2025/05/01

# Takada RF Labs, Inc. Technology Databook (Rev.5.0)

Takada RF Labs, Inc.

This document describes technology outline of products that Takada RF Labs, Inc provide to customers. In Chapter 1, fundamental technologies that are commonly applied for various products made by Takada RF Labs, are described. Chapter 2 and later chapters describe concrete application examples of these technologies to make various type of RF modules such as general RF modules, evaluation board and test fixture for RF devices and high frequency probe-card.

## Table of contents

# Chapter 1　Fundamental Technologies

## Section 1　RF connector

We use following connectors depending on requirements of operating frequency, module size and RF signal pin count.

0.8mm end-launch connector, 0.8mm connector/0.787mm $\phi$ semi-rigid cable assembly,
1.0mm end-launch connector, 1.0mm connector/0.787mm $\phi$ semi-rigid cable assembly,
1.85mm(V), 2.92mm(K), SMA, SMB, SMP(GPO), SMPM(GPPO), G3PO(SMPS), QSFP card edge, FPC connector, CEC (Cable Edge Connector)

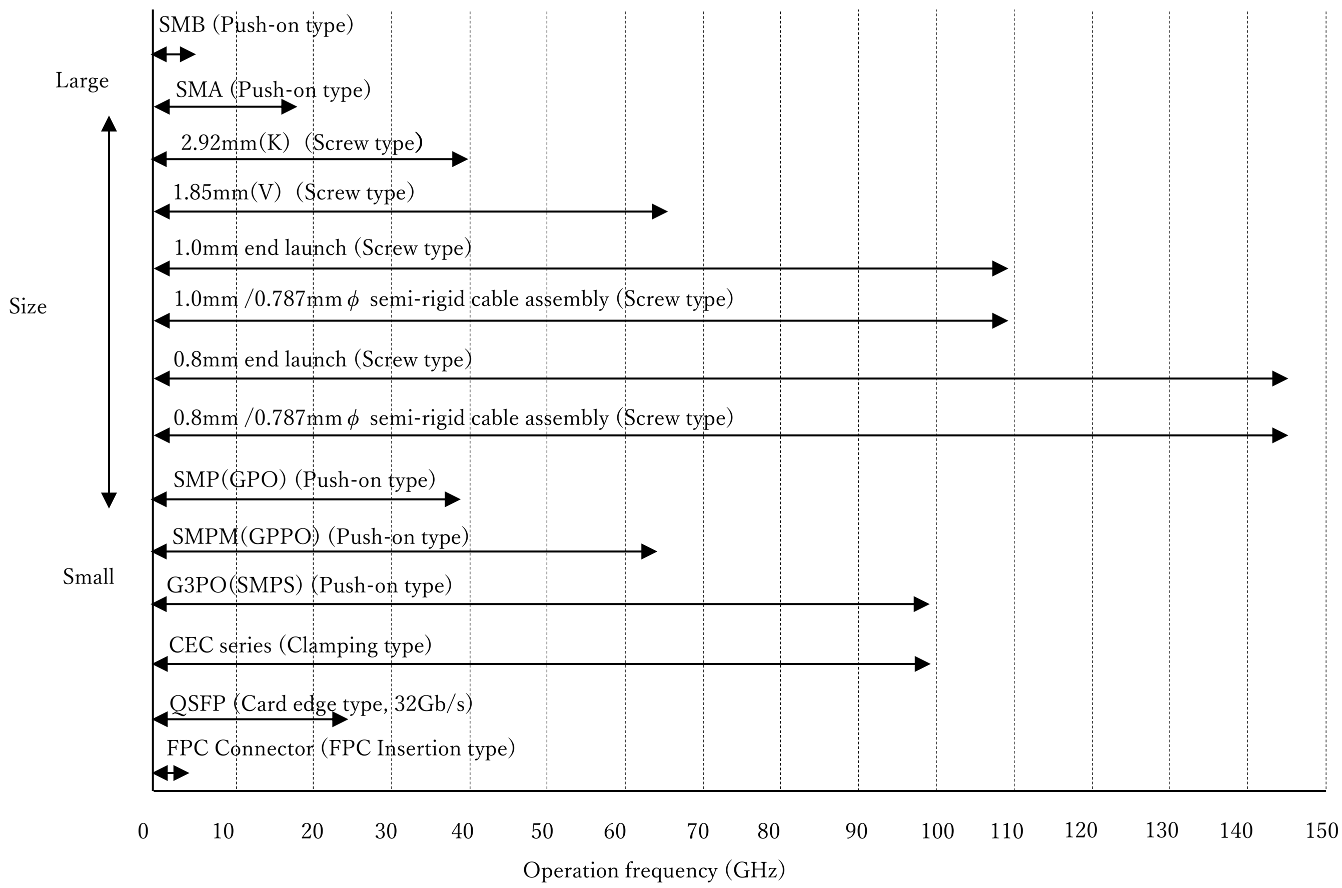
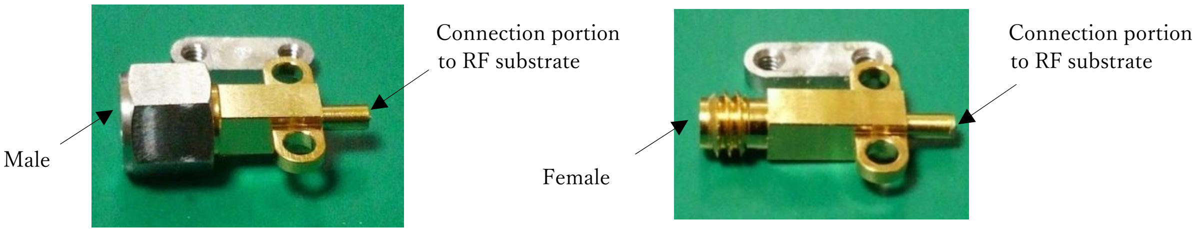



Fig. CP1-1 Operating Frequency and size of various connectors

Features of some of connectors mentioned above are described below.

1) 1mm-coaxial end launch connector, 1MMEL02 series(Takada RF Labs, Inc.'s original).

Photographs for 1MMEL02P and 1MMEL02J are shown in Fig. CP1-2. These are used by mounting at end launch portion of RF substrate.




1MMEL02P 1MMEL02J

Fig. CP1-2 Photograph of 1mm-coaxial end launch connector 1MMEL02 series

Back to back connector (B2B) was made to evaluate 1MMEL02 series performance. B2B has structure that two 1MMEL02s are combined each other at the connection portion to RF substrate. S-parameter of B2B is shown Fig.CP1-3.

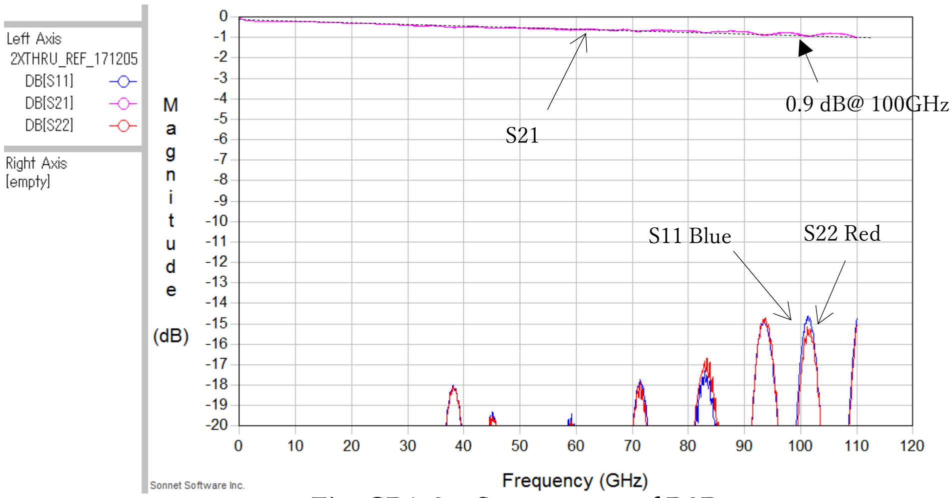



Fig. CP1-3 S-parameter of B2B

From Fig. CP1-3, we know that insertion loss of one 1MMEL02 is 0.45 (=0.9/2) dB at 100 GHz.

2) 1.0mm-connector /0.787mm $\phi$ semi-rigid cable assembly

Structure of 0.787mm $\phi$ semi-rigid cable assembly(CA) with female 1.0mm-conenctor at both end is shown in Fig.CP1-4. S-parameter for CA of which semi-rigid cable length is 25.1mm is shown in Fig.CP1-5.

Fig.CP1-4 structure is cut half when used for module fabrication.

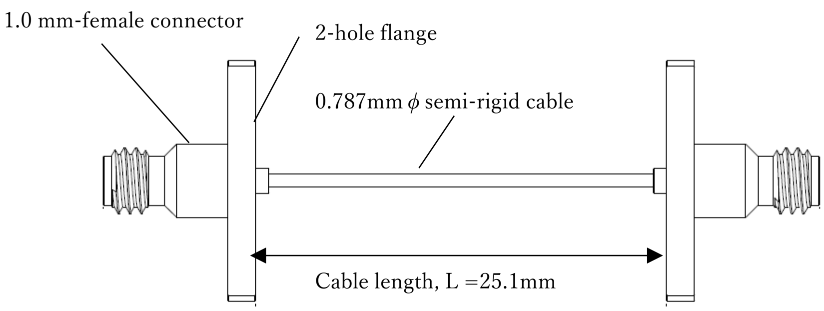



Fig.CP 1-4 Two 1.0mm-female connectors /0.787 mm ϕ semi-rigid cable assembly

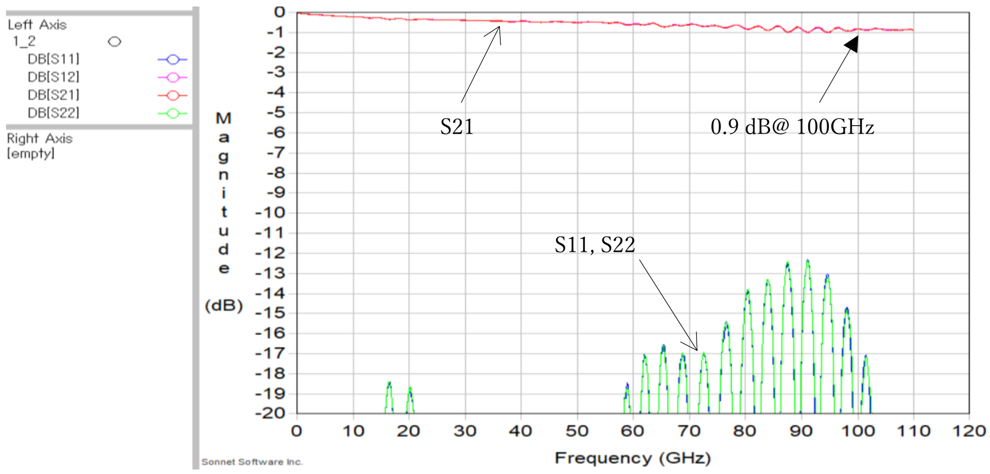



Fig. CP1-5 S-parameter of Fig. CP1-4 structure

3) 0.8mm-connector /0.787 mm ϕ semi-rigid cable assembly

Structure of 0.787mm ϕ semi-rigid cable assembly(CA) with female 0.8mm-connctor at both end is shown in Fig.CP1-6. S-parameter for CA of which semi-rigid cable length is 25.1mm is shown in Fig.CP1-7

Fig.CP1-6 structure is cut half when used for module fabrication.

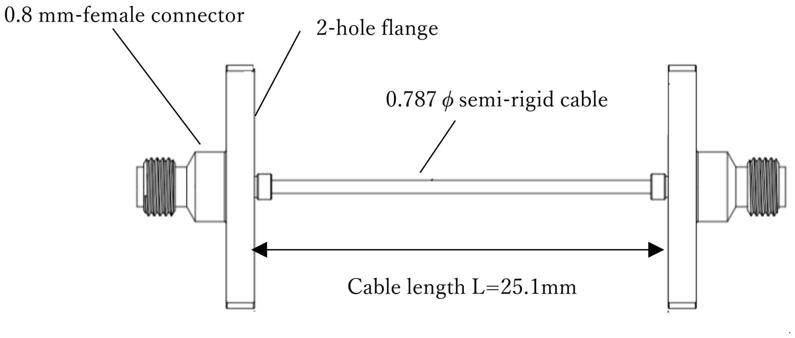



Fig.CP1-6　0.787mm φ semi-rigid CA with 0.8mm-female connectors

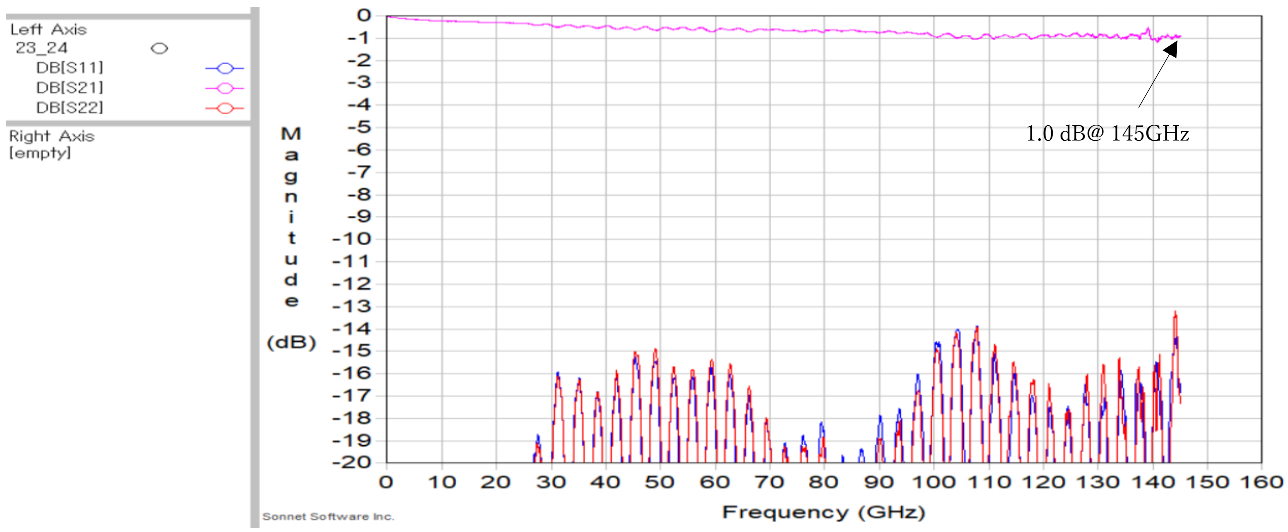



Fig. CP1-7 S-parameter of Fig. CP1-4 structure

4) 8-channel Cable Edge Connector, CEC8

This was developed in collaboration with Shin-Etsu Polymer Co.,Ltd. for applying to 8-channel RF module interface. The structure of CEC8 is shown in Fig. CP1-8.

8 of contactors are inserted into 8 holes of contactor holder and fixed.

Contactor is made by rubber sheet with coaxial structure, that is, outer and central portion is conductive and medium portion is non-conductive.

