Signal Transmission Loss due to Copper Surface Roughness in High-Frequency Region

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Abstract
Higher-speed signal transmission is increasingly required on a printed circuit board to handle massive data in electronic systems. So, signal transmission loss of copper wiring on a printed circuit board has been studied. First, total signal loss was divided into dielectric loss and conductor loss quantitatively based on electromagnetic theory. In particular, the scattering loss due to surface roughness of copper foil has been examined in detail and the usefulness of the copper foil with low surface roughness has been demonstrated.

Introduction
Higher performance IT electronic systems are strongly required to handle huge amounts of data in a shorter time in recent years. Transmission speed of the signals propagating inside the equipment has been increasing. Signal loss becomes remarkable on a printed circuit board in the GHz frequency range. It causes many problems, such as rising edge degradation of signals, or resulting higher bit error rate, and so on. Then, reducing the signal loss on a printed circuit board has become more important. Therefore, in this study, measurement of S21 has been carried out by fabricating various evaluation boards combining different copper foils with low roughness and low dielectric materials. And they were compared with the transmission loss of the commonly used material, FR-4. In particular, the reduction effect of signal loss has been demonstrated quantitatively by using copper foil with smooth surface roughness along with low dielectric loss material.

Signal transmission loss
Signal transmission loss on printed circuit boards can be classified into conductor loss due to the conductor and dielectric loss due to the dielectric. Then, total signal transmission loss can be expressed by two loss factors.

$$Loss = Loss_D + Loss_C \tag{1}$$

Where, $Loss_D$ is dielectric loss and $Loss_C$ is conductor loss.
Dielectric loss is represented by the following equation (2).

$$Loss_D = 90.9\sqrt{\varepsilon_r} \times \tan\delta \times f \tag{2}$$

where, ε_r is relative permittivity, $\tan\delta$ is dielectric loss tangent, and f is frequency in GHz. Conductor loss can be divided into scattering loss caused by surface roughness and the skin effect loss. Then, it is represented by the formula (3).

$$Loss_C = Loss_H + Loss_S \tag{3}$$

where, $Loss_H$ *is* the loss due to skin effect, and $Loss_S$ is scattering loss. Current distribution is concentrated at the surface or the edge of the conductor at high frequencies. Skin depth δ is an index representing skin effect. Skin depth δ is defined by the distance where the current amplitude becomes 1/e times of the surface current amplitude in the conductor, and it is represented by the formula (4).

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{4}$$

where, ω is angular frequency, μ is permeability, and σ is conductivity of copper.

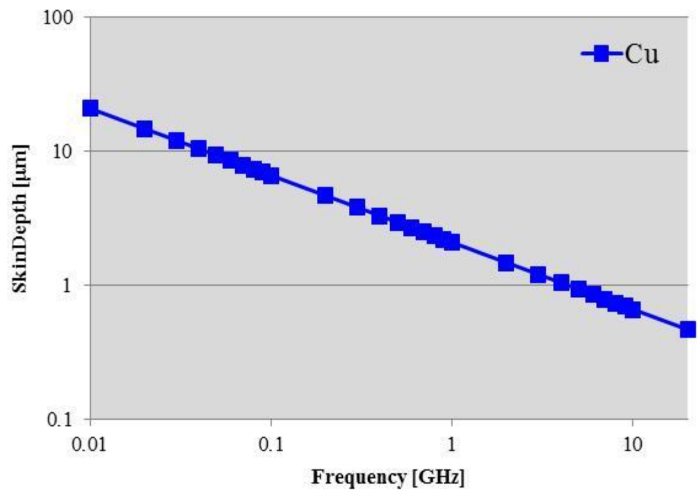

Figure 1 : Frequency dependency of skin depth for copper

Figure 1 shows frequency dependency of the skin depth in copper conductor. The skin depth is approximately 2.1 µm at 1 GHz. Effective cross-section area of the conductor for the current flow becomes restricted at high frequencies. Therefore, signal line impedance increases with the frequency. Signal loss due to skin effect is represented by the formula (5).

$$Loss_H = \frac{2.26 \times 10^{-8} \times \sqrt{f}}{W} \qquad (5)$$

where, *w* is *w*iring width of conductor. Figure 2 shows a SEM image of cross-section of a printed circuit board. Usually, the surface of the conductor in printed circuit boards is intentionally roughened to enhance the adhesion to the prepregs. Typical surface roughness Rz of the copper foil commonly used in printed circuit board is 6 µm. This is a value greater than 2.1 µm of the skin depth at 1 GHz. Here, Rz is a ten-point average roughness of the surface. Because skin depth becomes smaller than surface roughness at high frequency, the scattering loss becomes prominent[1][2][4][5].

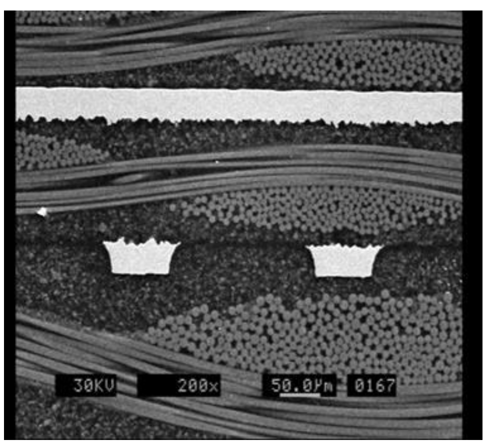

Figure 2 : Surface roughness of copper conductor

Configuration of the evaluation board

In order to investigate the relationship between the scattering loss and surface roughness of the conductor, various evaluation boards were fabricated by different surface roughness of copper foils. Evaluation boards were made of four conductive layers as shown Figure 3. In order to observe the difference in the transmission line structures, four types of transmission lines were designed in the board. They were single-ended microstrip line and strip line, and differential microstrip line and strip line. The characteristic impedance Zo for the single-ended transmission line was designed to 50 ohms, differential impedance was designed to 100 ohms. Moreover, three kinds of dielectric materials were examined. They were dielectric material G1

(Dk=3.7, Df=0.002), dielectric G2 (Dk=3.8, Df=0.005), and commonly used dielectric material, FR-4 (Dk=4.4, Df=0.02). Former two materials were low dielectric materials.

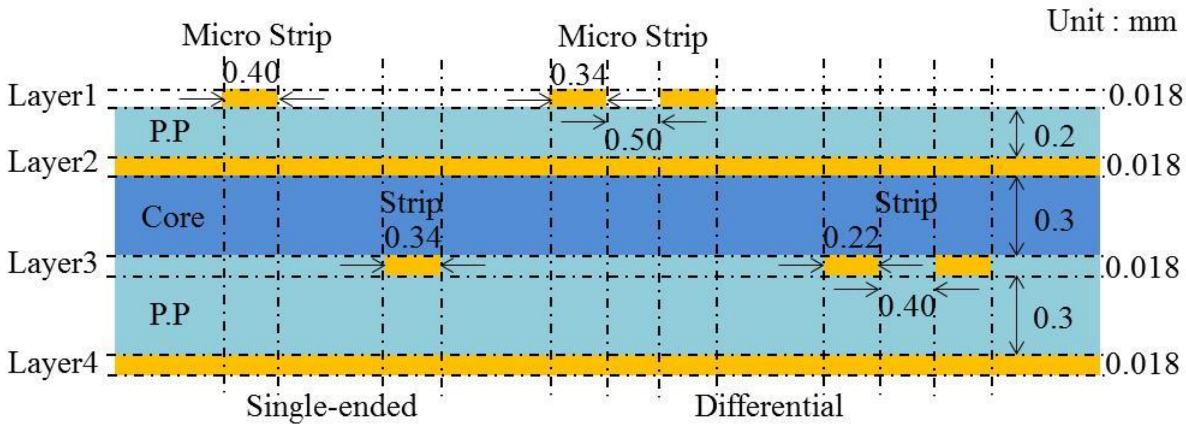

Figure 3 : Cross-section with 4 types of transmission lines

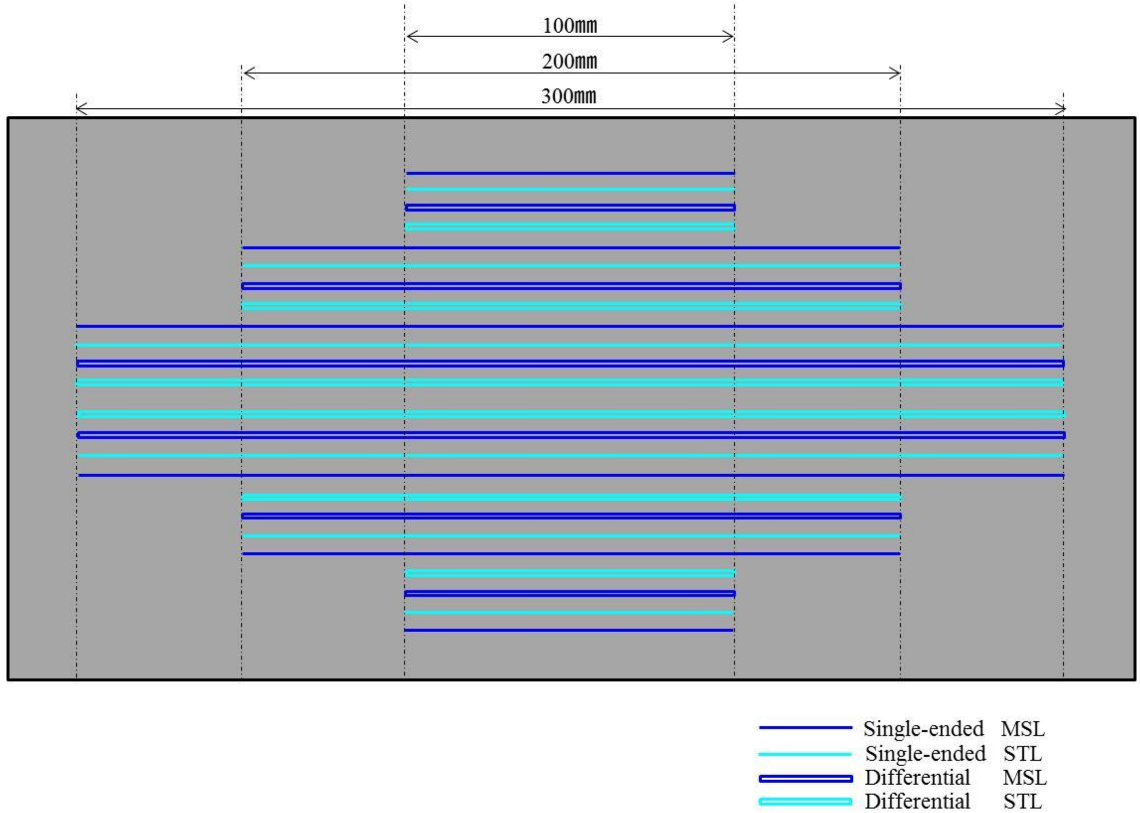

Figure 4 : Top layer layout of the evaluation board

Further, the evaluation board included three kinds of trace length in order to compare loss dependency due to differences in trace length as shown in Figure 4. Trace length were 100, 200, and 300 mm, respectively.

Measurement result

S parameters were measured with a vector network analyzer. The frequency range is from 300 KHz to 20 GHz. The evaluation boards were fabricated with different transmission line structures as shown in Figure 5. Either S21 or Sdd21 was measured for 200 mm line for the dielectric material of G1. Measured signal loss was about -8 dB for the single-ended line. On the other hand, it was about -6 dB for the differential transmission line. It has been confirmed that the signal loss for

differential transmission line is lower than the loss for single-ended transmission line. From this, it can be said that the differential transmission line is also useful to reduce the losses in high-speed signal transmission[1][2].
Also, evaluation boards were fabricated with different materials as shown in Figure 6. Measured total signal loss was about -19 dB for FR-4. On the other hand, it was about -10dB for the dielectric G2, and about -8 dB for the dielectric G1. The loss of dielectric G1was reduced by 68% compared with FR-4. It has been confirmed that the use of low dielectric constant material is necessary for high speed transmission.

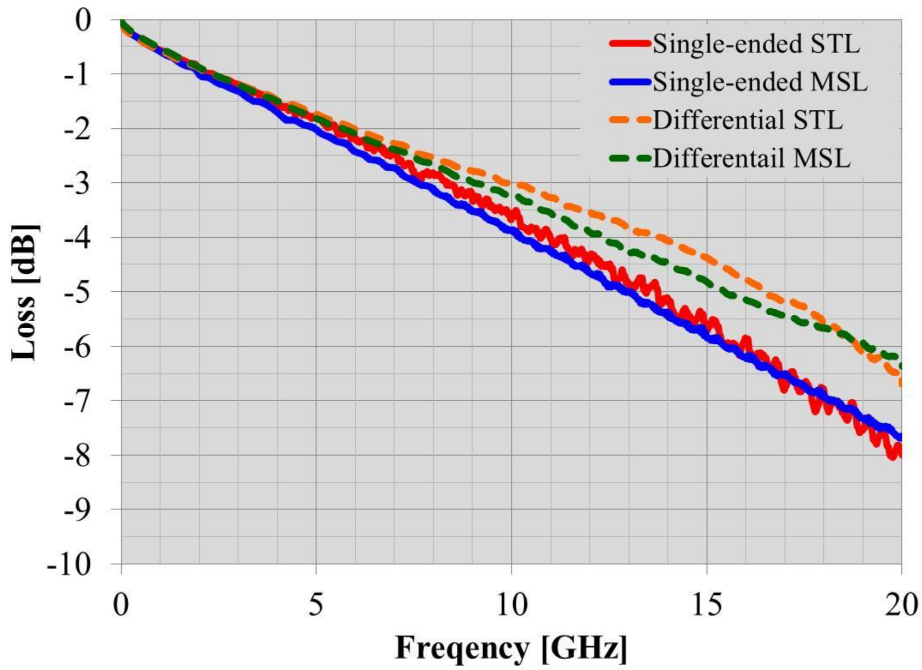

Figure 4 : Comparison of the signal losses of FR4 for the four different transmission structures

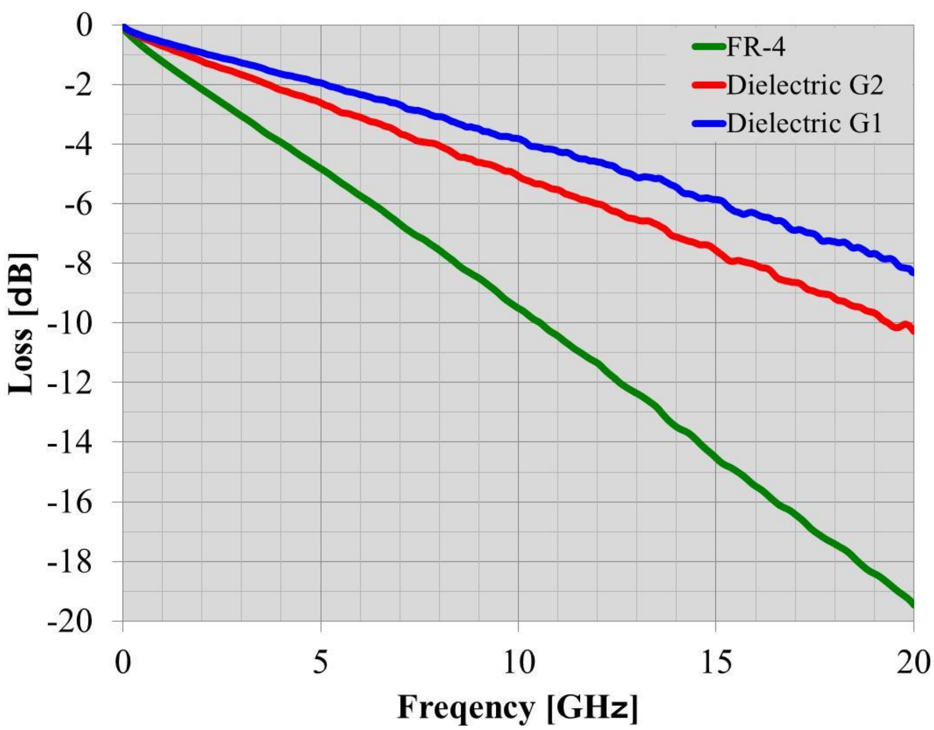

Figure 5 : Comparison of measured signal losses due to the difference of dielectric material

Decomposition of total loss into loss factors of copper and dielectric

Measured total signal losses for low dielectric constant materials were dramatically reduced, then the ratio of dielectric loss among total signal loss was decreased, and the ratio occupied by the conductor loss was relatively increased.

Next, the ratio of conductor loss and dielectric loss among the overall loss was examined. Total attenuation constant can be represented by the formula (6). As shown in the formula, the dielectric loss is proportional to the frequency, while the conductor loss is proportional to the square root of the frequency.

$$Loss = Loss_d + Loss_c = Af + B\sqrt{f} \tag{6}$$

In addition, equation (7) can be obtained by dividing the equation (6) by the square root of the frequency.

$$\frac{Loss}{\sqrt{f}} = A\sqrt{f} + B \tag{7}$$

Constants A and B are proportional coefficients of each loss. These values of constants A and B can be obtained by using the regression line obtained from the measured value of the S21. .

The regression line was obtained by dividing the transmission line loss for FR-4 with the square root of the frequency as shown in Figure7. Furthermore, constants A and B were obtained from the slope and intercept of the regression line. In this case, the constant A was -7.23E-10 and the constant B was -1.49E-5.

The total loss for FR-4 was divided into dielectric loss and conductor loss by inserting the obtained constants A and B to the equation (6). Figure 8 shows that as a result of isolation conductor loss and dielectric loss for FR-4. Calculated overall loss showed good agreement with the measured loss.

