Novel CCL Based on New Fluoropolymer Exhibits Extremely Low Loss Characteristics and New Evaluation Method for Separating Dielectric and Conductive Losses

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EXECUTIVE SUMMARY

We demonstrate here a novel CCL (Copper Clad Laminate) which exhibits an extremely low transmission loss at mm-wave band. The CCL which we developed is based on a new fluoropolymer with adhesive characteristics. In contrast to conventional PTFE, the adhesive fluoropolymer allows us to apply a wholly dry process for CCL fabrication, which contributes to environmental load reduction.

It is well known that the factor of transmission loss mainly consists of conductive loss and dielectric loss. However, in conventional CCL data sheets, only the loss tangent data at specific frequencies are disclosed. Neither the dielectric loss nor the whole transmission loss at the other frequencies is known. In order to minimize the transmission loss at mm-wave band, the quantitative analysis for those factors is essential.
We proposed the evaluation method which can clarify not only the dielectric loss but also the conductive loss of CCL up to 110GHz. Several transmission lines with different impedance were measured and analyzed; the two different losses were discriminated in straight forward manner. Besides the evaluation method, a highly accurate measurement technique for low loss transmission line was achieved.

Using several kinds of surface roughness of copper foil, we made CCL test samples and evaluated the transmission loss by the above-mentioned method. Since the results indicated that the surface roughness of copper foil remarkably influenced the transmission loss, profile free copper foil was used for developed CCL. Due to the adhesive characteristics of new fluoropolymer, enough peeling strength was obtained without extra surface treatment.

Finally we benchmarked our developed CCL to the Rogers RT/duroid 5880, world lowest loss characteristics, and the result showed improved loss characteristics compared to RT/duroid 5880.

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Overview

- Motivations
- Analytical calculation
- Loss separating approach
- Validity of the calculation
- Benchmarking
- Summary

Motivations

- Circuit designers
  - don't know how much the transmission loss in a desired frequency is from the conventional CCL data sheets.
- CCL manufacturers
  - don't know which factor is affected how much in the transmission loss in an assumed frequency.

Motivations

- It's very useful to understand a frequency response of each loss factor of some substrates.

➔We propose an evaluation method, which can clarify the three kinds of loss factors and their frequency responses.

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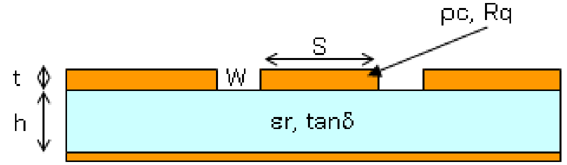
Analytical calculation

Impedance of CBCPW*

- Cross Section of CBCPW

*Conductor Backed CoPlanar Waveguide



- Quasi-static analysis based on the conformal mapping method

$$Z_{0cp} = \frac{60\pi}{\sqrt{\varepsilon_{re}}} \cdot \frac{1}{K(k_1)/K'(k_1) + K(k_6)/K'(k_6)} \quad (1)$$

ε_{re} : effective dielectric constant

$K(*), K'(*)$: elliptic integrals of first kind and its complement

[1] K. C. Gupta, and et al, *Microstrip Lines and Slotlines*, Artech House, Inc., 1996.

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Impedance of CBCPW

- Effect of metallization thickness

$$S_e = S + \Delta, W_e = W - \Delta \qquad (2)$$

$$\Delta = (1.25t/\pi)\cdot[1 + \ln(4\pi S/t)] \qquad (3)$$

- Frequency dispersion

$$\sqrt{\varepsilon_{re}(f)} = \sqrt{\varepsilon_{re}(0)} + \frac{\sqrt{\varepsilon_r} - \sqrt{\varepsilon_{re}(0)}}{1 + G(f/f_{TE})^{-1.8}} \qquad (4)$$

$$G = e^{u\ln(2a/(b-a))+v} \qquad (5)$$

$$u = 0.54 - 0.64p + 0.015p^2, v = 0.43 - 0.86p + 0.54p^2, \; p = \ln(2a/h) \qquad (6)$$

$$f_{TE} = \frac{c}{4h\sqrt{\varepsilon_r - 1}} \qquad (7)$$

- *Z_{0cp}* can be derived from substituting (4) in (1)