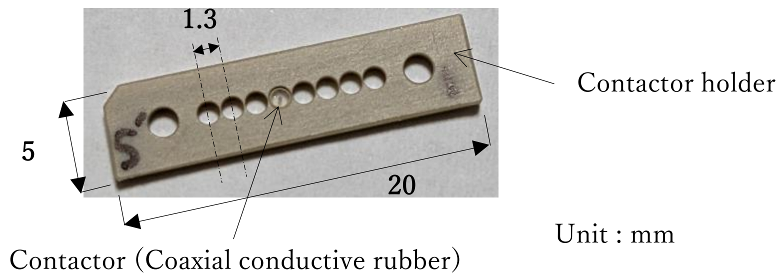



Fig. CP1-8 Structure of CEC8

Figure CP1-9 shows a test fixture to evaluate CEC8 RF performance. In this test fixture, CEC8 is sandwiched by two cable edge receptacles that fix the semi-rigid coaxial cables of which outer diameter is 1.2mm $\phi$ . Cable edges of two coaxial cables push the contactor inside CEC8 from one side and from another side, and electrical signal connection of two coaxial cables is performed.

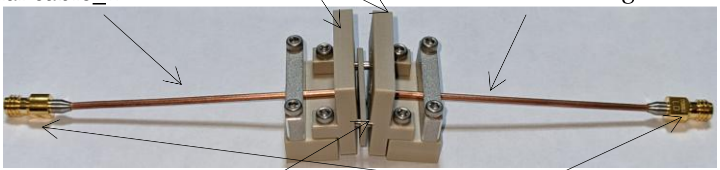



Fig.CP1-9 Test fixture of CEC8

When we apply this connector CEC8 for RF modules, CER8s are mounted at I/O portion of each modules of module_1 and module_2, for example. RF signal connection of module_1 and module_2 is performed by following way.

CEC8 is inserted between CER8 of module_1 and CER8 of module_2. When CER8s of module_1 and CER8 of module_2 are attached mutually by screws, cable end of semi-rigid coaxial cables push the contactor in CEC8 then RF signal connection is performed.

Features of connector CEC8 are below.

a) Small RF signal pitch : 1.3 mm
   Signal pitch is less than half of 2.79 mm signal pitch of 4CH SMPS that may be smallest in multi-channel connectors so far,
b) High RF performance :
   S21: typ. > -0.9 dB @ DC-100GHz
   S11, S22: typ. < -19 dB @DC-50GHz, typ. < -13 dB@ DC-100GHz

   S-parameter measured using Fig.CP1-9 test fixture is shown in Fig. CP1-10. Red line shows insertion loss from port 1 to port 2 and blue line shows sum of insertion loss of semi-rigid coaxial cable_1 and cable_2. Difference of two lines shows insertion loss of CEC8.

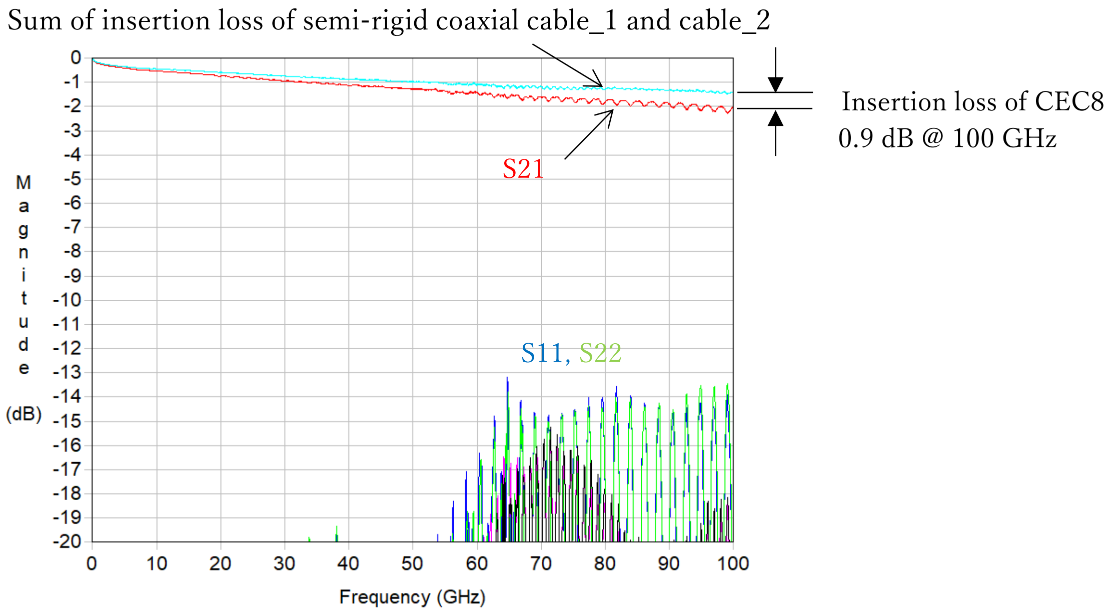



Fig.CP1-10 S-parameter of CEC8

5) 16-channel Cable Edge Connector, CEC16

In order to realize optical transceiver modules with Tera-bit class data speed by increasing channel count , we are now trying to develop 16-channel Cable Edge Connector. For detail, See Subsect.2, Section3 in Chapter 2.

## Section 2 Substrate base material

For making RF modules, we use following substrate materials depending on requirements of operating frequency, module size and RF signal pin count.

Organic substrate base materials:

Rogers RO4350B, Panasonic R-5775 (MEGTRON6), Teflon, FR4, FPC

These are used to make printed multi-layer circuit board, PCB.

Non-organic substrate base materials:

99.5% Alumina, Quartz, Aluminum nitride

These are used to make thin film circuit.

Features of the materials are summarized in Table 1.

Table 1. Feature of substrate base material

| Substrate base material | Relative dielectric constant Er | Loss tangent Tan δ @10GHz | Thermal conductivity (W/m・k) | Bending strength (MPA) | Thermal expansion Coefficient (1/K) | Avairav ility of resistor | Metal peeling resistance | Standard Substarte thickness (mm) | Minim um L/S (mm) | Minimum VIA diameter (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| RO4350B | 3.66 | 0.0037 | 50 | 255 | 50 x 10^-6 | No | Strong | 0.10, 0.17 | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MEGTRON6 | 3.6 | 0.004 | | | 14-16 x 10^-6 | No | Strong | 0.05, 0.10 | 0.08/ 0.08 | 0.25 $\phi$ |
| Tefron (CH2868D) | 2.28 @12GHz | 0.0015@12 GHz | | | | No | Strong | 0.221 | 0.05/ 0.05 | No VIA |
| 99.5 % Alumina | 9.8 | 10^-4 | 32 | 440 | 8 x 10^-6 | Yes | Strong | 0.25, 0.38, 0.635, 1.0 | 0.02/ 0.015 | 0.1 $\phi$ (@0.25t) |
| Aluminum nitride | 8.8 @1MHz | 5 x 10^-4 @1MHz | 170, 200, 230 | 330 | 4.6 x 10^-6 | Yes | Strong | 0.15, 0.2, 0.25, 0.38 | 0.02/ 0.015 | |
| Quartz | 3.8 | 10^-4 | 1.4 | 60 | 0.5 x 10^-6 | Yes | Not so strong | 0.1, 0.15, 0.2, 0.25, 0.38 | 0.02/ 0.015 | 0.1 $\phi$ (@0.25t) |

## Section 3 Transmission line

In RF module, we use planar transmission lines which are made on RF substrate and thin semi-rigid coaxial cables.

### Subsect.1 Planar transmission line

Most of cases, planar transmission lines described below are conveniently used since surface mount devices and bare dies can be easily assembled and wire-bonded. 4 kind of transmission lines are used depending on application.

<u>CPW (Coplanar waveguide):</u>

Signal line and GND pattern are formed on top surface of substrate.

<u>GCPW (Grounded coplanar waveguide):</u>

Ground-plane with wide enough width than signal line width is additionally formed at back side of substrate of CPW. Ground plane at top surface and ground plane at back side are electrically connected by many VIA holes.

<u>MSL (Microstrip Line) :</u>

Signal line is formed on top surface of substrate and ground plane with wide enough width is formed at back side of substrate.

<u>nMSL(narrowed MSL) ：</u>

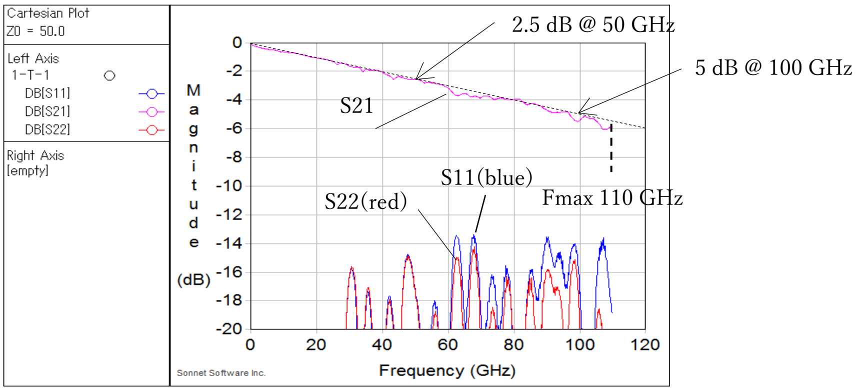
This is kind of MSL but substrate width is narrowed to close to the width of signal line. This is our company original structure invented to enhance frequency characteristics keeping micro strip mode.

RF characteristics of the planar transmission lines above mentioned depend on material and thickness of substrate. In addition, line patterning accuracy is an important design parameter. Easiness to have good match to connectors should also be important in design. We choose optimum solution depending on application from our experience and perform design verification by circuit simulation and 2D or 3D electromagnetic field simulation.

As one of examples, RF characteristics of CPW using Megtron6 is described below for the cases of using 1mm connector and SMPM.

## Characteristics of CPW（using 1mm connector）

Measured S-parameter of 8 mm length CPW transmission line on Megtron6 substrate with 1mm-end launch connector at both end of substrate is shown in Fig. CP1-11. S21 value is changing almost linearly as increasing frequency up to Fmax at which S21 value start to depart from approximate line drawn by dashed line. In this case, Fmax is about 110GHz that is close to guaranteed maximum frequency of 1mm-connector. Sum of insertion loss of 8 mm length CPW line and two 1mm-connectors is 5 dB@ 100GHz. Since insertion loss of two 1mm-connector is 0.9 dB@100GHz, insertion loss of 8mm CPW line is 4.1 dB@100 GHz. Insertion loss per 1mm @ 100 GHz, which we use as " Figure of merit of transmission line, L100G ", is calculated to 0.51 (=4.1/8) dB/mm @100GHz.




**connector loss of two 1mm connector：0.9 dB @ 100 GHz**
**CPW line loss is calculated to 0.51 dB/mm @100GHz**

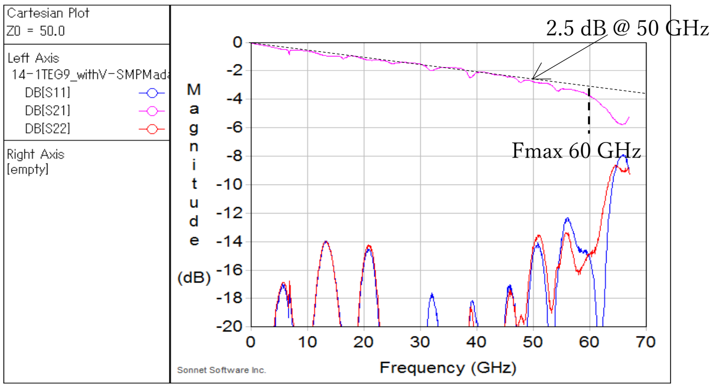
Fig.CP1-11 S-parameter of CPW(MEGTRON6, 1.0mm-connector) 8mm length THRU line

## Characteristics of CPW（using SMPM）

In case that we want to make small size RF module, push-on type small size connectors such as SMPM are used instead of screw type of connectors.

Measured S-parameter of 8 mm length CPW transmission line on Megtron6 substrate with SMPM at the end of substrate is shown in Fig. CP1-12. S21 is changing almost linearly up to the frequency Fmax at which S21 value start to depart from approximate line drawn by dashed line. In this case, Fmax is about 60GHz that is close to guaranteed maximum frequency of SMPM.

Sum of Insertion loss of 8 mm length CPW line and two SMPM is 2.5 dB@50GHz. Since insertion loss of two SMPM is 0.54dB@50GHz, insertion of 8mm CPW line is 1.96 (=2.5-0.54)dB@50 GHz implying 0.245 (=1.96/8) dB/mm @50GHz. This is extrapolated to 0.49 dB/mm @100 GHz.




connector loss of two SMPM：0.54 dB @ 50GHz
CPW line loss is calculated to 0.245 dB/mm @50GHz

Fig.CP1-12 S-parameter of CPW(MEGTRON6, SMPM) 8mm length THRU line

Not limited to CPW, insertion loss (IL) of another types of planar transmission lines formed on RF substrate gradually increases almost linearly as increasing frequency. When coming to one frequency, IL value starts to increase drastically implying that IL value departs from the linear line. We call this frequency " Fmax" . Fmax as well as unit length insertion loss extrapolated to 100 GHz (L100G) is also " Figure of merit" to show performance of planar transmission lines. Fmax is 110 GHz in Fig. CP1-11 and 60 GHz in Fig. CP1-12, for example. Sometimes, IL increases at Fmax then changes to decrease at over Fmax. We call this characteristics "Dip". In order to get broad-band characteristics of RF modules, it is necessary to let the RF module operate in the frequency region at less than Fmax.

Table 2 shows Fmax and L100G for various type transmission lines of various substrate materials with various connectors that were experimentally obtained by Takada RF Labs, Inc. , so far.

