Low Transmission Loss Multilayer PWB Materials for High-Speed and High-Frequency Applications

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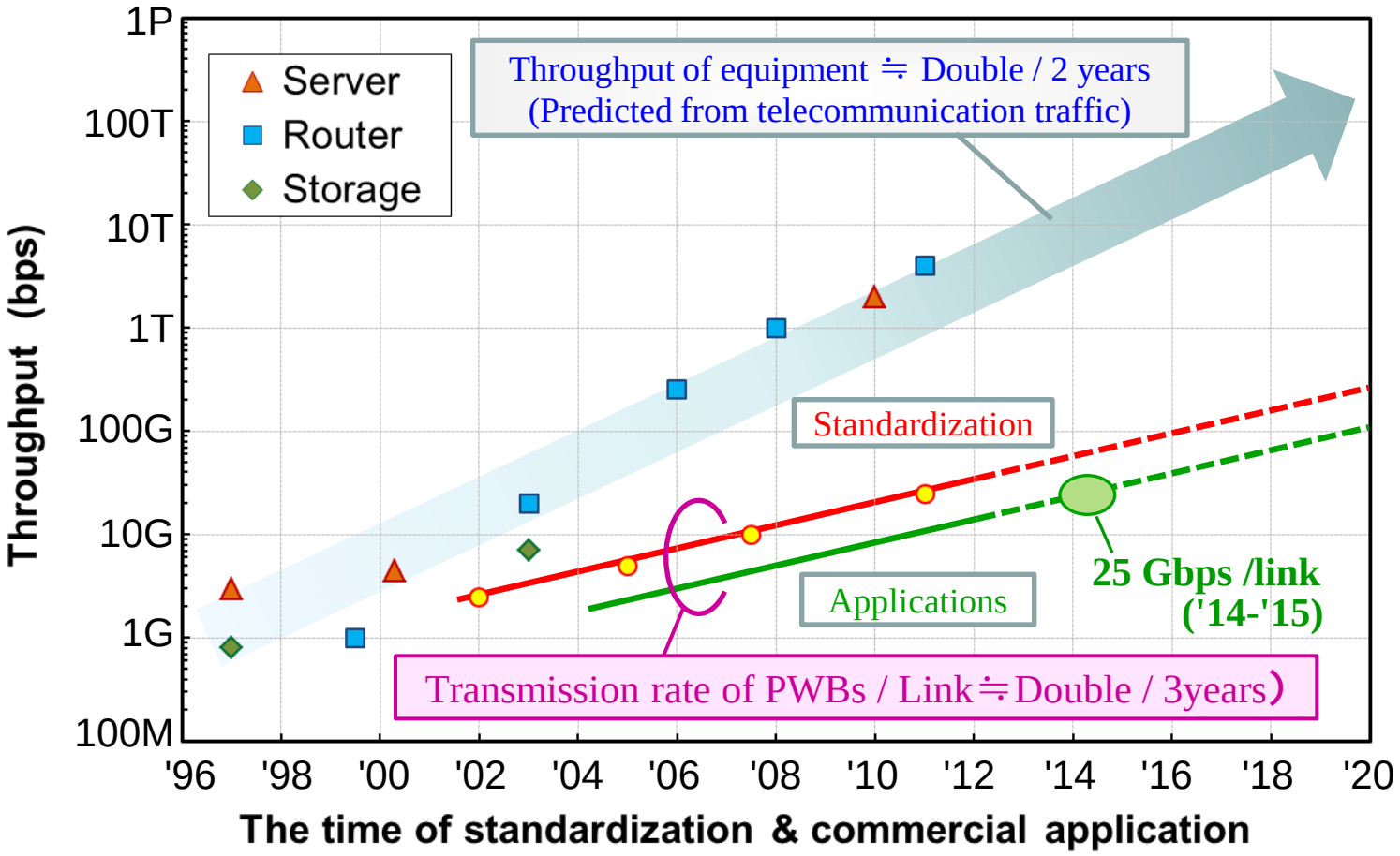
Outline

- Introduction
- Evaluation technologies of high-frequency performance by Hitachi Chemical
- Properties of new mid-loss PWB material
- Innovative ultra-low loss PWB material
  - / Target & Technical concept
  - / Features & Advantages
- Conclusions

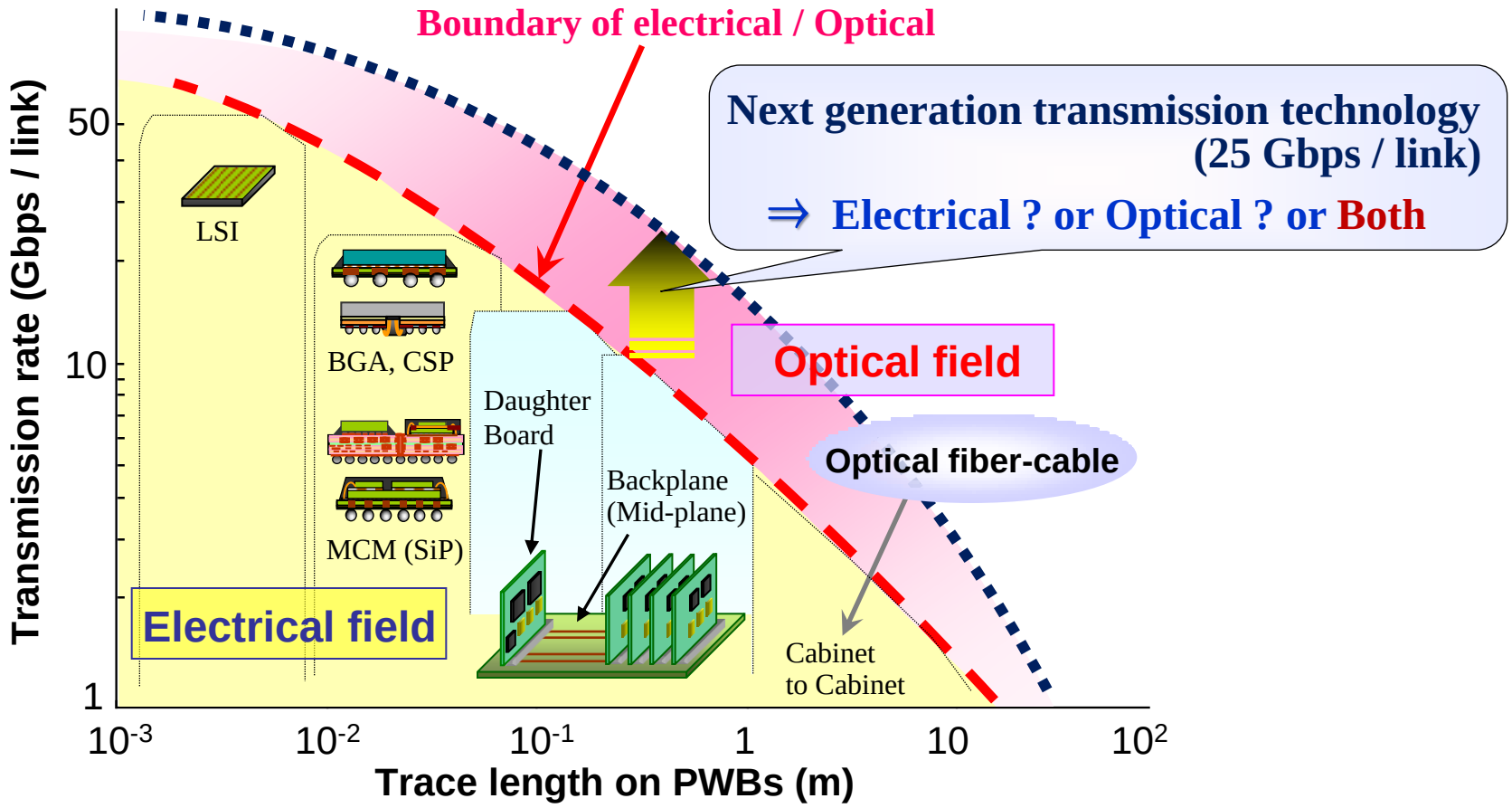
Background ; Trend of transmission rate

Higher performance of communication on network platform



Signal speed on PWBs is increasing year by year to meet the needs of large-volume data transmission.

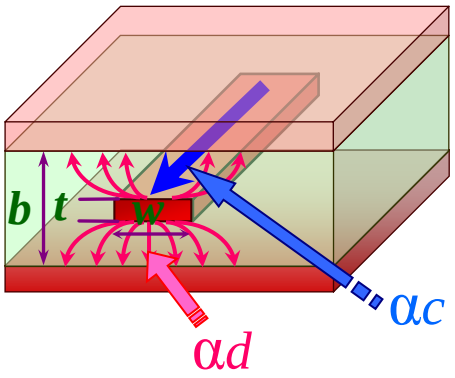
Transmission rate vs. trace length on PWBs



Need of the lower loss PWB material is increasing for the next generation electrical transmission.

Requirement for High-frequency PWB material

Transmission loss (α) ≒ Dielectric loss (αd) + Conductor loss (αc)



- $\alpha d \propto 27.3 \times \frac{f}{c} \times \sqrt{Dk} \times Df$
- $\alpha c \propto Rs(f, \rho, \cdots) \times \sqrt{Dk} \times (t, w, b,) \cdots$

***Dk* : dielectric constant, *Df* : Dissipation factor**

f : Frequency, *c* : Light velocity

Rs : Surface resistance of conductor

ρ : Resistivity of conductor, *b* : Dielectric thickness

w : Conductor width, *t* : Conductor thickness

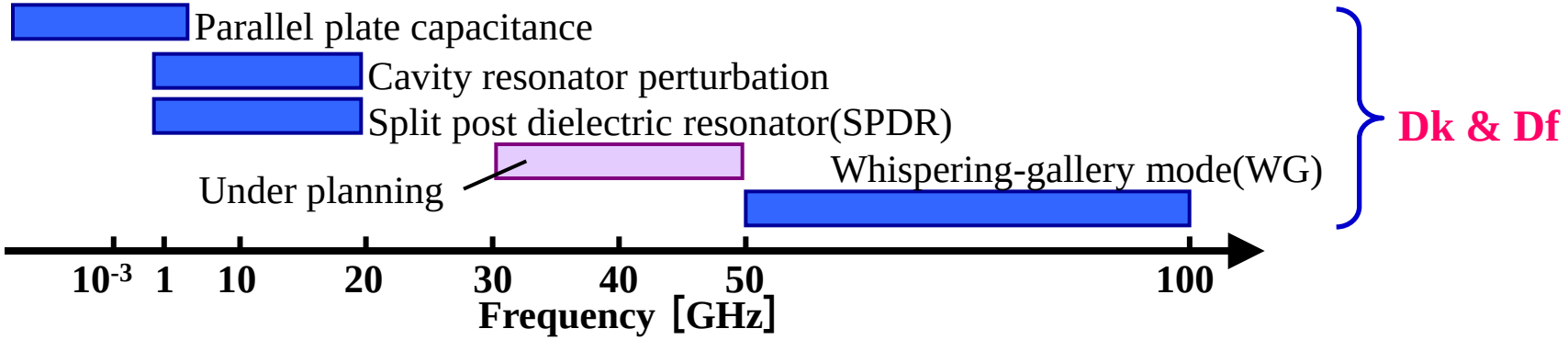
＜ Solution to lowering transmission loss ＞

