

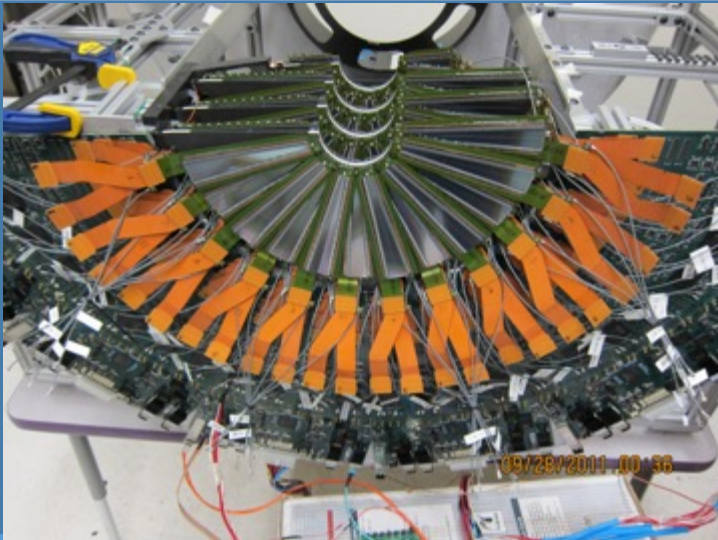
Development of INTT Conversion Cable Using μ -Coaxial Cable Technology

RIKEN/RBRC

Itaru Nakagawa

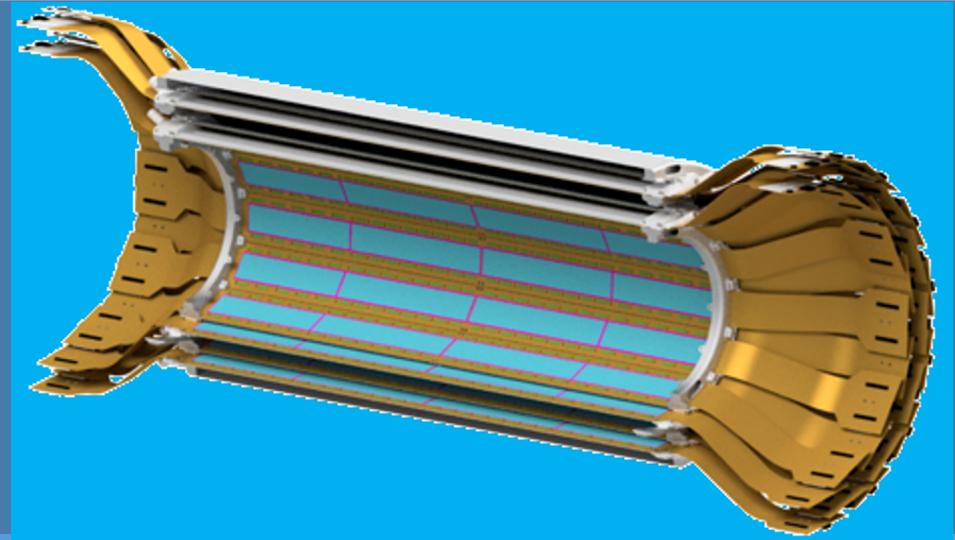
for INTT Team

FVTX



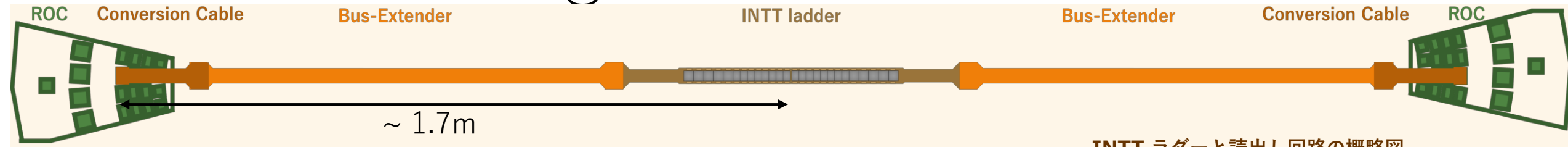
- **Disk Type**
- 4 Layers
- Silicon Strip Sensors
- 1M Channels
- FPHX Readout Chip
- FPHX-ROC-FEM-DCM-II