Table 2 Fmax and L100G

| 基板材料 | 項目 | 線路形態 | | | |
|---|---|---|---|---|---|
| | | CPW | GCPW | MSL | nMSL |
| RO4350B (Er:3.66), Connecter：SMPM | Fmax | | | 40 (GHz) | |
| | L100G | | | 0.43 (dB/mm) | |
| MEGTRON6 (Er:3.6), Connecter：1.0mm(W) end launch | Fmax | 110 (GHz) | | | |
| | L100G | 0.51 (dB/mm) | | | |
| MEGTRON6 (Er:3.6), Connecter：SMPM | Fmax | 60 (GHz) | | | |
| | L100G | 0.49 (dB/mm) | | | |
| Tefron (CH2868D) (Er:2.28), Connecter：G3PO | Fmax | >50 (GHz) | | | |
| | L100G | 1.0 (dB/mm) | | | |
| 99.5 % Alumina, 0.25t (Er:9.8), Thin semi-rigid coaxial cable (SX-09I ) with 1.85 mm(V) connecter is directly soldered to substrate. | Fmax | | 67 (GHz) | | |
| | L100G | | 0.31 (dB/mm) | | |
| 99.5 % Alumina, 0.25t (Er:9,8), Wide width line (W/S=0.17/0.165 mm) Connecter: 1.85mm(V) glass bead | Fmax | | 67 (GHz) | | |
| | L100G | | 0.12 (dB/mm) | | |

| | | | | | |
|---|---|---|---|---|---|
| 99.5 % Alumina, 0.25t (Er:9,8),<br>Medium width line (W/S=0.1/0.08 mm)<br>Connecter: 1.85mm(V) glass bead | Fmax | | 67 (GHz) | | |
| | L100G | | 0.15 (dB/mm) | | |
| 9.5 % Alumina, 0.25t (Er:9,8),<br>Connecter: 1.85mm(V) glass bead<br>Narrow width line ( W/S=0.055/0.0275 mm) | Fmax | | 67 (GHz) | | |
| | L100G | | 0.24 (dB/mm) | | |
| 9.5 % Alumina, 0.25t (Er:9,8),<br>Connecter：hermetically sealed type G3PO | Fmax | | | | 65 (GHz) |
| | L100G | | | | 0.32 (dB/mm) |
| Quartz 0.5t (Er:3.8)<br>Thin semi-rigid coaxial cable (SX-09 ) with 1.0 mm(W) connecter is directly soldered to substrate. | Fmax | >110 (GHz) | | | |
| | L100G | 0.33 (dB/mm) | | | |
| Quartz 0.25t, Line W/S=0.08/0.025 mm<br>Connecter：1.0mm(W) end launch | Fmax | | >110 (GHz) | | |
| | L100G | | 0.35 (dB/mm) | | |
| Quartz 0.25t , Line W/S=0.2 /0.045 mm,<br>both end 0.8mm-connector / 0.787mm $\phi$ 8.3 mm length semi-rigid cable See Fig. CP1-13 ( Loss of two connector + two 8.3mm cable =1.0 dB@100GHz, See Fig. CP1-14 ) | Fmax | | 145 GHz | | |
| | L100G | | 0.25 (=(1.5-1.0)<br>/2.0)<br>(dB/mm) | | |

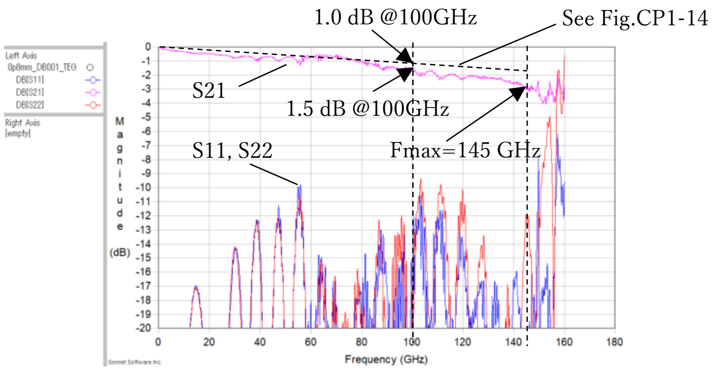



Fig.CP1-13 S-parameter of 0.8mm-connector/ 8.3mm length 0.787 $\phi$ semi-rigid cable +2.0mm length GCPW +8.3 mm length 0.787 $\phi$ semi-rigid cable/0.8mm-connector

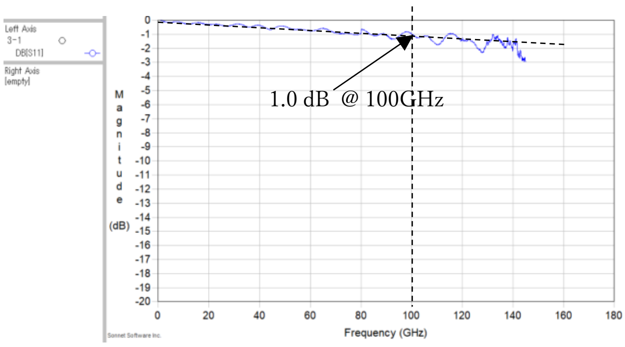



Fig.CP1-14 S11 of 0.8mm-connector/ 8.3mm length 0.787 $\phi$ semi-rigid cable (open end)

We can say followings from the Table 2.

1) 110 GHz of Fmax can be attained by CPW formed on Megtron-6 substrate. L100G of the CPW is 0.51 dB/mm @100G that is larger than GCPW of Almina or Quartz.
2) There is no possibility that Fmax becomes higher than maximum recommended frequency of connectors that are connected to transmission lines.
3) GCPW by 0.25 mm thickness Alumina substrate is used for the frequency region of DC to 67 GHz. Insertion loss depends on signal line width, that is, wider line width has smaller insertion loss. L100G for wide width line (W/S=0.17/0.165 mm) that are used for main signal line is 0.12(dB/mm)@100GHz.
4) GCPW by 0.25 mm thickness Quartz substrate can be used for the frequency region of DC to 145 GHz. L100G of line (W/S=0.2/0.045 mm) is 0.25 dB /mm @100GHz.

**Subsect.2　Thin semi-rigid coaxial cable**

As mentioned above, planar transmission lines formed on the substrate are normally used in RF modules. However, we often use thin semi-rigid coaxial cable line in addition to planar transmission lines. The main purpose of using thin semi-rigid coaxial cable lines is to decrease total insertion loss of RF module. Since unit length insertion loss of thin semi-rigid coaxial cable is much smaller than that of planar transmission lines as explained later, implementation of thin semi-rigid coaxial cables drastically enhances the performance of RF modules.

We usually use thin semi-rigid coaxial cable (privately called as LDC08) having outer diameter of about 0.787 mm $\phi$. Figure CP1-15 shows frequency dependency of unit length transmission loss (L) of LDC08. L at 100 GHz (L100G) is 0.0162 dB/mm which is about 1/15 small that of planar transmission line (Quartz 0.25t GCPW) of 0.25 dB/mm.

By the way, maximum operating frequency of coaxial cable is determined by higher order moding frequency Fc. Fc of LDC08 is 180 GHz.

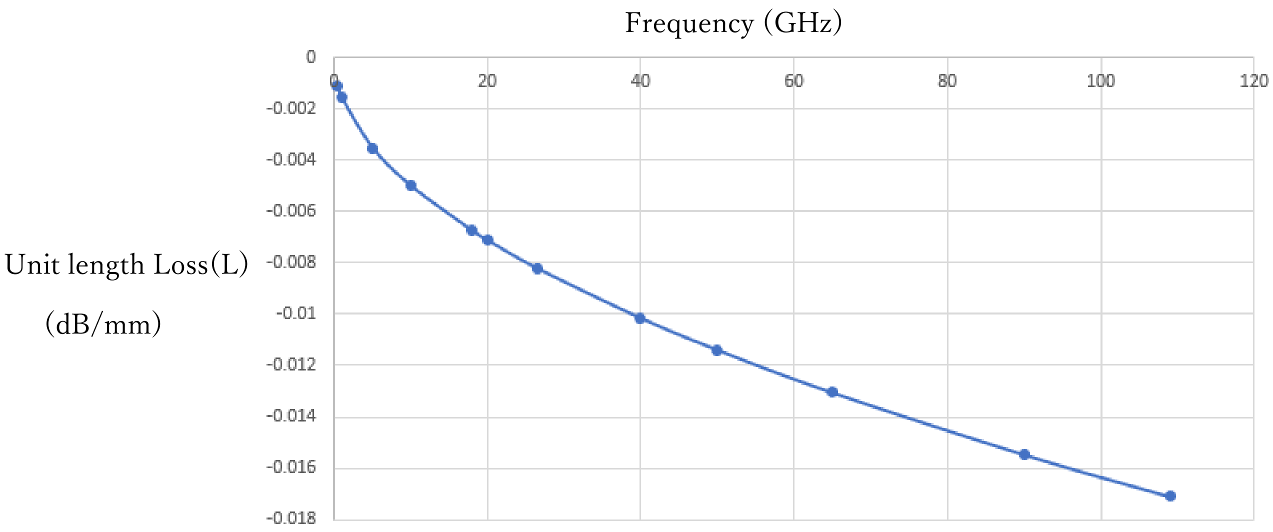



Fig.CP1-15 Unit length transmission loss of thin semi-rigid coaxial cable line LDC08

While thin semi-rigid coaxial cable transmission line LDC08 has advantage that transmission loss is low, it is impossible to connect coaxial cable end to IC chip signal pad. This is because coaxial cable diameter of 0.787 mm $\phi$ is too larger than GSG signal pad pitch of IC of about 0.15 mm. So, when we draw out IC signals to RF connectors as module I/Os, we use hybrid type assembly configuration in which we put planar transmission lines on RF substrate near IC chip and the planar transmission lines are spread out to wider signal pitch on the RF substrate, then thin semi-rigid cables are connected to pads with wider signal pitch as shown in Fig.CP1-16. This is the case that eight GSG configuration signals are drew out to eight 1.85 mm connectors. If we use RF substrate planar transmission lines for entire portions from near IC chip to RF connector, transmission loss becomes significantly larger than the case of Fig. CP1-16 because line length is long due to RF connector size bigness.

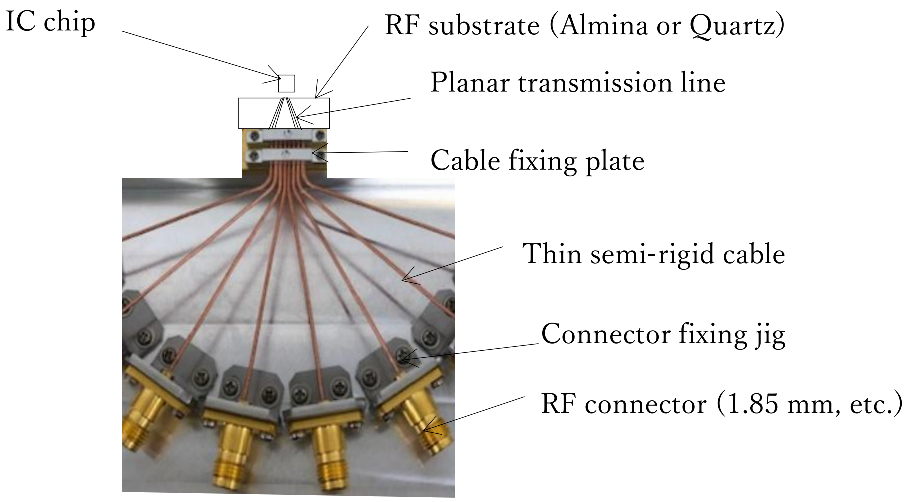



Fig.CP1-16 Hybrid type assembly configuration using planar transmission line on RF substrate and thin semi-rigid coaxial cable line

We normally use the hyibrid type assembly configuration for making evaluation module to evaluate RF performance of RF devices or test fixture for final product inspection

## Section 4 Assembly

We are using following assembly technologies.

1) Pb free soldering with Reflow or using soldering iron
   --- for packaged IC, multilayer-ceramic chip capacitor, chip resistor, pin header, RF connector and thin semi-rigid coaxial cable, etc.
2) Die bonding by AuSn or conductive epoxy
   --- for IC chip, single layer capacitor, chip resistor
3) Au wire bonding by Au wire (25 um $\phi$ , 20 um $\phi$ or 13um $\phi$ , ultra-sonic wedge bond)
   --- for pad with minimum 30 x 30 $\mu$ m size
4) Ribbon bonding by Au
5) Flip chip bonding
   After Au-bumps are formed on the IC pads, conductive epoxy is put on the top of bumps , then IC chip with bumps is flipped onto substrate and cured, and then non-conductive epoxy is underfilled around the bumps on the substrate.

## Section 5 Design

In design, we normally perform simulations described below.

1) Circuit simulation
   DC analysis, AC analysis, transient analysis, S-parameter calculation, harmonic balance analysis, etc. using circuit models of lumped parameter circuit model, semi-lumped parameter circuit model or distributed parameter model

2) 3-dimensional electromagnetic field simulation
Multi-port calculation of single-end or differential S-parameter, electromagnetic radiation distribution

3) Circuit parameter conversion by software
Single-end-to differential conversion, TDR conversion from S-parameter, eye pattern conversion from S-parameter, S-parameter de-embedding /embedding

4) 3-dimentional temperature simulation
This is performed to estimate chip temperature inside the module or for designing module structure with adequate heat resistance when making TEC controlled modules.

### Section 6 Measurement

We use following measurement tools for performance evaluation and intermediate / final inspection of fabricated product.

2-port vector network analyzer VNA (1mm coaxial connector interface, up to 120 GHz)

4-port VNA (1.85mm coaxial connector interface, up to 67 GHz)

Pulse pattern generator, Error detector, oscilloscope, etc.

## Chapter 2 RF module fabrication

### Section 1 Procedure of RF module fabrication

We do design and fabricate various types of custom RF modules used in optical transmission systems, wireless communication systems or high frequency measurement tools. We perform high-level macro design of module according to customer requirements at first, then makes initial proposed specification and provide it to the customer. And then, by repeating question, answer, and discussion with customer, we refine the initial proposed specification. Finally, we make ”target specification sheet “ before starting fabrication, which includes module block diagram, module structure, recommended operating conditions, maximum absolute ratings, RF performance, sample implementation, etc. Then start fabrication. When developing modules having both electrical and optical function as shown below,
our company takes responsibility of design and fabrication of electrical portion and customer takes responsibility of design and fabrication of optical portion.

## Section 2 RF module configuration

Block diagram of n-channel RF module with electrical/optical interface and n-channel RF module with electrical/electrical interface is shown in Fig.CP2-1(a) and Fig.CP2-1(b), respectively.

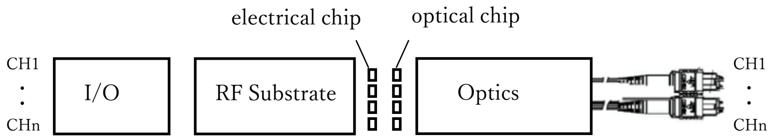



Fig. CP2-1 (a) Block diagram of n-channel electrical/ optical (E/O) interface RF module

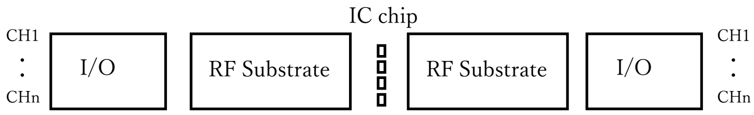



Fig. CP2-1 (b) Block diagram of n-channel electrical/electrical (E/E) interface RF module

We use Fig. CP2-1(a) configuration having E/O interface for making all types of E/O interface modules of optical transmitter, optical receiver, and optical transceiver. In case of transmitter, electrical chip becomes laser driver, modulator driver and optical chip becomeVCSEL, DML or EML laser, etc.

In case of receiver, electrical chip becomes TIA and optical chip becomes receiver chip such as PINPD or APD. In case of optical transceiver, devices for both transmitter and receiver are implemented in one module.

We use Fig.CP2-1(b) configuration having E/ E interface for making driver module, for example, which is externally connected to non-driver integrated optical transmitter. We also use Fig.CP2-1(b) configuration for making TIA module, for example, which is externally connected to non-TIA integrated optical receiver.

## Section 3 RF performance of module

"Maximum operating data speed, MDS (b/s) " is convenient to show total performance of RF module capability. MDS is defined as

MDS (bit/s)= ( MS (baud) x SB (bit/symbol) ) / ch x N(ch)

Where MS is modulation speed (baud, symbol/s) and SB is symbol bit number (bit/symbol). In case of PAM4 modulation, for example, that is widely used for data center transceiver application, SB is 2. N is channel count (ch).