- Reduction of αd ⇒ Low Dk & Df Resin technology
- Reduction of αc ⇒ High adhesion technology between resin and conductor with very low surface roughness

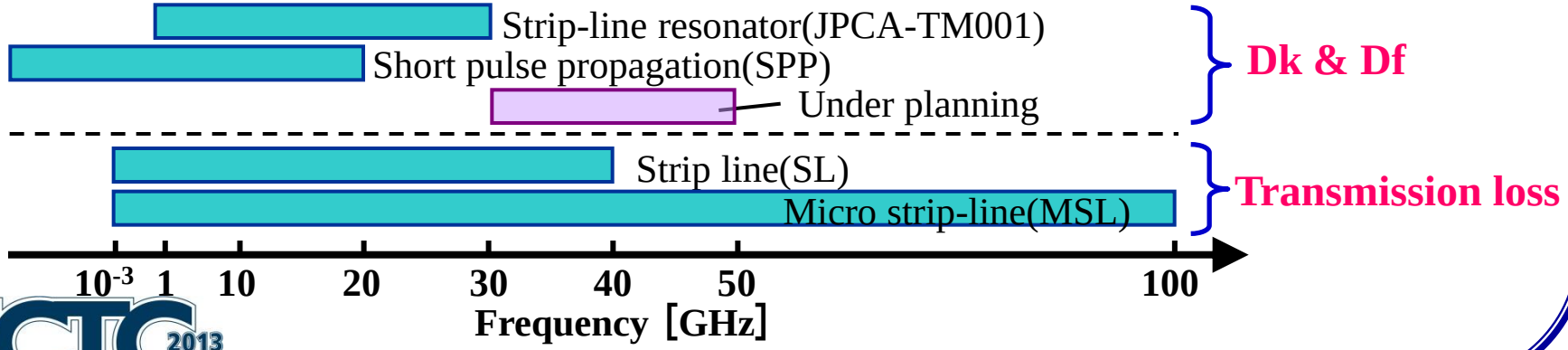
Evaluation technologies of high-frequency PWBs

- Hitachi Chemical can satisfy various evaluation requirements of high-frequency performance of materials & PWBs (e.g. Frequency bands, Form of specimen, Environmental test, etc.)

(1) Dielectric properties of materials (without conductor)

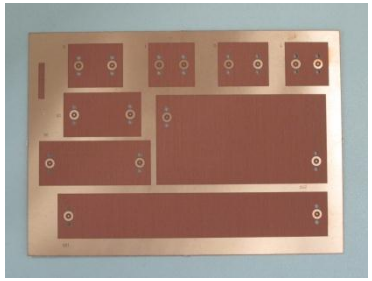


(2) Practical electrical properties of PWBs (containing conductor)

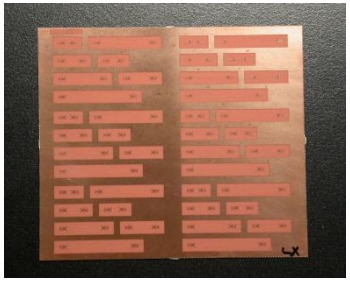


Evaluation of PWB (SL & MSL)

Strip·line(SL) structure

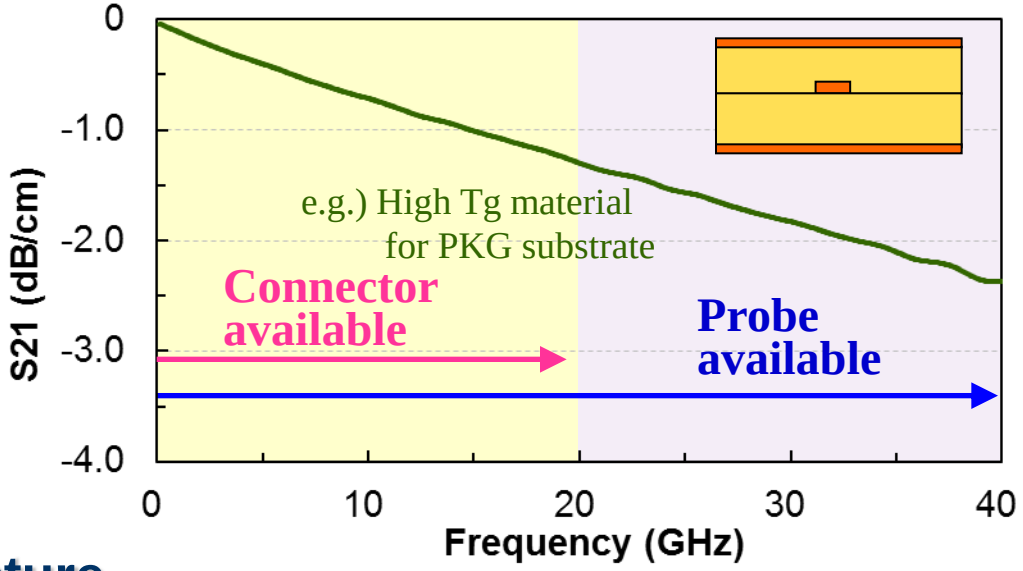


SMA connector type
(up to 20 GHz)

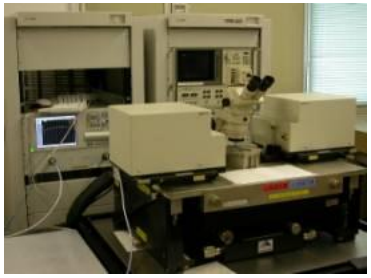


Probe type
(up to 40 GHz)

Test board (SL)

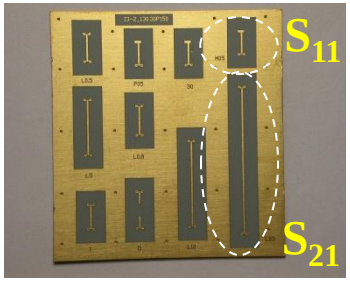


Micro strip·line(MSL) structure

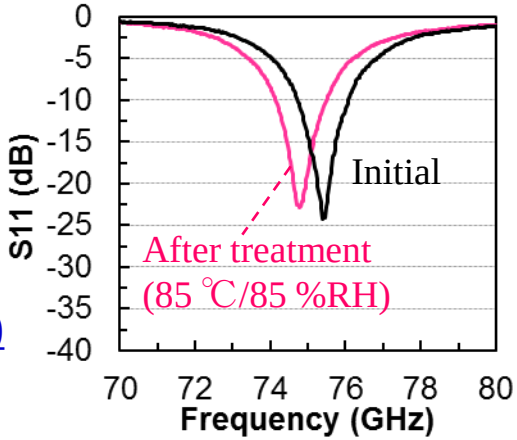


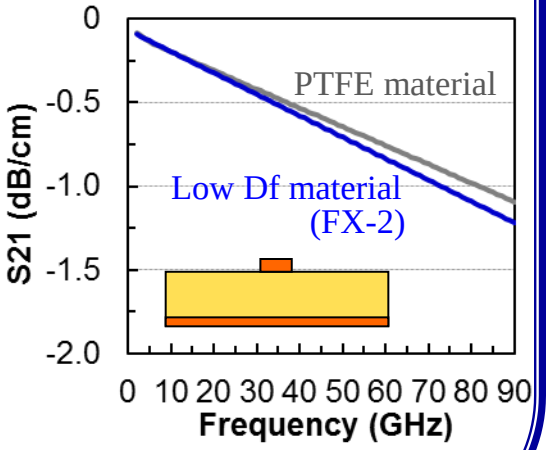
V-NA & Probe station

Measurement system



Test board (MSL)





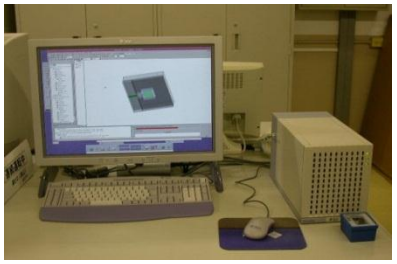
Various high-frequency properties of PWBs can be evaluated.

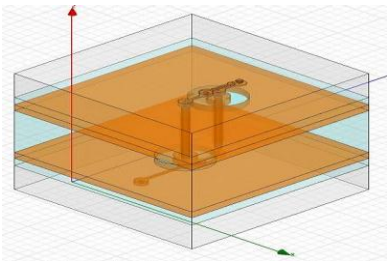
Simulation technologies

Simulator

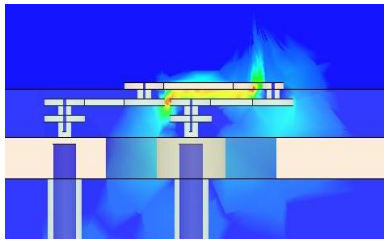
- **3D EM field solver (HFSS)**
- **Circuit simulator (ADS)**

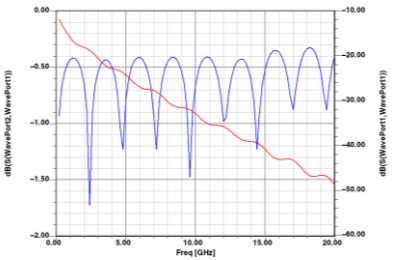
HFSS : High-Frequency Structure Simulator
ADS : Advanced Design System

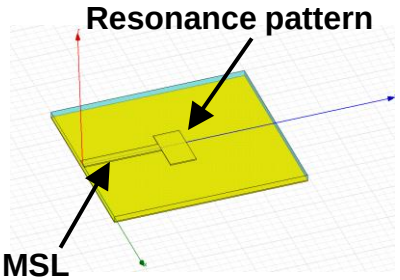


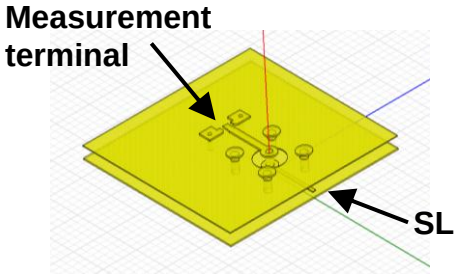


- Guessing of electrical performance, combination of structures, and the suitable materials
- Designing of PWB structure (e.g. measurement terminals, etc.) for evaluation of transmission properties to W-band, 100 GHz
- Verification of the measured Df value by fitting calculated transmission loss, S_{21}, to measured loss S_{21}
- Guessing of dielectric drift properties, ⊿Dk, by fitting calculated resonance properties, S_{11}, to measured S_{11}, etc.



