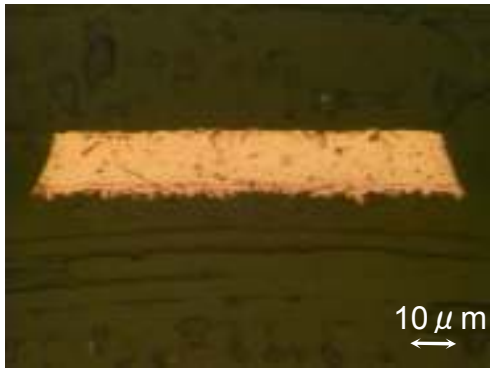
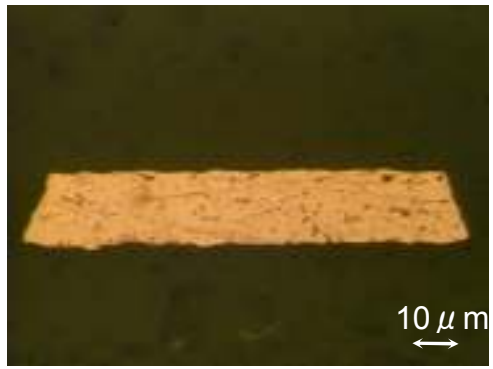
Rz=2.5 μm



Rz=0.5 μm

Copper Roughness ; Etching Effect

- Closs-section of stripe line : Line width 100 μm, Thickness 18 μm

Standard	VLP	Profile-free
		
		

Transmission Loss Evaluation (Up to 20 GHz) (- Copper Impact)

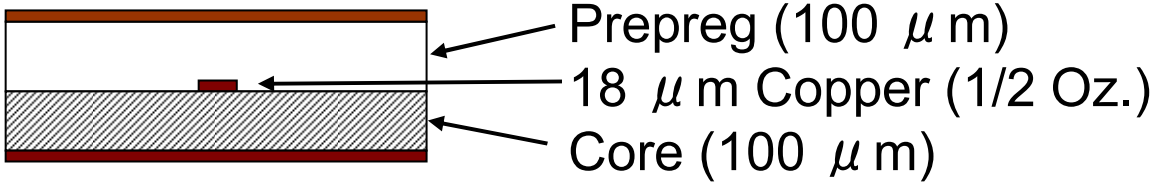
(1) Copper Foils

Base Material	Copper	Supplier
MCL-FX-2	PF foil	Hitachi original
	HVLP foil	F
	VLP foil	M
	Std. foil	N

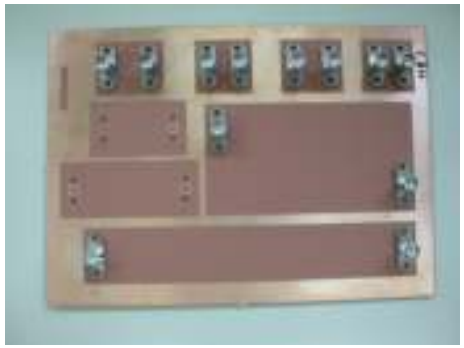
(2) Measurement Method

Agilent : E8364B

Measurement condition : Strip-line resonator method S21 (Zo:50 Ω)