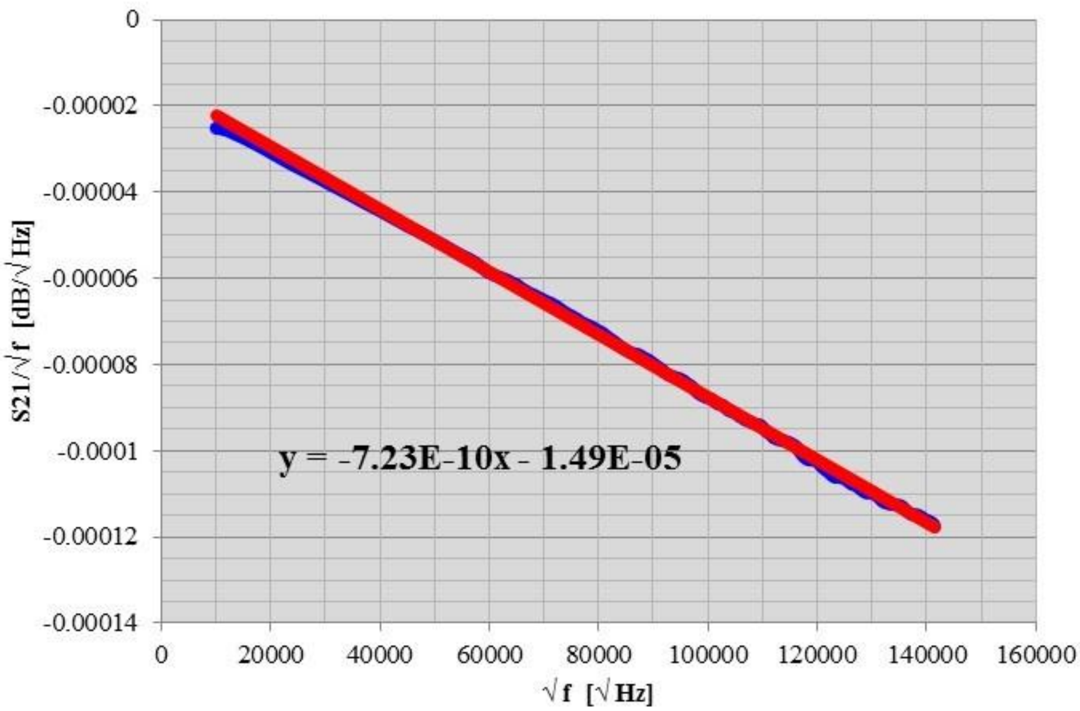

Figure 7 : The loss in the transmission line for FR-4

In the same method, the loss for dielectric G1 was divided into conductor loss and dielectric loss. Figure 9 shows that as a result of conductor loss and dielectric loss for dielectric G1.

The ratio of the conductor loss to the total loss was about 13 % for FR-4 at the frequency of 20 GHz. However, the ratio of conductor loss to the total loss rose to approximately 30% in the case of dielectric G1 with a low dielectric constant. From

this result, it can be said that reducing conductor loss is relatively more effective in reducing the overall loss when a low dielectric loss material is used.
Therefore, the scattering loss as a part of conductor loss becomes more and more important in reducing the total signal loss in the high frequency region. Then, the surface roughness of copper foil has been examined in the next section.

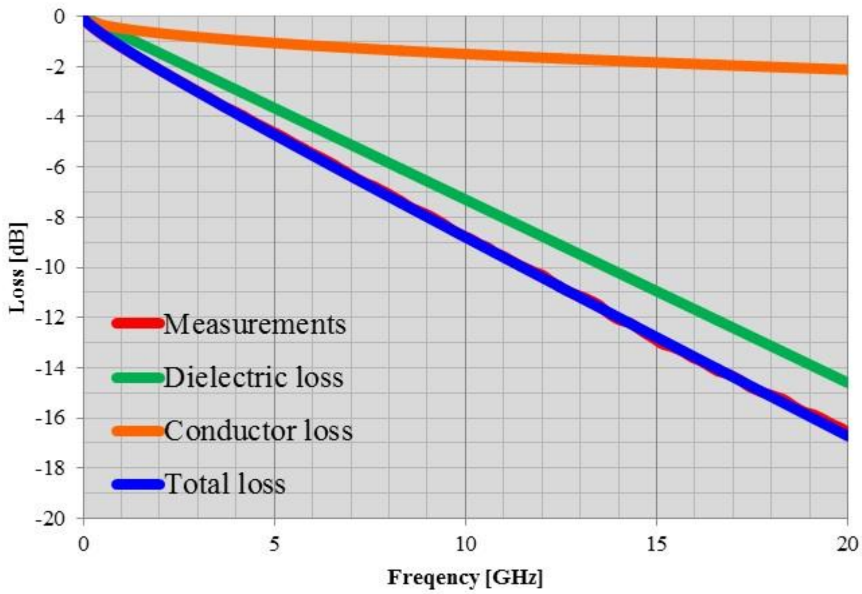

Figure 8 : Decomposing total loss into dielectric loss and conductor loss for FR-4

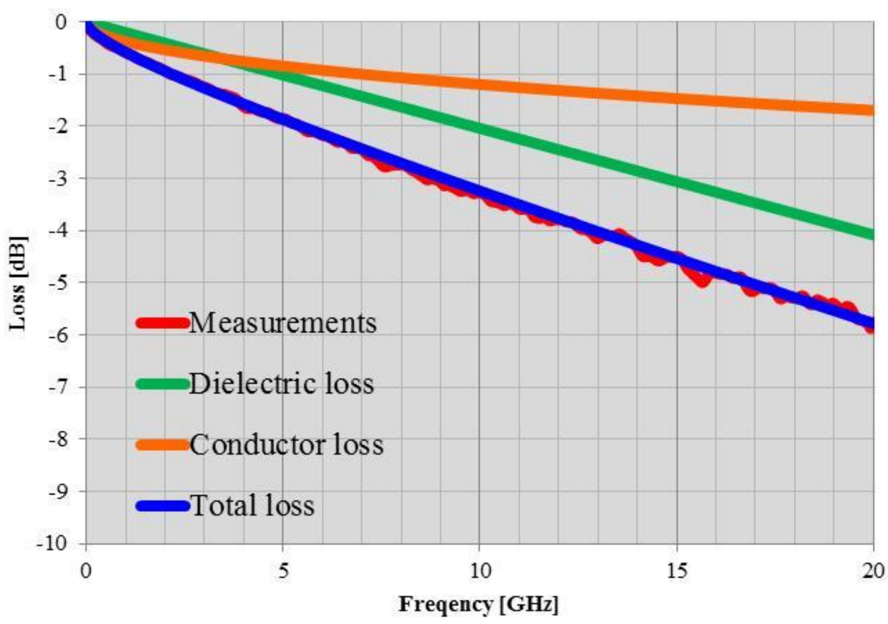

Figure 9 : Decomposing total loss into dielectric loss and conductor loss for dielectric G1

Surface roughness of copper foil

Figure10 shows SEM images five types of copper foils examined. Surface textiles of copper foils were different from each other. Roughening treatment is applied to surface of copper foils by depositing copper nodules. Figure 11 show schematic views of the surface roughened shape of each copper foils.

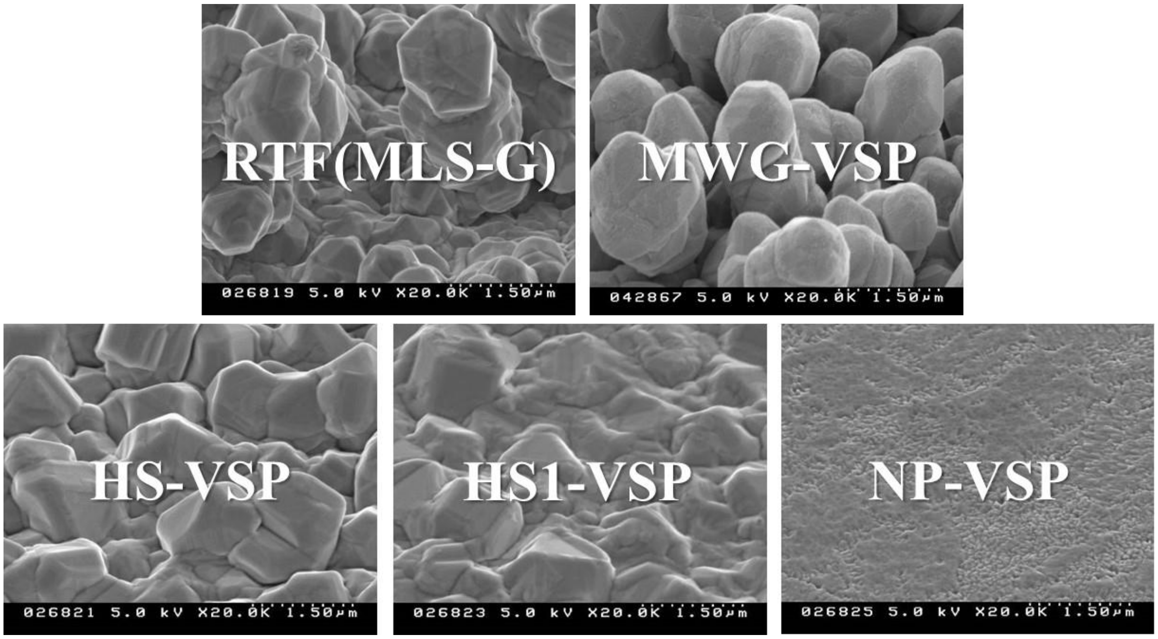

Figure 10 : SEM image for four types of copper foil (×20K)

In the photo of RTF, around 1.5 um diameter sphere shape copper nodules are densely deposited on the "shiny" (drum) side of standard copper foil. Even the second story structure (nodule on nodule) is observed. MWG-VSP shows similar but more dense nodules on its surface. However, the height of the sphere shape decreases and shifts to hemisphere in HS- and HS1-VSP. NP-VSP is the copper foil with totally no nodule. Tall nodule is not acceptable for high frequency circuit as skin depth is smaller than radius of the sphere nodules at 10 GHz.

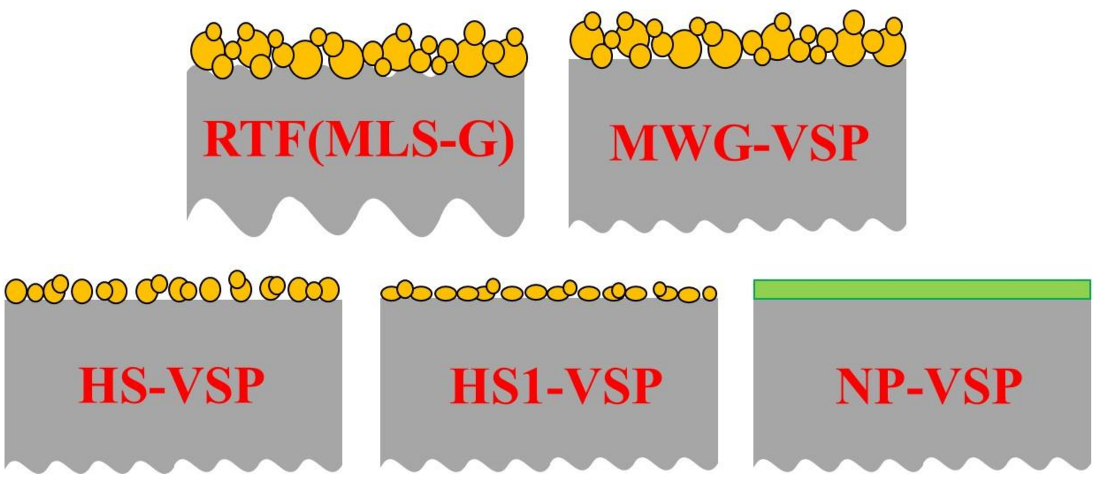

Figure 6 : Schematic views of the surface roughened shape of each copper foils

The surface roughness was measured by a ten point average roughness Rz and root mean square roughness Rq were summarized in Tables 1 to 4. Bonding side is a surface which has nodules of copper. On the other hand, resist side is a surface which has no nodules. Two types of non-contact profilometers, Confocal laser scanning microscopy and scanning white light interferometer were used. Comparison of surface roughness of each of the copper foils are shown in Figures 12 to 15.

Table 1 : Surface roughness Rz of the bonding side

[μm]

copper foil	Laser microscope	Zygo
RTF	3.95	4.21
MWG-VSP	3.75	3.86
HS-VSP	2.13	1.80
HS1-VSP	1.42	1.09
NP-VSP	0.19	0.29

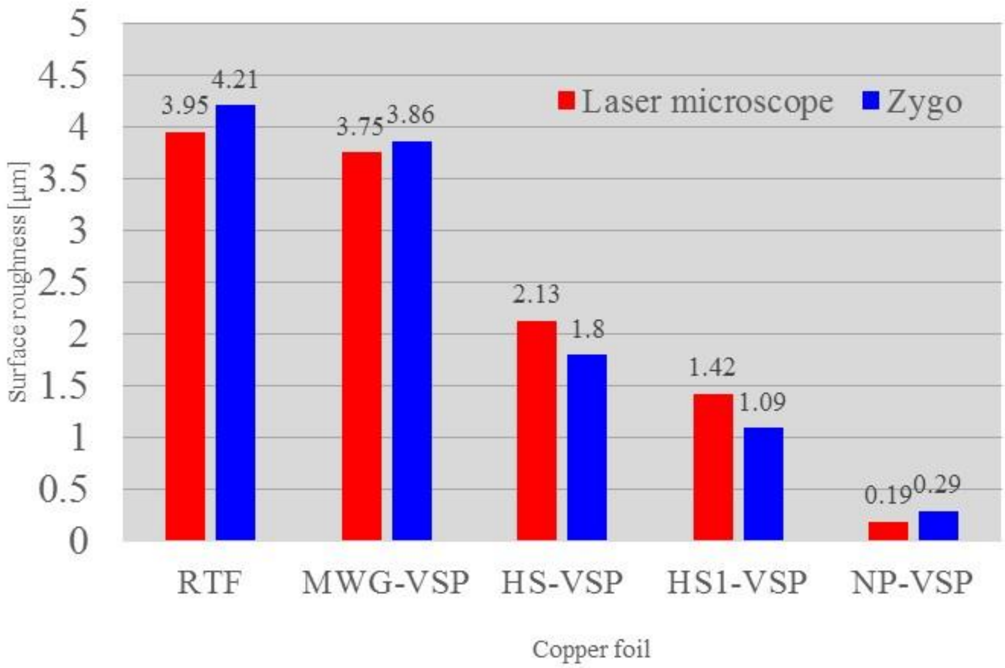

Figure 7 : Surface roughness Rz of the bonding side

Table 2 : Surface roughness Rz of the resist side

[μm]

copper foil	Laser microscope	Zygo
RTF	2.49	3.13
MWG-VSP	0.99	1.21
HS-VSP	0.97	1.23
HS1-VSP	1.06	0.99
NP-VSP	1.25	1.15

The surface roughness of the bonding side were RTF>MWG-VSP>HS-VSP>HS1-VSP>NP-VSP. The value of Rz of the foil HS1-VSP was about 26% compared with that of foil RTF. On the other hand, values of surface roughness of resist side were RTF>MWG-VSP=HS-VSP=HS1-VSP=NP-VSP. The reason is shown in Figure 11. The resist side of RTF was mat surface (solution side of standard copper foil) with wave. While the resist sides of the others were smooth (drum side) surface. The value of surface roughness of resist side for RTF was the largest in fiver types copper foil. This is the same with Rq as shown in Tables 3 to 4, and Figures 14 to 15.

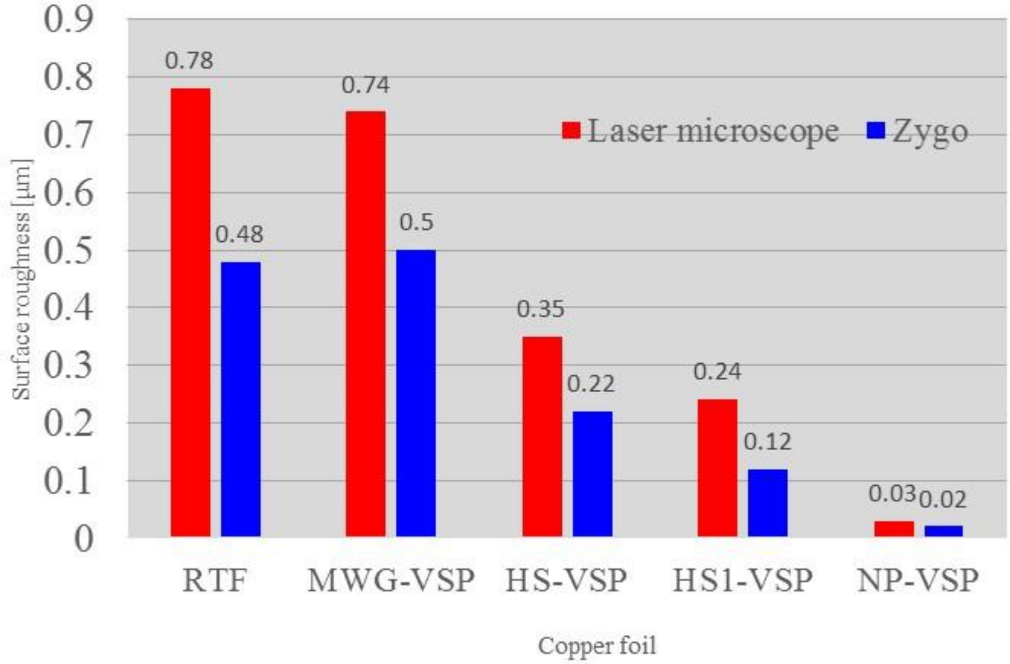

Figure 13: Surface roughness Rz of the resist side

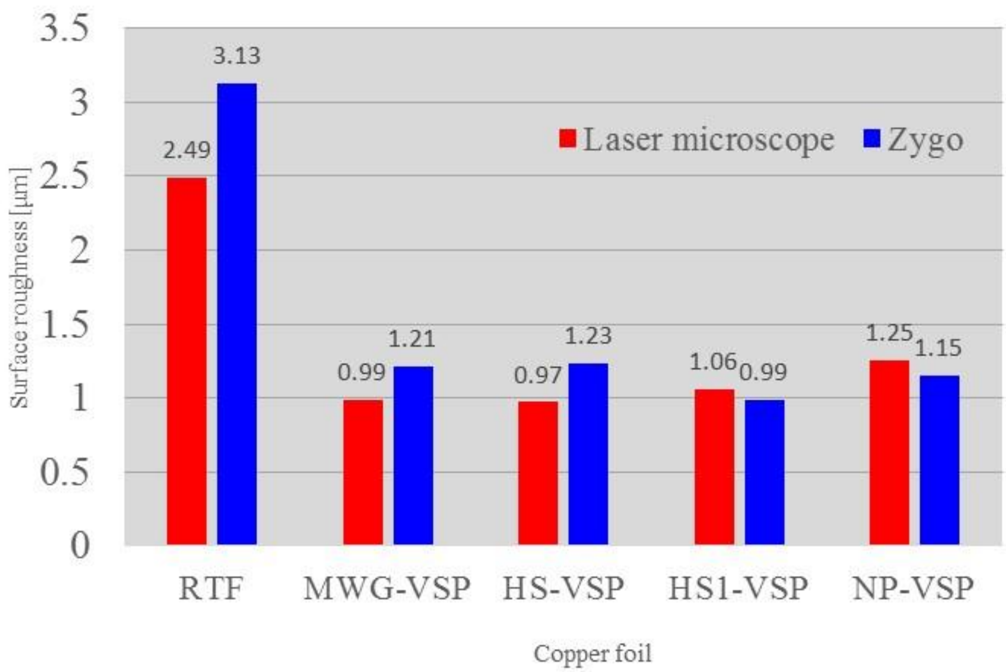

Figure 84 : Surface roughness Rq of the bonding side

Table 3 : Surface roughness Rq of the bonding side

[μm]

copper foil	Laser microscope	Zygo
RTF	0.78	0.48
MWG-VSP	0.74	0.50
HS-VSP	0.35	0.22
HS1-VSP	0.24	0.12
NP-VSP	0.03	0.02