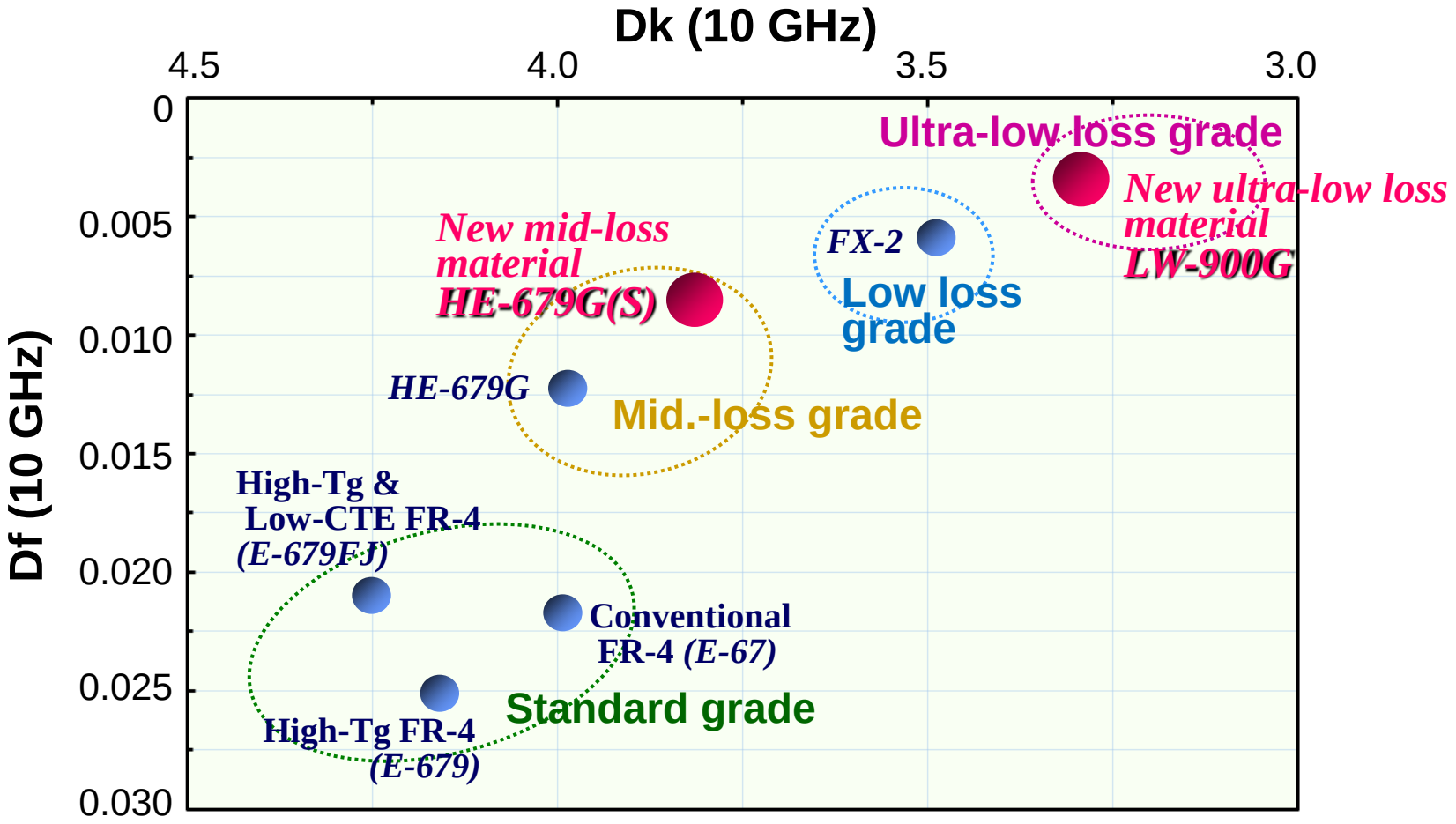






Verification of the measured properties, Dk & Df by using simulation, & feedback of them to the material design.

HC's high-layer & high-frequency materials line-up



Mid-loss material, HE-679G(S), and ultra-low loss material, LW-900G have been newly developed.

Laminate properties of new mid-loss material

Item		New mid-loss HE-679G(S)	Current HE-679G	High-Tg FR-4	Conventional FR-4
Glass type		E	E	E	E
Source of flame retardant		Halogen free	Halogen free	Halogen	Halogen
Dk (JPCA-TM001)	1 GHz 10 GHz	3.70-3.80 3.65-3.75	4.00 3.95	4.20 4.15	4.05 3.98
Df (JPCA-TM001)	1 GHz 10 GHz	0.0065-0.0070 0.0085-0.0090	0.0095 0.0120	0.0220 0.0250	0.0195 0.0215
Copper peel strength (kN/m, 1/2 oz)	Standard RTF	0.90 0.60	0.90 0.60	1.2 -	1.8 -
Tg (℃)	TMA	185	185	180	125
CTE(ppm/℃)	XY Z(α1) Z(α2)	14 40 230	14 40 220	15 55 260	15 60 260
Solder heat resistance	288 ℃	> 300 s	> 300 s	> 300 s	> 300 s
T-300	TMA	> 60 min	30 min	<10 min	<5 min
Flammability	UL-94	V-0	V-0	V-0	V-0
Reliability(CAF, IST, etc.)		Good	Good	Low	NG

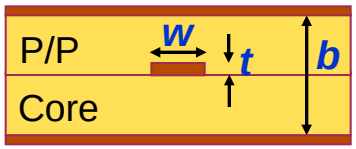
Dk & Df of the newly developed mid-loss material, HE-679G(S), have been enhanced with maintaining the other properties as HE-679G.

Transmission loss of new mid-loss material

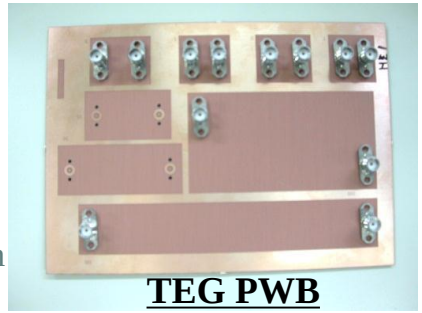
＜ Measurement conditions ＞

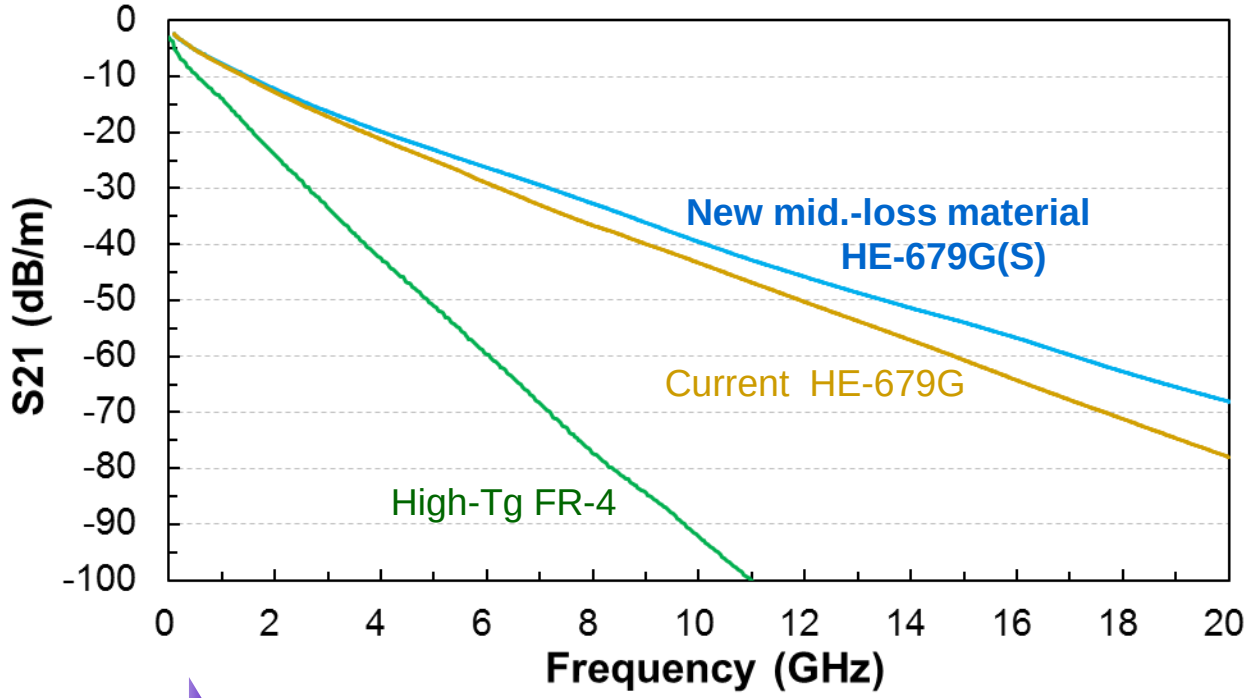
/ Evaluation structure : Strip-line
/ Temperature & Humidity : 25 ℃/60 %RH
/ Characteristic impedance : ca. 50 Ω
/ Interlayer surface treatment : Black-reduction
/ Proofreading method: TRL

/ Dimension parameters



・Trace width(***w***) : 0.11-0.12 mm
・Dielectric thickness(***b***) : 0.22-0.23 mm
・Trace thickness(***t***) : 18 μm





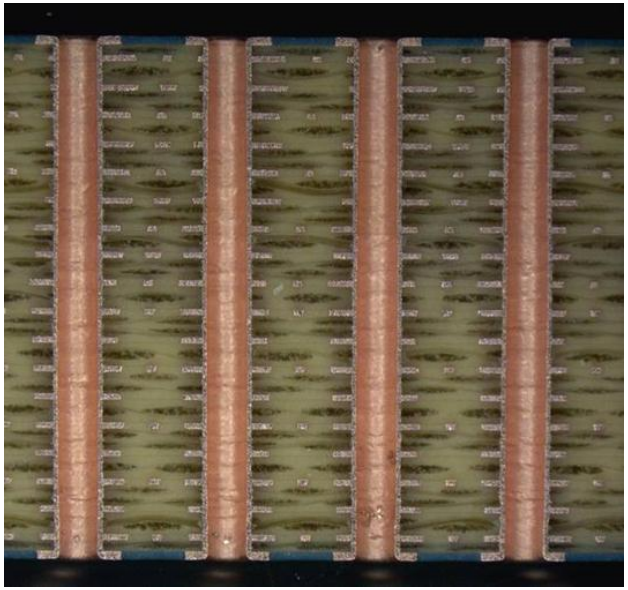
Transmission loss of HE-679G(S) has been improved, comparing with the current HE-679G.