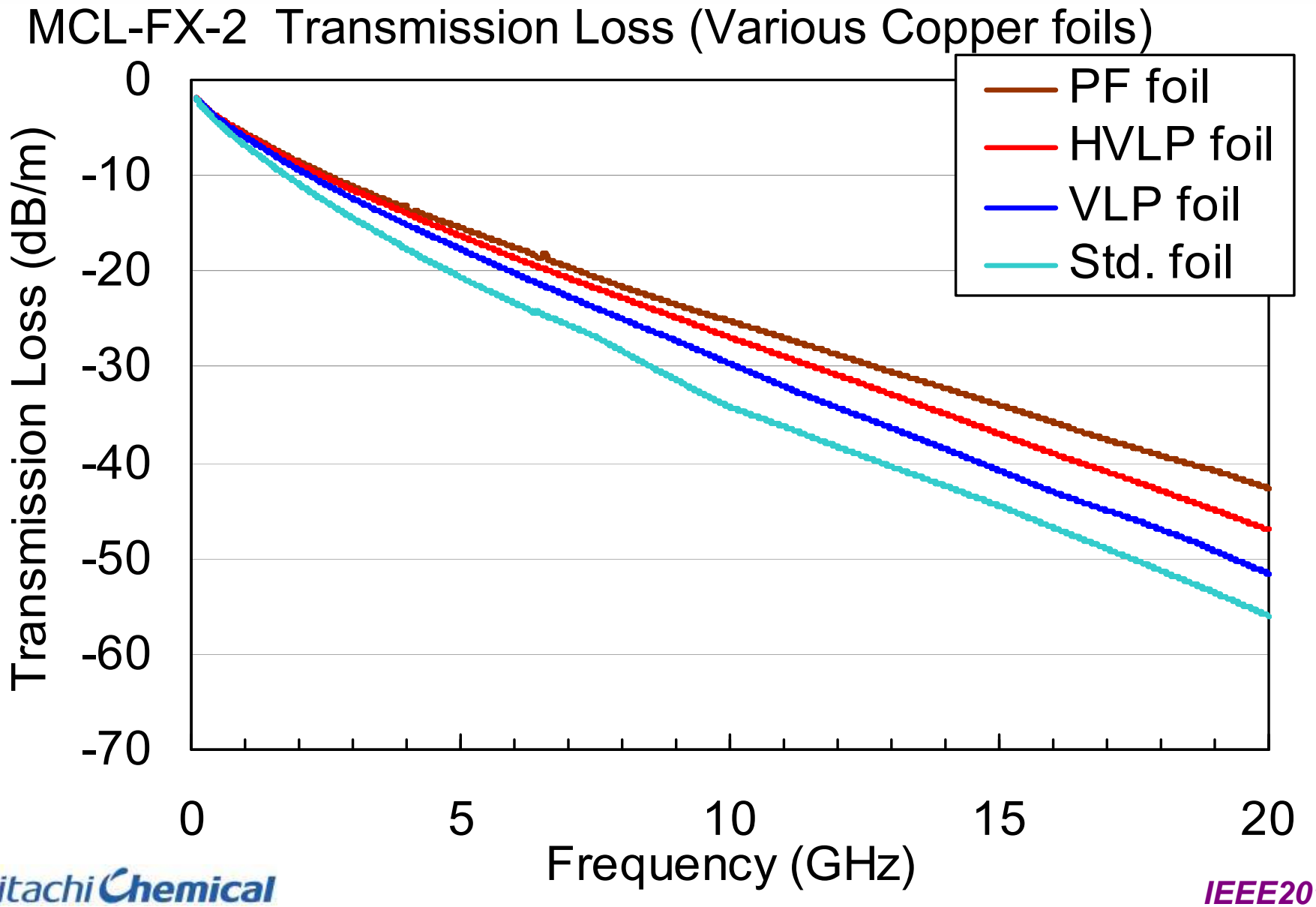


Strip-Line Structure



Test Board

Transmission Loss (- Copper Impact)



General Properties of FX-3

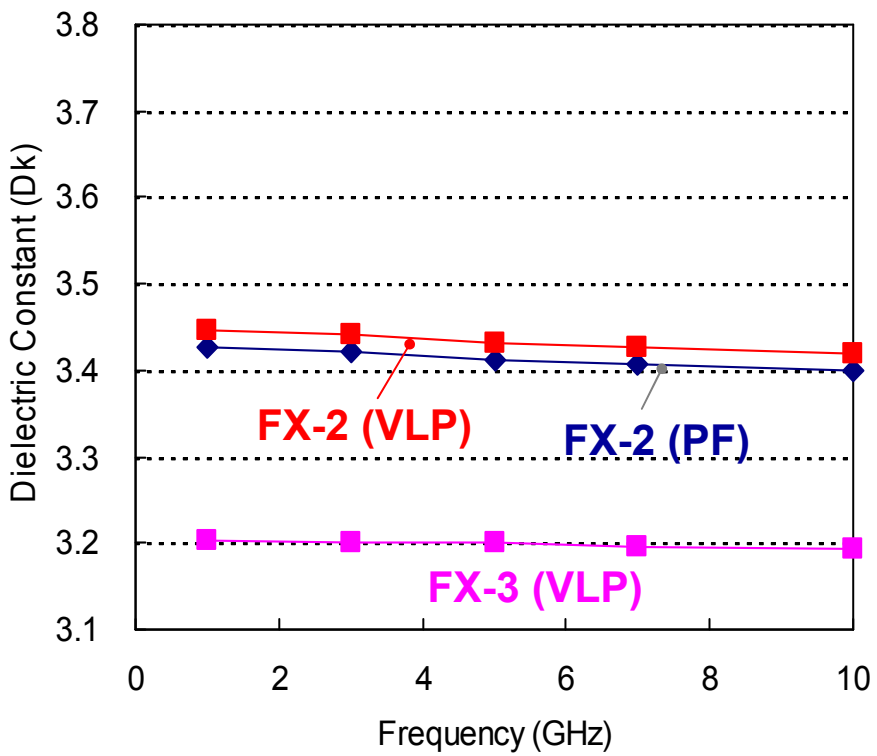
Item		Cond.	Unit	FX-2	FX-3
Glass Fabric Type		-	-	E	NE
Dk	1 GHz	IPC-TM650 2.5.5.1	-	3.40 - 3.45	3.15 - 3.20
	3 GHz			3.40 - 3.45	3.15 - 3.20
Df	1 GHz		-	0.0024 - 0.0029	0.0020 - 0.0025
	3 GHz			0.0034 - 0.0039	0.0024 - 0.0028
Copper Peel Strength		Standard (18 μm)	kN/m	0.8 - 0.9	0.8 - 0.9
		VLP (18 μm)		0.6 - 0.7	0.6 - 0.7
		PF (18 μm)		0.7 - 0.8	0.7 - 0.8
Td		TGA 5 % loss	°C	370 - 390	370 - 390
Tg		TMA	°C	175 - 185	175 - 185
CTE		αx1	ppm/°C	14 - 17	14 - 17
		αz1		45 - 55	45 - 55
		αz2		100 - 130	100 - 130
Solder Resistance		288 °C/20 s *1		> 5 h	> 5 h
Water Absorption		PCT-5 h	wt%	0.20 - 0.30	0.20～0.30