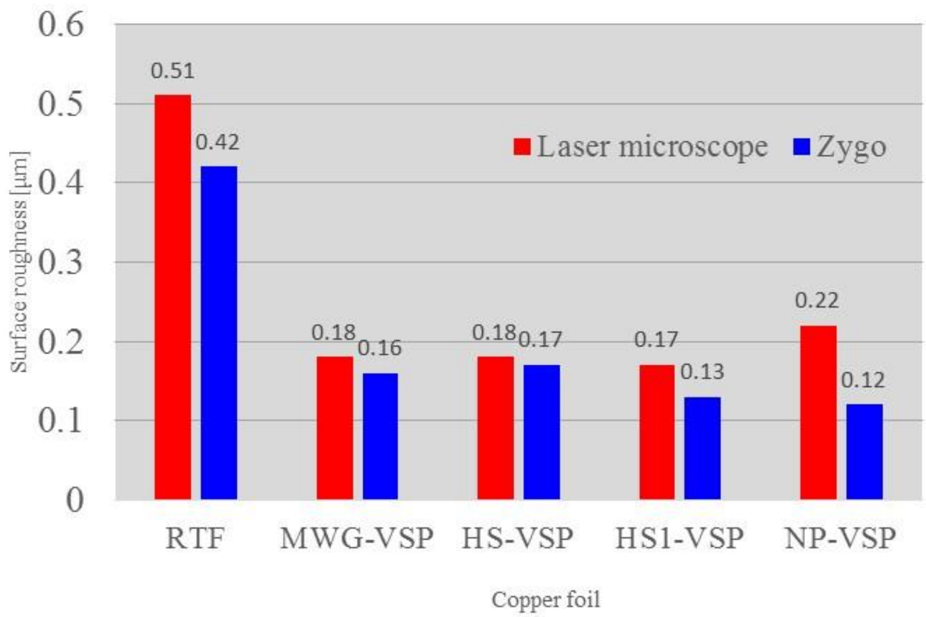

Figure 94 : Surface roughness Rq of the bonding side

Table 4 : Surface roughness Rq of the resist side

[μm]

copper foil	Laser microscope	Zygo
RTF	0.51	0.42
MWG-VSP	0.18	0.16
HS-VSP	0.18	0.17
HS1-VSP	0.17	0.13
NP-VSP	0.22	0.12

Figure 10: Surface roughness Rq of the resist side

Peel strength of low profile copper foil

As mentioned in the previous paragraph, the bonding side surface of copper foil is densely covered with copper nodules. Lowering profile means the reduction of the height of the nodules. Bonding strength of copper foil relies on the anchor effect and physical and chemical adhesion between copper foil and resin interface. Lowering the profile means reducing all these powers of bonding. Peel strength (P/S) is used to measure the bonding strength of laminate materials. Low P/S raises a concern of delamination during processing of PCBs. However, large and dense nodules are not acceptable for high frequency. Figure 16 explains two different approaches to improve peel strength without increasing surface roughness of copper foil.

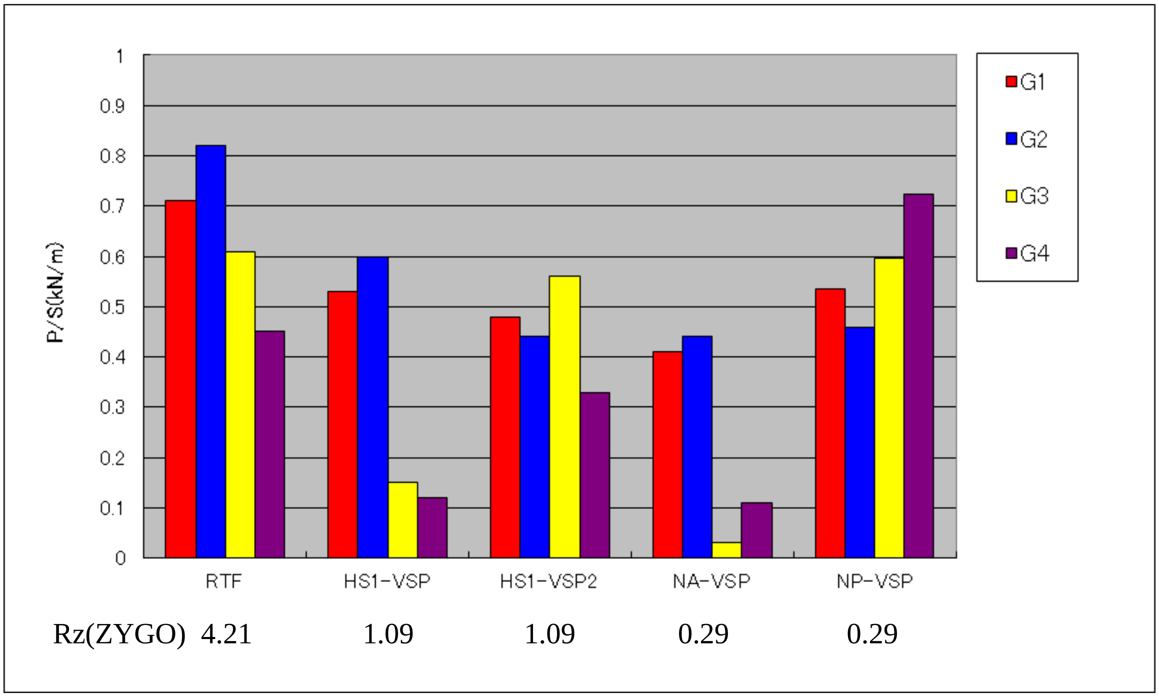

Figure 16: Peel strength of low profile copper foils with low loss laminate materials

G1, G2, G3, and G4 are industry available low loss laminate materials for high frequency circuits. HS1-VSP and HS1-VSP2 are both exactly the same very low profile, but a new chemical bonding treatment was applied on HS1-VSP2. The treatment was very effective for G3 and G4 laminate. NA-VSP is totally no nodule copper foil with very thin resin coating as shown in Figure 14. The coating was extremely effective for improving P/S of G3 and G4. Effectiveness of the new chemical treatment and the thin resin coating were proven by this experiment.

Relationship between signal transmission loss and surface roughness of copper foil

Figure 17 shows the measurement of S21 for the single-ended strip line structure with line length 200 mm in dielectric G1. In addition, this figure shows the difference of losses due to surface roughness. The loss of the foil RTF in a frequency of 20 GHz was about -8.7 dB. On other hand, the loss of the foil NP-VSP in a frequency of 20 GHz was about -7.2 dB. It is confirmed that there was difference of signal loss about 1.5 dB between foil RTF and foil NP-VSP in a frequency of 20 GHz.

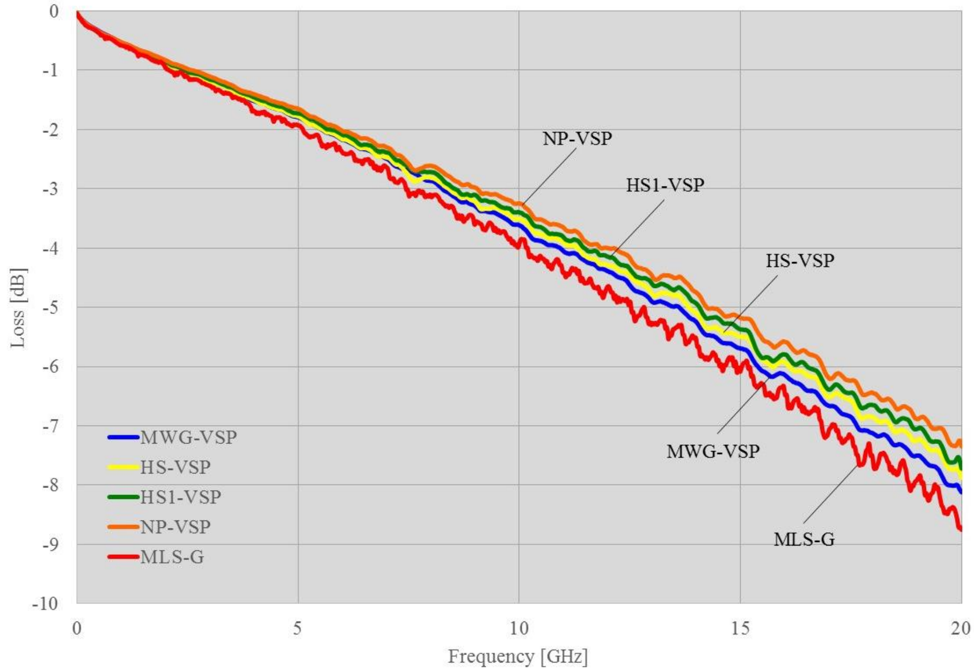

Figure 17: Comparison of measured signal losses due to difference of copper foil

Figure18 shows the relationship between surface roughness Rz of each copper foil and the signal loss in a frequency of 20 GHz. The referred signal loss was the data for the stripline structure with the length of 200 mm in dielectricG1.

Vertical axis on the left shows the roughness Rz of copper foil, the right vertical axis shows the signal loss. The horizontal axis indicates the type of copper foil. It can be proven that the signal loss became lower with the smaller surface roughness. When the foil RTF with the largest roughness was compared with the foil NP-VSP with the lowest roughness, the signal loss of the foil NP-VSP was reduced by approximately 17% of the signal loss of foil RTF. This corresponded to about 77 % reduction of conductor loss, compared with the analysis result. This shows that the usage of copper foil with low surface roughness is effective to reduce the scattering loss of the conductor. The signal loss can be improved by adopting low roughness copper foil and low dielectric constant material.

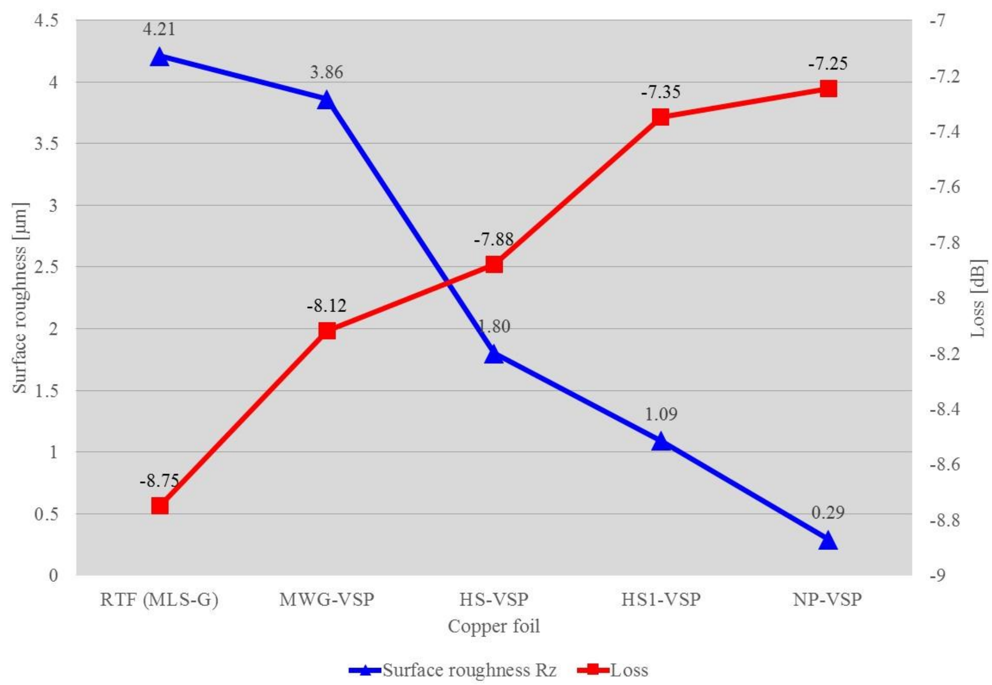

Figure 18 : Relationship between surface roughness of each copper foils and the signal loss at a frequency of 20 GHz

Summary

In this research, S parameters of various types of transmission line structures on an evaluation board were measured and analyzed in detail.

- It was confirmed that reduction of signal loss for differential transmission line was greater than that for single-ended transmission line. From this, it was shown that differential transmission line is useful for the reduction of losses in high-speed signal transmission.
- Signal loss has been greatly reduced by adopting low dielectric constant material. It has been confirmed that the signal loss of dielectric G1 was reduced by about 68% compared with the signal loss of FR-4.
- When using the low dielectric constant materials instead of FR-4, the ratio of the conductor loss against the entire loss increases. The ratio of conductor loss for FR-4 was 13% of the total signal loss, but the conductor loss in dielectric G1 will increase to 30% among the overall loss.
- If low dielectric material is used as dielectric, low roughness copper foil is effective in reducing the overall loss. Low roughness copper foil was found to reduce by 73% of the scattering loss compared with commonly used surface roughness of copper foil.
- The chemical treatment on very low profile and the thin resin coating on no nodule copper foil are both very effective to improve bond strength of laminates.

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AGENDA

1. Introduction and research purpose
2. Signal transmission loss
3. Configuration of the evaluation board
4. Measurement and simulated results
5. Loss and surface roughness of copper foil
6. Summary

☐ Introduction

1. Higher-speed signal transmission is strongly required on a printed circuit board to handle massive data in a shorter time in electronic systems. So, signal transmission loss of copper wiring on a printed circuit board has been intensively studied.
2. Total signal loss was divided into dielectric loss and conductor loss quantitatively based on electromagnetic theory.
3. In particular, the scattering loss due to surface roughness of copper foil has been examined in detail.

☐ Research Purpose

- ◆ To demonstrate the usefulness of the copper foil with low surface roughness for higher-speed signal transmission.

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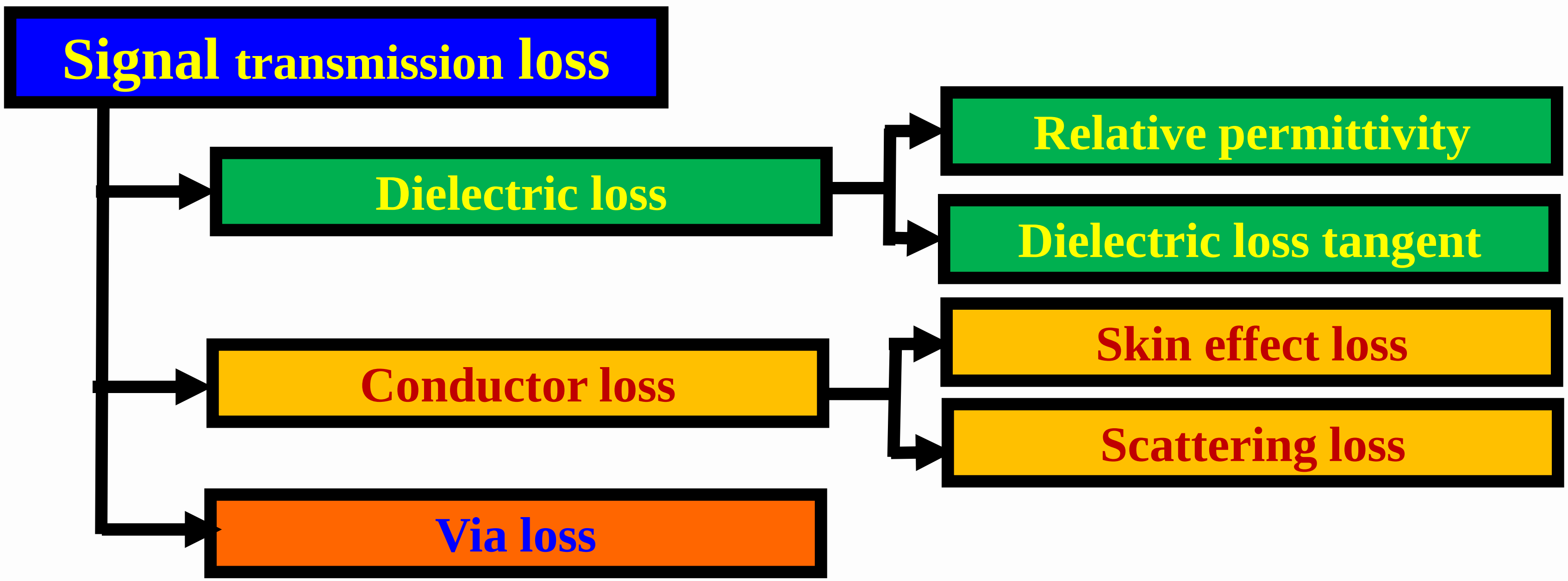
□Total signal loss

Total signal transmission loss can be expressed by two major loss factors and physical structure such as vias.

$$Loss = Loss_D + Loss_C + Loss_{via}$$

where, $Loss_D$ is dielectric loss, $Loss_C$ is conductor loss, $Loss_V$ is loss due to vias



□ Dielectric loss

Dielectric loss is represented by the following equation.

$$Loss_D = 90.9\sqrt{\varepsilon_\gamma} \times \tan\delta \times f$$

Where, ε_γ is relative permittivity, $\tan\delta$ is dielectric loss tangent and f is frequency.

◆ Dielectric loss is proportional to the frequency.