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Transmission loss of CBCPW

- Caused by the conductivity

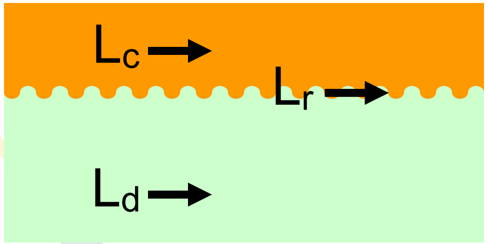
$$L_c = 4.88\times10^{-4}\cdot R_s\varepsilon_{re}Z_{0cp}\frac{P'}{\pi W}\left(1+\frac{S}{W}\right)\cdot\left\{\frac{1+1.25t/\pi S+(1.25/\pi)\ln(4\pi S/t)}{\left[2+S/W-(1.25t/\pi W)(1+\ln(4\pi S/t))\right]^2}\right\} \quad (8)$$

$$R_s = \sqrt{\pi\cdot f\cdot\mu_0/\sigma}$$

- Caused by the surface roughness

[5] Goldfarb, Marc E., "Losses in GaAs Microstrip,"

$$L_r = L_c\cdot\frac{2}{\pi}\tan^{-1}\left[1.4\cdot\left(\frac{R_q}{\delta}\right)^2\right] \quad (9)$$



R_q : the rms conductor surface roughness

δ : the skin depth, $\left(=\sqrt{\pi\cdot f\cdot\mu\cdot\sigma}\right)$

- Caused by the dielectric tangent

$$L_d = 27.3\frac{\varepsilon_r}{\sqrt{\varepsilon_{re}}}\frac{\varepsilon_{re}-1}{\varepsilon_r-1}\frac{\tan\delta}{\lambda_0} \quad (10)$$

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Loss separating approach

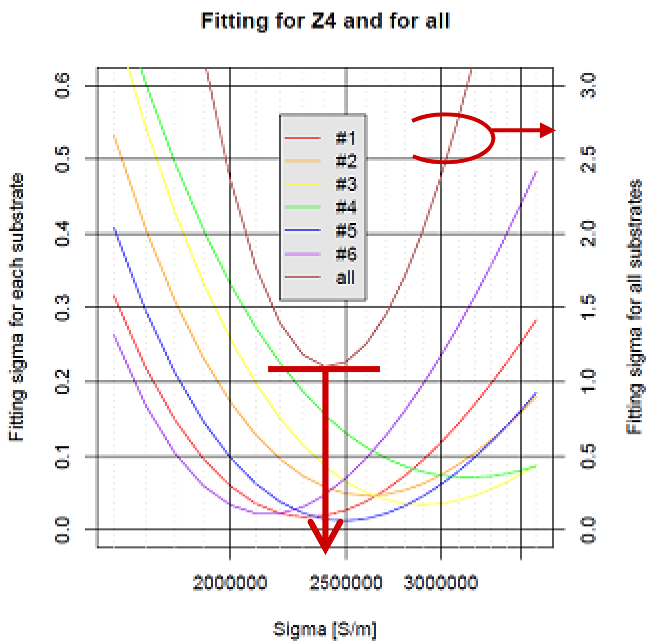
Evaluated substrates

Substrate #	εr	tanδ	h(mm)	t(um)	Rq(um)	Cu foil
#1	2.2	0.0015	0.25	29	0.37	low profile
#2	2.2	0.0011	0.25	30	0.36	profile free
#3	2.2	0.0011	0.25	27	0.46	low profile
#4	2.2	0.0011	0.25	25	0.77	general
#5	2.2	0.0009	0.25	30.5	0.40	unknown
#6	2.5	0.0018	0.31	29	0.45	unknown

- #1 to #4 are our new developing fluoropolymer CCLs
- #5 is the Rogers RT/duroid 5880
- #6 is the major fluoropolymer CCL in Japan.
- For all, we designed transmission lines with Z_c=45~55ohm (8 kinds of Z_c, named Z1-8 in descending order) , L=8mm