To have large MDS, we have been making effort of two directions. One direction is baud rate increase. The other direction is channel count increase.

### Subsect.1 Baud rate increase activity

<u>Connector development :</u>

To make module with data speed as high as possible, we have to make connector that has high band width of RF characteristics. We have newly developed 1mm end-launch connector that can be mounted on RF substrate end. Band width of the connector is over 110 GHz which enables to work at 220 Gbaud. See Fig. CP1-2 and Fig. CP1-3 in Section1 in Chapter 1, for detail.

In addition to the 1.0 mm end launch connector, we have developed 1mm-connector /0.787mm $\phi$ semi-rigid cable assembly. See Fig.CP1-4 and Fig. CP1-5 for detail. We have also developed 0.8mm-connector /0.787mm $\phi$ semi-rigid cable assembly. See Fig. CP1-6 and Fig. CP1-7. This works at up to 145 GHz which can be used to make 290 Gbaud module.

Push on-type connector G3PO(SMPS) is suitable for multi-IO high baud rate modules. It can be operated at over 80 Gbaud.

RF substrate high frequency design:

We have established GCPW design of thin film transmission line using substrate of alumina and quartz. Maximum confirmed operating frequency of alumina thin film circuit is over 67 GHz and that of quartz thin film circuit is 145 GHz. See Table 2 and Fig. CP1-13 for detail.

Assembly process

We have established assembly process of "Flip chip bonding " on quartz substrate to decrease wiring inductance between IC pad and thin-film transmission line. This enhances operation frequency drastically. See 5) at section 4 in Chapter 1.

Module development examples

1) 130 GHz-bandwidth broad band amplifier module

NTT Device Tech Labs, has developed an amplifier module with Over 130 GHz Bandwidth (Note 1) using their InP-DHBT technology and Takada RF's module technology.

Thru line evaluation module for this amplifier development is shown in Fig. CP2-2(a) which consists of 1mm-end launch connectors and Quartz GCPW transmission thru line.

S-parameter of the thru line module is shown in Fig. CP2-2(b).

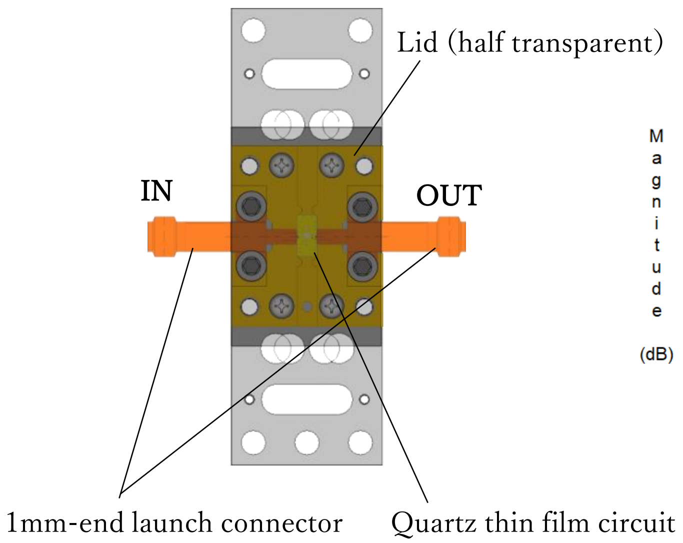



Fig.CP2-2(a) Top view of thru line evaluation

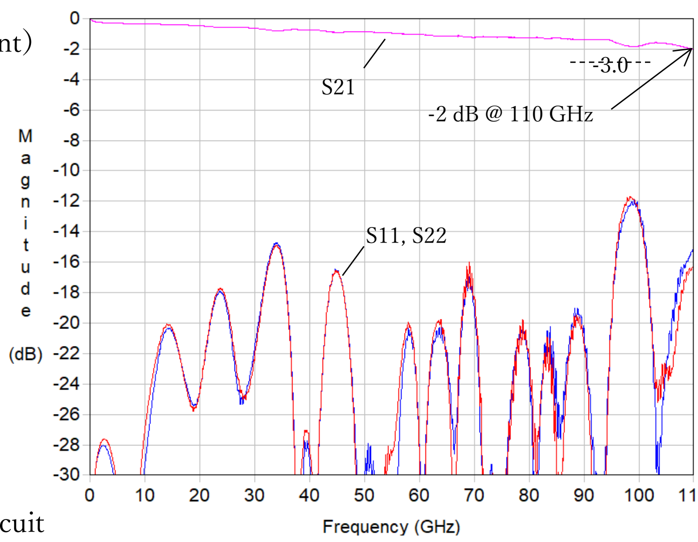



Fig.CP2-2(b) S-parameter of thru line evaluation module

*Note 1:*
*"An Over 130 GHz-Bandwidth InP-DHBT Base band Amplifier Module", NTT DTL, BCICTS, 2021*

2) 165 GHz-bandwidth broad band amplifier module

NTT Device Tech Labs, NTT corp. has developed an amplifier module with Over 165 GHz-Bandwidth (Note 2) using their InP-DHBT technology and Takada RF's module technology for applying it to a driver module for future over-300 Gbaud optical transmitter.

Fig.CP2-3(a) shows top view of the module of which S-parameter is shown in Fig.CP2-3(b).

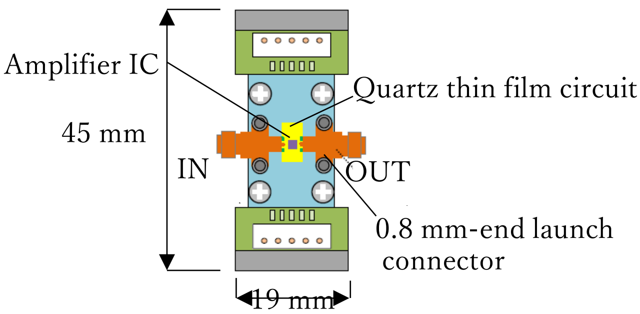



Fig.CP2-3(a) Top view of amplifier module

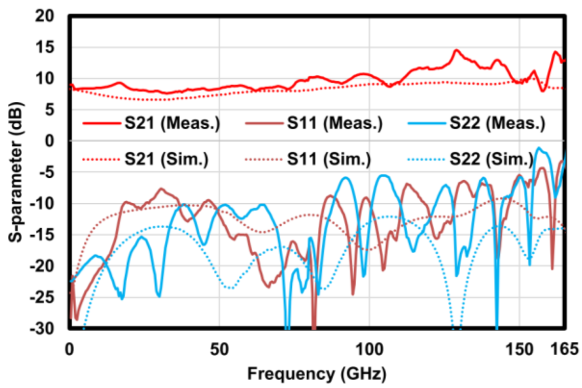



Fig.CP2-3(b) S-parameter of amplifier module

*Note 2 : "Over 200-GHz-Bandwidth InP DHBT Baseband Amplifier ICs and Ultrabroadband Modules with 1-/0.8-mm Coaxial Connectors" T. Jyo , M. Nagatani, H. Wakita , M. Mutoh, Y. Shiratori and H. Takahashi, NTT Device Tech. Labs., NTT corp., IEEE MTT, VOL. 72, NO. 9, Sept. 2024*

3) 140 GHz-bandwidth DC block module

We have developed a DC block module which is necessary to be used when two amplifiers are cascaded to have higher gain, for example.

Fig.CP2-4(a) shows top view of the module of which S-parameter is shown in Fig.CP2-4(b).

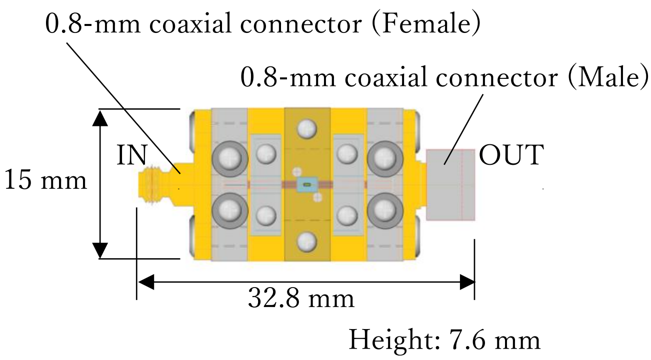



Fig.CP2-4(a) Top view of DC block module

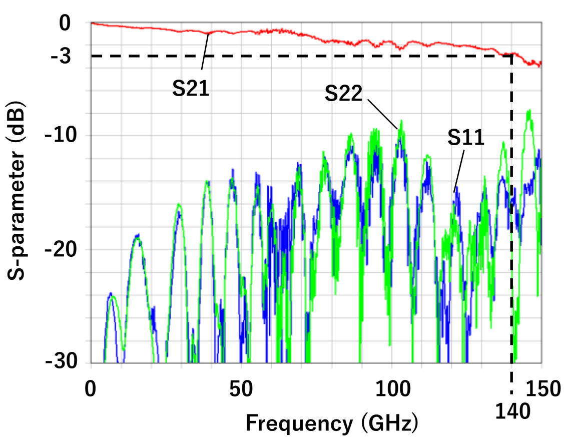



Fig.CP2-4(b) S-parameter of DC block module

4) DC-to 150 GHz Active combiner module

NTT Device Tech Labs, NTT corp. has developed a DC-to 150 GHz Active combiner Module (Note 3) using their InP-DHBT technology and Takada RF's module technology. NTT applied analog band width interleaving (ABI) technology (shown in Fig.CP2-5 using a combiner module and a mixer module later described) to extend band width of DSP DAC from 70 to 140 GHz.

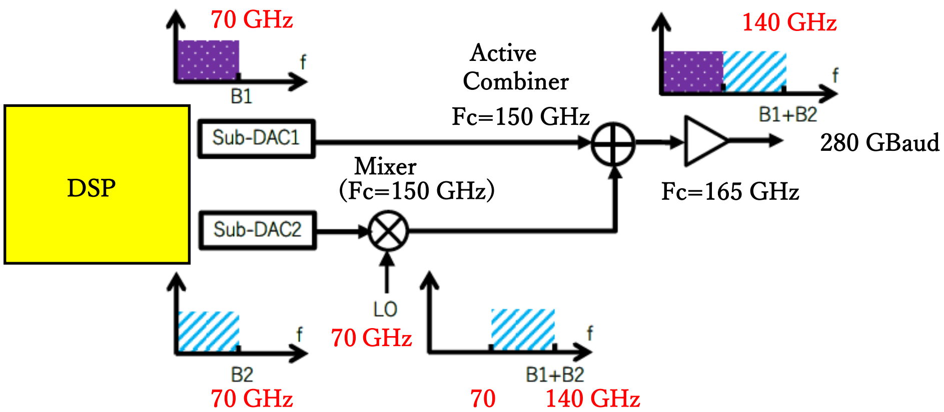



Fig.CP2-5 Analog band width interleaving (ABI) circuit for 280Gbaud signal generation

Fig.CP2-6(a) shows structure of DC-to 150 GHz Active combiner module of which S-parameter is shown in Fig.CP2-6(b).

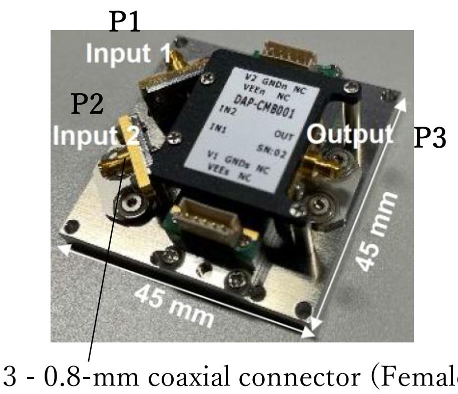



Fig.CP2-6(a) DC-150 GHz active combiner module

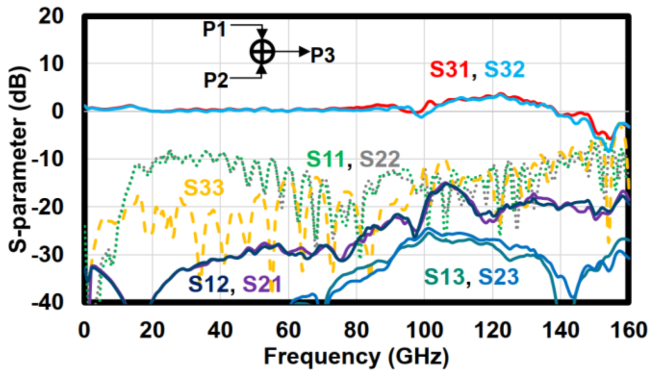



Fig.CP2-6(b) S parameter of active combiner module

*Note 3: "A DC-to-150-GHz InP-DHBT Active Combiner Module for Ultra-Broadband Signal Generation" T. Jyo, M. Nagatani, M. Mutoh, Y. Shiratori, H. Wakita, H. Takahashi, NTT Device Tech. Labs., NTT corp., 2023 IEEE BiCMOS and Compound Semiconductor Integrated Circuit Technology Symposium (BCICTS)*

5) DC-to 150 GHz Mixer module

NTT Device Tech Labs, NTT corp. has developed a DC-to 150 GHz Mixer module (Note 4) using their InP-DHBT technology and Takada RF's module technology.

Fig.CP2-7(a) shows top view of the module of which S-parameter is shown in Fig.CP2-7(b).
NTT applied analog band width interleaving (ABI) technology (shown in Fig.CP2-5 using this a mixer module and the combiner module above described) to extend band width of DSP DAC from 70 to 140 GHz.

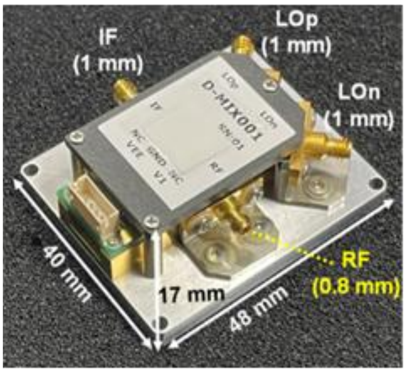



Fig.CP2-7(a)　DC-150 GHz mixer module

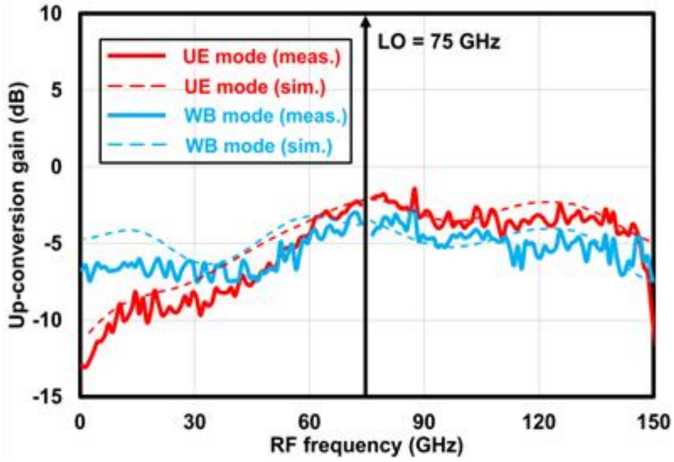



Fig.CP2-7(b)　S parameter of mixer module

*Note 4: "DC-to-150 GHz Bandwidth InP HBT Mixer Module With Upper-Sideband Gain-Enhancing Function" T. Jyo, M. Nagatani, H. Wakita, M. Mutoh, Y. Shiratori, H. Takahashi, NTT Device Tech. Labs., NTT corp., IEEE Transactions on Microwave Theory and Techniques (Early Access), 05 Dec. 2024*

6)　80 Ghz band width butterfly package type E/O module
Figure CP2-8 (a) shows structure of butterfly package type E/O module . Hermetic type G3PO connector is embedded in 14-pin metal package wall and Quartz RF substrate is mounted in the package. Cover is put over transmission line of the substrate to prevent box resonance of package.