◆ Dielectric loss is affected by dielectric loss tangent and relative permittivity of the dielectric.

□Conductor loss

Conductor loss $Loss_C$ is composed of two factors; one is skin effect $Loss_K$ and another is scattering loss $Loss_S$.

$$Loss_C = Loss_K + Loss_S$$

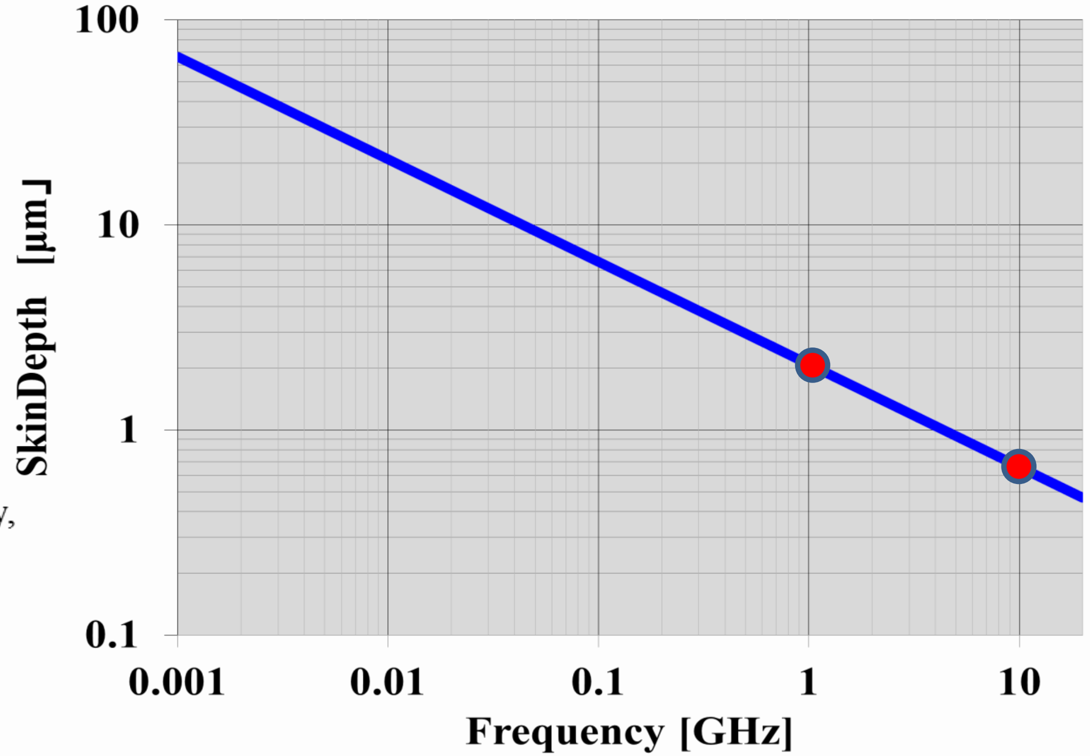
◆ Conductor loss is composed of scattering loss and skin effect loss.

□Skin effect

Skin depth is represented by following equation.

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \frac{1}{\sqrt{\pi f \mu\sigma}}$$

where, δ is skin depth, ω is angular frequency, μ is permeability, σ is conductivity of copper and f is frequency.



◆Skin depth δ is inversely proportional of the square root of the frequency.

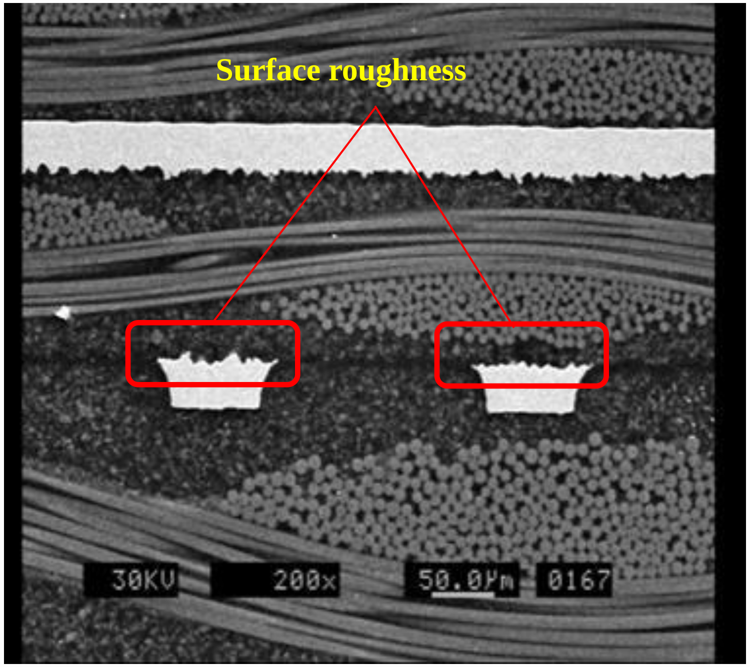
□Skin effect loss

The loss due to skin effect is represented by following equation.

$$Loss_K = \frac{2.26 \times 10^{-8} \times \sqrt{f}}{w} \quad \text{[dB/m]}$$

where, *w* is wiring width of copper.

◆Skin effect loss is affected by the width of signal line and proportional to the square root of frequency.



Cross Section of Copper Conductor

- ◆Usually, the surface of the conductor in printed circuit boards is intentionally roughened to enhance the adhesion to the prepreg.
- ◆Typical surface roughness of the copper foil commonly used in printed circuit boards was 6 μm. This is a value greater than 2.1 μm of the skin depth at 1GHz.
- ◆Because skin depth becomes smaller than surface roughness at high frequency, the scattering loss becomes prominent.

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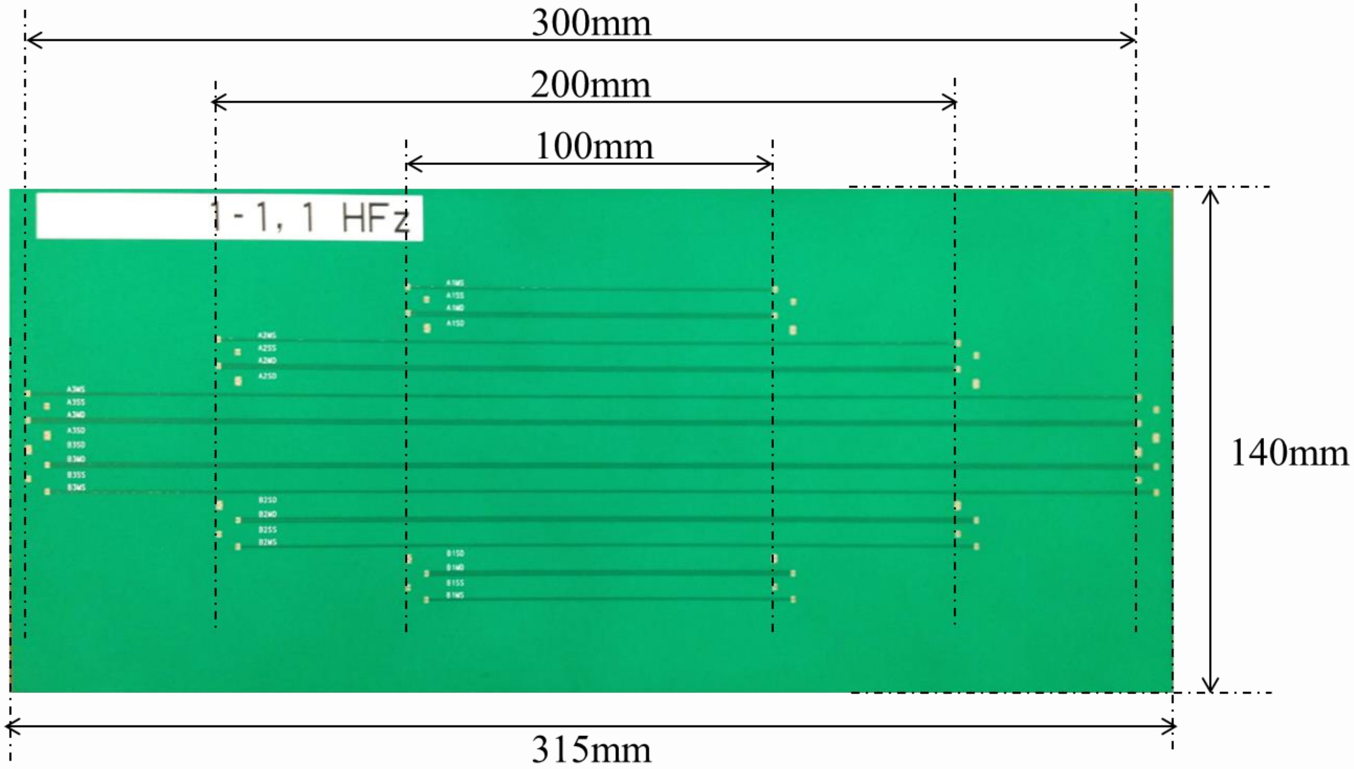
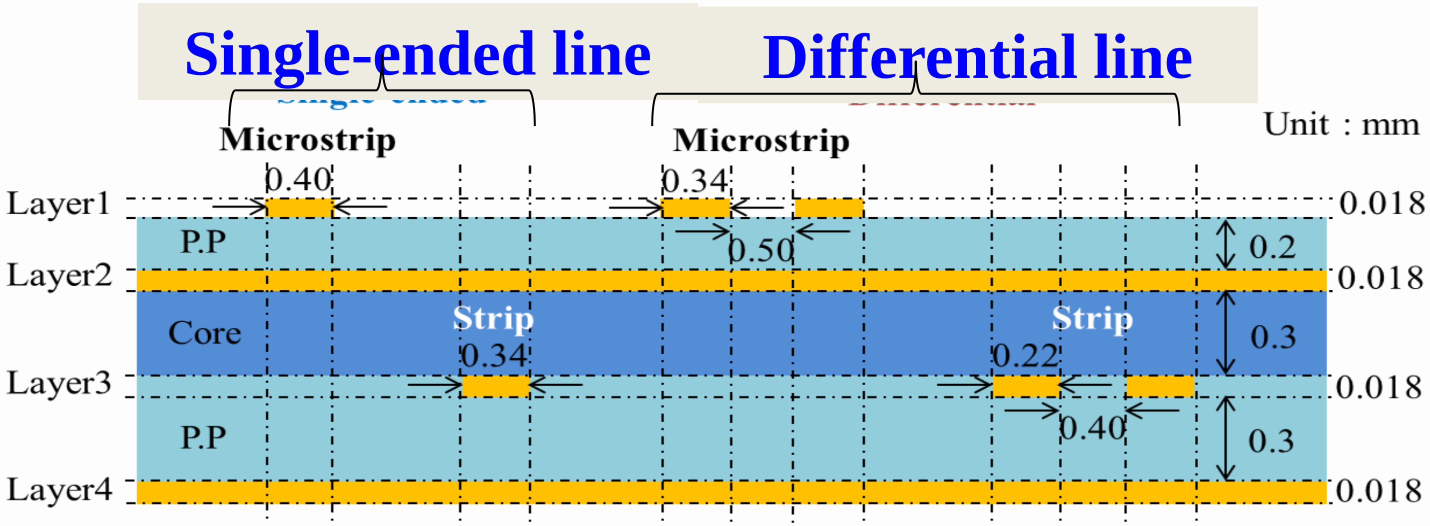
Evaluation Board (Top View)



- The evaluation boards have been fabricated with three kinds of wiring length, 100mm, 200mm and 300mm.
- The evaluation boards have been fabricated with four types of structures.

Schematic – Cross Section Diagram



- The evaluation boards included into the four types of transmission line structures.
- They are microstrip and strip structures for single-ended transmission line and those structures for differential transmission line.
- The dotted red lines on the conductors show mat faces of copper foils.
- The characteristic impedance for single-ended line was configured to 50 ohms and the differential impedance for differential line was configured to 100 ohms.

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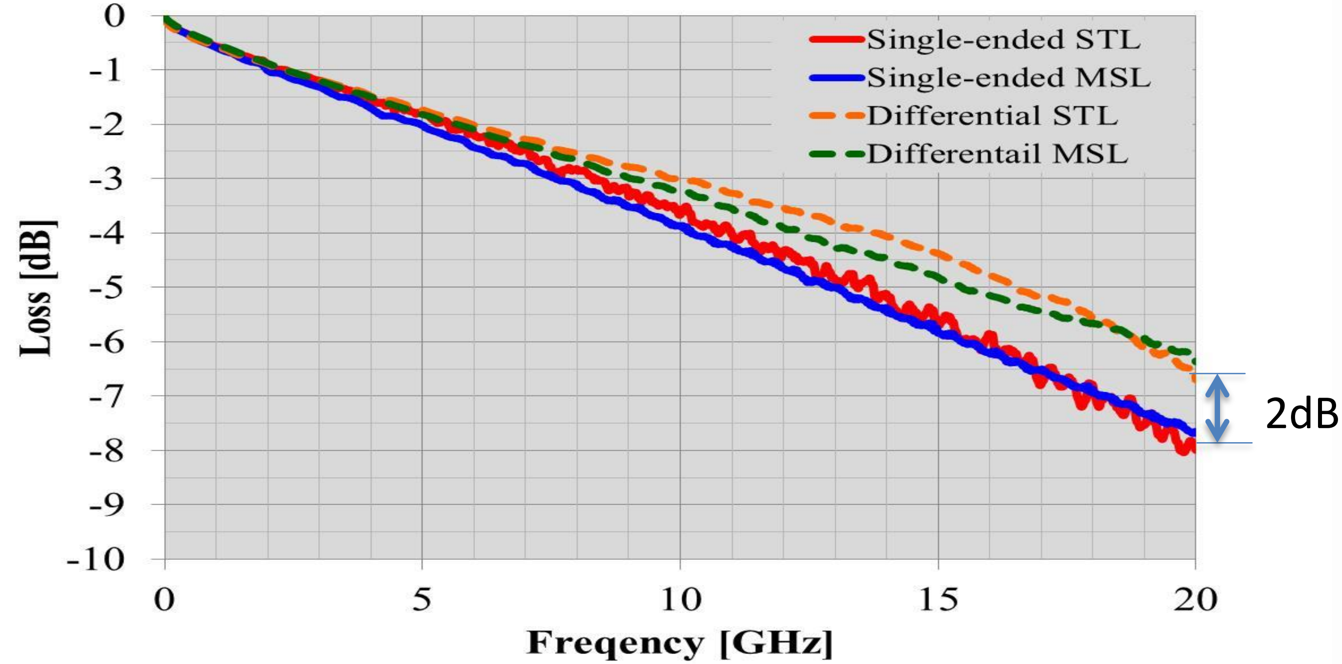
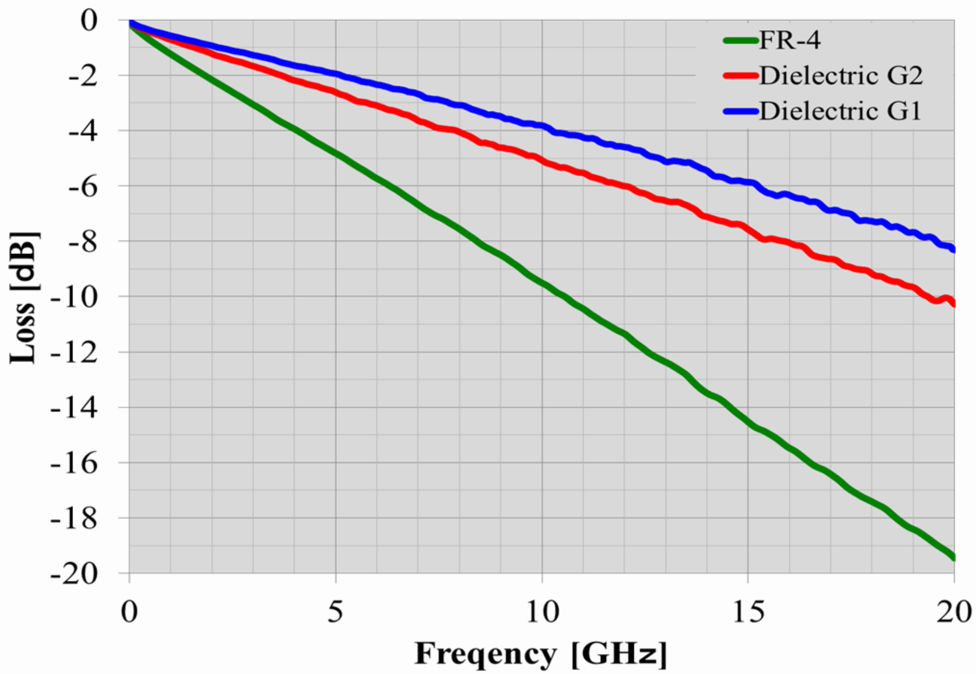
Comparison of Signal Losses of FR4 for the four different transmission structures



G1 Laminates

->Measured signal loss was about -8 dB for the single-ended line while it was about -6 dB for the differential transmission line.
-> From this, it can be said that the differential transmission line is also useful to reduce the losses in high-speed signal transmission.