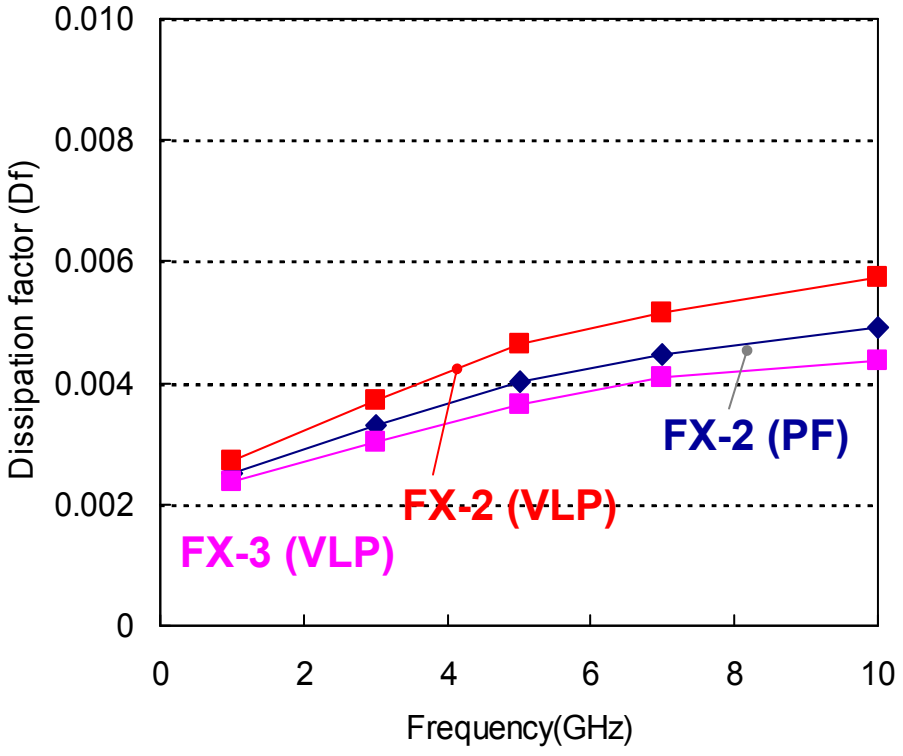
*1) PCT(121 °C/0.22 MPa)

Dielectric Properties (vs. Frequency)

< Measurement Conditions >

/ Method: Triplate-Line Resonator by Vector Network Analyzer (JPCA-TM0001,IPC-TM-650 2.5.5.1)
/ Temperature & Humidity: 25 ℃/ 60 %RH
/ Laminate Thickness: 0.8 mm (Signal-Ground Distance: 800 μm), Copper foil: 18 μm
/ Signal Conductor Line Width: 1 mm (Zo: approx.50 Ω)





Excellent stability of dielectric properties in wide frequency bands

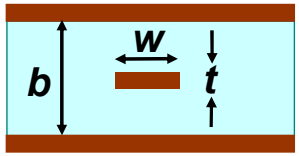
Electrical Performance in High Frequencies