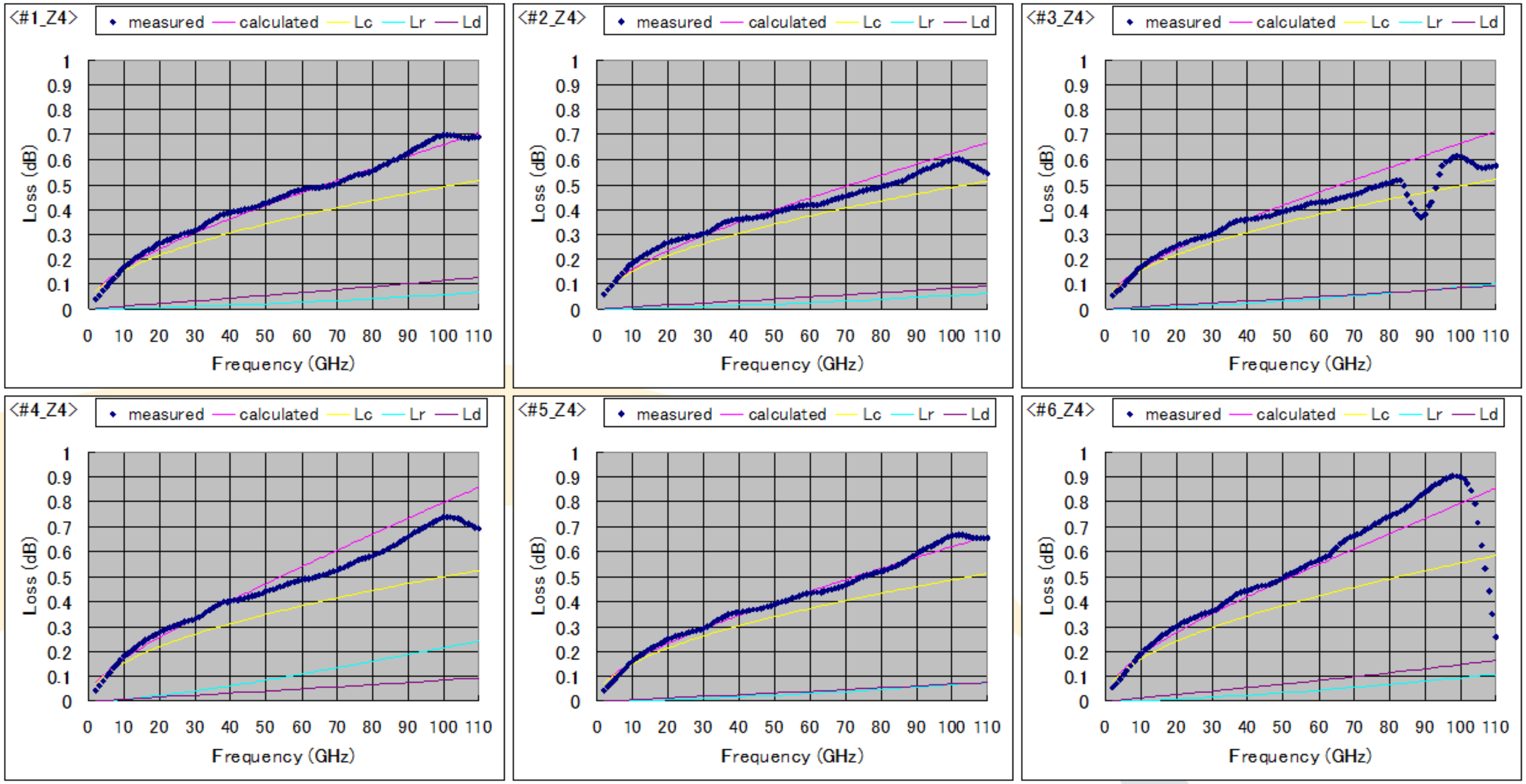
Loss separating approach

- Fitting with σ as a parameter
  - The only σ is unknown parameter



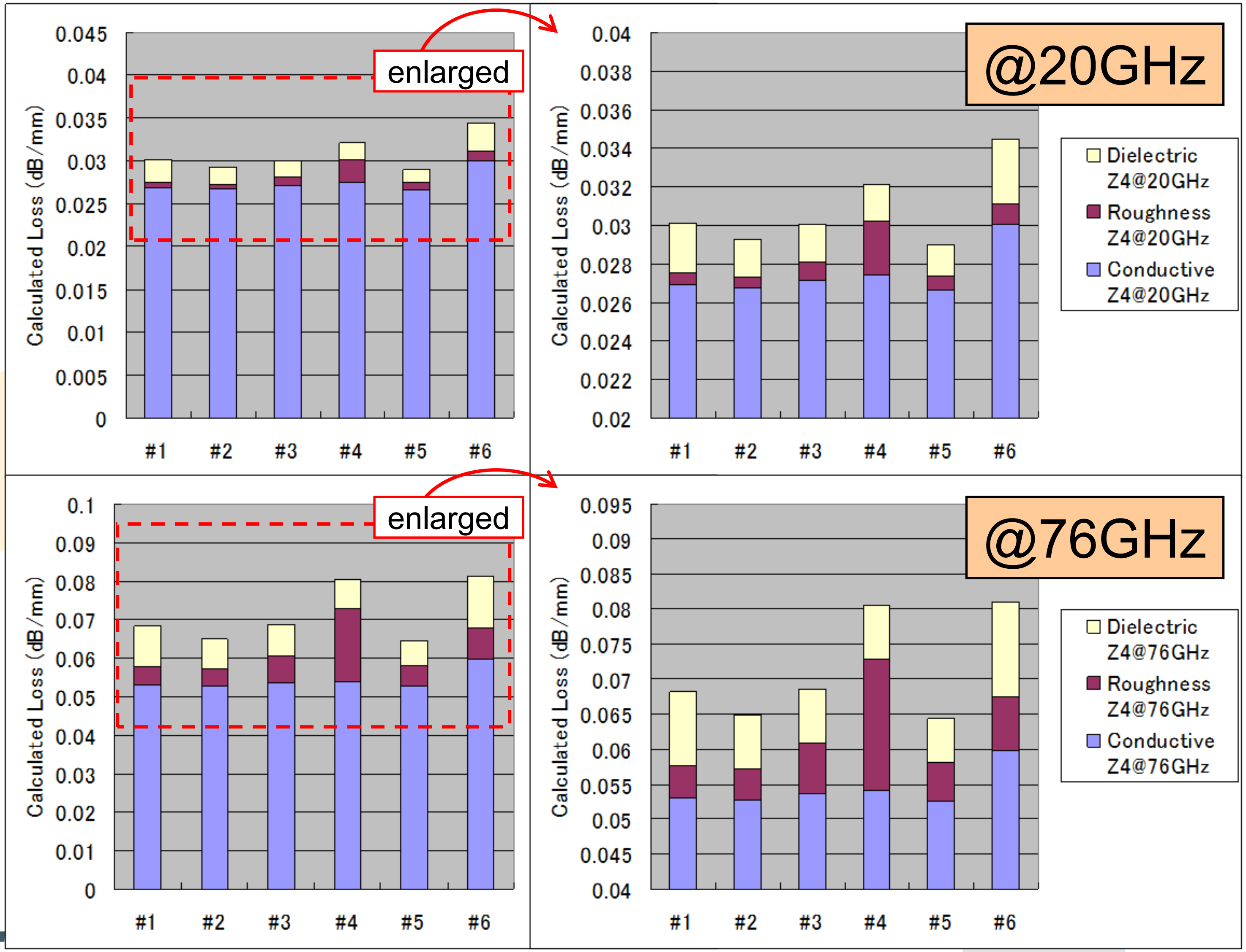