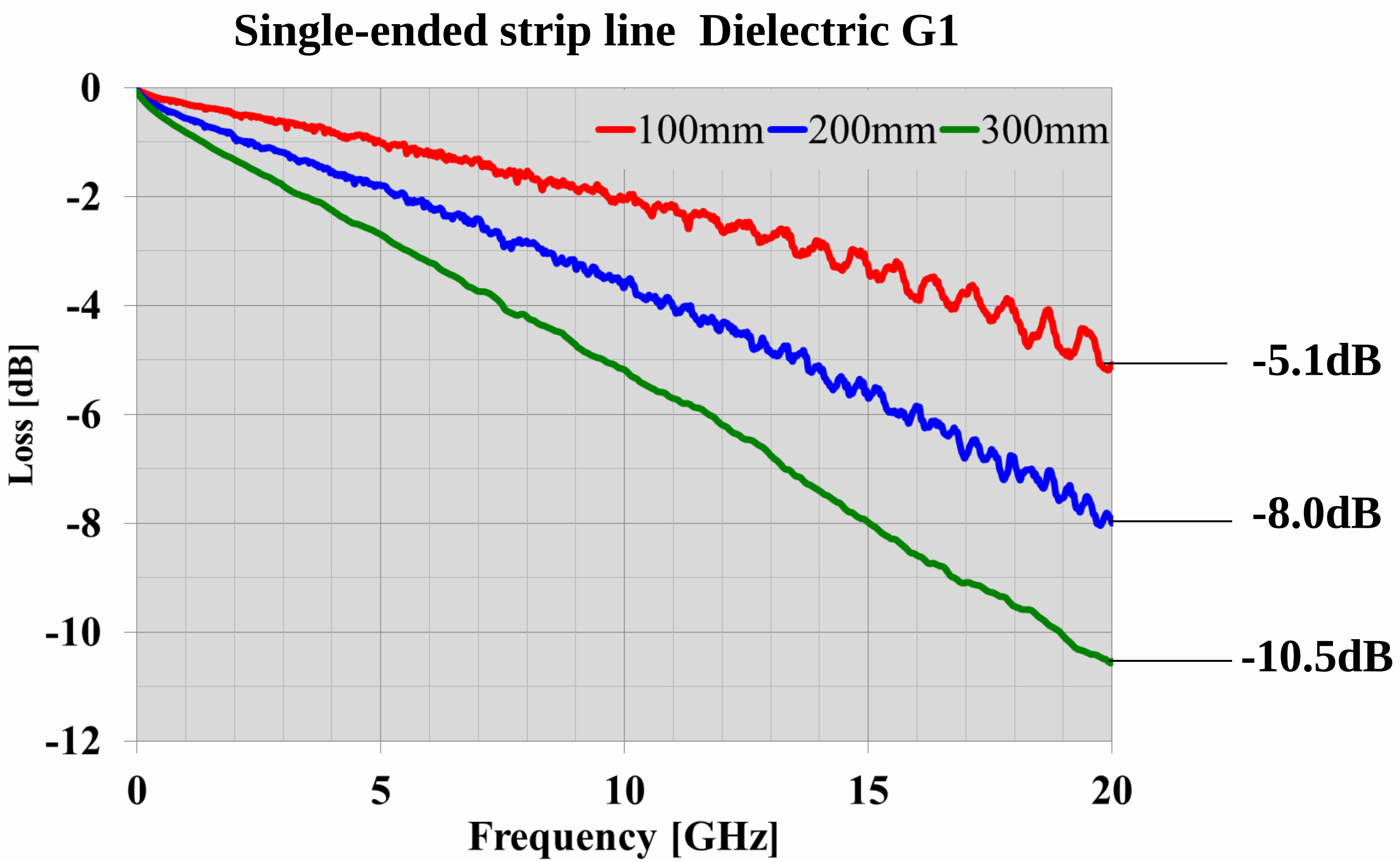
Loss measured in Three Dielectric Materials



Single-ended strip line wiring length 200mm

- S parameters were measured with a vector network analyzer. The frequency range is from 300 KHz to 20GHz. This measurement results includes the signal loss due to vias.
- The losses were reduced to more than half by adopting dielectric G1 and G2 as compared with the loss for FR-4.

Loss measured in 3 wiring lengths



- This figure shows the comparison with loss difference caused by wiring length .
- In case of 100mm, the loss value was about -5.1 dB at 20 GHz.
- On the other hand, the loss value for 300mm was about -10.5 dB at 20 GHz.

Decomposition of Signal Loss – Dielectric & Conductor

- The total pure loss for flat surface transmission l ne is represented by following equation.

$$Loss = Loss_D + Loss_C = Af + B\sqrt{f}$$

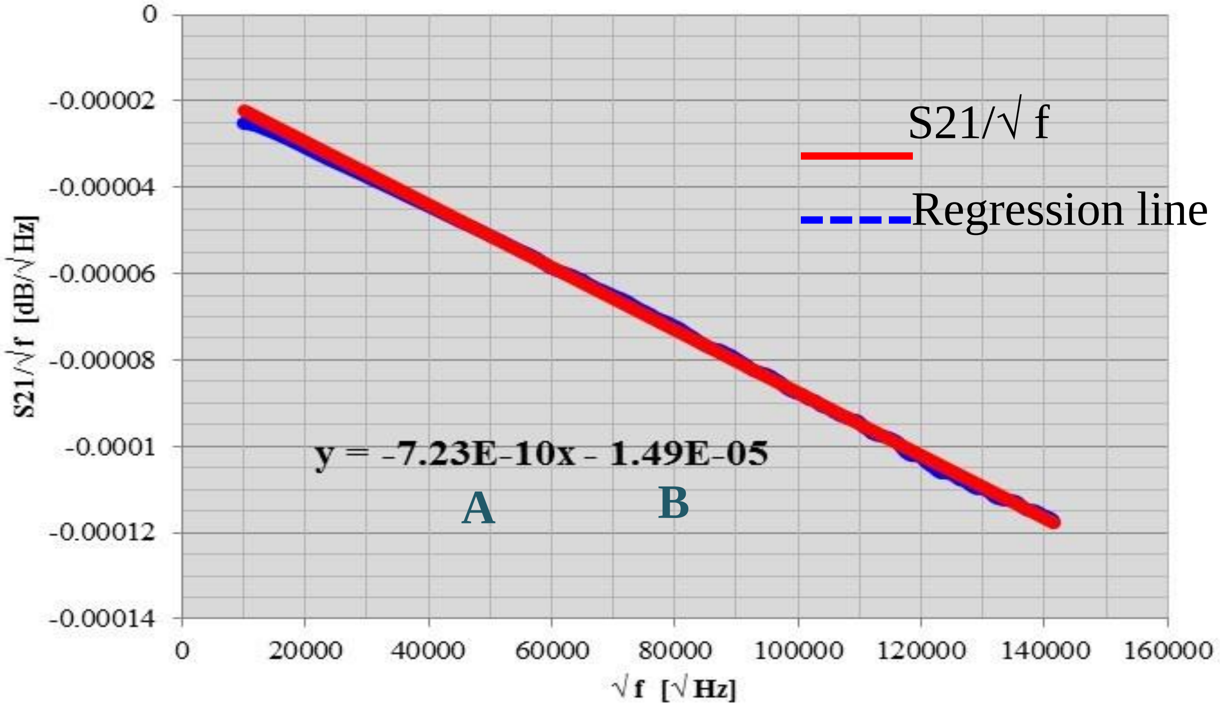
where, **A** and **B** are proportional constant of each loss.

- The following equation is the result by dividing the entire loss with the square root of the frequency.

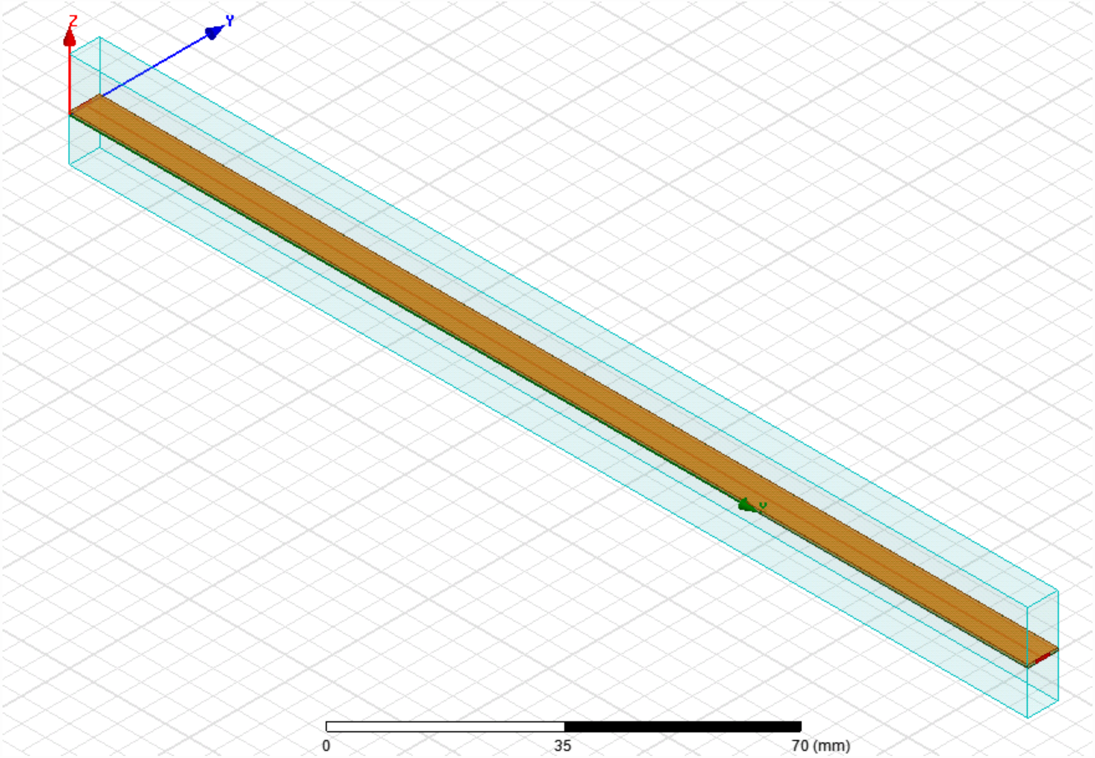
$$\frac{Loss}{\sqrt{f}} = A\sqrt{f} + B$$

- The amount of each loss factor can be obtained by determining the values of A and B.
- The constant A is the slope and the constant B is the intercept of the graph.

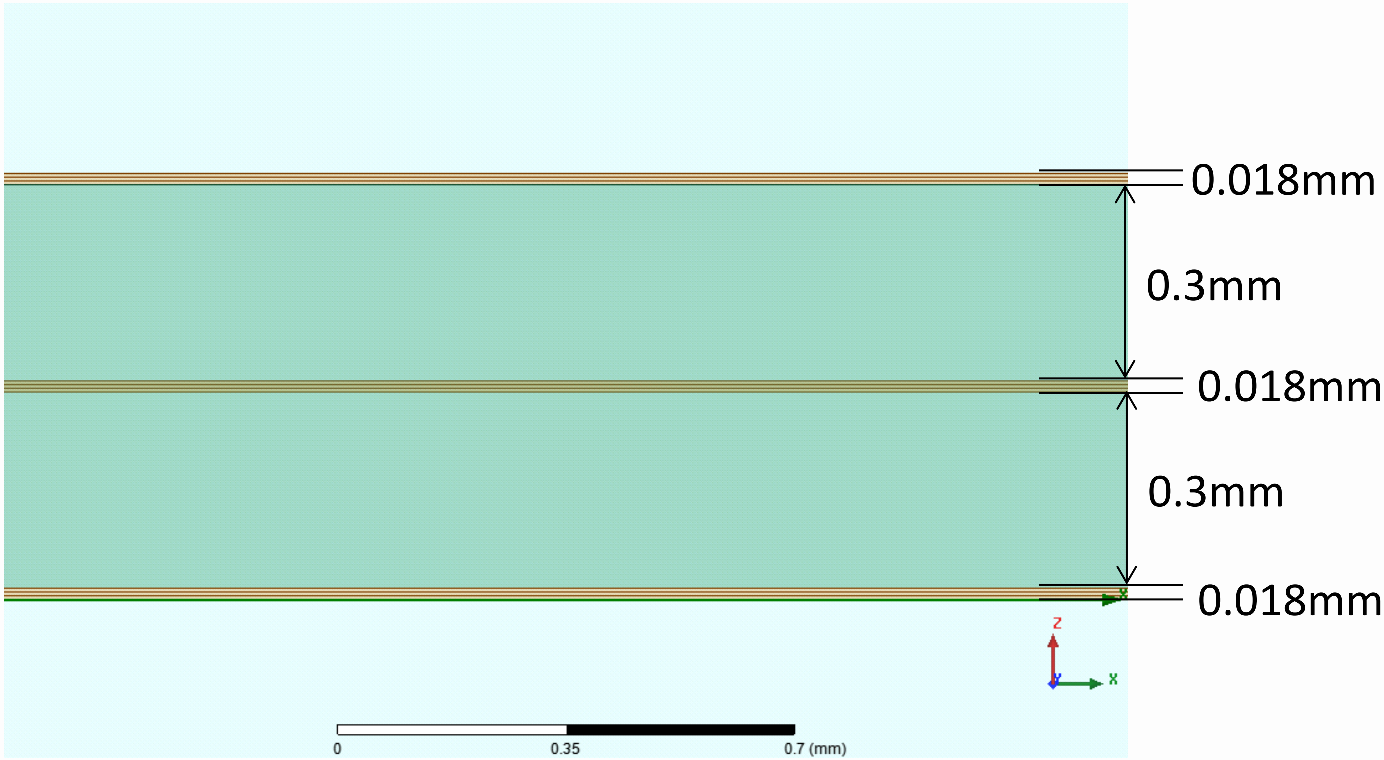
$S21/\sqrt{f}$ & Regression Line



◆The red line shows plots of the S21 divided by the square root of the frequency for FR-4 and blue line shows the regression line of that.
◆The constant A and B were obtained from the regression line.

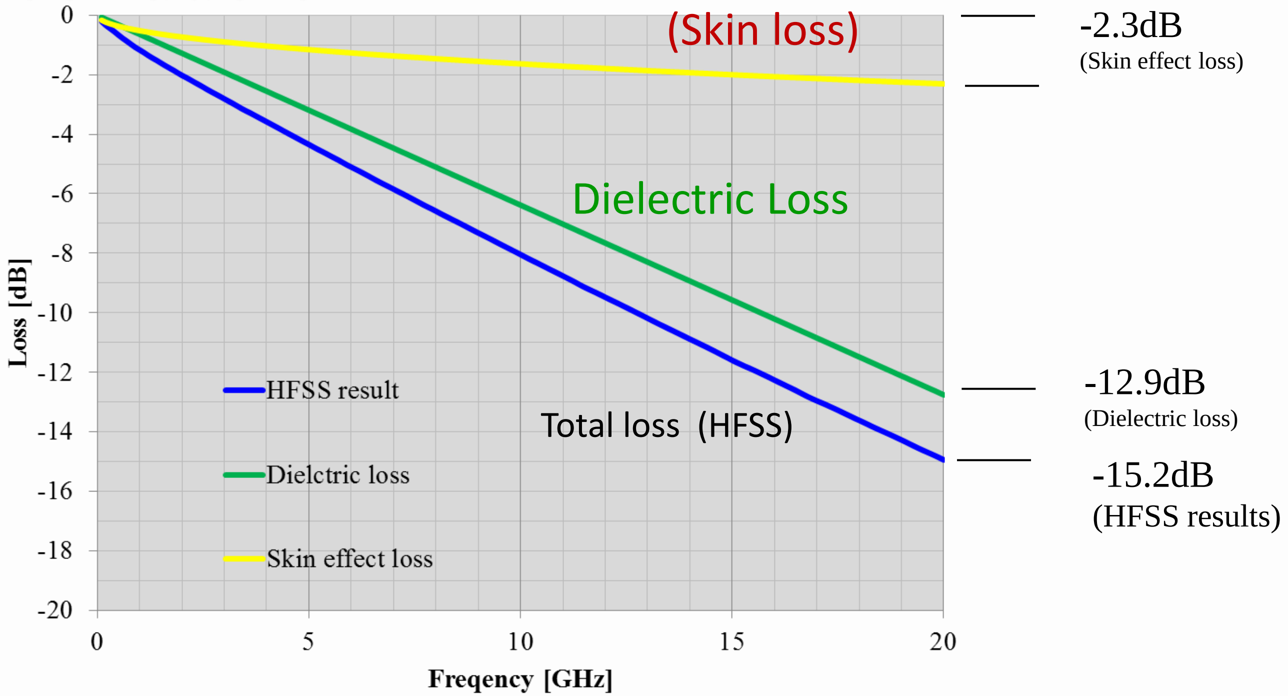


- The signal loss was estimated for flat surface transmission line by 3D electromagnetic solver, HFSS.
- The model was single-ended strip structure and wiring length was 200mm, too.



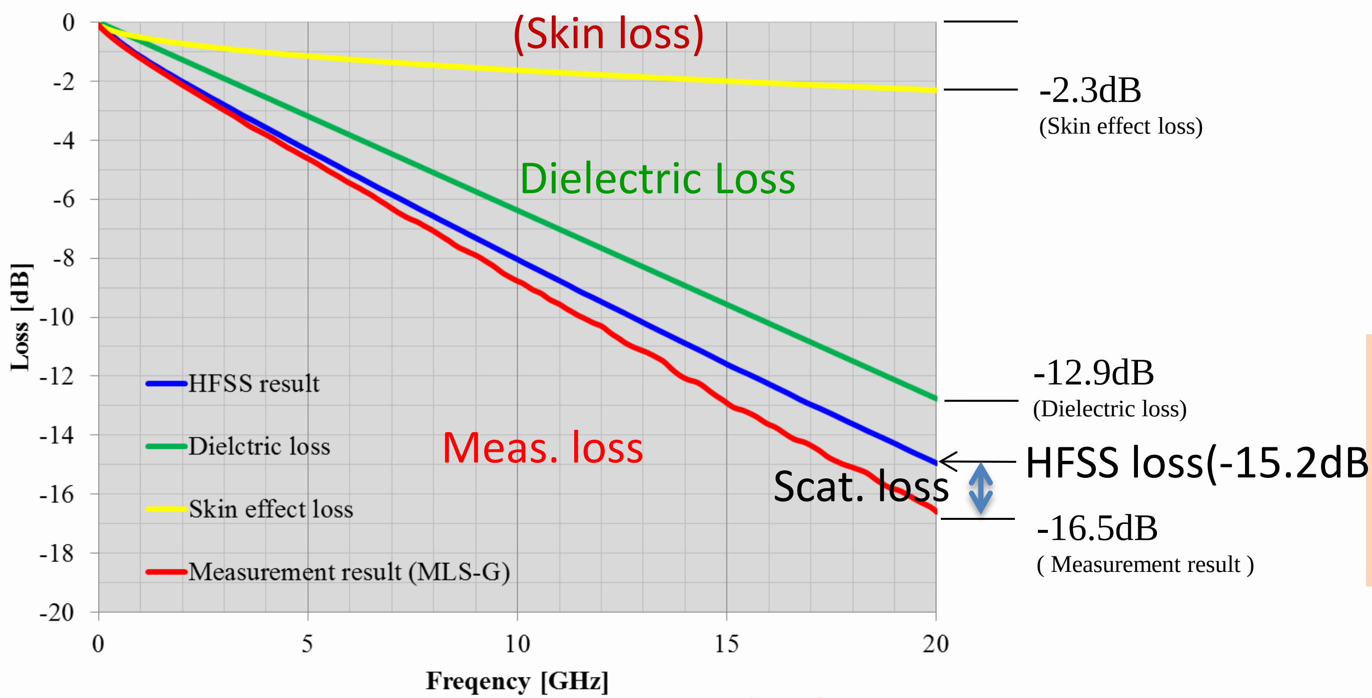
- This figure shows the cross-section of the HFSS model. The thickness of conductors was set to 18 μm.