Transmission Loss（S-Parameter(S21)）

＜ Measurement Conditions ＞

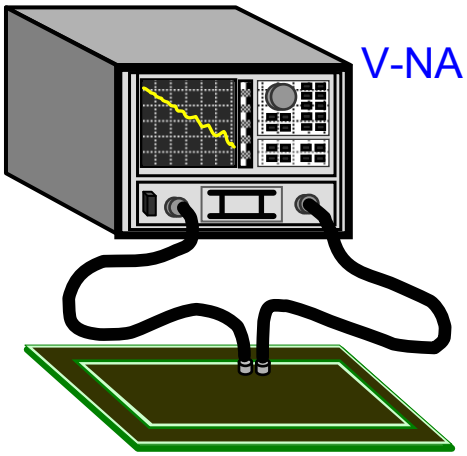
/ Evaluation PWB：Strip-Line Structure
/ Material：FX-2, FX-3
/ Temperature & Humidity：25 ℃/60 %RH
/ Characteristic Impedance：50 Ω
/ Connection：Though Hole-SMA（by Solder）
/ Inner Layer Surface Treatment：Reduction Treatment

/ Dimension Parameters

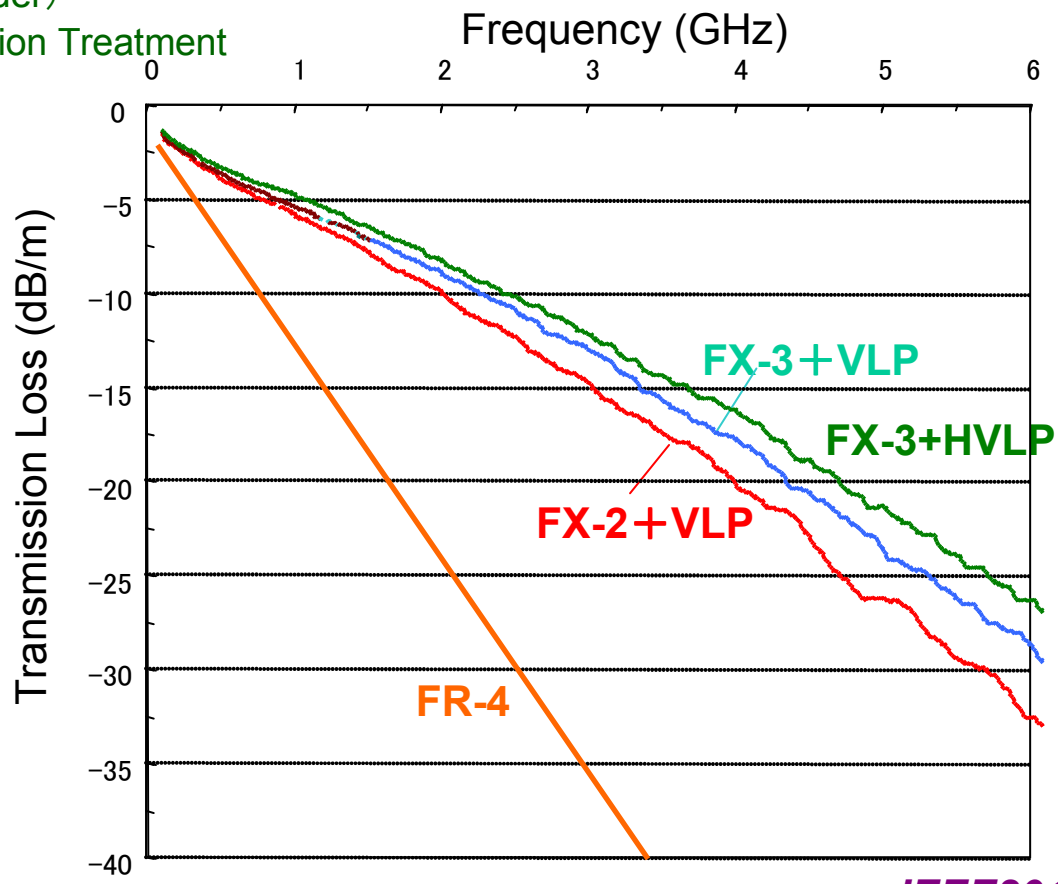


・Line-Width (***w***)：0.124～0.138 mm
・Dielectric Thickness (***b***)：0.26 mm
・Copper Thickness (***t***)：18 μm
・Line-Length：500 mm

＜ Evaluation System ＞



Testing Board



Conclusions

1. Several factor need to be considered for 100G channel construction

   (1) Resin system, resin content
   (2) Filler, filler size and coating
   (3) Copper foil roughness
   (4) Glass wave impact

2. Demonstrated two materials (FX-2/FX-3) can meet 1M channel objective reach.