Reliability of new mid-loss material

Heat resistance

＜Evaluation conditions＞

/ Test board : t2.47 mm / 20 layer PWB
/ Diameter : Φ0.25 mm (TH-TH pitch : 0.8 mm)
/ Pre-condition : 85 ℃/85 %RH/120 h
+ Reflow max.260 ℃ × 10 times

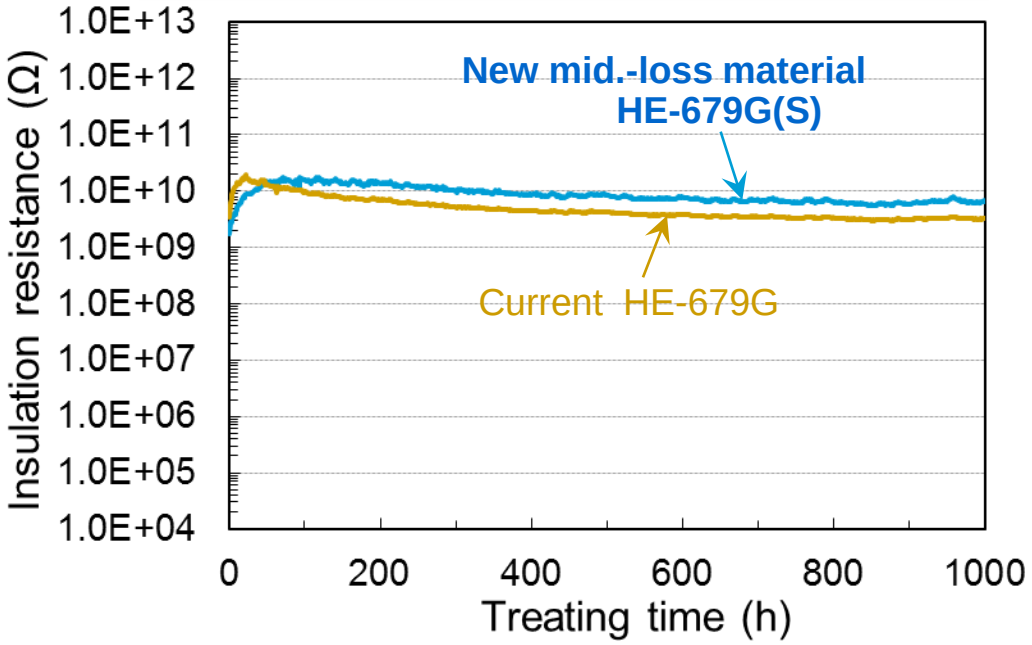


⇒ Passed (No defect)

CAF Test

＜Evaluation conditions＞

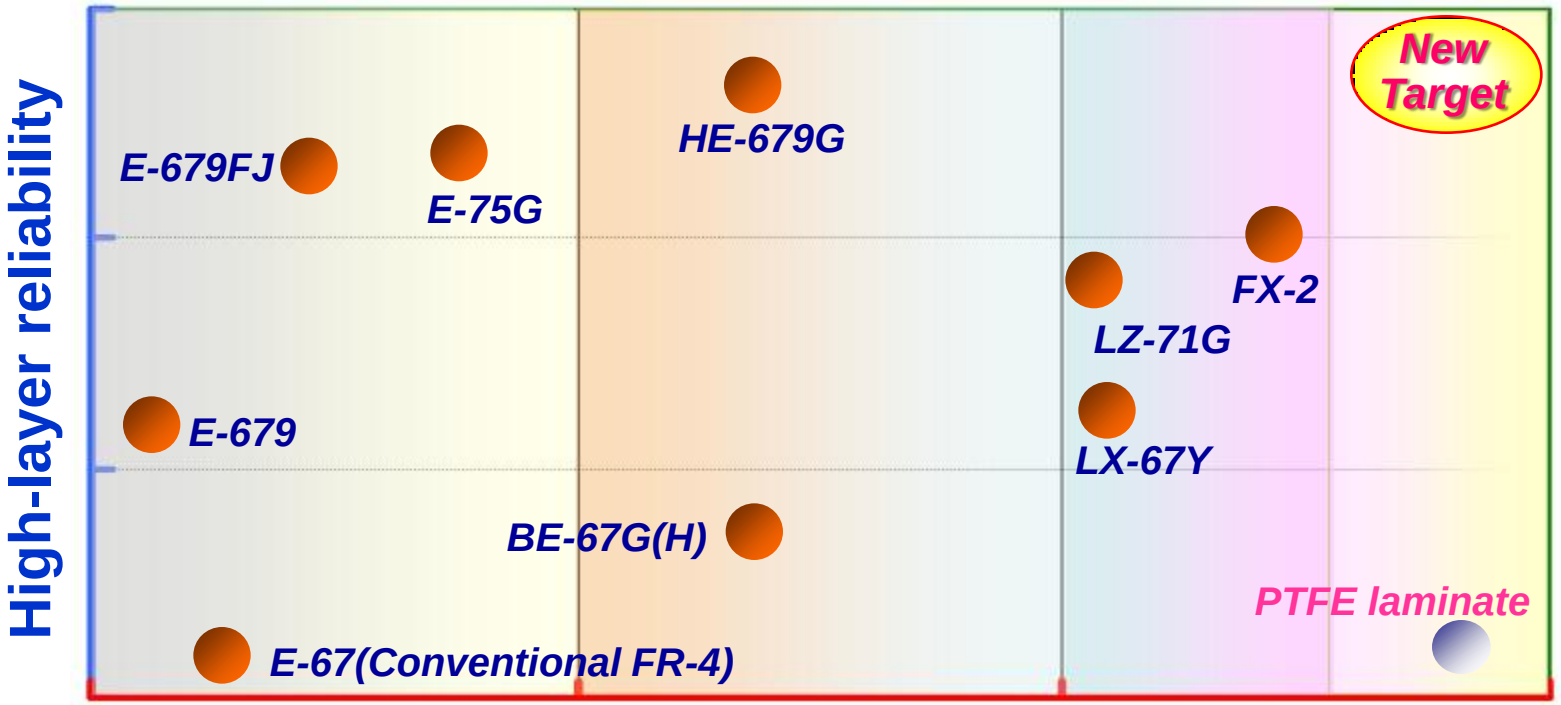
/ Test board : t1.4 mm / 2 layer PWB
/ TH-TH spacing: 0.5 mm / 2000 holes
/ Pre-condition : 30 ℃/ 60 %RH / 168 h
+ Reflow max.260 ℃ × 6 times
/ Measurement condition : 85 ℃/85 %RH, DC 100 V)
(Measurement of insulation resistance in chamber)



⇒ Excellent reliability as that of the current HE-679G

Target properties of new ultra-low loss material

HF-Performance vs. Reliability（Heat-resistance, CAF, IST, ･･･）

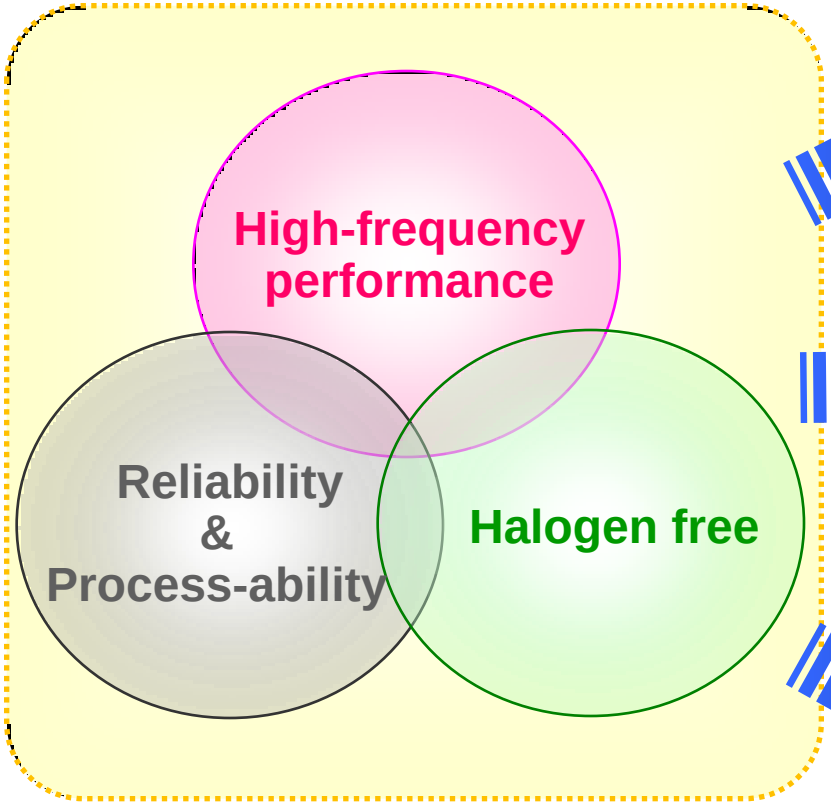


High-frequency performance

Target of new ultra low loss material is the compatibility of high-frequency performance & reliability of high-layer PWBs.

Concept & target applications of new ultra-low loss material

Development concept



Target applications & requirement

High-speed Digital / High-layer (Servers, Routers, HPC, etc.)

- High frequency performance
- High heat resistance
- High reliability(Low-CTE, CAF, etc)

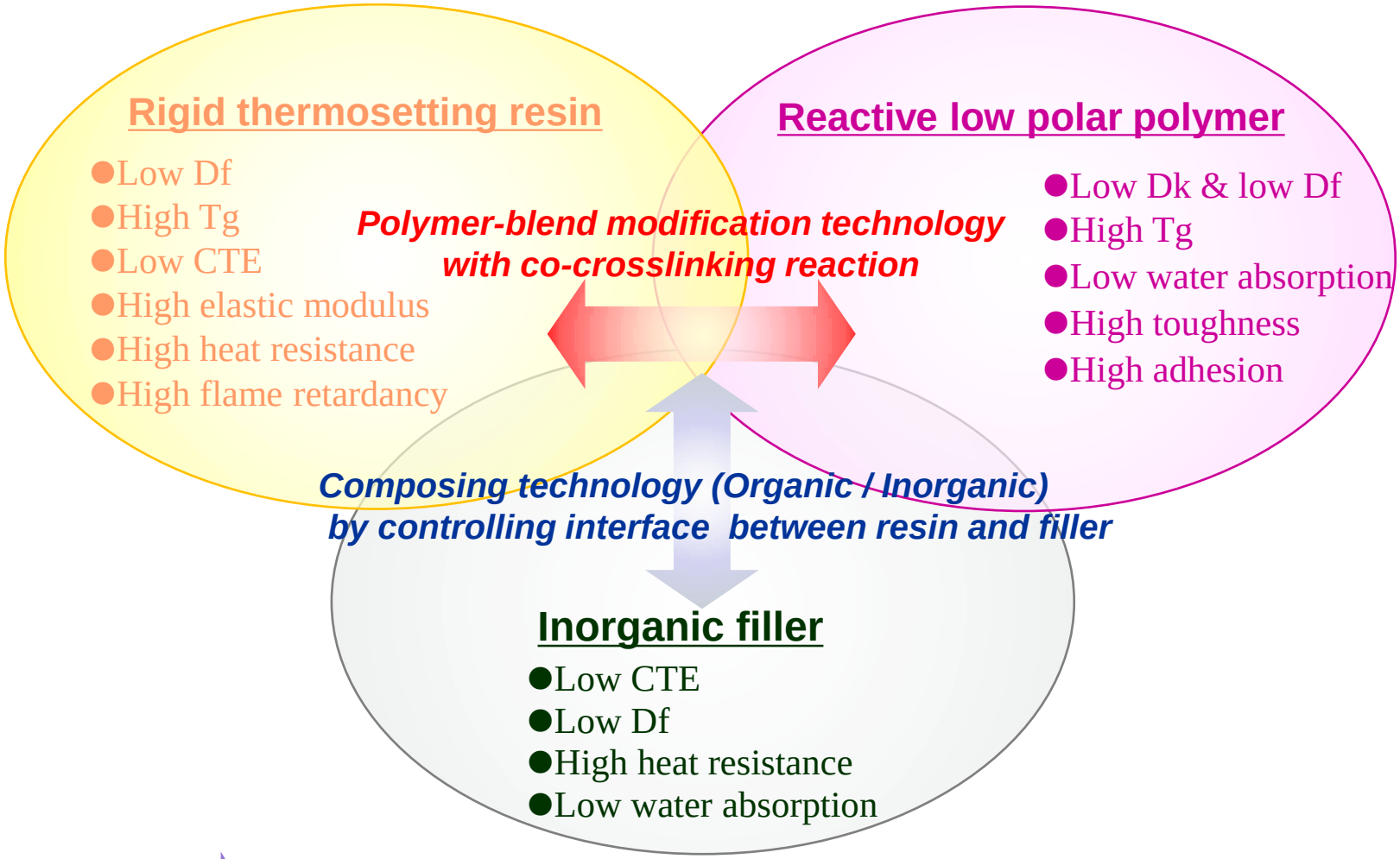
RF / Wireless (Antenna, RF-modules, etc.)