Total loss and decomposed loss factors for flat surface conductor in FR4



- Based on the previous procedure, total loss was decomposed into two loss factors.
- This figure shows simulated total loss and decomposed each loss factors for the flat surface conductor. in FR-4.
- The orange trace indicates the skin effect loss, and green line shows the dielectric loss.
- Yellow trace shows the sum of them which shoes total loss

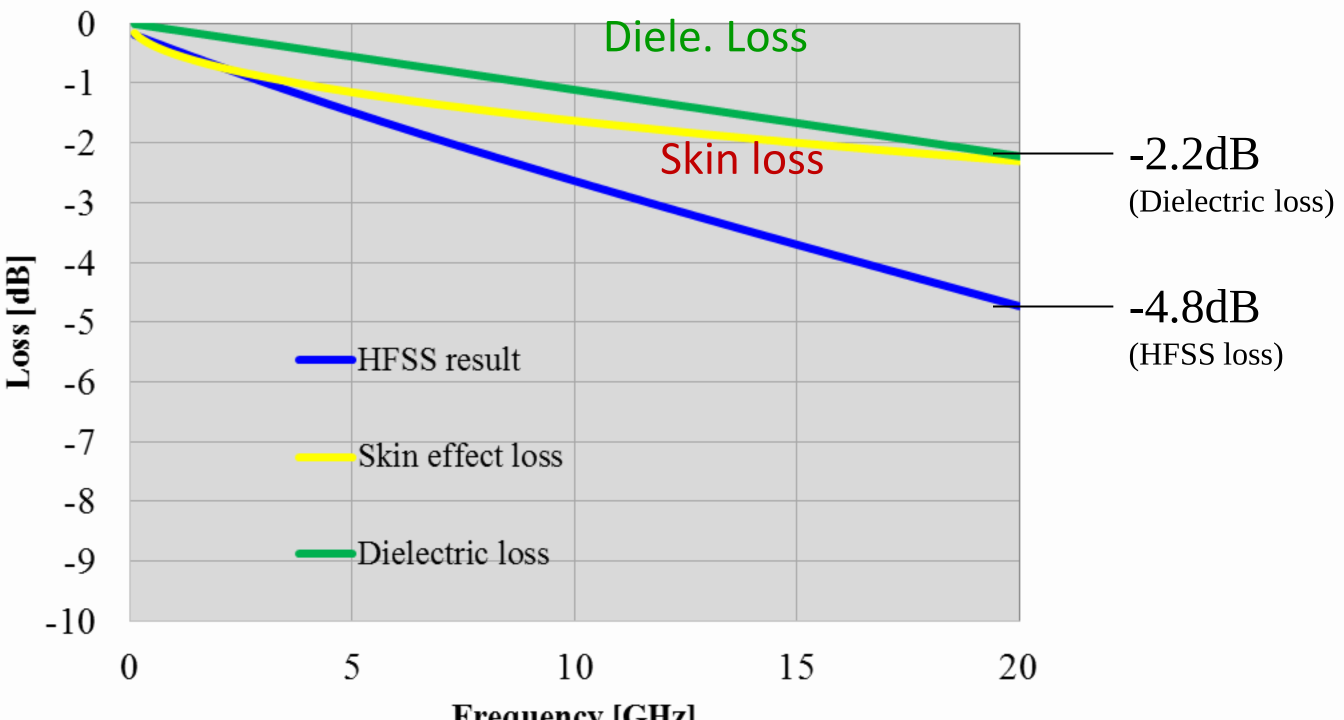
Measured Total Loss & Decomposed Loss for rough surface conductor in FR4



Scat. Loss =1.3 dB
Cond. Loss =3.6dB

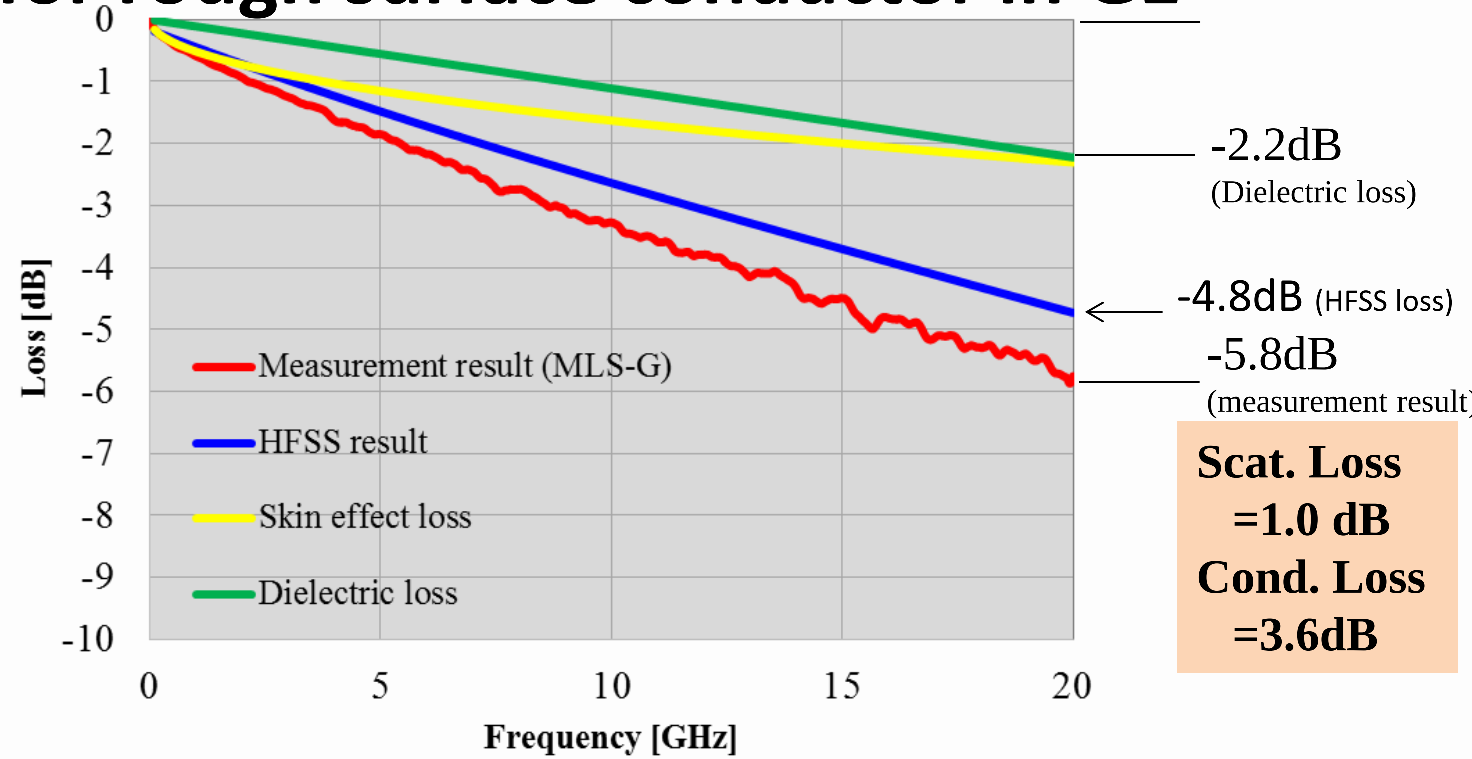
- The red trace shows the measured result for foil RTF(MLS-G).
- The sum of two loss factors were adjusted to meet with the simulated loss by HFSS.
- The estimated scattering loss was 1.3dB, and conductor loss was about 3.6 dB at 20 GHz. Conductor loss occupies about 22% against total signal loss at 20 GHz.

Total loss and decomposed loss factors for flat surface conductor in G1



- This figure shows the decomposed each loss factors for dielectric G1and flat conductor.
- Each loss factor was well decomposed from the total loss so that it was adjusted to meet with simulated result by HFSS.
- In comparison with FR-4, the dielectric loss was reduced considerably, then the percentage of the skin effect loss was relatively increased.

Measured total loss and decomposed loss factors for rough surface conductor in G1



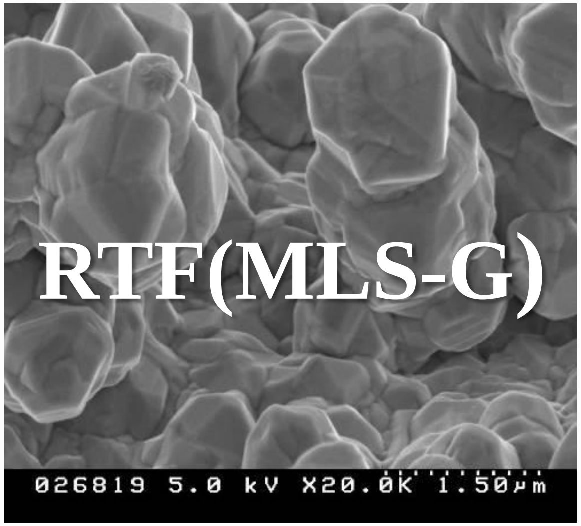
Scat. Loss =1.0 dB
Cond. Loss =3.6dB

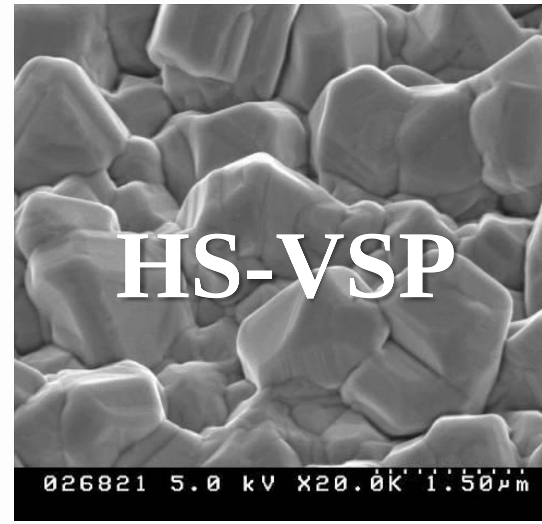
- Red trace is measured loss, and yellow trace is the sum of dielectric loss and skin effect loss.
- The difference between measured S21 and HFSS result was the scattering loss.
- The scattering loss was about 1dB at 20 GHz, and the percentage of conductor loss against the total loss was about 62%.

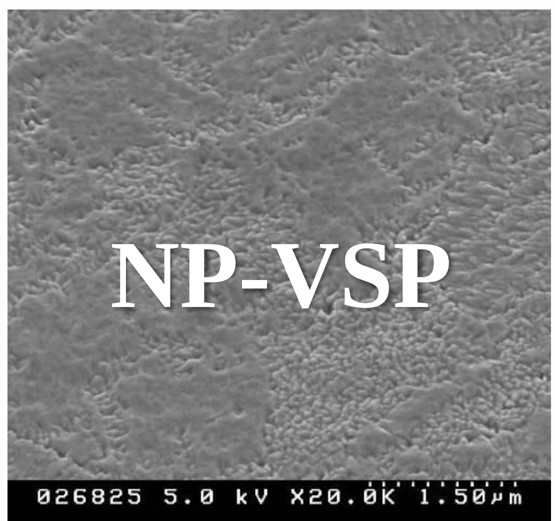
AGENDA

1. Introduction and research purpose
2. Signal transmission loss
3. Configuration of the evaluation board
4. Measurement and simulated results
5. **Loss and surface roughness of copper foil**
6. Summary

Matte side roughness of various Foil



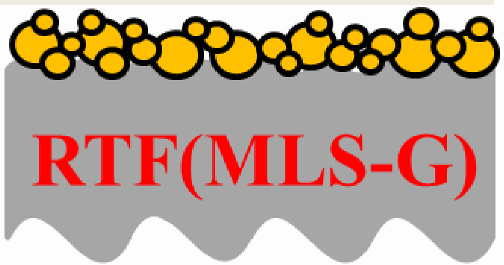




- These figures show SEM image.

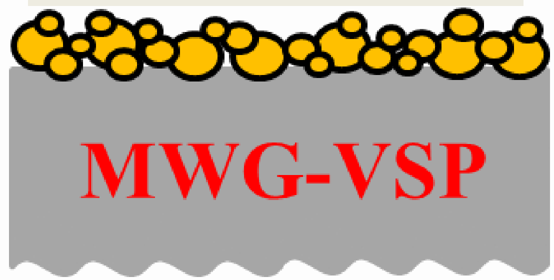
Schematic Diagram of Foils Roughness

Large copper tangles



Resist side : Large waving

Large copper tangles

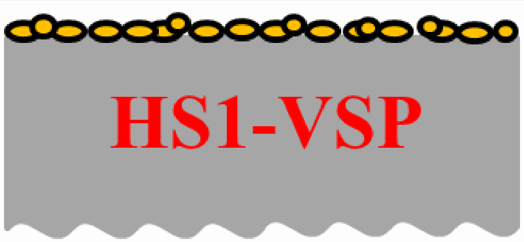


Resist side : Little waving

Small copper tangles

Resist side : small waving

Very small copper tangles



Resist side : small waving

No tangled Cu
(Primer was used instead of tangles.)

Resist side : small waving

- These figures show schematic image of each copper foil.

Roughness Measurement

[μm]

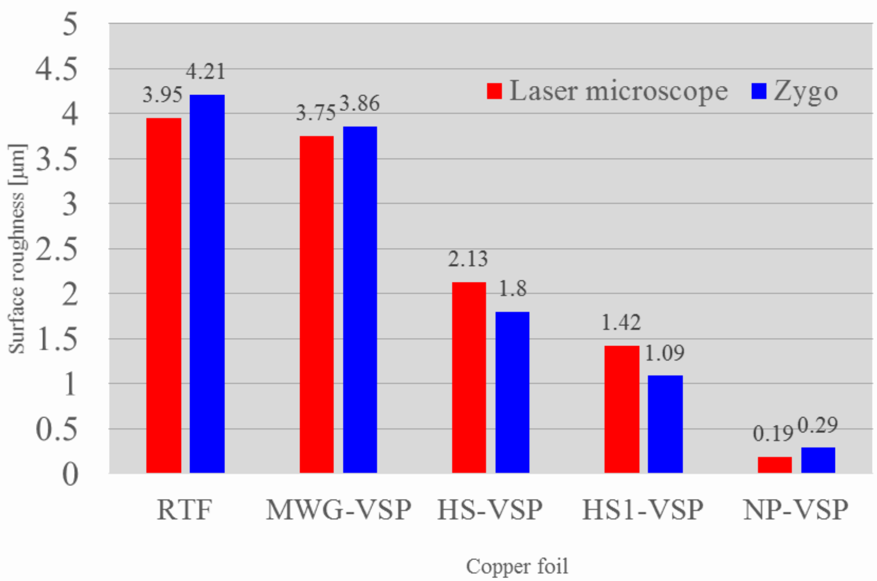
copper foil	Laser microscope	Zygo
RTF	3.95	4.21
MWG-VSP	3.75	3.86
HS-VSP	2.13	1.80
HS1-VSP	1.42	1.09
NP-VSP	0.19	0.29

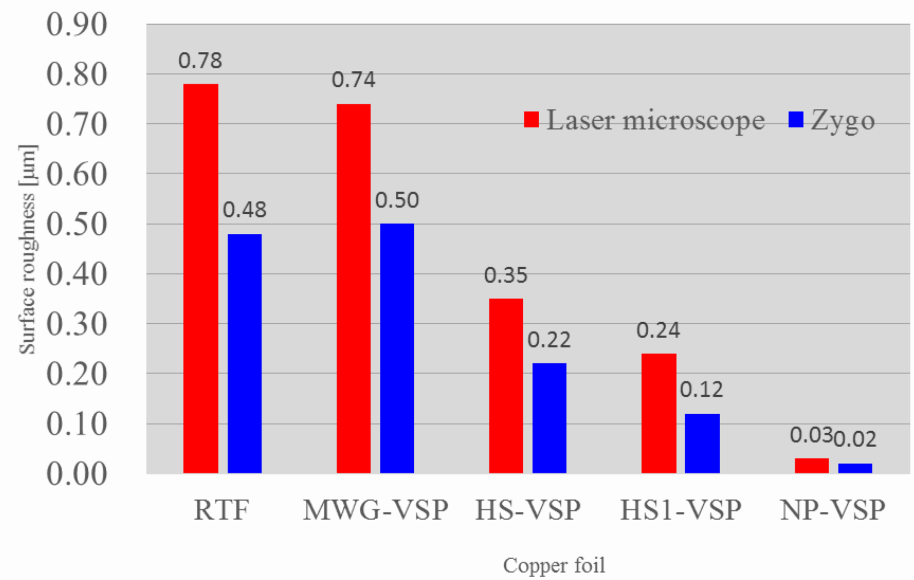
Rz : average of ten points on the surface

[μm]

copper foil	Laser microscope	Zygo
RTF	2.49	3.13
MWG-VSP	0.99	1.21
HS-VSP	0.97	1.23
HS1-VSP	1.06	0.99
NP-VSP	1.25	1.15

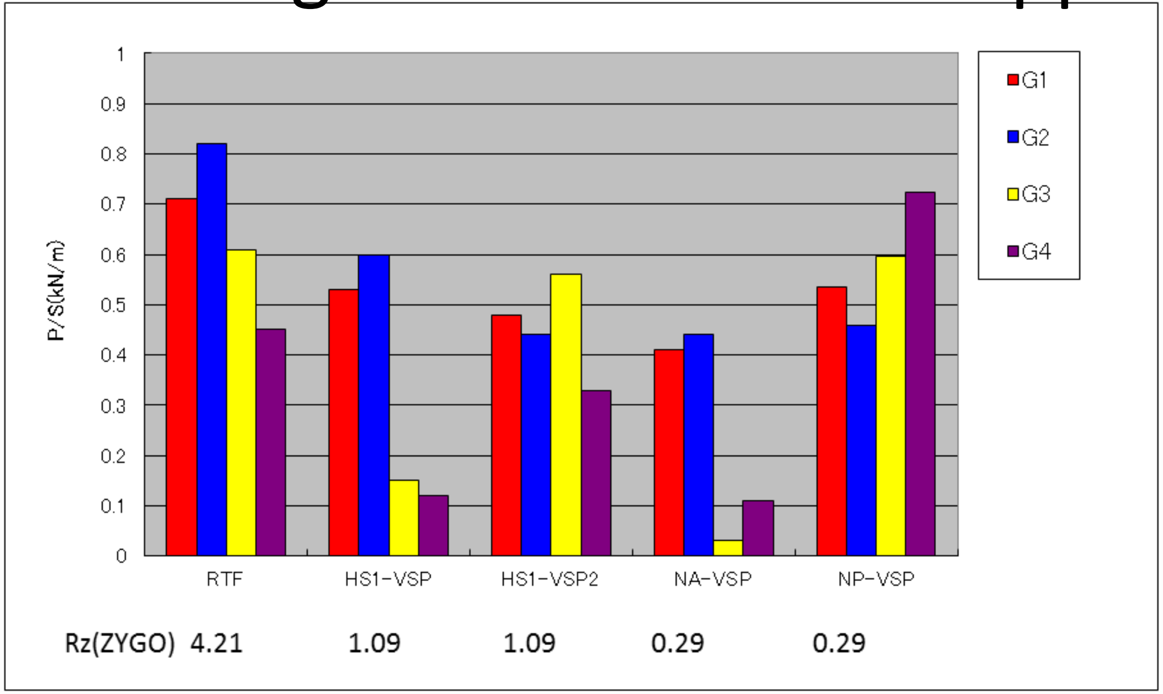
Rq : root-mean-square of roughnesses





◆ Surface roughness of each copper foils were RTF > MWG-VSP > HS-VSP > NP-VSP.