- Using optimum σ for Z4(≈50ohm) of #1~6, we derived the separated loss factors

Separated loss factors w/ meas.



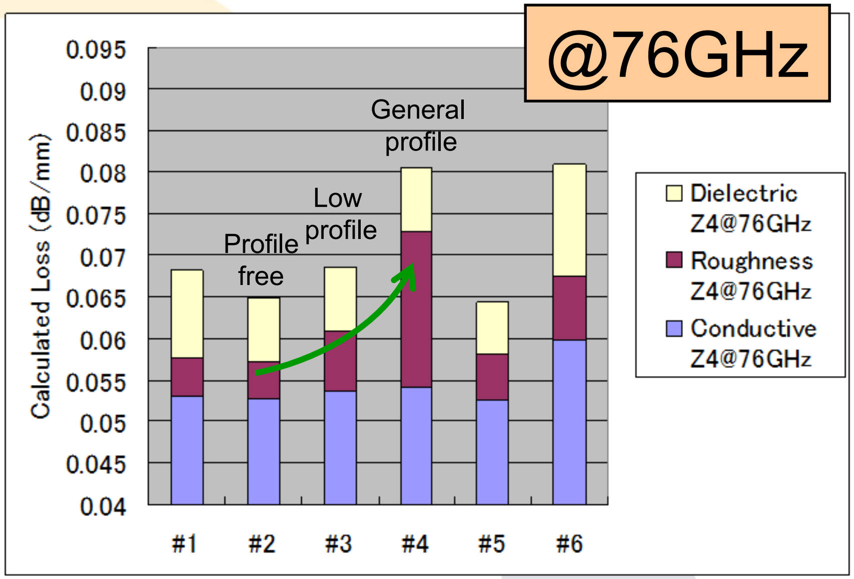
- σ_{opt} = 2.43E6 [S/m]
- Fitting in frequency range up to 80GHz