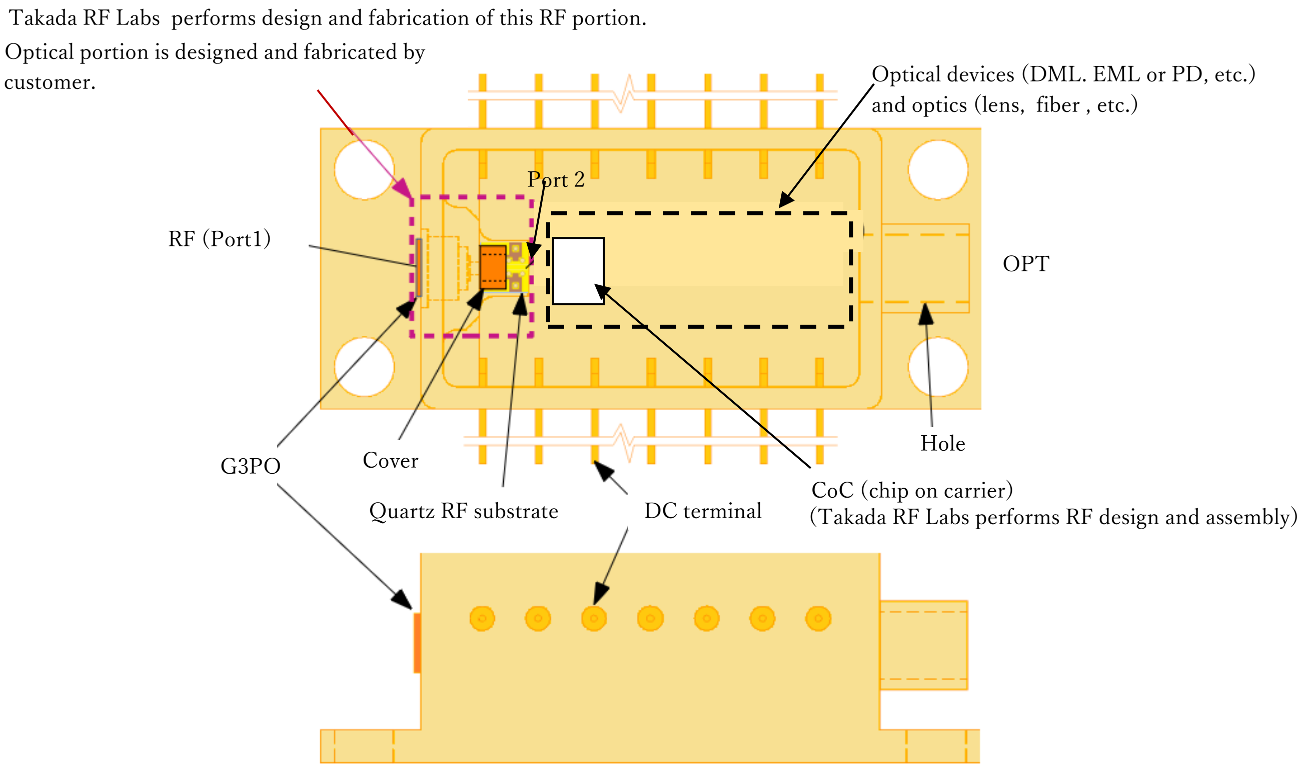



Fig. CP2-8 (a) Structure of 14-pin bufterfly package type E/O module

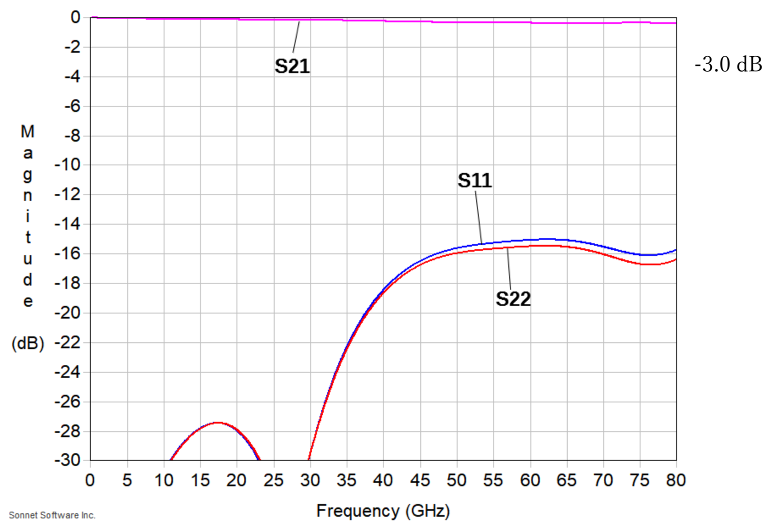



Fig. CP2-8 (b)) Estimated S-parameter of red broken line portion

Figure CP 2-8(b) shows an estimated S-parameter of the portion indicated with red broken line in Fig. CP2-8(a). This is obtained from S11 measurement data (using Quartz substrate). -3dB band width is much higher than 80 GHz. So, this technology can be applied for making over 100 Gbaud module

### Subsect.2 Channel count increase activity

When we make multi-channel RF module to make high data speed more, screw type connectors such as 1.85mm, 1.0 mm and 0.8 mm connectors are not adequate to be used because connector size is very big. They are originally made for the purpose of measurement interface and used for single channel evaluation module. For multi-channel module application, there are push-on type small size connectors such as SMP, SMPM and G3PO. 4 ch SMPS (compatible to G3PO) edge mount receptacle called 3811-60051 seems to be most advanced connector among push-on type connectors. It's signal pitch is 2.79 mm and maximum operating frequency of 65 GHz. However, if we consider to make 8 ch or 16 ch module that are recent requirement, 2.79 mm signal pitch is still very big to make reasonable size of module. Moreover, there is another big problem. Since IC pad signal pitch is small (normally around 0.15mm), signal line traces on RF substrate should be spread out to large connector signal pitch. This makes signal line length long because of requirement of equalizing multi-channel signal line length. Long length signal line has large insertion loss that reduces -3dB bandwidth of the module. In this point of view as well, connectors with large signal pitch reduce RF module performance significantly even if maximum operating frequency of connector itself is high.

We propose to use Cable Edge Connector(CEC series ) to cope with above mentioned big problems, which is developed specially for multi-channel module RF signal interface.

8 ch CEC(CEC8) with 1.3 mm signal pitch (meaning less than half of 2.79 mm SMPS pitch) has been developed and performance has been confirmed (See Chapter1, Section1, page 5). Maximum operating frequency is much higher than 100 GHz implying over 150 Gbaud.

Farther more, we are now under development of 16 ch CEC(CEC16) of which signal pitch is as small as 0.9 mm.

We privately call the module using connector CEC series as "Cable Edge Connector Module, N Channel, CECMn" Structure example of 16 CH electrical/ electrical interface is shown in Fig.CP2-9. Module width is 40 mm which is same as width of pluggable module CPF8.

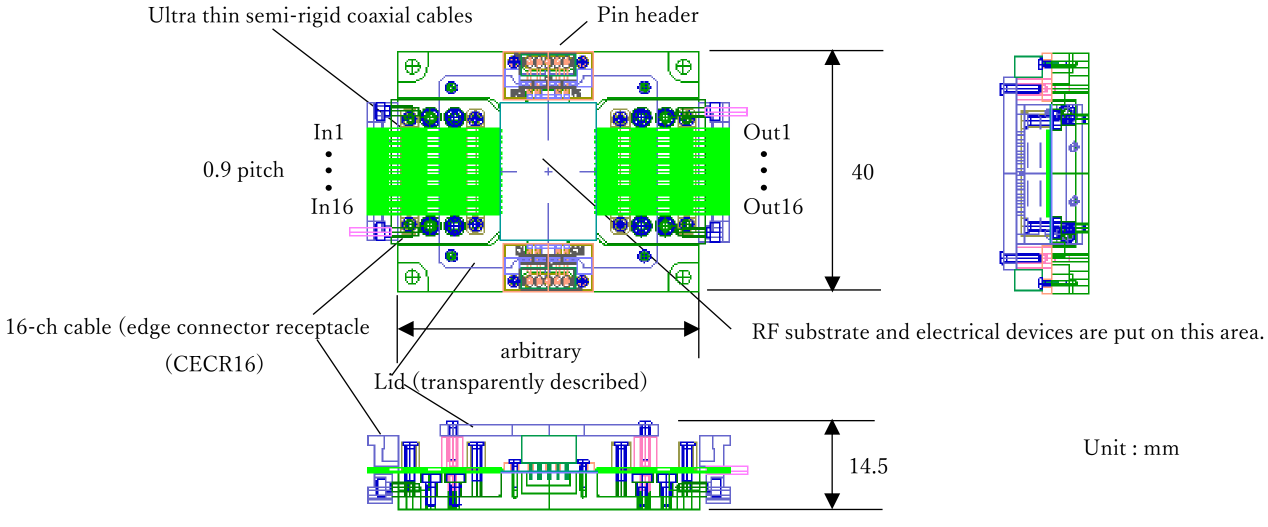



Fig. CP2-9 Structure example of 16-ch electrical/electrical interface CECM16

If we make an optical transceiver using this technology with current available chips assuming 50 Gbaud rate , data speed becomes 800 Gb/s (8 ch x 2 bit x 50 Gbaud).

If we make an optical transceiver using this technology with near future available chips assuming 100 Gbaud rate, data speed becomes 1.6 T b/s (8 ch x 2 bit x 100 Gbaud).

Construction image of transmission system using eight CEC16s which use currently available chips is shown in Fig. CP2-10. Data speed of this transmission system is 3.2 Tb/s . If we use near future available 100 Gbaud chips, it becomes as high as 6.4 Tb/s.

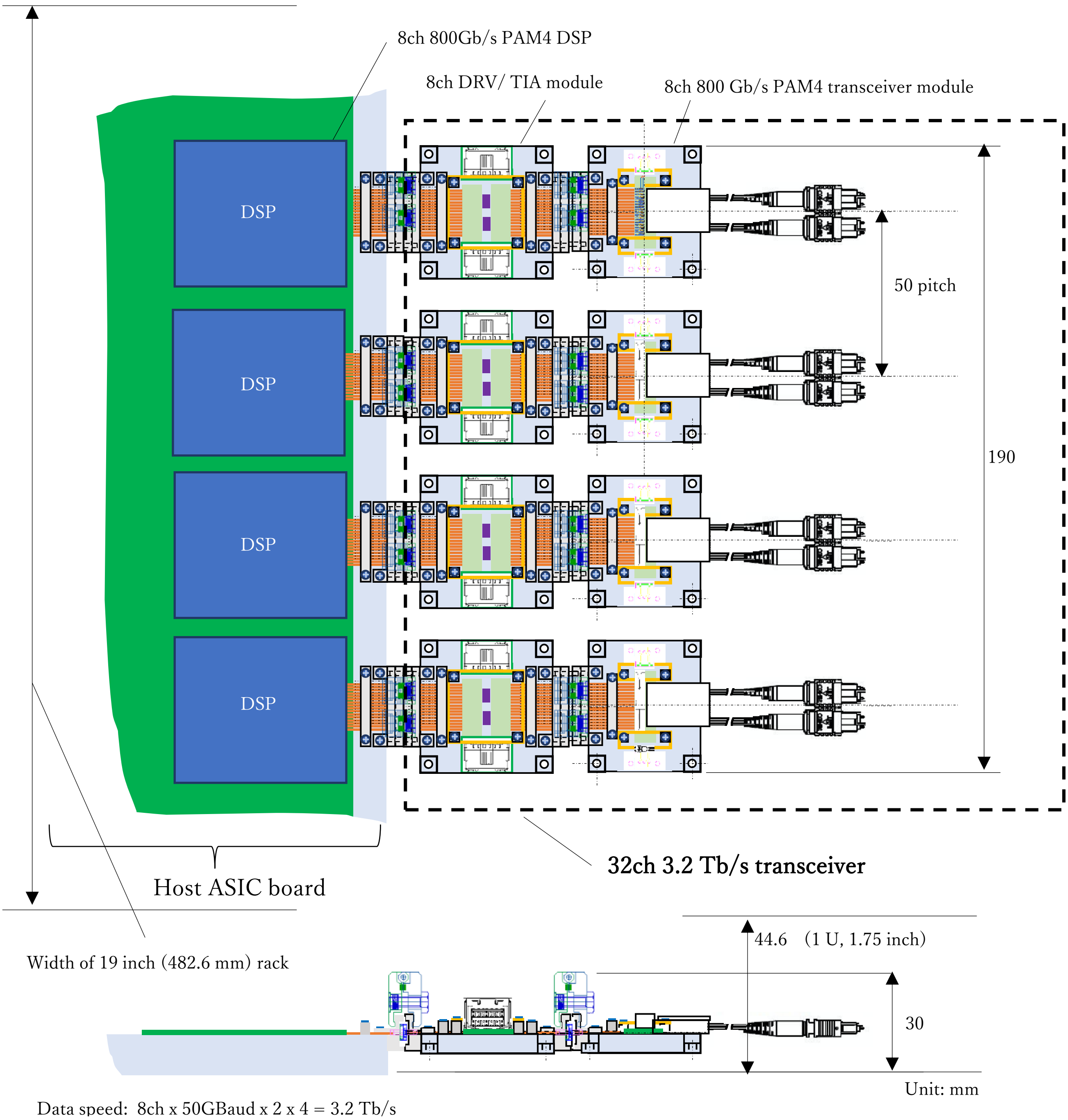


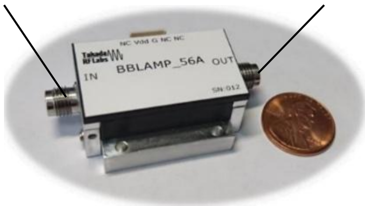

Fig.CP2-10 Construction image of 3.2Tbit/s (32ch 50Gbaud PAM4) transmission system using currently available chips

## Section 4 Other Examples of RF module

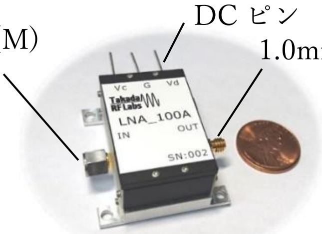
Our company makes custom modules basically. So, we do not sell general purpose standard product.

Followings are RF module examples that were actually fabricated. By seeing data sheet of various kind of RF modules , customers can estimate our company's capability of custom module fabrication.