Peel Strength of Low Profile Copper Foil

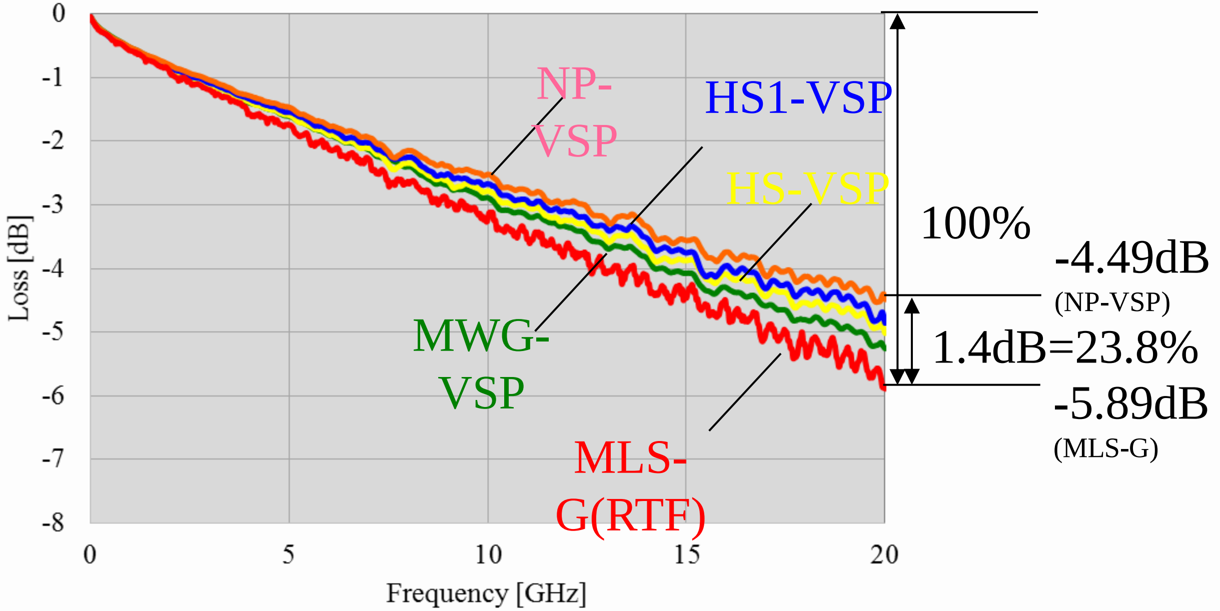


G1, G2, G3 & G4 are industry available low loss laminates for high frequency application

→New chemical bonding treatment was applied on HS1-VSP2. The treatment was very effective for G3 and G4 laminate.

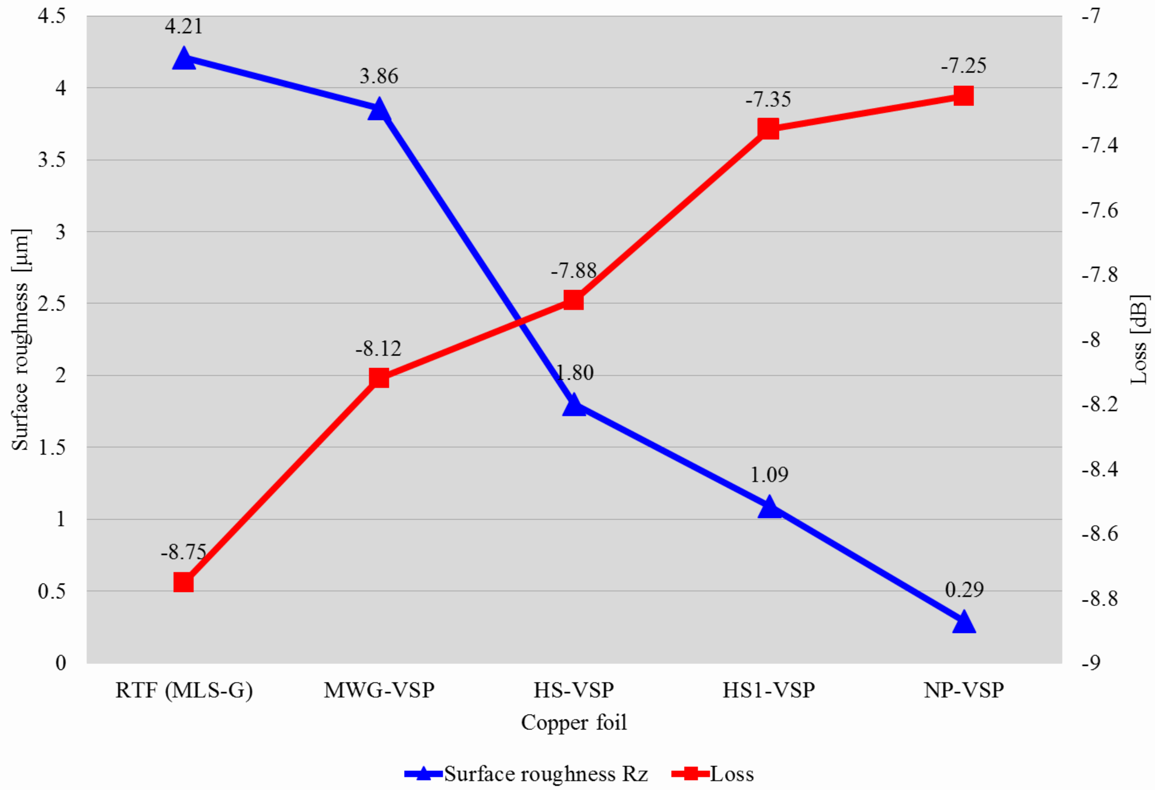
→NA-VSP is totally no nodule copper foil with very thin resin coating . The coating was extremely effective for improving P/S of G3 and G4. Effectiveness of the new chemical treatment and the thin resin coating were proven by this experiment.

Comparison - Loss on various Foils



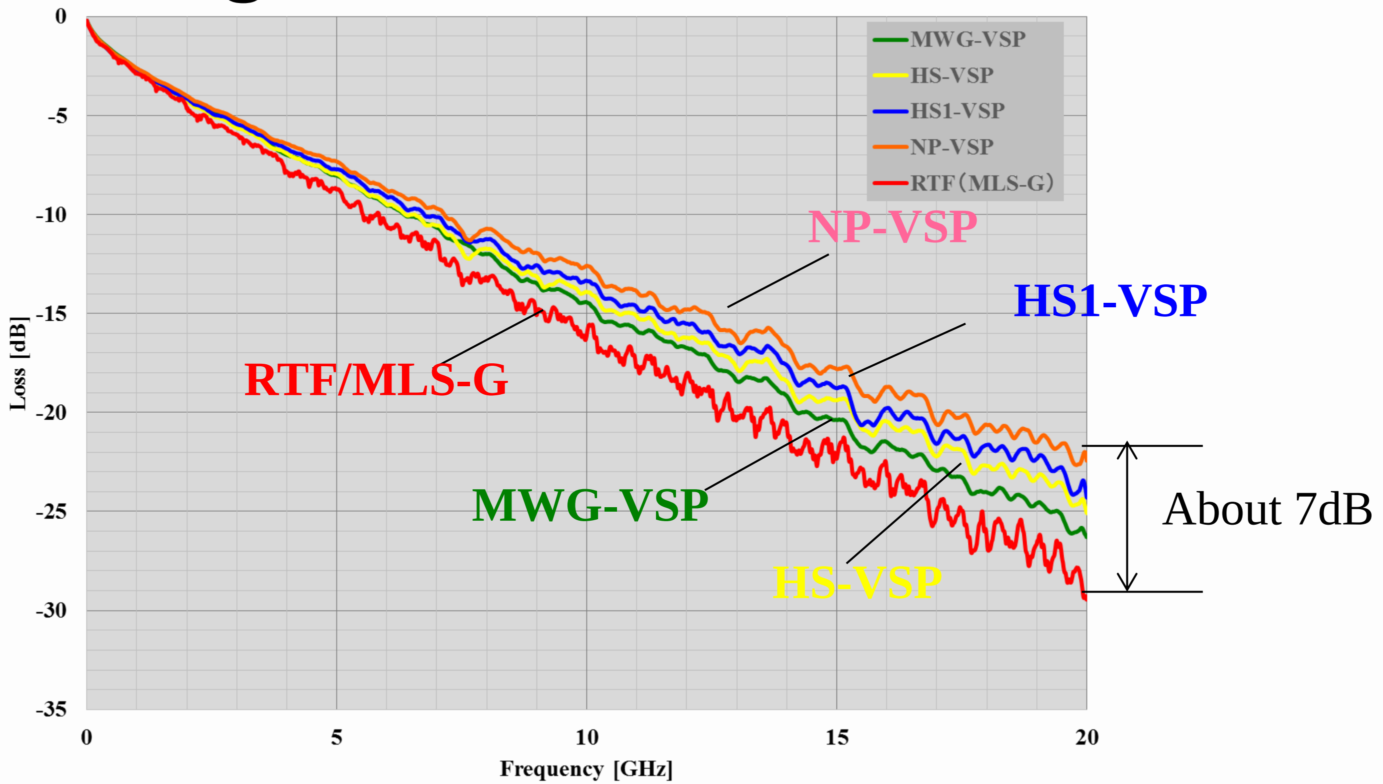
- When the foil MLS-G(RTF) was compared with the foil NP-VSP, the signal loss of the foil NP-VSP was reduced by approximately 23.8% of the signal loss of the foil MLS-G.
- This shows that the usage of copper foil with low surface roughness is effective to reduce the scattering loss of the conductor

Relationship : Signal Loss Vs Roughness



- This figure shows the relationship between loss and surface roughness of each copper foils.
- It was confirmed that as the roughness became smaller, the loss was decreased.

Normalised Signal Loss of S21 in 1 m



- This figure shows normalized signal loss, S21. The vertical axis is dB/m.
- The loss difference between RTF foil and NP-VSP foil became much larger than that of 200 mm wiring length. It was about 7dB at 20GHz.

AGENDA

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SUMMARY

In this research, S parameters of various types of transmission lines structures on an evaluation board were measured and analyzed in detail.

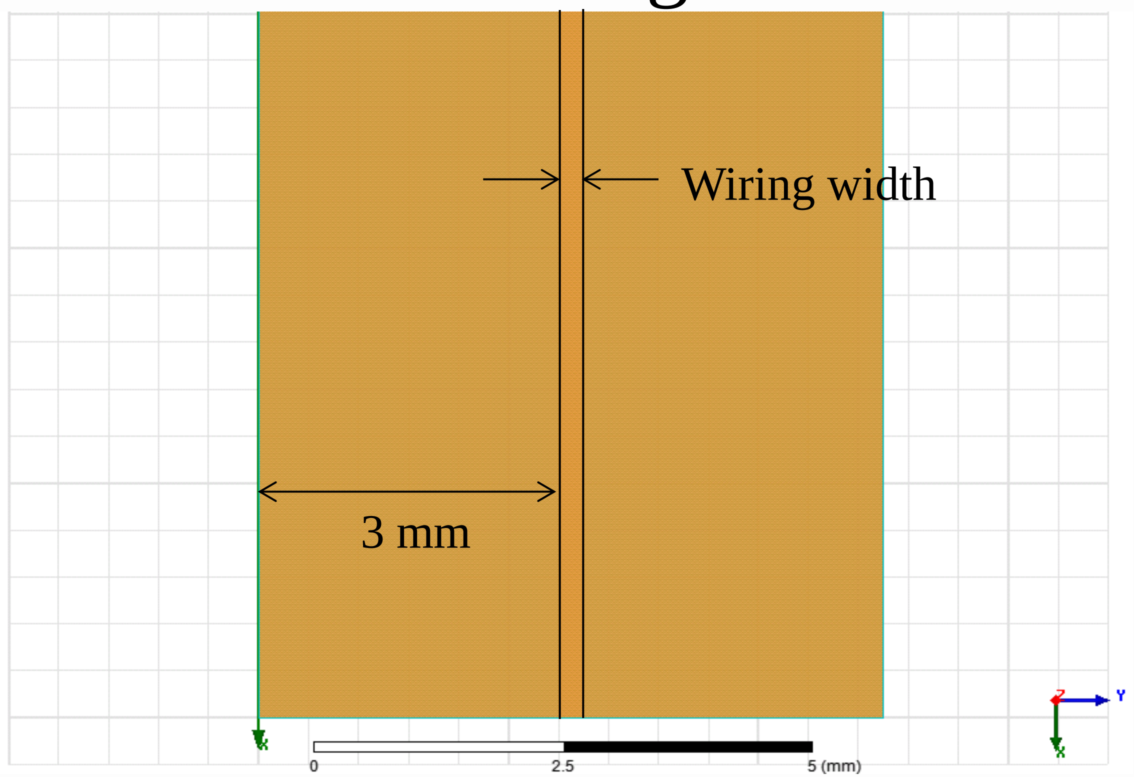
1) It' been demonstrated that low roughness copper foil is effective in reducing the signal loss under higher frequency, reduce by 73% of the scattering loss compared with commonly used surface roughness of copper foil.

2) When using the low dielectric constant materials instead of FR-4, the ratio of the conductor loss against the entire loss increases. The ratio of conductor loss for FR-4 was 13% of the total signal loss, but the conductor loss in dielectric G1 will increase to 30% among the overall loss.

3) The chemical treatment on very low profile and the thin resin coating on no nodule copper foil are both very effective to improve bond strength of laminates.

THANK YOU

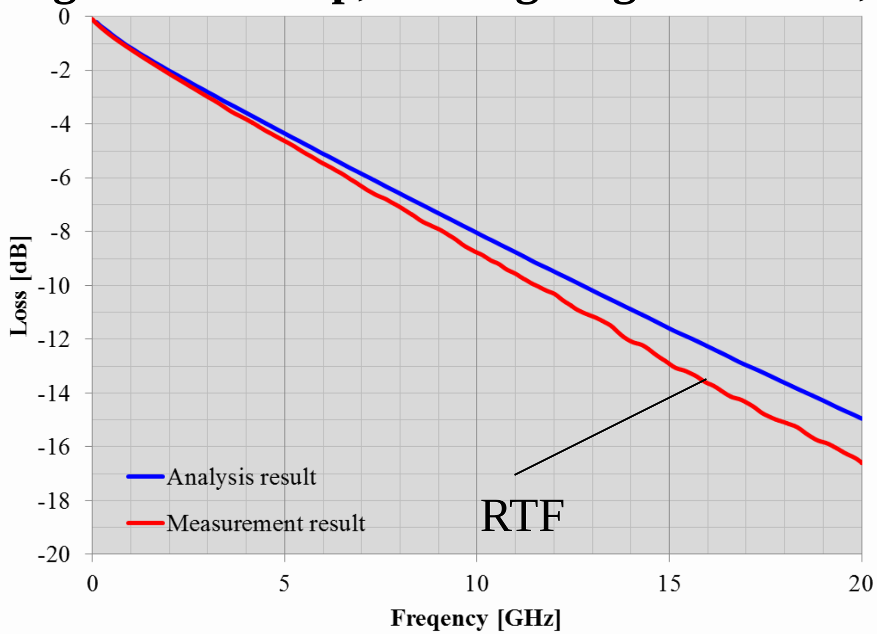
Plane view of wiring trace in HFSS



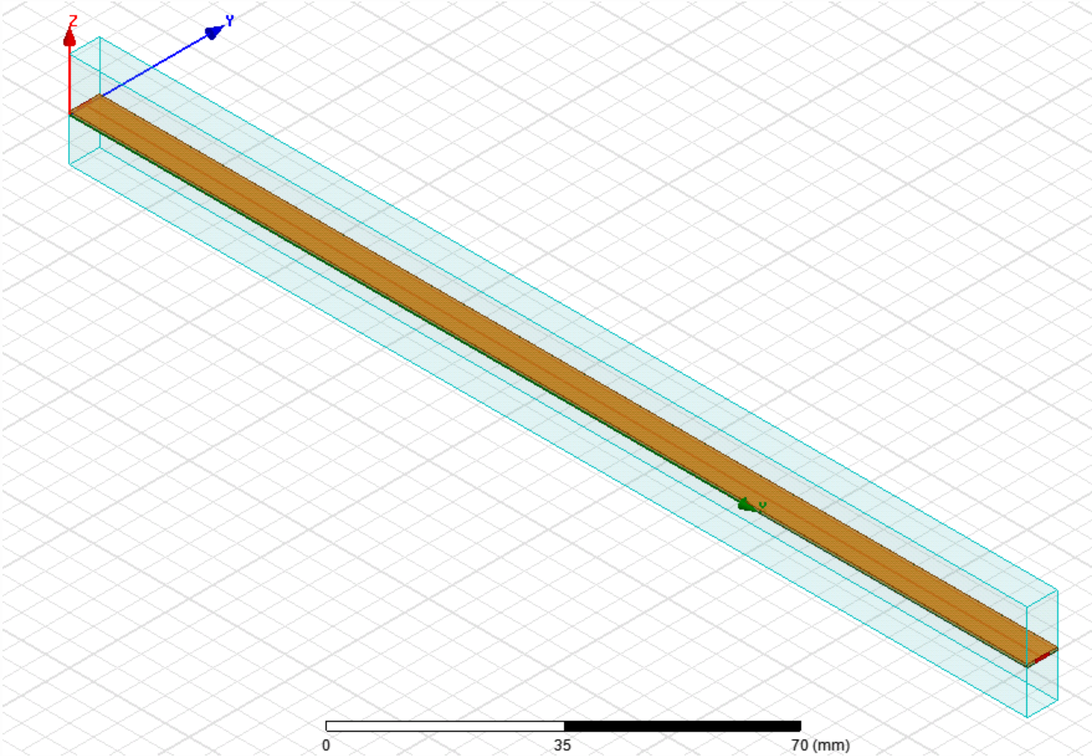
- This figure shows plane view of wiring trace in HFSS model.
- The distance between the edge of the wiring and the wiring model was 3mm.