- High frequency performance
- Dk & Df drift stability (Temperature, Humidity)

High-speed PKG (MMIC-PKG, OEIC-PKG, etc.)

- High frequency performance
- High heat resistance
- High reliability(Low-CTE, CAF, etc)
- Halogen free

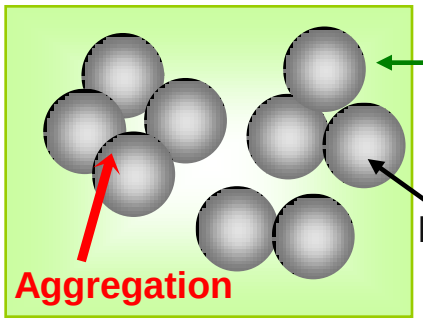
Technical composition of novel resin system designed for new ultra-low loss material



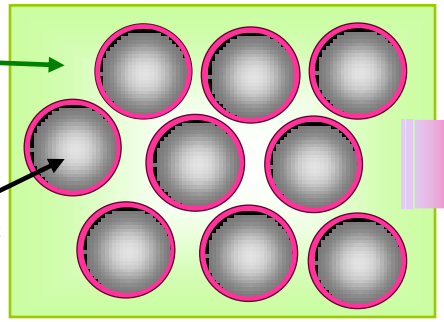
New material has been designed by using both the resin-modification technology & filler-composition technology.

Filler / Resin - composing technology

Conventional



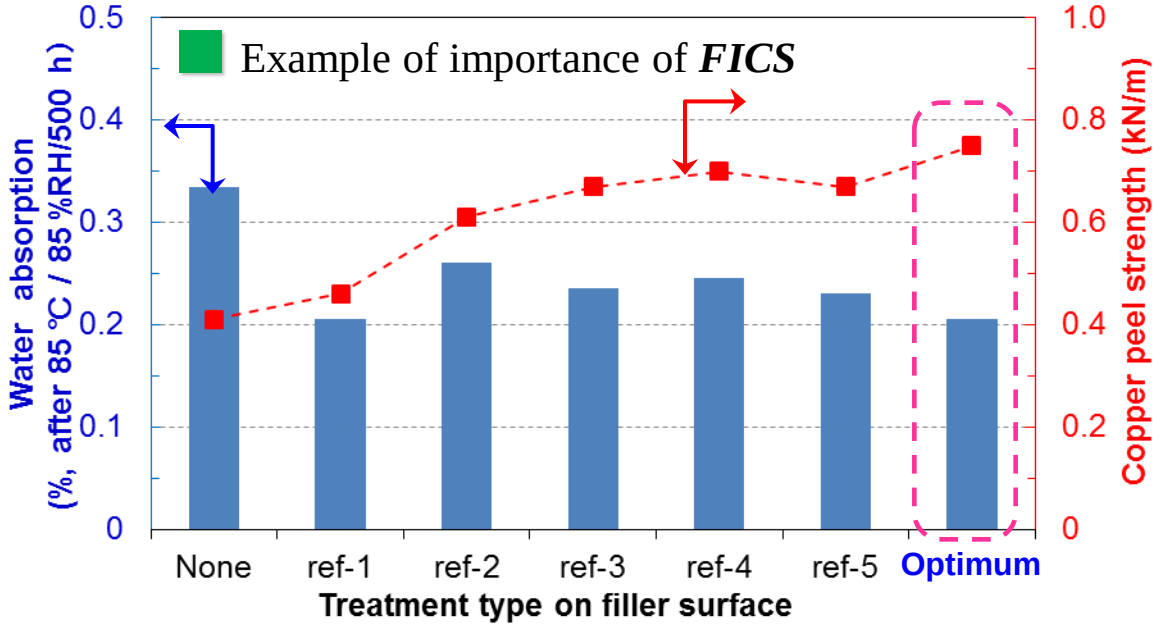
Filler interface control system (*FICS*)



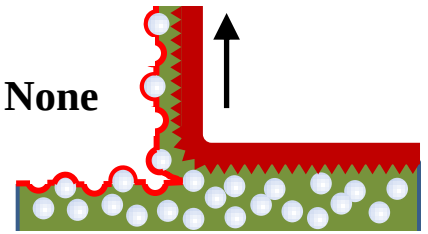
Optimization of interface(Filler / Resin)

⇒ **Excellent adhesion & dispersion**

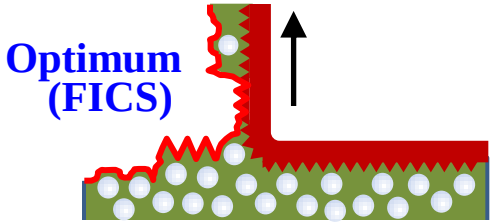
/ Low water absorption
/ High peel strength
/ Excellent heat resistance
/ Excellent CAF restraining property



Exfoliation mode on Cu-peeling test



→ Exfoliation between filler & resin



→ Cohesive failure of resin

The control of interface between resin and filler is important to enhance various properties.

Laminate properties of new ultra-low loss material

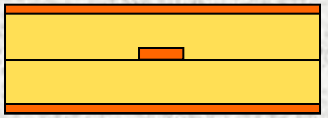
Item		New ultra-low loss LW-900G		Current low loss FX-2	HE-679G	Standard PTFE laminate
Resin system		Thermosetting		Thermosetting	Thermosetting	Thermoplastic
Glass type		E	NE (Low Dk)	E	E	E
Source of flame retardant		Halogen free		Halogen	Halogen free	-
Dk (JPCA-TM001)	10 GHz	3.57	3.32	3.45	3.95	2.62
Df (JPCA-TM001)	10 GHz	0.0048*1)	0.0038*1) 0.0034*2)	0.0058	0.0120	0.0038
Copper peel strength (kN/m, 1/2 oz)	RTF HVLP	0.75 0.63	0.75 0.63	0.60 -	0.60 -	1.2(Std.-foil) -
Tg (℃)	TMA	198	198	185	185	30
CTE(ppm/℃)	XY Z(α1) Z(α2)	13 40 250	13 40 250	15 47 110	14 40 220	18 105 310
Solder heat resistance	288 ℃	> 300 s	> 300 s	> 300 s	> 300 s	> 300 s
T-300	TMA	> 60 min	> 60 min	> 60 min	20 min	-
Flammability	UL-94	(V-0)	(V-0)	V-0	V-0	V-0
Reliability(CAF, IST, etc.)		On internal evaluation	On internal evaluation	On evaluation by PWB maker	Good	-

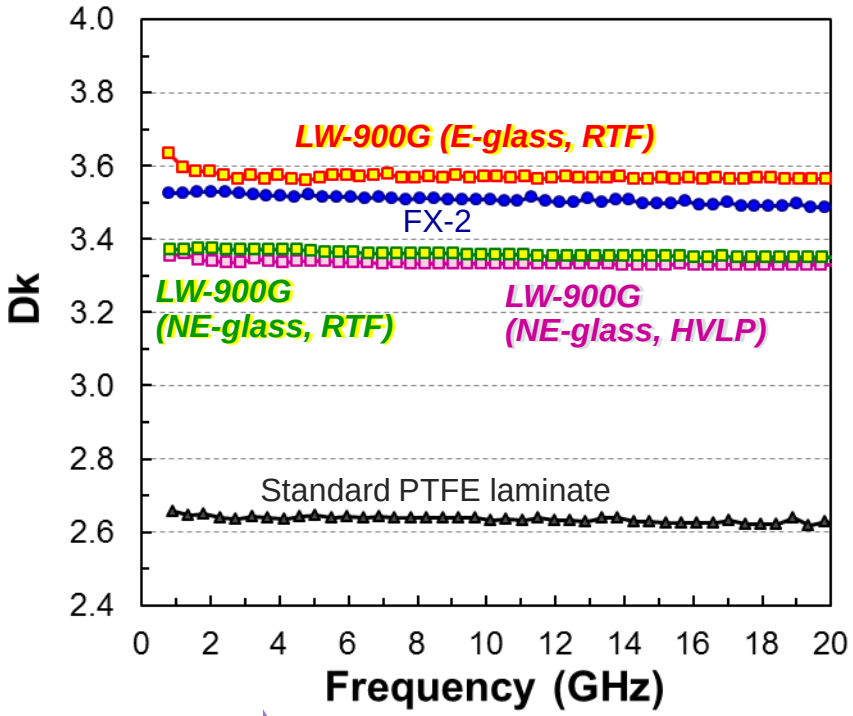
***1)** Practical value calculated by the condition of strip-line structure with Cu-foil(RTF , Rz≒3 μm)
***2)** Practical value calculated by the condition of strip-line structure with Cu-foil(HVLP, Rz≒1.5 μm)