Loss factors of each substrate (1)



Loss factors of each substrate (2)

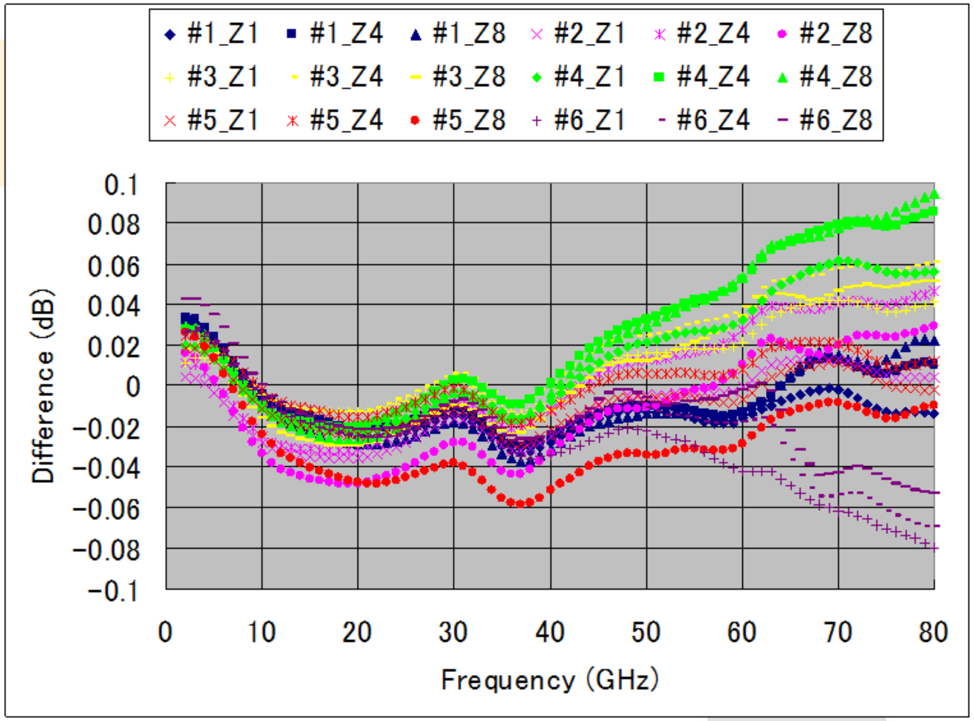
- Comparison of #2 with #5
  - Lr：#2＜#5, Ld：#2＞#5
  - Same level in total loss
- Comparison between #2, #3 and #4
  - Rougher conductor, the greater Lr
  - Ratio of Lr in total loss
    - #2：7%
    - #3：11%
    - #4：23%



Validity of the calculation

Difference bet. meas. & calc.

- Diff. = Calc. – Meas.
  - Hypothesis :
    The trend of diff. is caused by dispersion of ε_r.