Comparison -measured S21 and HFSS result

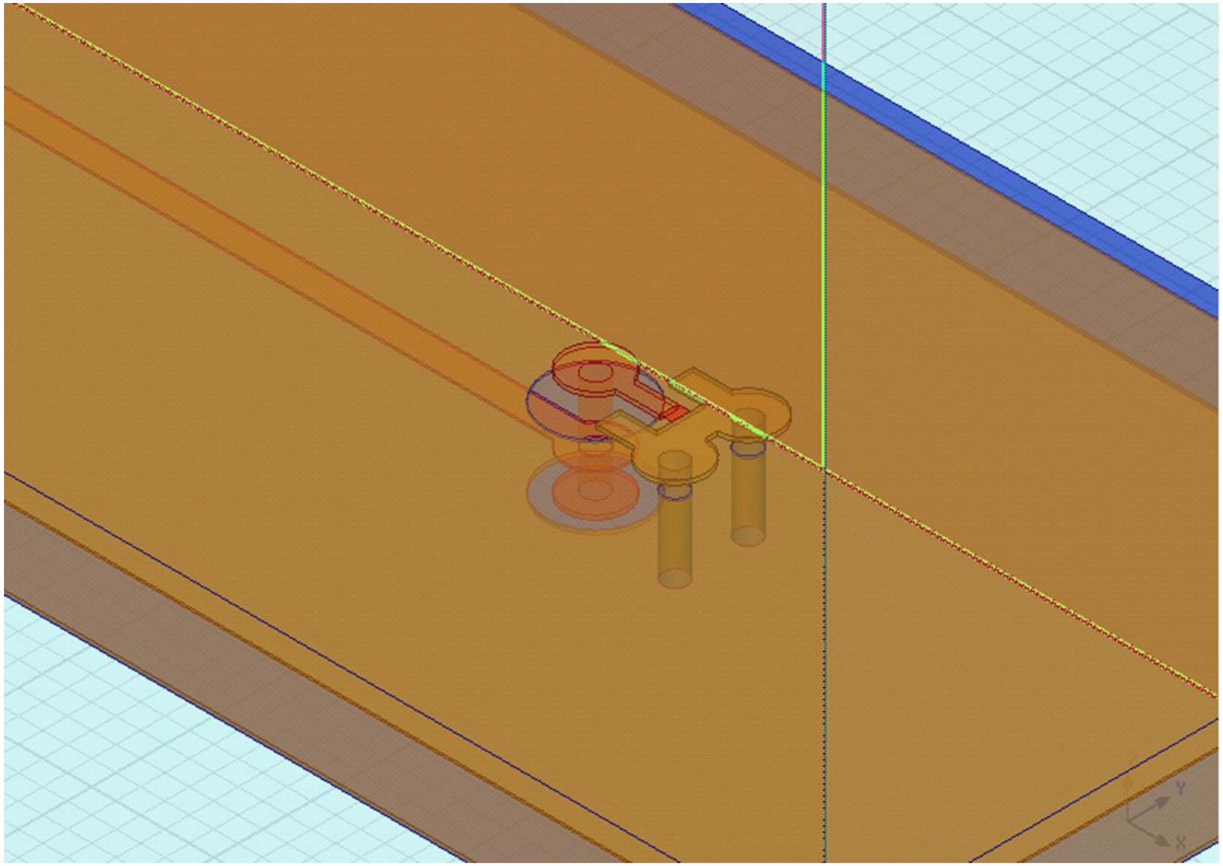
Structure : Single-ended strip, Wiring length: 200mm, Dielectric : FR-4



- The measured S21 includes the scattering loss caused by surface roughness of the conductor.
- On the other hand, simulated S21 with HFSS does not include the scattering loss due to surface roughness. The simulated model by HFSS was assumed to be completely smooth surface.
- Then, the difference of S21 between measured S21 and HFSS result shows the amount of scattering loss, which was estimated to be approximately 1.5 dB at 20 GHz.



- The signal loss was analyzed with 3D electromagnetic solver, HFSS.
- This figure shows the analysis model of wiring on a printed circuit board.
- The model was single-ended strip structure and wiring length was 200mm.



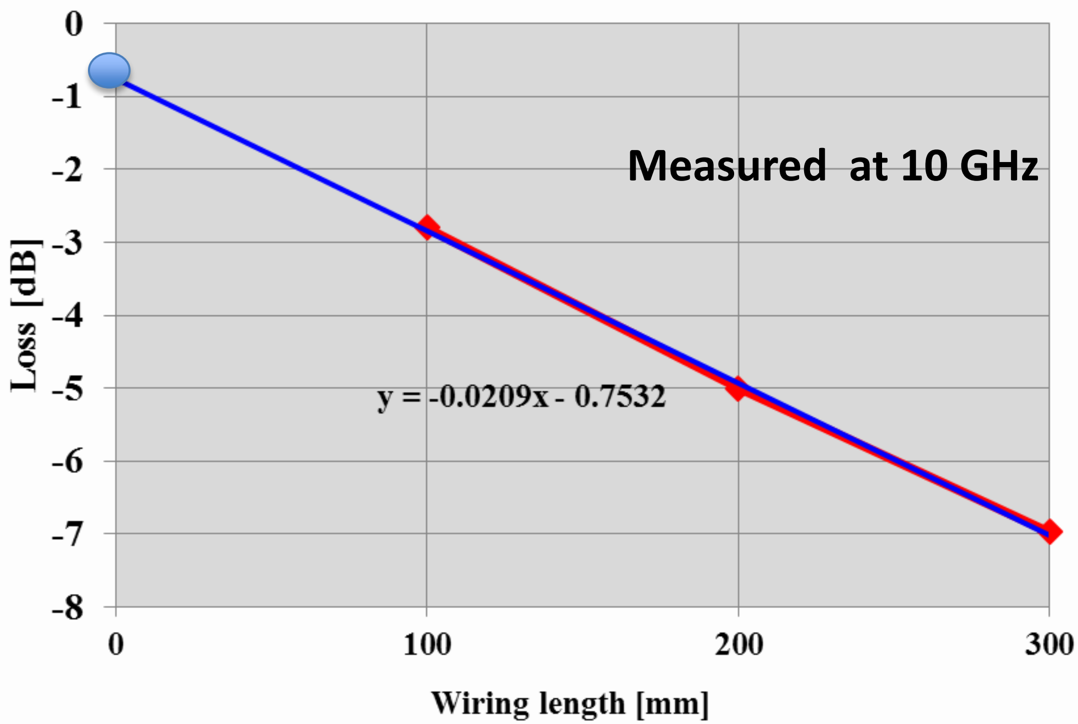
- This figure shows the via in the HFSS model.

	Microstrip		Strip	
	Single-ended	Differential	Single-ended	Differential
W $[mm]$	0.40	0.34	0.34	0.22
H $[mm]$	0.20	0.30	0.20	0.30
S $[mm]$	-	0.50	-	0.40
T $[mm]$	0.018	0.018	0.018	0.018
$Z_o[\Omega]$	50	100	50	100

	Relative permittivity	Dielectric loss tangent
G1	3.6	0.002
G2	3.8	0.005
FR-4	4.4	0.02

- This table shows relative permittivity and dielectric loss tangent of three dielectric materials used for the evaluation board.
- Dielectric materials; G1, G2 are low dielectric materials, and FR-4 is commonly used dielectric material.
- Loss tangent value of G1 is one tenth of that of FR-4, and that of G2 is one fourth of FR-4.

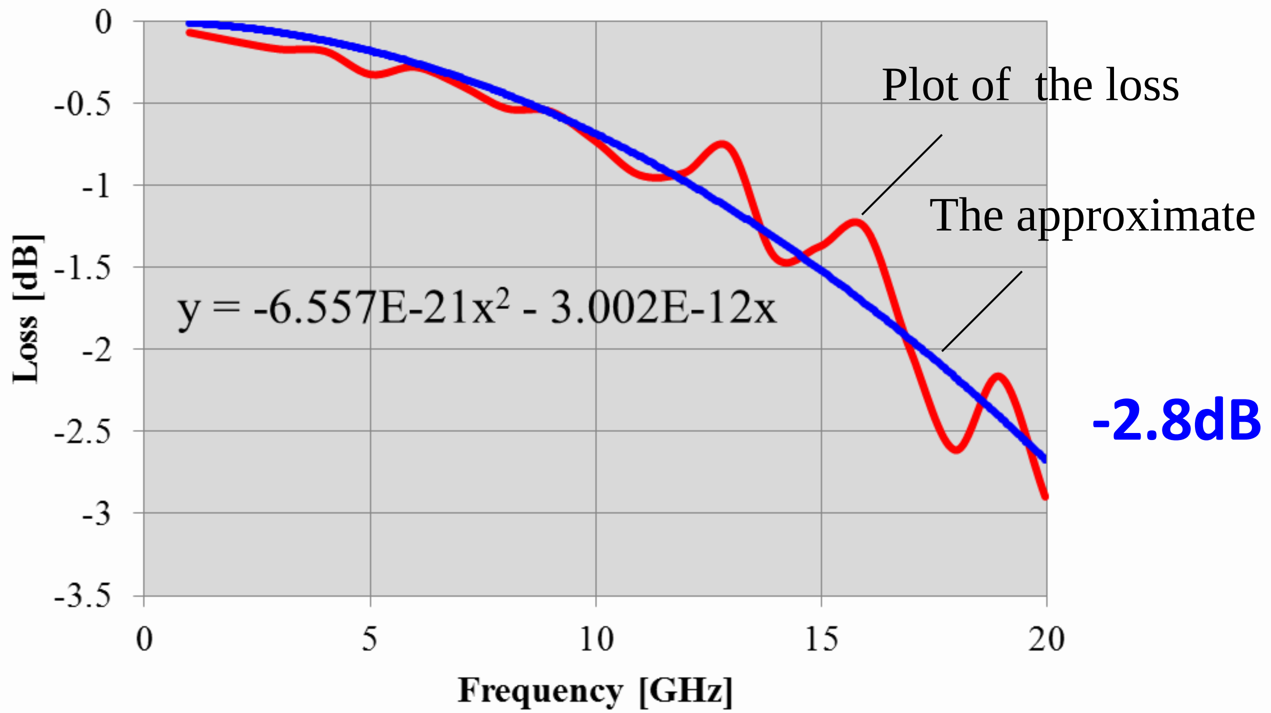
How To extract loss due to Via ?



◆This figure shows the losses for three wiring lengths at 10GHz.

◆The intercept of the blue line shows the via loss value. The value of the via loss was -0.7532dB at 10GHz.

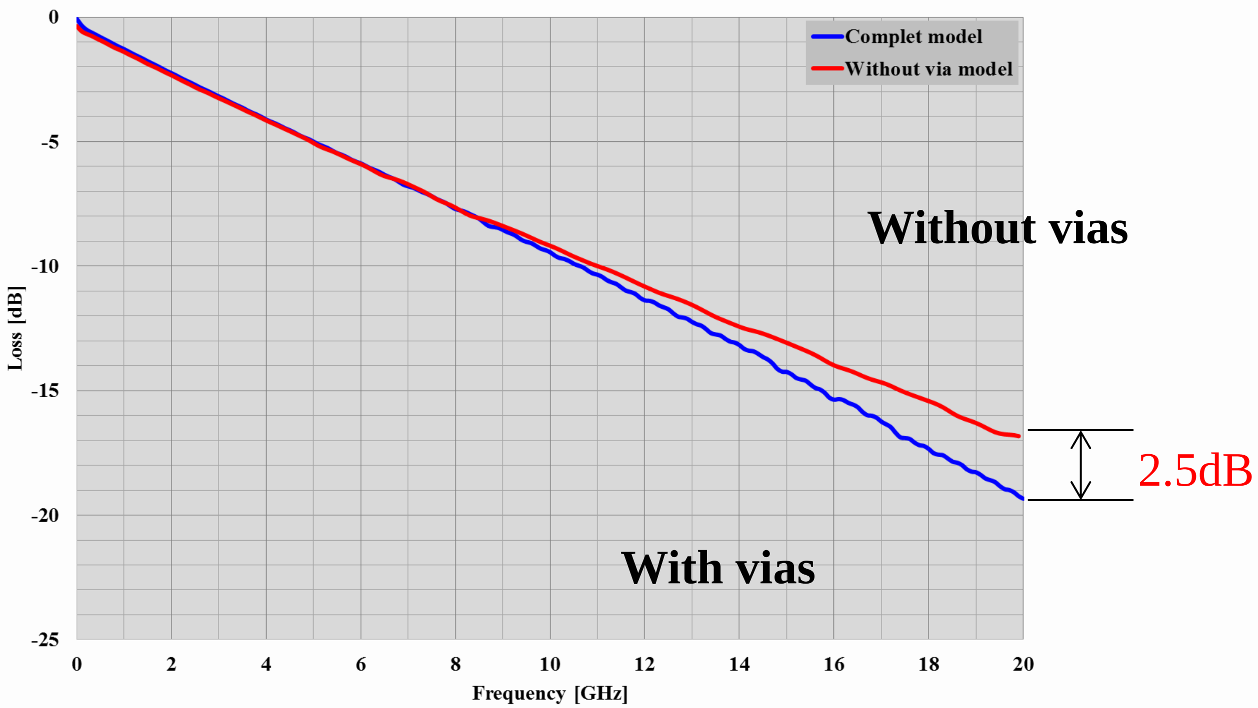
Extracted Via loss from Measurement



◆This figure shows the deduced via loss from 1GHz to 20 GHz.

◆The red line shows plots of loss due to via in each frequency. The blue line shows approximated curved line for the red line.

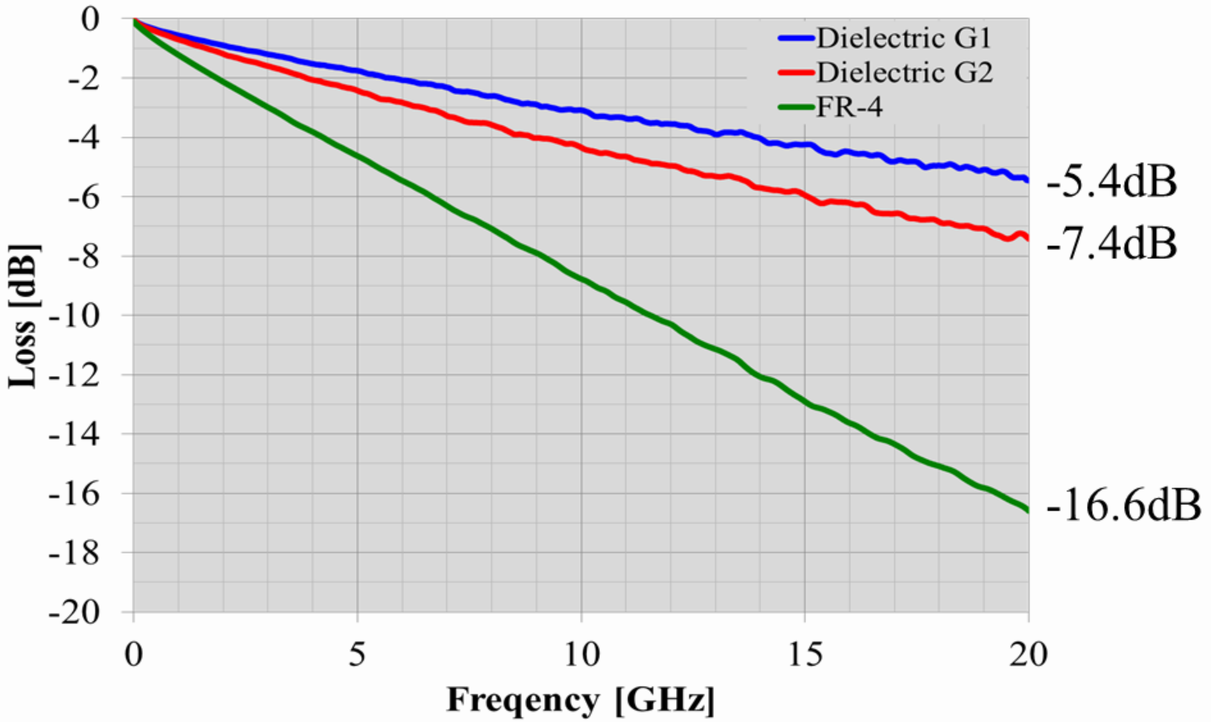
◆The deduced via loss was approximately -2.8 dB at 20 GHz.



- This figure shows the comparison with simulated result with HFSS.
- The signal loss difference at 20GHz was about 2.5dB.
- This value agreed well with the via loss which was extracted by the measurement

Calibrated Signal Loss without Via Loss

Single-ended strip line wiring length 200mm



- This figure shows calibrated S21 that does not include the loss due to vias.
- In case of dielectric G1, the loss value was about -5.4 dB at 20 GHz.
- On the other hand, the loss value for FR-4 was about -16.6 dB at 20 GHz.