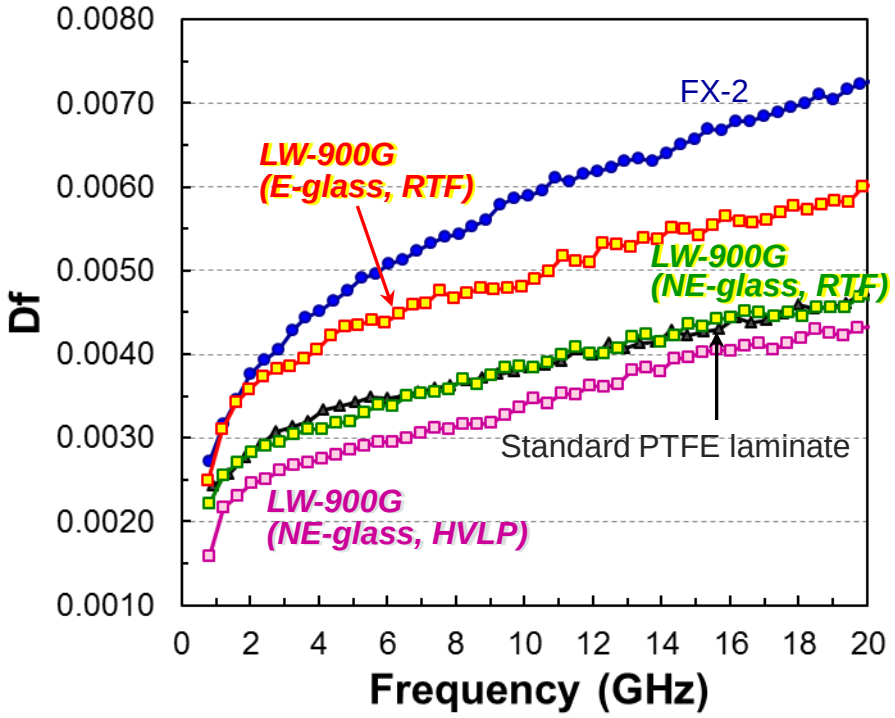
Dk & Df vs. Frequency

< Measurement conditions >

/ Method : Strip-line resonator (JPCA-TM001)
/ Temperature & Humidity : 25 ℃/ 60 %RH
/ Dielectric thickness : 1.6 mm(Ground - Ground), Copper foil : 18 μm







Excellent stability of Dk in wide frequency range

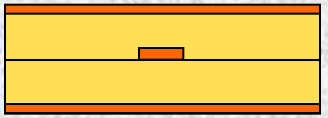
Df of standard type is lower than the current low loss material(FX-2).

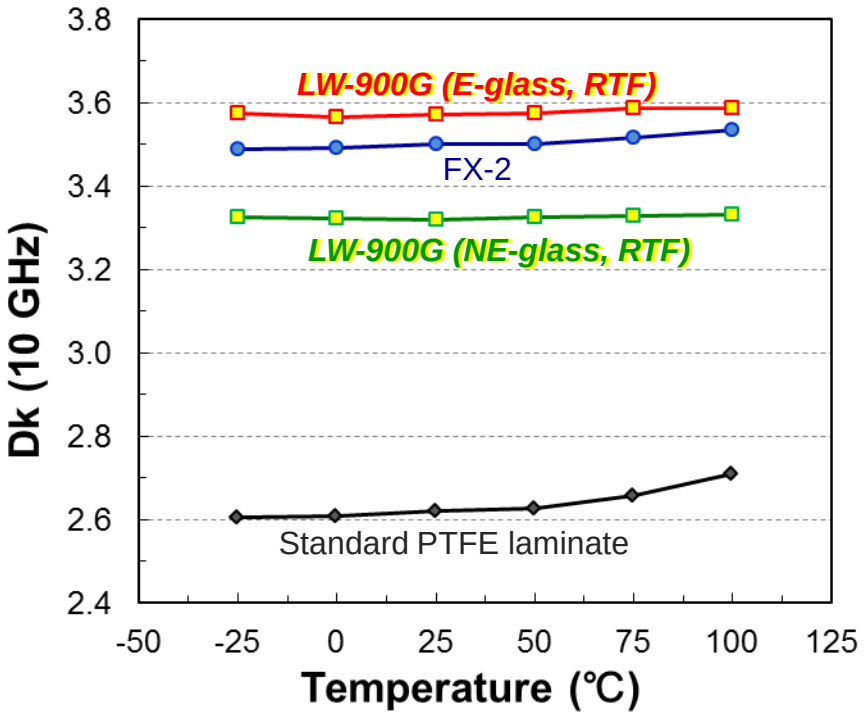
Df of low-Dk type with HVLP is better than that of PTFE laminate.

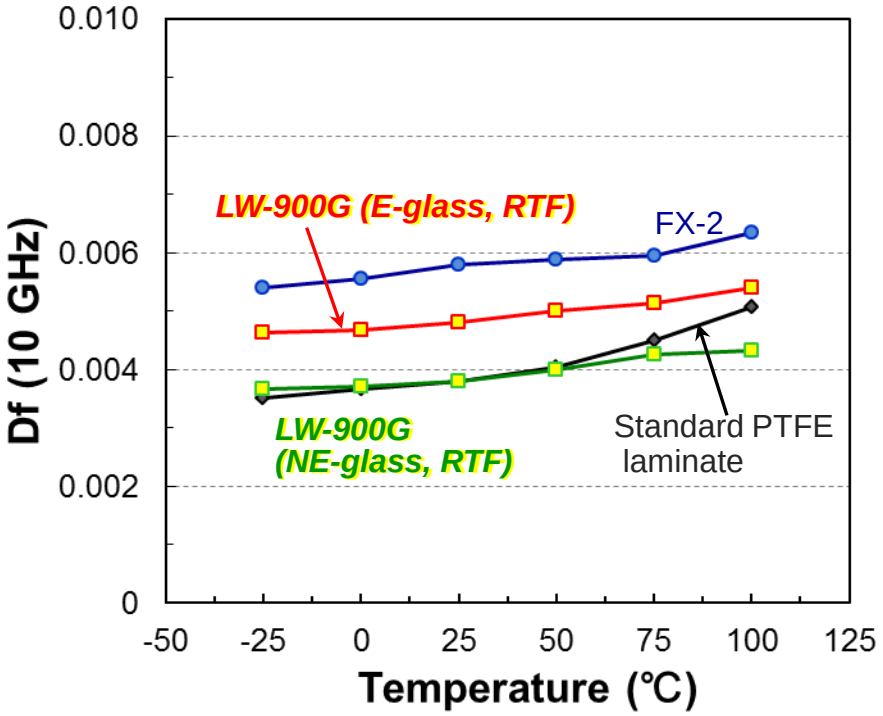
Dk & Df vs. Temperature

< Measurement conditions >

/ Method : Strip-line resonator (JPCA-TM001)
/ Temperature : -25～100 ℃
/ Dielectric thickness : 1.6 mm(Ground - Ground), Copper foil : 18 μm





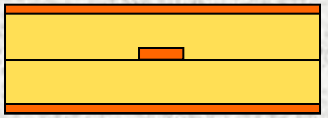


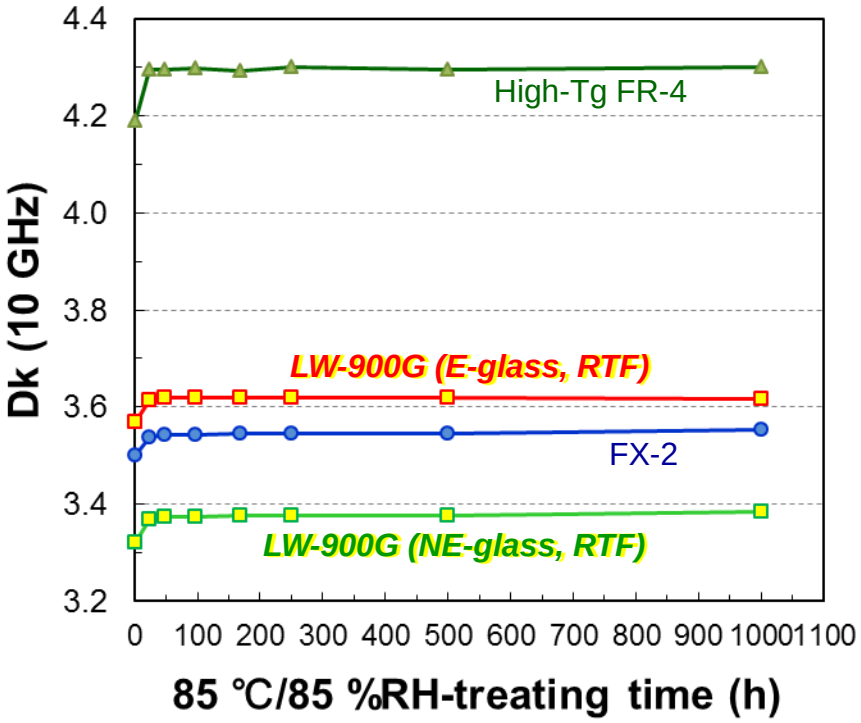
➡ Excellent stability against temperature change

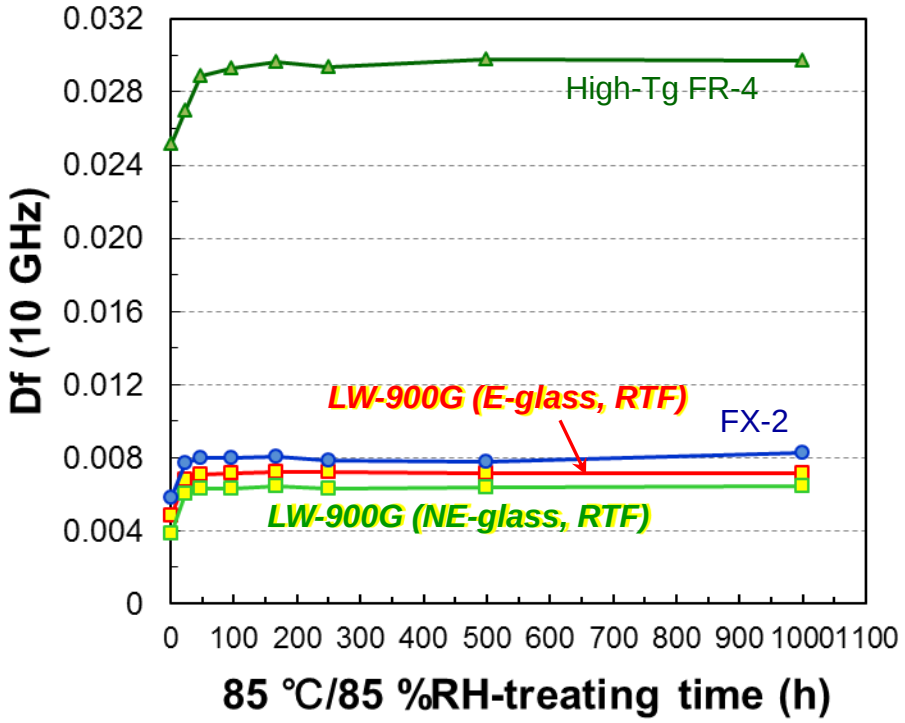
Dk & Df vs. Moisture absorption

< Measurement conditions >

/ Method : Strip-line resonator (JPCA-TM001)
/ Moisture absorption treatment : 85 ℃/85 %RH/－1000 h
/ Dielectric thickness : 1.6 mm(Ground - Ground), Copper foil : 18 μm







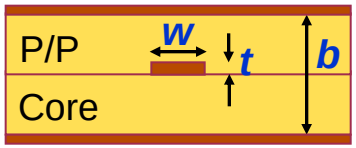
Better stability against moisture absorption treatment compared with high-Tg FR-4