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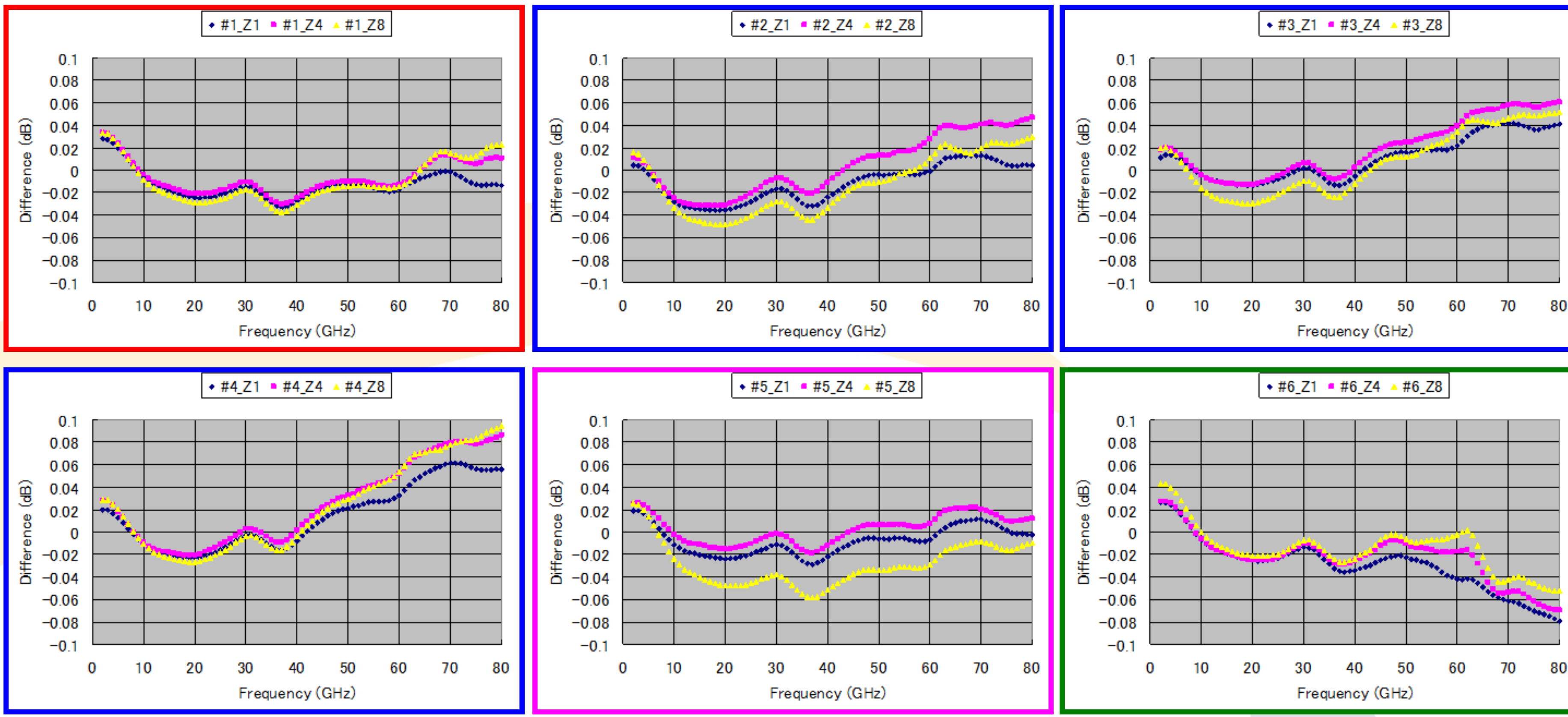
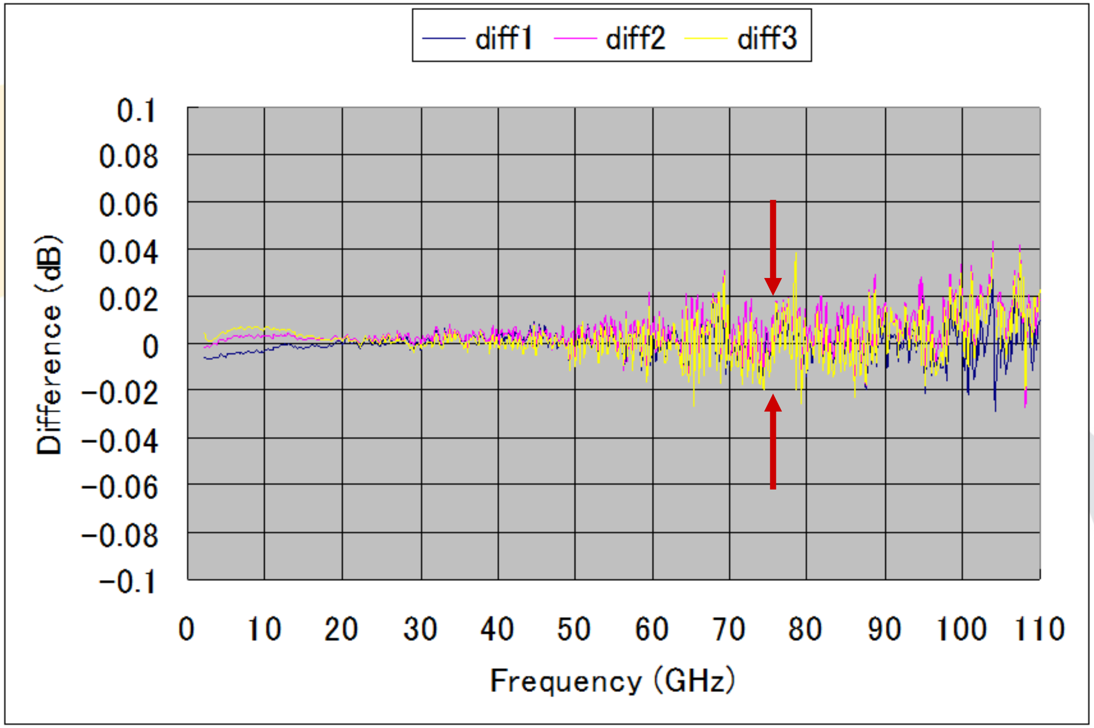
Individual difference