INTT

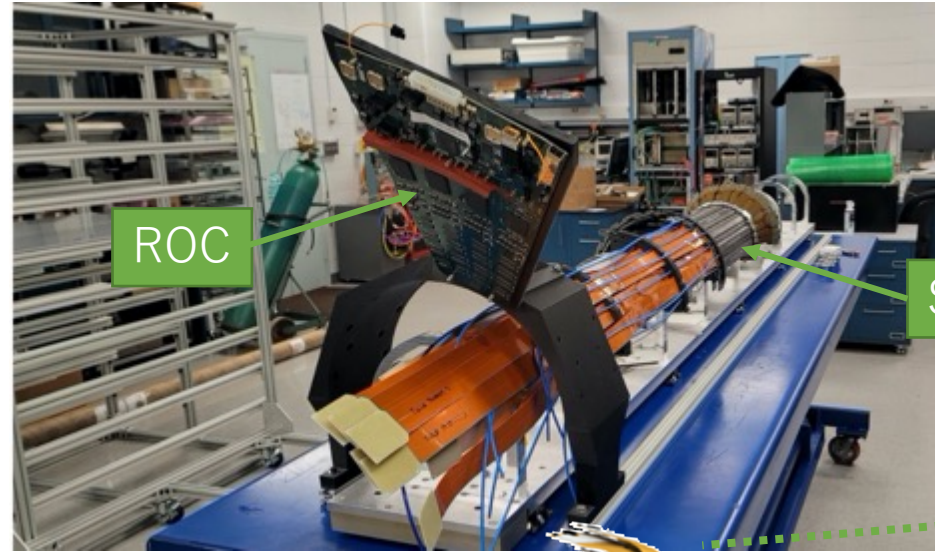


- **Barrel Type**
- 2 layers
- Silicon Strip Sensors
- 37k channels
- FPHX Readout Chip
- FPHX-ROC-FELIX

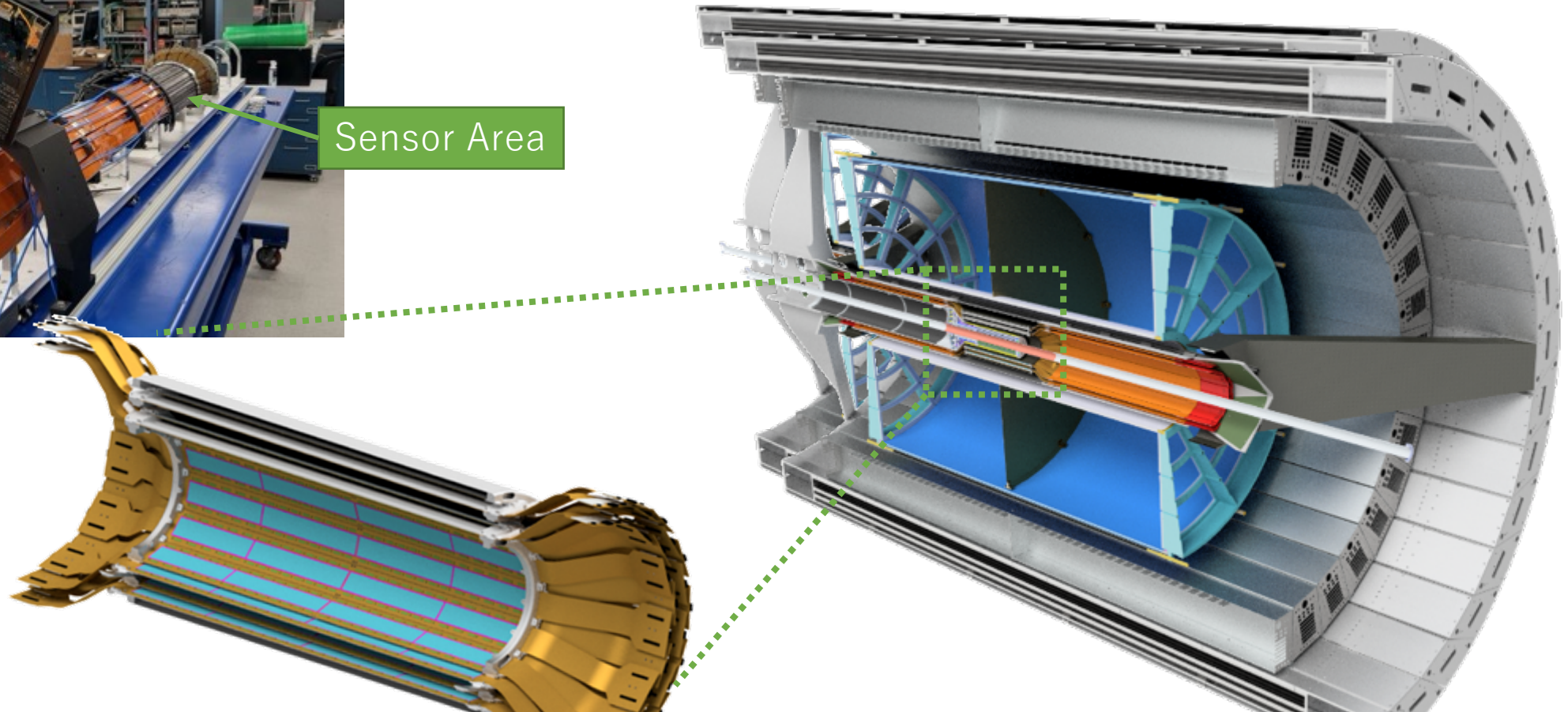
Technical Challenge ~ INTT Readout Cable ~