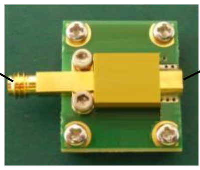
FigureCP 2-11 shows photographs of representative RF modules.



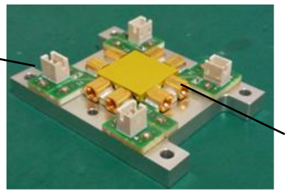

a) 1.85mm(V) connector interface module



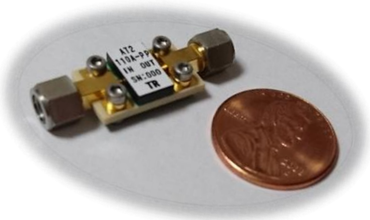

b) 1.0mm(W) connector interface module



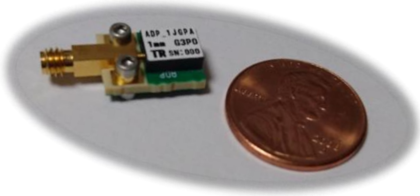

c) 1.0mm(W) /SMPM connector interface module



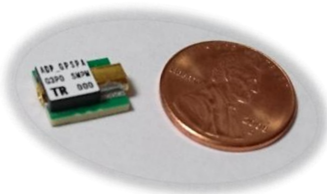

d) SMPM interface module



e)1.0mm(W)(M)-1.0mm(W)(M) Adapter



f) 1.0mm(W)(F)-G3PO Adapter



g) G3PO–SMPM Adapter


h) SMPM amplifier


i) SMPM Coupler

j) SMPM fixed Attenuator

k) SMPM terminator

Fig.CP2-11 Photograph of representative RF modules

Table 3 and Table 4 summarize main performance, connector used and application for active modules and passive modules respectively that were made and confirmed performance so far.

The detail specification of the products listed in Table 3 and Table 4 is described in the document "Data sheets of Takada RF lab's RF products".

Table 3 Active module specification outline

| Category | Product name, Product No. | Main performance and connector used | Application | Data sheet name |
|---|---|---|---|---|
| Broad- band linear amplifier for fiber optic | 56Gbaud broad- band Linear amplifier BBALMP_56A | FRQ: DC- 48 GHz, Gain: 12.7 dB<br>P-3dBout：16 dBm, PS: +6 V,<br>Connector (CNT): 1.85 mm | 56 Gbaud TIA, DML /EML driver for PAM4/NRZ signal Base band amp for wireless | BBLAMP_56A_DS_Rev 5.1 |
| 8-40 GHz general purpose amplifier | 8-20 GHz Amplifier FA20C | FRQ: 8-20GHz, Gain: 20 dB,<br>P-1dBout:19 dBm, PS: +5 V, CNT : SMPM | Gain block for variable subsystems, Clock signal amplifier | FA20C_DS Rev.1.0 |
| | 12-28 GHz Amplifier FA30A | FRQ: 12-28GHz, Gain:13 dB,<br>P-1dBout: 15 dBm, PS：+5 V, CNT: SMPM | | FA30A_DS Rev.1.0 |
| | 20-40 GHz Amplifier FA40A | FRQ：20-40 GHz Gain: 15 dB, P-1dBout: 21 dBm, PS：+5 V, CNT: SMPM | | FA40A_DS Rev.1.0 |
| | 6-18 GHz Variable Gain Amplifier VA15A | FRQ：6-18 GHz, Gain: -12 ～+16dB,<br>P-1dB in: 4 dBm, PS：+5 V, CNT: SMPM | | VA15A_DS Rev.1.0 |
| | 8-32 GHz Variable Gain Amplifier VA30A | FRQ：18-32 GHz, Gain: -18 ～+13dB,<br>P-1dB in: 3 dBm, PS：+5 V, CNT: SMPM | | VA30A_DS Rev.1.0 |
| 100GHz amplifier | 65-110GHz Amplifier Module LNA_100A | FRQ：65-110GHz, Gain：13dB, P-3dBout: -6～+1 dBm, PS：+1.0 V, CNT: 1mm | Wireless E-band/W-band amplifier, Rader, imaging | LNA_100A_API_Rev1.1 |
| VCO | 10-20 GHz VCO SG20A | FRQ：10-20 GHz, Pout : 0 dBm PS：+5V<br>Cont. Voltage：0 ~ +20V , CNT: SMPM | Signal generator for variable subsystems | SG20A_DS Rev.1.0 |
| | 20-28GHz VCO SG30A | FRQ：20-28 GHz, Pout : 13 dBm, PS：+5V<br>Cont. Voltage：0 ~ +7V, CNT: SMPM | | SG30A_DS Rev.1.0 |
| Frequency multiplier | 19-28 GHz out x2 Freq. Multiplier ML25B | FRQ：19-28 GHz out Pin: +5 dBm Pout: +11 dBm (variable) PS: +5, -3.3 V, CNT: SMPM | Signal generation by frequency multiplier for variable subsystems | ML25B_DS Rev.1.0 |
| | 65-87 GHz Output Freq. Tripler X3A_80A | FRQ : 65-87 GHz out Pin: +9 dBm Pout: +10 dBm, PS +1.0 V, CNT: Input SMPM Output 1mm | | X3A_80A_API_Rev.1.0 |
| Variable Time delay | 14GHz/12.5 Gb/s Time Delay with variable amplification, PS14B | FRQ：DC-14 GHz, 5bit switch control,<br>Gain：10 dB, 0.6Vpp out, PS: -3.3 V, CNT: SMPM | Phase control for Data / Clock signal | PS14B_DS Rev.1.0 |
| Laser Driver | GHz /1 A -Class Laser driver | FRQ：50 kHz-over 1GHz<br>Driving current：over 1.0 App, | Measurement instruments for Optical devices | Custom |
| Short pulse generation | High speed short pulse repetition generator | Repetition freq:：50kHz-over 20GHz<br>Pulse half width：18 ps, Pulse output: 0.4Vpp | Evaluation of Optical devices | Custom |
| MUX/ DEMUX | 64Gb/s 2:1 MUX | Input: DC- 32 Gb/s, Output : DC- 64 Gb/s<br>CNT: SMPM | Measurement tool for optical fiber system | Custom |
| Analog MUX | Analog 2-1 MUX | 3 dB band width: over 50 GHz,<br>CNT: Input SMPM, Output 1mm | Over 80 Gbaud Optical transmission system | Custom |
| DA converter | DAC Mod | Analog band width : over 40GHz<br>CNT: Input 10 SMPMs, Output two 1mmCNTs | Over 70Gbaud Optical transmission system | Custom |
| | Multi-channel DAC Mod | Over 64 Gbaud,<br>CNT: Input 20 G3PO, Output two 1mmCNTs | Measurement instruments for fiber optic | Custom |
| RF module for wireless | TX/RX Front-end module | 40GHz band、TX Amp, 2-1 switch, RX amplifier multichip module CNT: there SMPMs | mm-wave wireless system | Custom |
| | Mixer module | 40 GHz band, RF/LO/IF CNT: three SMPMs | | |
| Optical TX/RF | 4 CH differential TX | 25 Gbaud | 25 Gbaud Optical | Custom |

| | | | | |
|---|---|---|---|---|
| | module | CNT: Input 4 CH G3PO Output 4 CH G3PO | transmission system | |
| | Ultra high speed optical RX module | 56 Gbaud 1CH differential out<br>CNT: Output two 1.85mms | 56 Gbaud Optical transmission system | Custom |
| Optical TX | Differential signal spread out RF substrate | 60 GHz bandwidth 4 differential input<br>CNT: eight 1.85mm | Ultra high speed optical transmission system | Custom |

Table 4 Passive module specification outline

| Category | Product name,<br>Product No. | Main performance and connector used | Application | Detail document |
|---|---|---|---|---|
| Signal distribution | DC-32 GHz Power Divider,<br>DV30A | FRQ: DC-32 GHz, Insertion loss : 8 dB, CNT: SMPM | Data signal distribution, combiner | DV30A_DS Rev.1.0 |
| Coupler | 10-18 GHz 3dB Directional Coupler DV15A | FRQ: 10-18GHz, Insertion loss : 3.5dB, 5 dB, CNT: SMPM | Sinusoidal signal distribution, Power monitor | DV15A_DS Rev.1.0 |
| | 18-32 GHz 3dB Directional Coupler DV25A | 18-32GHz, Insertion loss: 6 dB, 6dB , CNT: SMPM | | DV25A_DS Rev.1.0 |
| Fixed attenuator | DC-40 G Hz 3dB Fixed Attenuator AT03 | FRQ: DC-40GHz,<br>CNT: SMPM | Signal level/ gain control | AT03_DS Rev.1.0 |
| | DC-40 GHz 6dB Fixed Attenuator AT06 | FRQ: DC-40GHz,<br>CNT: SMPM | | AT06_DS Rev.1.0 |
| | DC-35 GHz 10dB Fixed Attenuator AT10 | FRQ: DC-35GHz,<br>CNT: SMPM | | AT10_DS Rev.1.0 |
| | 70- 110 GHz 2dB Fixed Attenuator AT2-110A | FRQ: 70-110GHz,<br>CNT: 1mm | | AT2_110A_API_Rev.1.0 |
| | 70- 110 GHz 3dB Fixed Attenuator AT3-110A | FRQ: 70-110GHz,<br>CNT: 1mm | | AT3_110A_API_Rev.1.0 |
| | 70- 110 GHz 5dB Fixed Attenuator AT5-110A | FRQ: 70-110GHz,<br>CNT: 1mm | | AT5_110A_API_Rev.1.0 |
| | 70- 110 GHz 8dB Fixed Attenuator AT8-110A | FRQ: 70-110GHz,<br>CNT: 1mm | | AT8_110A_API_Rev.1.0 |
| | 70- 110 GHz 9dB Fixed Attenuator AT9-110A | FRQ: 70-110GHz,<br>CNT: 1mm | | AT9_110A_API_Rev.1.0 |
| Variable Attenuator | 6-30 GHz variable Attenuator (for clock signal) V T 30A | 6-30 dB, Attenuation range : 30 dB, P-1dB in: 25 dBm,<br>PS：-3.3 V, CNT: SMPM | Clock/ Data signal level/ gain control | VT30A_DS Rev.1.0 |
| | DC-28 GHz variable Attenuator (for 32Gb/s data signal) | FRQ：DC-28 GHz,<br>Attenuation range : 24 dB,<br>Max. input power : 24 dBm,<br>CNT: K | | Custom |
| | DC-40 GHz variable Attenuator ( for up to 40 GHz clock signal, 56 Gb/s data signal | FRQ：DC-40GHz , over 56Gb/s signal data, Attenuation range : 24 dB, Max. input power : 24 dBm,<br>CNT: K | | Custom |
| DC Block | 40GHz DC Block , DB_40A | FRQ：20kHz-40GHz, CNT: SMPM | Clock data signal AC coupling | DB40A_DS Rev.1.0 |
| | 60GHz DC Block, DB_60A | FRQ: 50kHz-60GHz, CNT: G3PO | | DB_60A_API_Rev.1.0 |
| Bias-T | 64Gb/s Bias-T, BT_64A | FRQ：50kHz-55GHz,<br>CNT: G3Po | Bias-T | Module Data sheet (Rev. 1.1, Eng.) p.82 |
| Bias-Feed | 64Gb/s Bias-Feed | FRQ：50kHz-65GHz, | Bias Feed | Performance of G3PO 64 |

| | | | | |
|---|---|---|---|---|
| | DF_64A | CNT: G3PO | | Gbaud DC Block, Bias-T, DC Feed |
| 50Ω Terminator | 40 GHz 50Ω Terminator TM_40L | FRQ：DC-40GHz, CNT: SMPM | Signal termination | TM40L_DS Rev.1.0 |
| | 110 GHz 50ΩTerminator TM_110A | FRQ：DC-110GHz, CNT: 1mm | | TM_110A_API_Rev.1.1 |
| Power detector | 30kHz-110GHz broad-band Power Detector Module PD_110A | FRQ：30kHz-110GHz, CNT: 1mm | Power detection | PD_110A_API_Rev.1.0 |
| Filter | 5 GHz Low Pass Filter | Fc : 5 GHz, Pass band insertion loss：< 3 dB, CNT: SMA | Low pass filter | Custom |
| | 28 GHz Low Pass Filter | Fc : 28 GHz, Pass band insertion loss：< 2 dB, CNT, K(2.92mm) | | Custom |
| | 35 GHz High Pass Filter HPF_35A | Fc : 35 GHz, Pass band: 40- 60 GHz, Pass band insertion loss: 3 dB, CNT: SMPM | High pass filter | HPF_35A_API_Rev.1.0 |
| | 70-110 GHz Pass-Band High Pas Filter, HPF_63A-XY | Fc : 63GHz, Pass band : 70-110GHz, Pass band insertion loss:：5 dB, CNT: 1mm | | HPF_63A_API_Rev.1.0 |
| Equalizer | Less than 1.5 GHz band equalizer | S11: <-18 dB CNT: SMA | S21 flattening | Custom |
| Connector adapter | 1mm Female / Male Adapter ADP_1X1YA | FRQ：DC-110GHz | Connection between different type connectors | ADP_1X1YA_API_Rev.1.0 |
| | 1mm-G3PO Adapter, ADP_1XGPA | FRQ：DC-92 GHz | | ADP_1XGPA_API_Rev.1.0 |
| | 1mm-SMPM Adapter, ADP_1XSPA | FRQ：DC-65 GHz | | ADP_1XSPA_API_Rev.1.0 |
| | G3PO-SMPM Adapter ADP_GPSPA | FRQ: DC-65 GHz | | ADP_GPSPA_API_Rev.1.0 |
| | SMPM(P) SMPM(P) Adapter ADP_SPSPA | FRQ: DC-62 GHz | | ADP_SPSPA_API_Rev.1.1 |

# Chapter 3 Evaluation board and test fixture of high frequency (speed) devices

## Section 1 Evaluation board

We design/fabricate and supply the evaluation board (EVB) to high frequency device suppliers by using our fundamental technologies shown in Chapter 1.

EVB is made mainly for the purpose that device users, who intends to use high frequency device in their system, confirm device performance before implementing them in their system board. The other purpose of EVB is that device supplier shows customers sample implementation of the device, that is, show example of circuit board design and assembly method of the device. Sometimes, EVB is used to make an experimental system board.

Our company's EVB technology is capable to apply to the devices that operate up to over 150 Gbaud, 110GHz range .

By considering functionality and maximum operating frequency, optimizations of substrate material, connector and transmission line are done using various kind of simulations.

When DUT device is packaged device, it is soldered on the EVB. When DUT device is die form, it is die bonded on the circuit board or board base and wire bonded.

Figure CP3-1 shows a structure example of EVB for package device with 4 channel single-end inputs and 4 channel differential outputs. In most of cases for multi-channel device, small size of connectors such as SMPM and G3PO on the PCB are used to have low insertion loss of board. We often use ultra-thin semirigid cables and Alumina or Quartz substrate to have highest performance.