- There are trends depending on substrates



Measurement accuracy

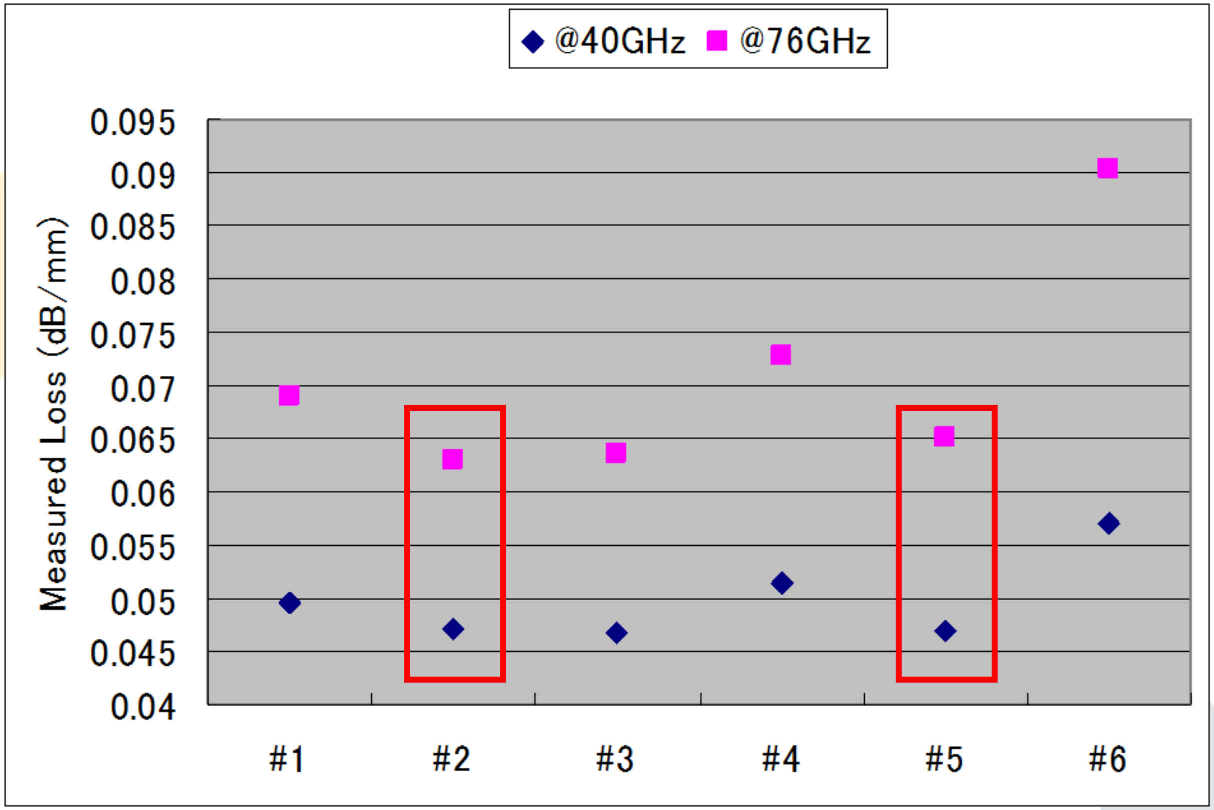
- Repeatability
  - Difference of raw S21 data per 8mm length
  - +/- 0.0025dB/mm (@76GHz)