Transmission loss of new ultra-low loss material

＜ Measurement conditions ＞

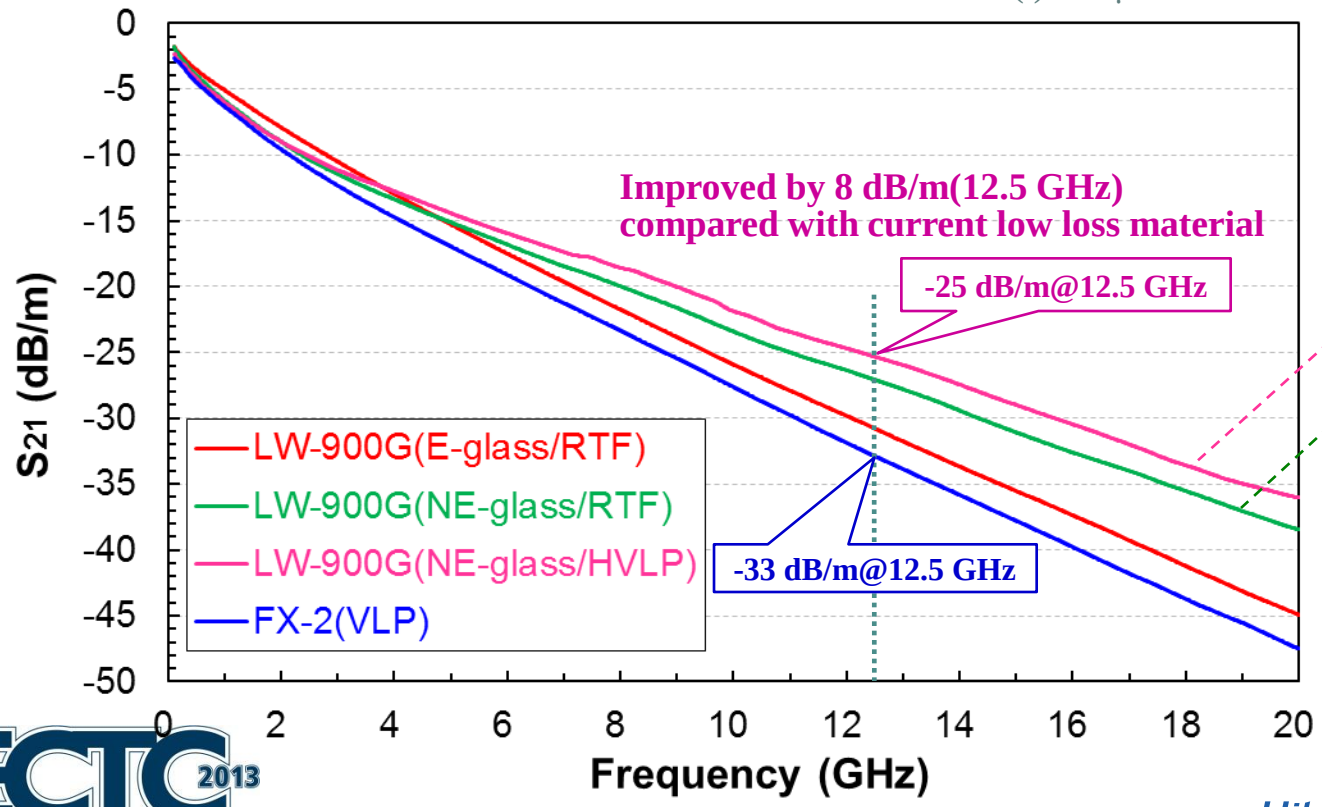
/ Evaluation structure : Strip-line
/ Temperature & Humidity : 25 ℃/60 %RH
/ Characteristic impedance : ca. 50 Ω
/ Interlayer surface treatment : Black-reduction
/ Proofreading method: TRL

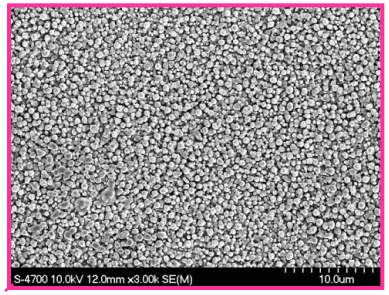
/ Dimension parameters



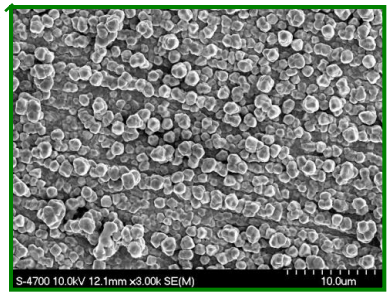
- Trace width(***w***) : 0.120 mm
- Dielectric thickness(***b***) : 0.23-0.25 mm
- Trace thickness(***t***) : 18 μm

TEG PWB





HVLP(Rz≒1.5 μm)

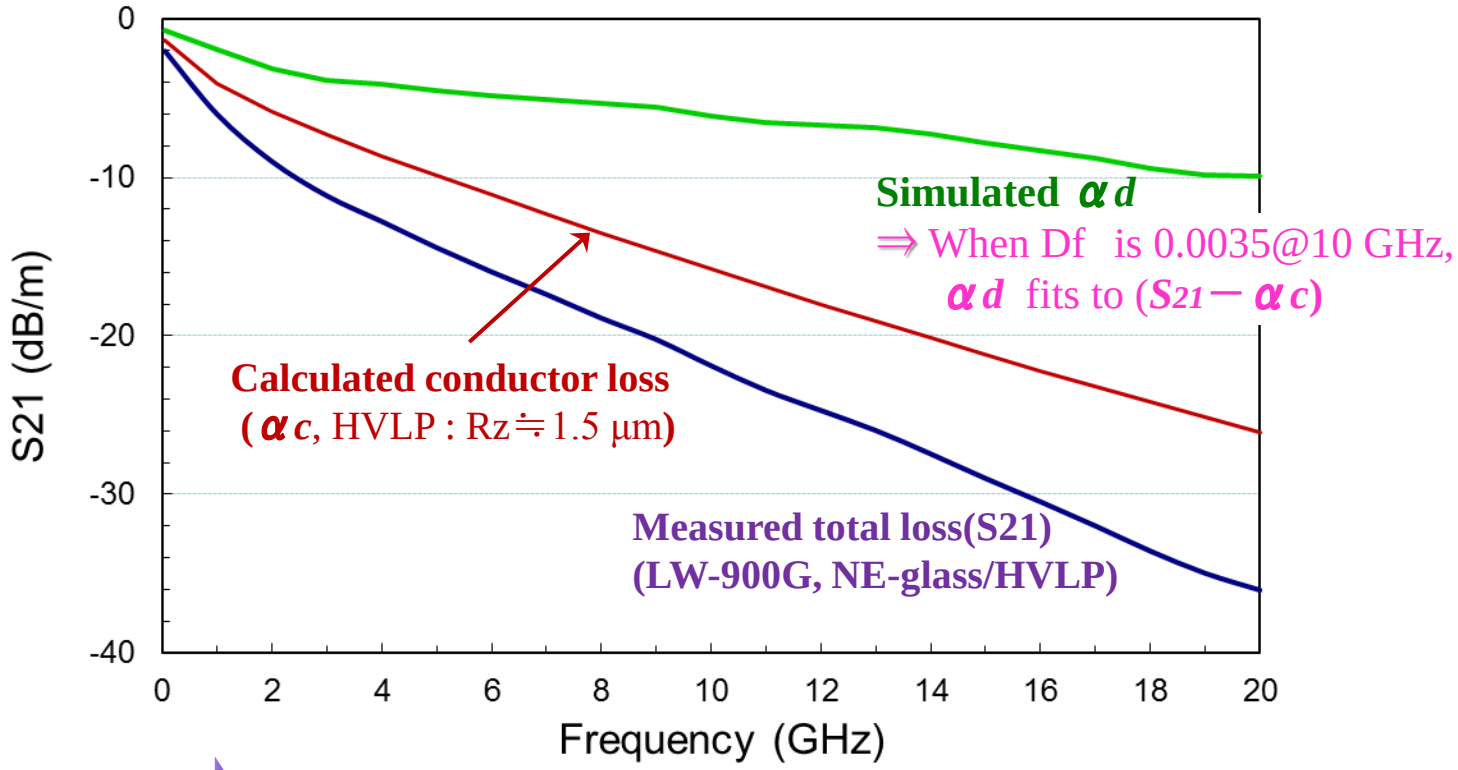


RTF(Rz≒3 μm)

Verification of Df by simulation

Verification procedure

(1) Calculating of the conductor loss(αc) in the case of HVLP foil by using simulator (HFSS)
(2) Calculating of Df which fitting dielectric loss(αd) to the loss value which subtracted simulated αc from the measured actual total loss(S_{21}) (Df ← $\alpha d = S_{21} - \alpha c$)



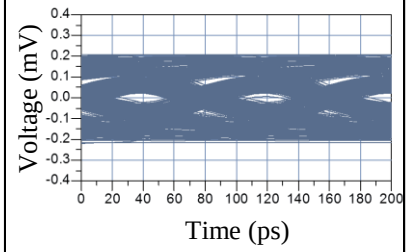
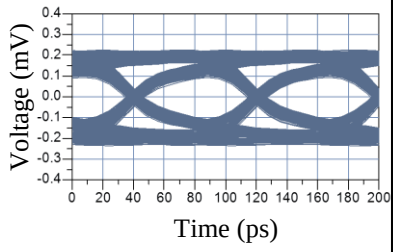
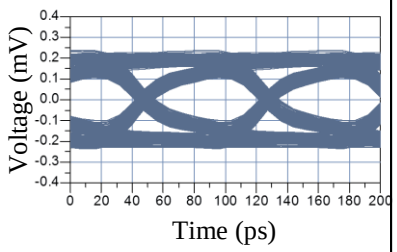
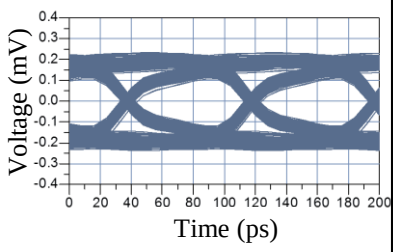
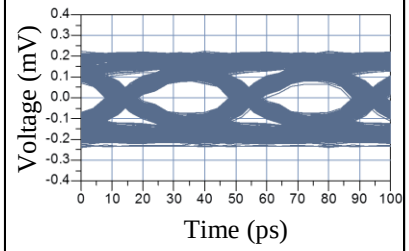
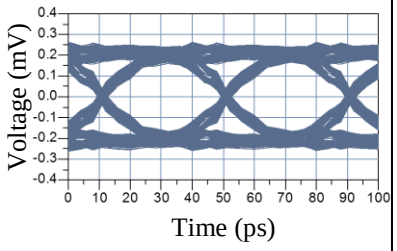
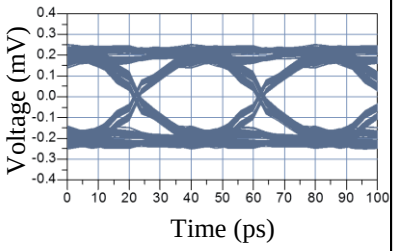
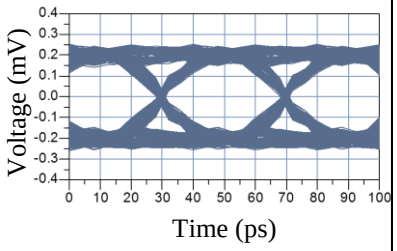
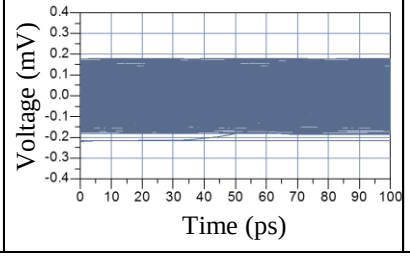
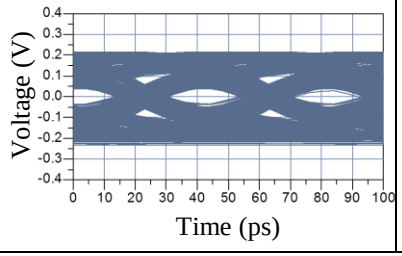
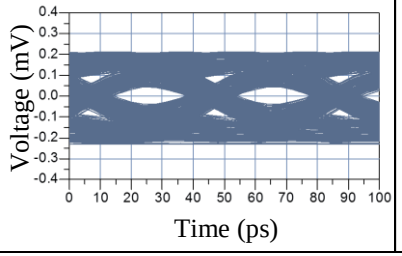
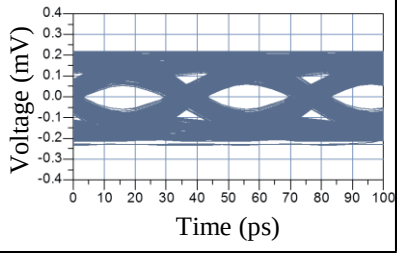
Df@10GHz=0.0035(NE-glass/HVLP foil) was verified by simulation(HFSS), too.