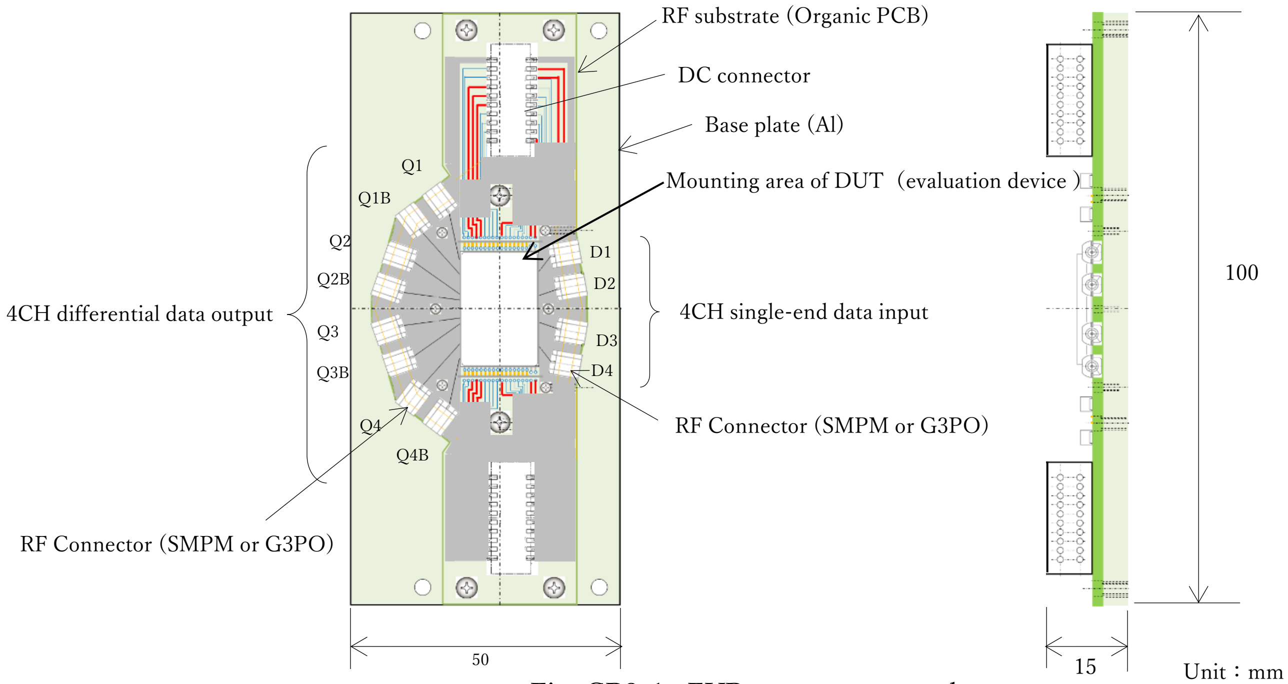



Fig. CP3-1 EVB structure example

## Section 2 Test fixture for high frequency devices

### Subsect.1 Basic structure of test fixture

The purpose of test fixture for high frequency devices is different from EVB. While EVB is used to evaluate device performance, test fixture is used to measure RF performance in shipping inspection, acceptance inspection or failure analysis. Big deference in structure between EVB and test fixture is that DUT electrodes in the test fixture are not soldered but be mechanically contacted to the circuit board at RF measurement. Figure CP3-2 shows basic structure of test fixture.

Although it is not so easy to have good RF performance in such mechanical contact condition, it should be designed so that characteristics degradation by test fixture portion is as small as possible.
However, in many cases, it is difficult to make sufficient performance test fixture of which degradation is negligibly small. So, measurement data obtained in inspection measurement using test fixture can not be compared directly with pass fail criterion. We have to perform Pass/Fail decision as counting test fixture degradation accurately. One of the ways to remove test fixture characteristic from measurement data and to know DUT characteristic itself is performing calibration at DUT electrode instead of performing calibration at coaxial connector portion. For this calibration, we make 3 kind of calibration standard (Open, Short, Load) and THRU standard for performance confirmation, of which bottom

structure is same as DUT bottom structure. We can supply these calibration standard kit with test fixture if needed.

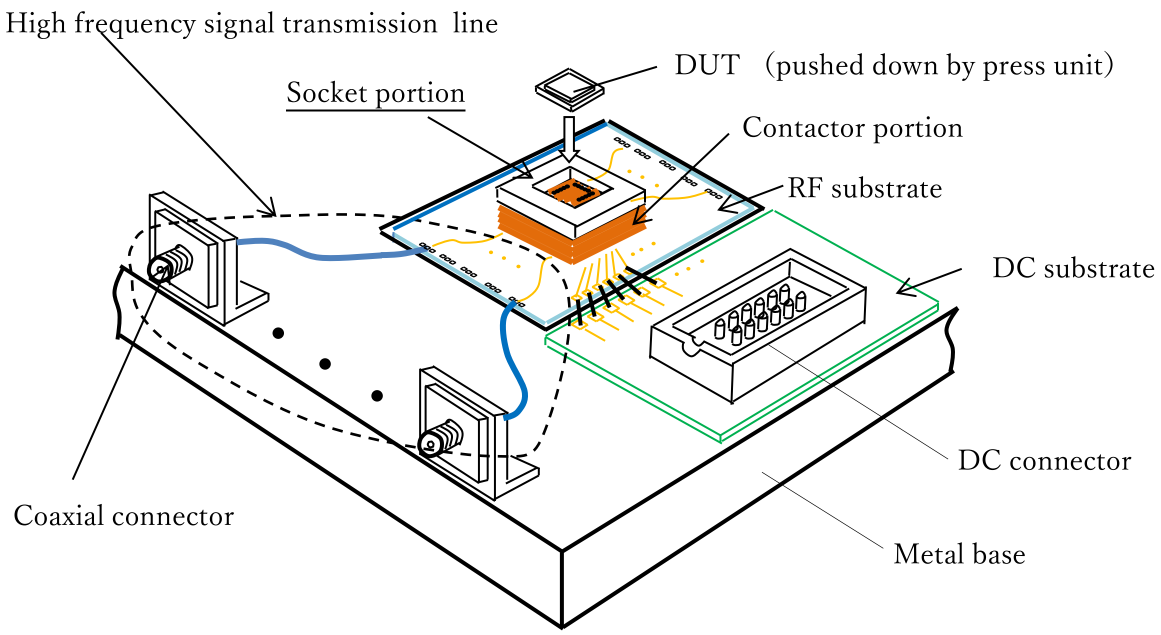



Fig. CP3-2　Basic structure of test fixture for high frequency device

As shown in Fig.CP3-2, test fixture consists of 1) high frequency signal transmission line portion 2) socket potion for device position alignment and 3) device electrode contactor portion.

To have good performance of high frequency signal transmission line portion, technologies same as transmission line for RF module that are explained in Section 3 in Chapter1 are required.

For socket potion that is made with resin machined parts, high accuracy machining with small tolerance is the key to have good positioning of DUT electrodes. Detail is not described here.

Contactor portion RF characteristics mainly determines performance of test fixture assuming that good DUT positioning and good transmission line are realized. There are various types of contactors. Our company is using three types of contactors shown in Table 5. These are used properly depending on DUT structure (QFN, LGA, BGA, etc.) , operation frequency and application.

Table5 Contactor type and feature

| Contactor type | Max. frequency | Application |
|---|---|---|
| Spring pin base vertical contact probe | About 30 GHz | Multi-pin count DUT |
| Anisotropic conductive sheet (ACS)<br>(Shin-Etsu Polymer Co., Ltd) | 110 GHz | Mainly used for ultra high frequency medium pin count DUT |

| | | |
|---|---|---|
| Metal-rod vertical multi-contact-pin probe (MRP) | About 80 GHz | For high frequency multi-pin count DUT |

**Subsect.2 Contactor with spring pin base vertical contact probe**

Typical structure of spring pin base vertical contact probe is that a small spring is inserted into metal pipe and pins are put on or under the spring inside the pipe.

The contact probes are inserted into pin-holder and these pins individually stroke under the DUT pads(electrodes) and electrical contact is performed. There are many kind of probes with different diameter, length , pin end structure and stroke distance , etc.

Spring pin base vertical contact probe generally provides stable contact performance because stroke distance is large . Frequency characteristic of this probe is worth than the other types of contactors, however, it can be applicable to be used for up to 30 GHz frequency devices, thus widely used for many applications. Figure CP3-3 shows two port (GSG configuration) S-parameter measurement results for spring pin base vertical contact probe KHP3060 (4mm length, made in MORIMOTO)

Pink color line is S21 for entire measurement set-up. Blue color line is S21 of Ref-THRU that is circuit excluding DUT. The difference between pink color and blue color lines becomes S21 of KHP3060 with GSG configuration. 3dB down frequency F-3dB is 33 GHz

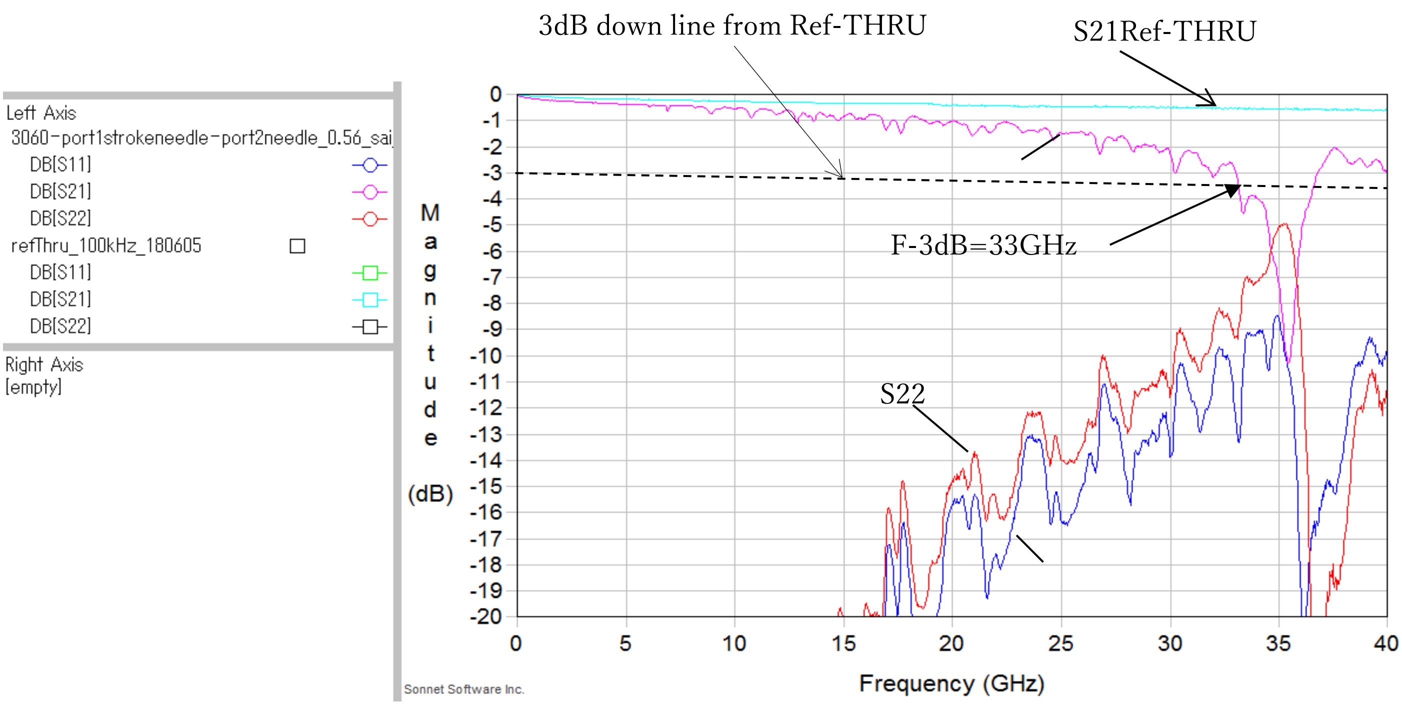
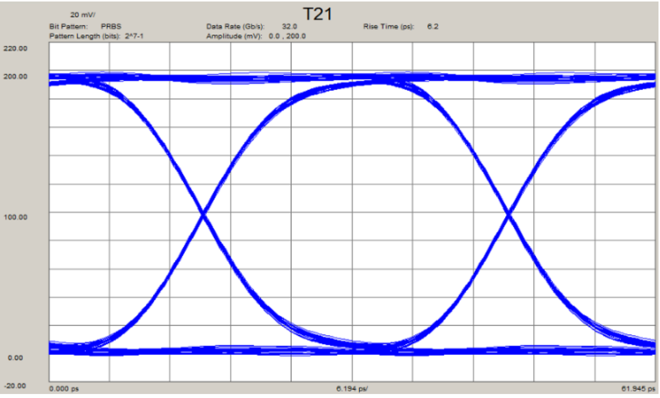



Fig. CP3-3 S-parameter of spring pin base vertical contact probe

Figure CP3-4 shows an output eye diagram of this probe obtained from the above S-parameter data using frequency/time domain conversion software (PLTS, Keysight Technologies) in the case of 32

Gb/s PRBS 2^7-1 input data with 5 ps Tr/Tf. High quality output waveform with small jitter is obtained. Since characteristics shown in Fig.CP3-3 and Fig.CP3-4 are for contact probe only , characteristics of test fixture including transmission line portion becomes a little bit degraded actually but not so big degradation.




6.2 ps/div

Fig.CP3-4 32 Gb/s output eye diagram of spring pin base vertical contact probe

**Subsect.3 Contactor with anisotropic conductive sheet**

When anisotropic conductive sheet (ACS) is compressed, vertical direction of sheet becomes conductive and horizontal direction becomes nonconductive. This anisotropic function is realized by making structure in which many thin metal wires are embedded vertically into insulating rubber, for example. Contactor with ACS has advantages described below .

1) DUT position alignment is easy because only one time position alignment between DUT pads and substrate pads is needed while other types of contactors need two times alignment among DUT pads, contactors, and substrate pads.
2) Maximum operation frequency is significantly high as comparing spring contact probe . This is because sheet thickness becomes transmission line length between DUT and substrate. Sheet thickness is around 0.15 mm to 0.25 mm that is much shorter than contact pin length around 3 mm to 10 mm.

Figure CP3-5 shows S-parameter of contactor using ACS with 0.15 mm thickness. Pink color line is S21 for entire measurement set-up. Blue color line is S21 of Ref-THRU that is circuit excluding DUT. The difference between pink color and blue color lines becomes S21 of ACS. 3dB down frequency F-3dB is over 110 GHz. By comparing with Fig.CP 3-3 , we know that frequency characteristics of ACS is significantly high.

Figure CP3-6 shows an output eye diagram of this probe obtained from the above S-parameter data using frequency/time domain conversion software (PLTS, Keysight Technologies) in the case of 32, 64 and 100 Gb/s PRBS 2^7-1 input data with 2ps (20-80%) of Tr/Tf. By comparing 32 Gb/s waveform of spring contact probe shown in Fig.CP3-4 and waveform of ACS shown in

Fig.CP3-6(a) , we know that Tr/Tf of output wave of ACS is much smaller than that of spring contact probe. Even at 100 Gb/s , ACS shows enough wide eye opening and very low jitter.