Benchmarking

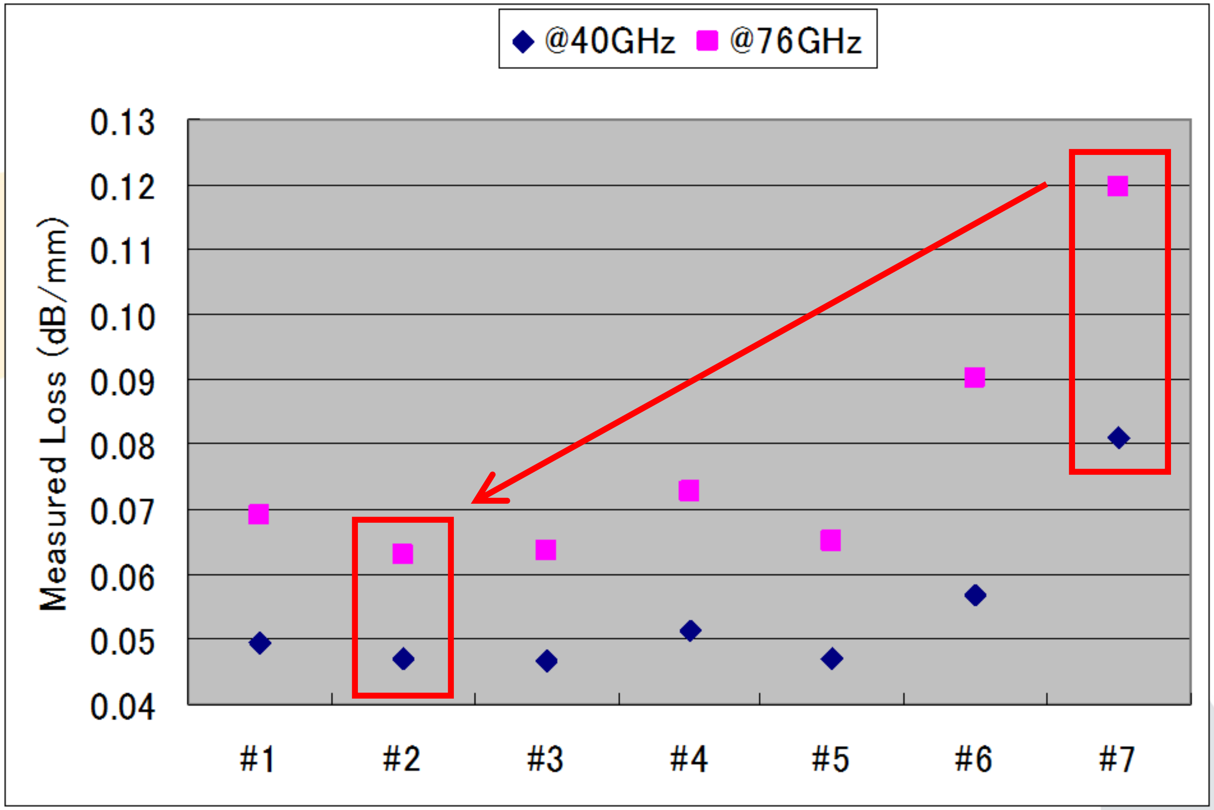
Loss of CBCPW

- #2 with profile-free Cu foil is same as or less than the world lowest loss level.



Loss of CBCPW (2)

- #7 : standard fluoropolymer CCL of consumer use - ~40% reduction of loss



Summary

- Clarify the three loss factors :
  - Dielectric, conductor and roughness losses
- Very useful separated loss factors :
  - To understand the loss properties of PCBs at any frequency
  - To judge which CCL is better

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Summary

- Roughness is significant loss factor
  - Same as or more than dielectric loss at high frequency

- Our CCL with profile-free Cu foil :
  - Demonstrate the lowest loss level in the world

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Thank you for your attention.