Eye pattern diagrams

< Measurement conditions >

/ Evaluation PWB : Former S21 evaluation PWB(Strip-line)

/ Bit rate : 12.5 Gbps (Trace length : 300 mm) , 25 Gbps (Trace length : 100 & 300 mm)

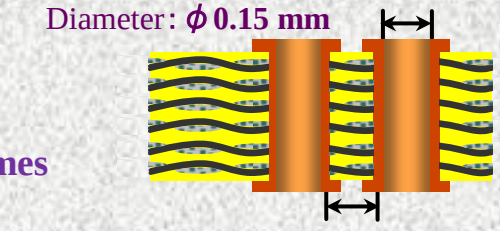
Item	HE-679G	FX-2	LW-900G(E-glass)	LW-900G(NE-glass)
12.5 Gbps L:300mm				
25 Gbps L:100mm				
25 Gbps L:300mm				

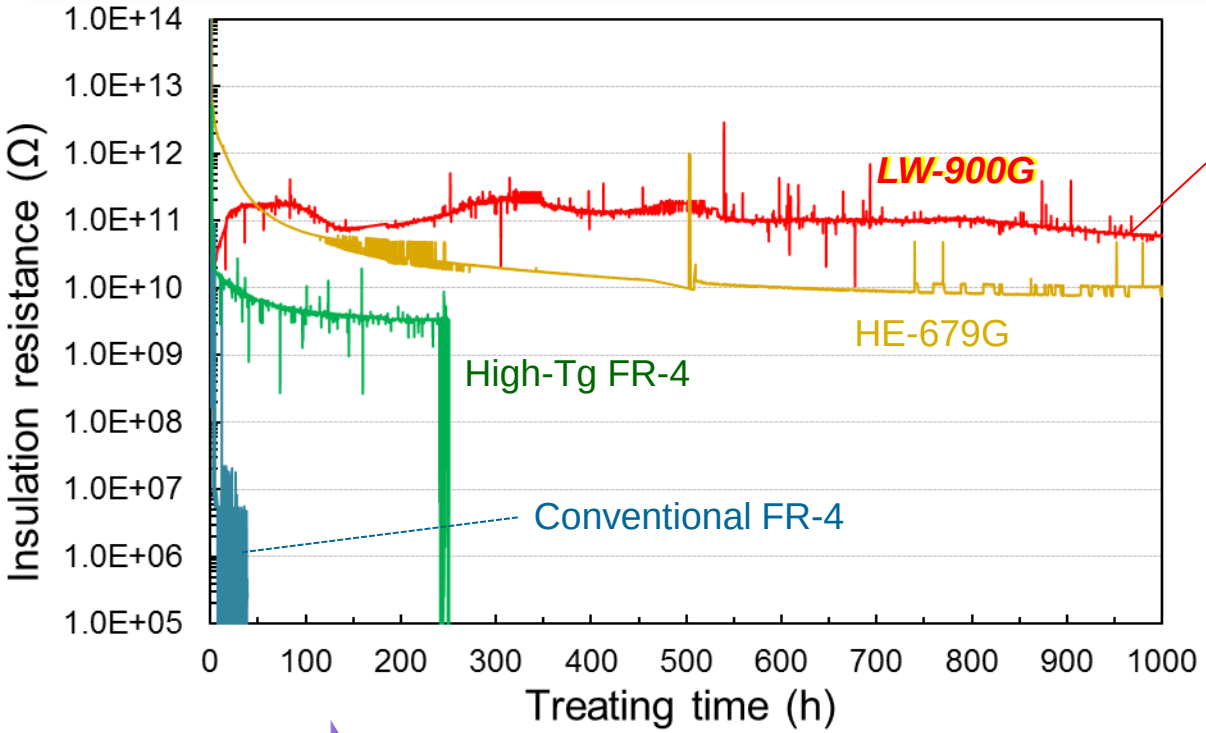
Eye-opening of LW-900G is better than the others.

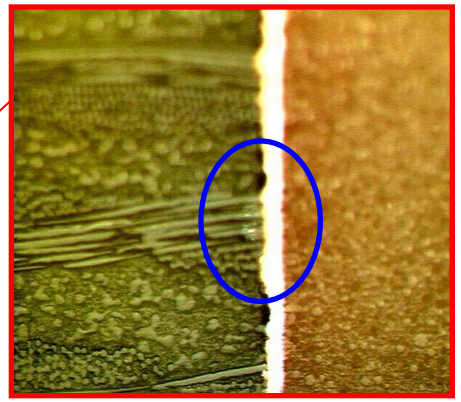
Insulation reliability(CAF evaluation)

＜ Evaluation conditions ＞

- / Evaluation board : t0.8 mm(Cu:18 μm) / 2 layer PWB
- / Diameter : Φ0.15 mm / TH-TH spacing : 0.2 mm
- / Pre-condition : 85 ℃/85 %RH/120 h + Reflow max.260 ℃ × 8 times
- / Measurement condition : HAST(130 ℃/85 %RH), DC 5.5 V
  (Continuous measurement of insulation resistance in chamber)







Crack (glass/resin) by drilling : <10～20 μm

Excellent CAF restraining property & drilling process-ability

Features & Current status of new ultra-low loss material (*LW-900G*)

Features of LW-900G

- Df@10 GHz ⇒ E-glass type : Lower than current low loss material(FX-2)
  Low-Dk type : same or better compared with PTFE material
- Thermal-mechanical properties（Tg, CTE, etc）⇒ Better than FX-2
- Heat resistance ⇒ Excellent
- Flame retardancy ⇒ V-0 by Halogen-free resin system
- Reliability of high-layer PWB (CAF, TCT, IST, etc.) ⇒ On evaluation
- Drilling process-ability of high-layer PWB ⇒ On evaluation

Ongoing study

- Optimization of mass production process
- Reliability test & process-ability test of high-layer PWB
- Further improvement of dielectric properties for the next generation material
  (Df Target : < 0.002@10-20 GHz)

Road Map of HC's high-frequency Materials

Applications		～2000	2002	2004	2006	2008	2010	2012	2014
Transmission rate/link (Backplane)		300 Mbps～1 Gbps		1.25～2.5 Gbps		3.2～6.4 Gbps		～12.5 Gbps	>25 Gbps
(Mobile)		<2.4 Kbps	9.6 bps～144 Kbps	2 Mbps		3.8 Mbps	5.7 Mbps	7.2 Mbps	>12 Mbps
High-end digital (High-speed & High-layer)	・Router ・Server ・Storage ・Transport ・HPC ・Measurement equipment ・IC-tester, etc.	Dk<3.8/Df<0.005				Dk<3.7/Df<0.003			Dk<3.3 Df<0.002
		LX-67/LX-67Y Dk:3.5/Df:0.005		LZ-71G Dk:3.6/Df:0.006		FX-2 Dk:3.5/Df:0.003		LW-900G Df:0.002	New Df:<0.002
Middle～Std. digital		Dk<4.5/Df<0.025		Dk<4.5/Df<0.018		Dk<4.0/Df<0.01			Dk<3.8 Df<0.007
		E-67/E-679 Dk:>4.0/Df:>0.02		E-679FJ Dk:4.3/Df:0.018		HE-679G Dk:4.0/Df:0.009		HE-679G(S) Df:0.006	New Df:<0.005
RF/Wireless (Analog high-Freq.)	・Antenna ・Sensor ・RF-Module ・Base station ・Mobile devices	Df<0.01		Df<0.005		Dk<3.5 Df<0.003			Dk<3.3 Df<0.002
		HD-67 Dk:10.2/Df:0.009		LX-67F Dk:3.7/Df:0.003		FX-2/FX-3 Dk:3.2-3.5/ Df:0.0025-0.0028			
High-speed -PKG	・PC/Server ・Mobile devices ・RF-Module ・MMIC-PKG	Df<0.015				Df<0.01			Df<0.005
			E-679F/E-679FG Dk:4.5/Df:0.014			LZ-71G Dk:3.6/Df:0.006	E-800G Dk:4.0/Df:0.005		LW-900G Df:0.002
Build-up material for PKG	・PC/Server ・Mobile devices ・RF-Module ・MMIC-PKG					Df<0.02		Df<0.015	Df<0.005
						AS-Z2 Df:0.015	AS-Z3(K) Df:0.013		AS-Z5 Df:0.005

Dk&Df: value of 1GHz

Conclusions

- We have lined up low transmission loss PWB materials for high-speed and high-frequency applications.
- The new mid-loss material, HE-679G(S) has lower Dk and Df than current material, HE-679G, and has the excellent reliability as HE-679G.
- Novel low loss and halogen free thermosetting resin system has been designed for the next generation high-speed applications.
- Innovative ultra-low loss material, LW-900G with the novel resin technology shows lower Df than standard PTFE laminate, which is characterized by high Tg, low CTE, high heat resistance, the excellent CAF property, and the process-ability almost similar to FR-4.

Note: *The contents of this report are based on the results of experiments and do not represent a guarantee of the values for each property.*

Thank you for your attention!