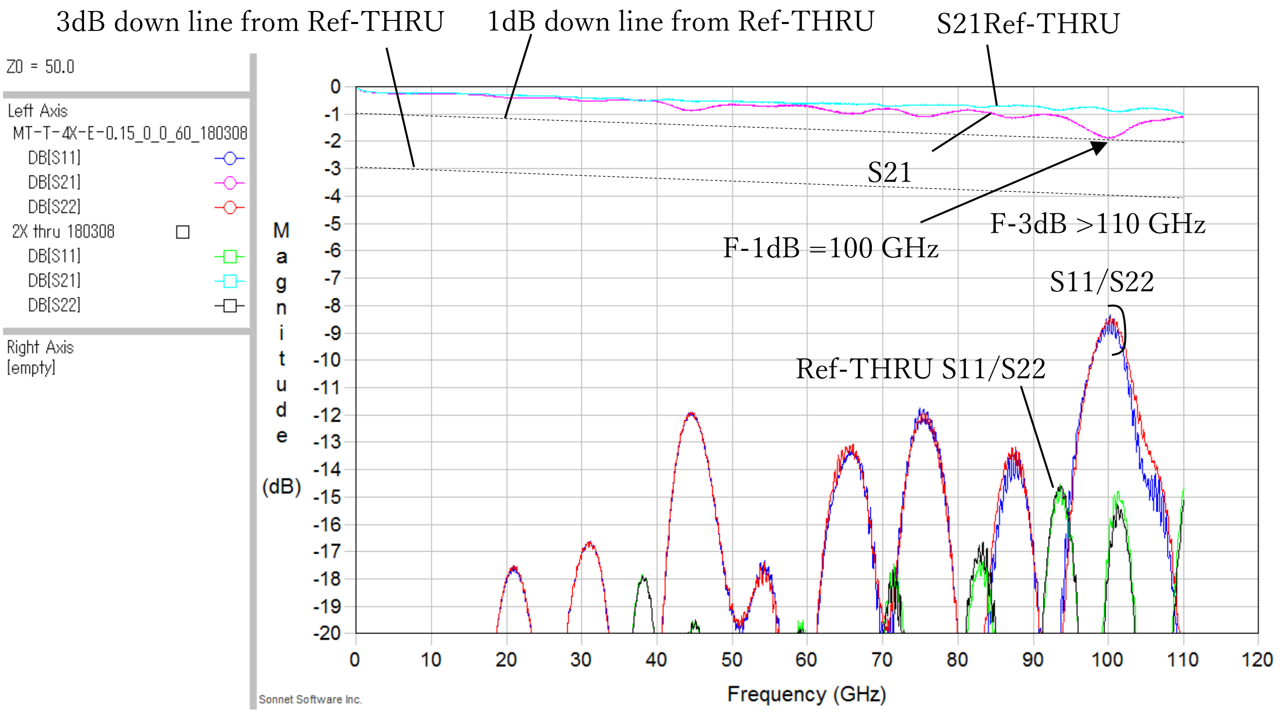
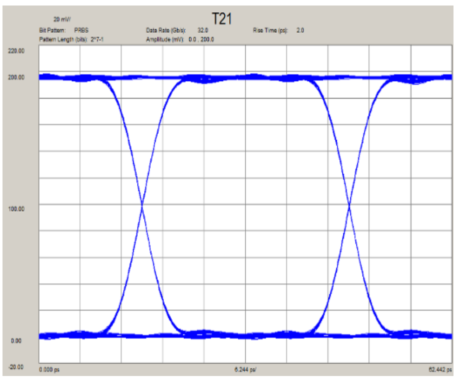
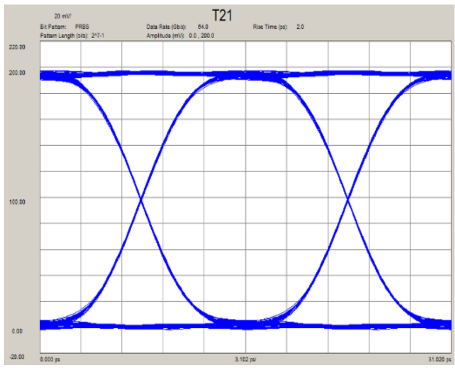



Fig.CP3-5 S-parameter of ACS with 0.15mm thickness



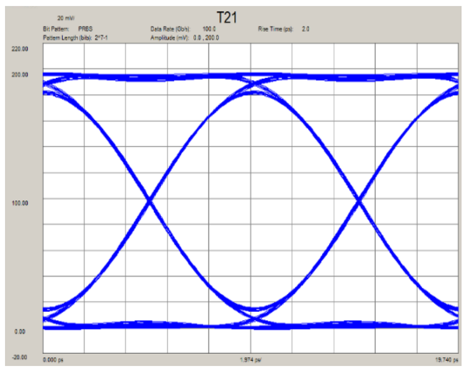

6.2 ps/div

Fig.CP3-6 (a) 32 Gb/s




3.1 ps/div

Fig.CP3-6 (b) 64 Gb/s




1.6 ps/div

Fig.CP3-6 (c) 100 Gb/s

Fig. CP3-6 32, 64 and 100 Gb/s output eye diagram of ACS with 0.15mm thickness

**Subsect.4 Metal-rod vertical multi-contact pin probe (MRP) as contactor**

Metal rod vertical multi-contact pin probe (MRP) is modified version of contactor with ACS. This was developed for the purpose that contactor does not make scars on DUT pads at measurement unlike contactor with ACS. Multiple metal rod pins, that are fixed on and under ACS in pin holder, make electrical contact individually between DUT pads and substrate pads like contactor with multiple spring pin base contact probe.  Figure CP3-7 shows S parameter measurement results of Quarts substrate short length thru line with GSG input and output pads (160 um pad pitch) by test fixture using MRP as contactor.

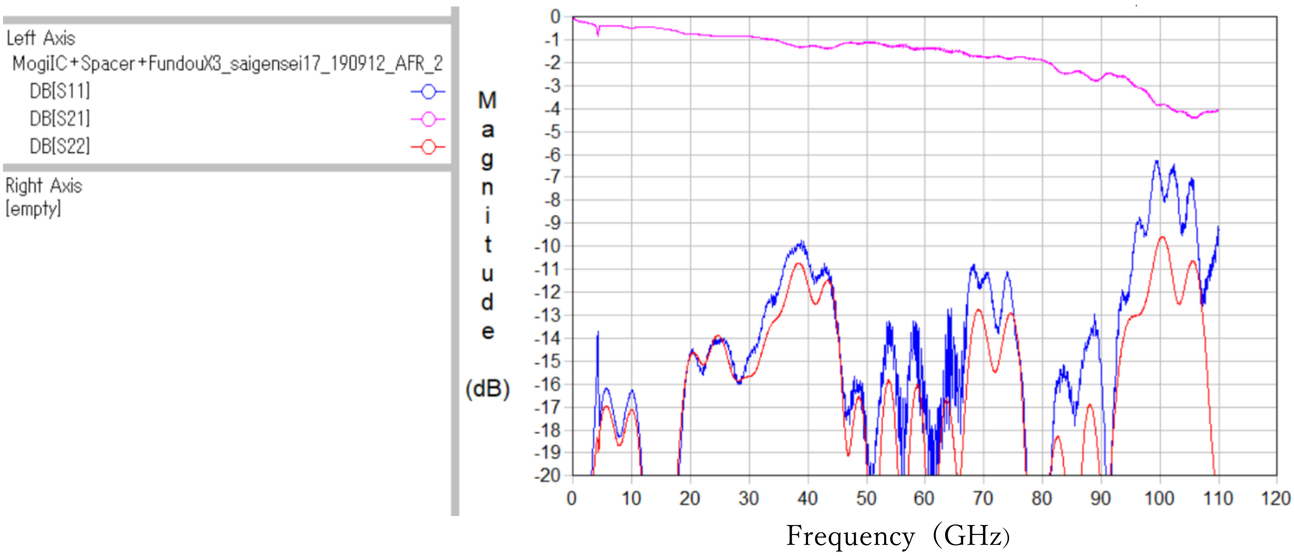
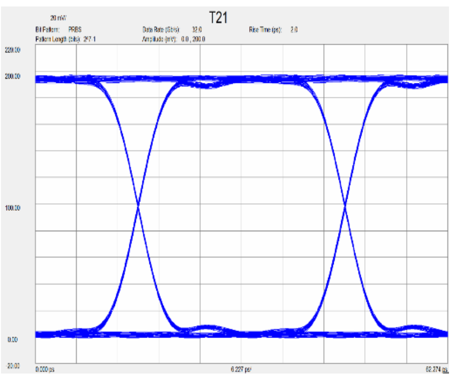



Fig.CP3-7  Quartz substrate thru line S-parameter measured by test fixture using MRP as contactor

Although this measurement data shows entire performance of thru line (DUT) and test fixture transmission line, F-3db reaches 96 GHz that is lower than pure ACS F-3db of >110 GHz but is significantly better than characteristics of spring pin base vertical contact probe shown in Fig.CP3-3.

Figure CP3-8 shows output eye diagrams of test fixture obtained from the above S-parameter data using frequency/time domain conversion software (PLTS, Keysight Technologies) in the case of 32, 64 and 100 Gb/s PRBS 2^7-1 input data with 2ps (20-80%) of Tr/Tf. By comparing 32 Gb/s waveform of spring contact probe shown in Fig.CP3-4 and waveform shown in Fig.3-8(a), we know that Tr/Tf of Fig.CP3-8(a) is much smaller than that of spring contact probe. Even at 100 Gb/s, waveform show enough wide eye opening and very low jitter.

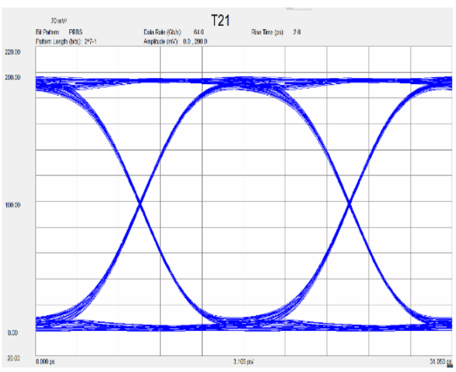
32 Gb/s




6.2 ps/div

Fig.CP3-8 (a)  32 Gb/s

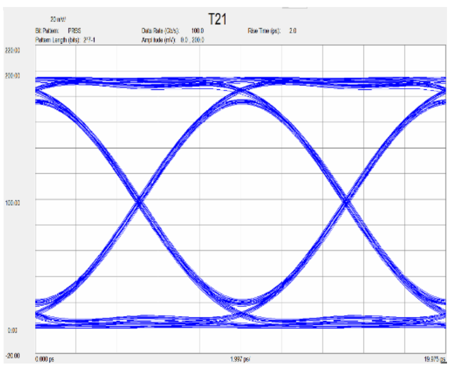
64 Gb/s




3.1 ps/div

Fig.CP3-8 (b)  64 Gb/s

100 Gb/s




1.6 ps/div

Fig.CP3-8(c)  100 Gb/s

Fig. 3-8  32, 64 and 100 Gb/s output eye diagram of output eye diagrams of test fixture contactor using MRP as contactor

## Chapter 4 High frequency probe-card using MRP

Test fixture described in chapter 3 is normally used to test packaged IC device in which IC die is mounted. The die performance is normally inspected using on-wafer probe card before being cut and mounted in the package. We call passed die in this test “known good die (KGD)”. To get KGD, sometimes only DC test is performed, however, it is better to perform high frequency AC test in addition to DC test. There are many devices having AC coupled interface. For these devices, AC test is mandatory.
So, on-wafer probe-card with high RF performance is needed.

On-wafer probe-card with three types of structure such as cantilever type, membrane type and spring pin base vertical contact probe type are mainly used.

Cantilever type structure can make high frequency performance probe card for ICs of which signal pads are placed on periphery, but it is very difficult to have good frequency performance to ICs of which pads are placed near the center such as BGA.

Membrane type probe card has excellent RF performance available to measure RF IC with operating frequency is up to around 80 GHz and also easily applied for large pin count ICs. However, since probe-card fabrication process is similar to semiconductor fabrication process, initial cost may not be small and delivery time may not be short, it may not be suitable for small scaled ICs and for R&D application.

Spring pin base vertical contact probe type probe card is suitable for the ICs of which pads are located at entire device surface area and has advantage that damage to DUT pads by probing is very small. However, it is difficult to apply high frequency devices because maximum operating frequency is limited at around 30 GHz as explained at section 2 in chapter 3.

We have newly invented the MRP type probe card. In this probe card, MRP is fixed on the RF substrate and has following many advantages compared with other types of probe-cards.

1) Excellent high frequency performance having 90 GHz of F-3dB
2) Available to apply to relatively large co-planarity devices.
3) Available to apply to devices of which signal pads are located at entire device surface area
4) Available to apply to devices with large pad count of around several hundreds
5) No damage to DUT pads by probing
6) Low Initial cost

(Note) Our company will not supply this type of probe-card to the probe card users but will supply only contactor portion using MRP to probe card manufacturers.

Revision History

| Rev. | Date | Modification place and modification contents |
|---|---|---|
| Rev.1 | 2020/7/21 | Initial version is issued. |
| Rev. 1.1 | 2020/8/11 | Modify wording partially |
| Rev. 1.2 | 2020/8/19 | Modify wording partially |

| | | |
|---|---|---|
| Rev. 1.2.1 | 2020/8/20 | Modify revision history |
| Rev. 2.0 | 2021/3/22 | Update Table 1-2 and Table 1-3　Modify wording partially |
| Rev. 3.0 | 2022/6/15 | 1) Page2: 0.8mm connector and CECN connector are added in Fig. 1-1.<br>2) Page3: Description about CECN is added.<br>3) Page5: Tefron (CH2868D) is added in Table 1-1 and information about minimum L/S and minimum VIA diameter is added in Table 1-1<br>4) Page8, Page9: Contents of Table1-2 are updated.<br>5) Page9: Comments of 3) is modified.<br>6) Page13, Page 14: Description of broad band technology and multiport technology are added as recent topics. |
| Rev.4.0 | 2023/6/19 | 1) Language is changed from Japanese to English<br>2) Page 16, Page 17:<br>Detailed module fabrication technologies are described, which includes ultra-high frequency technology and multi-channel technology for optical transceiver application. |
| Rev.5.0 | 2025/05/01 | 1) Page 2, 3, 4, 5: Description on 1.0mm-connector/ 0.787mm $\phi$ semi-rigid cable assembly and 0.8mm-connector/ 0.787mm $\phi$ semi-rigid cable assembly are added.<br>2) Page 11: Description on 145 GHz quartz thin film circuit performance is added in Table2.<br>3) Page 14: Description on 3-dimensional temperature simulation is added.<br>4) Page15: Description is updated at connector development and at RF substrate high frequency design.<br>5) Page16: At module development example, descriptions on following modules are added.<br>130GHz-bandwidth broad band amplifier module,<br>165GHz-bandwidth broad band amplifier module,<br>140GHz-bandwidth DC block module,<br>DC-to 150 GHz Active combiner module<br>DC-to 150 GHz Mixer module |