INTT ラダーと读出ケーブルの概略図

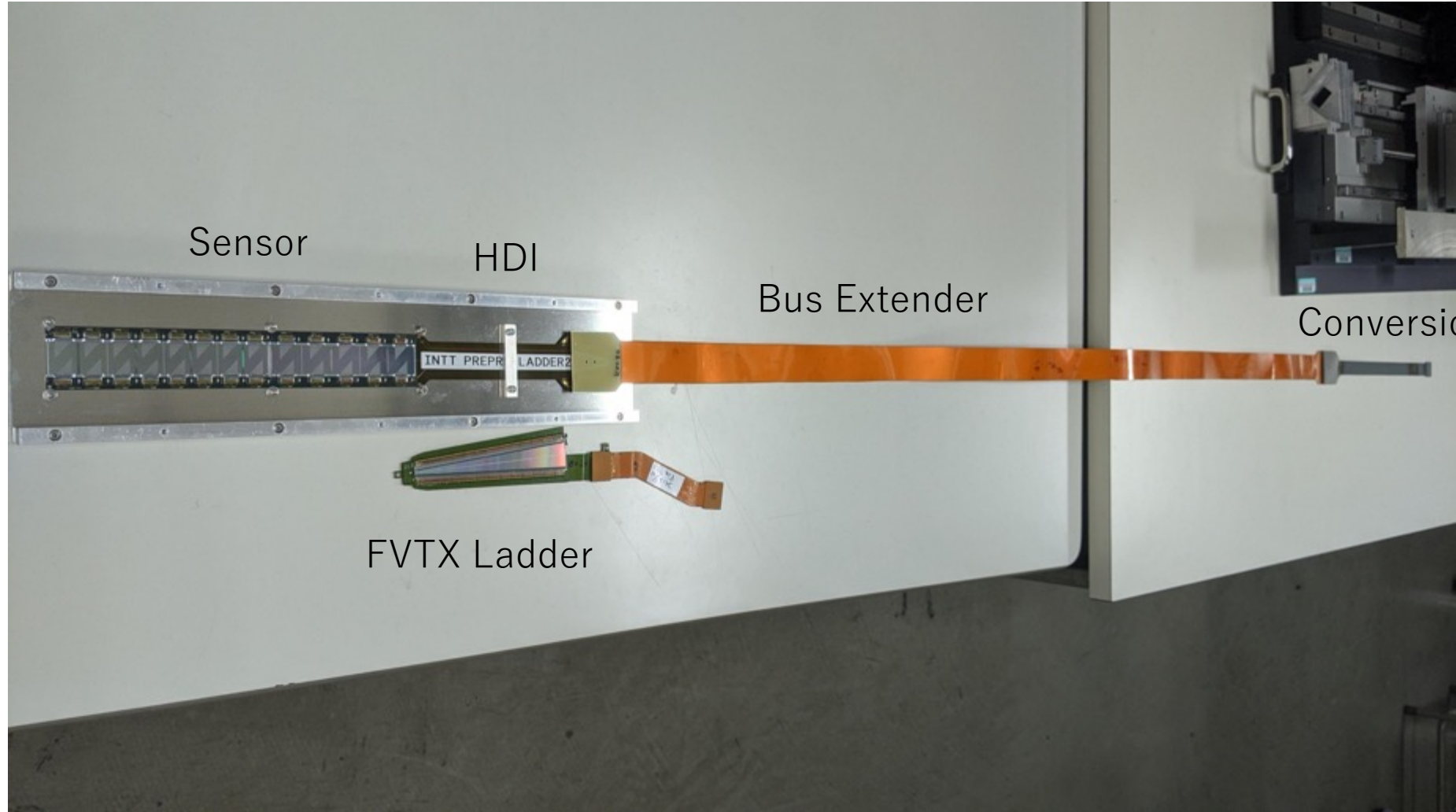


INTT Barrel Mock-Up

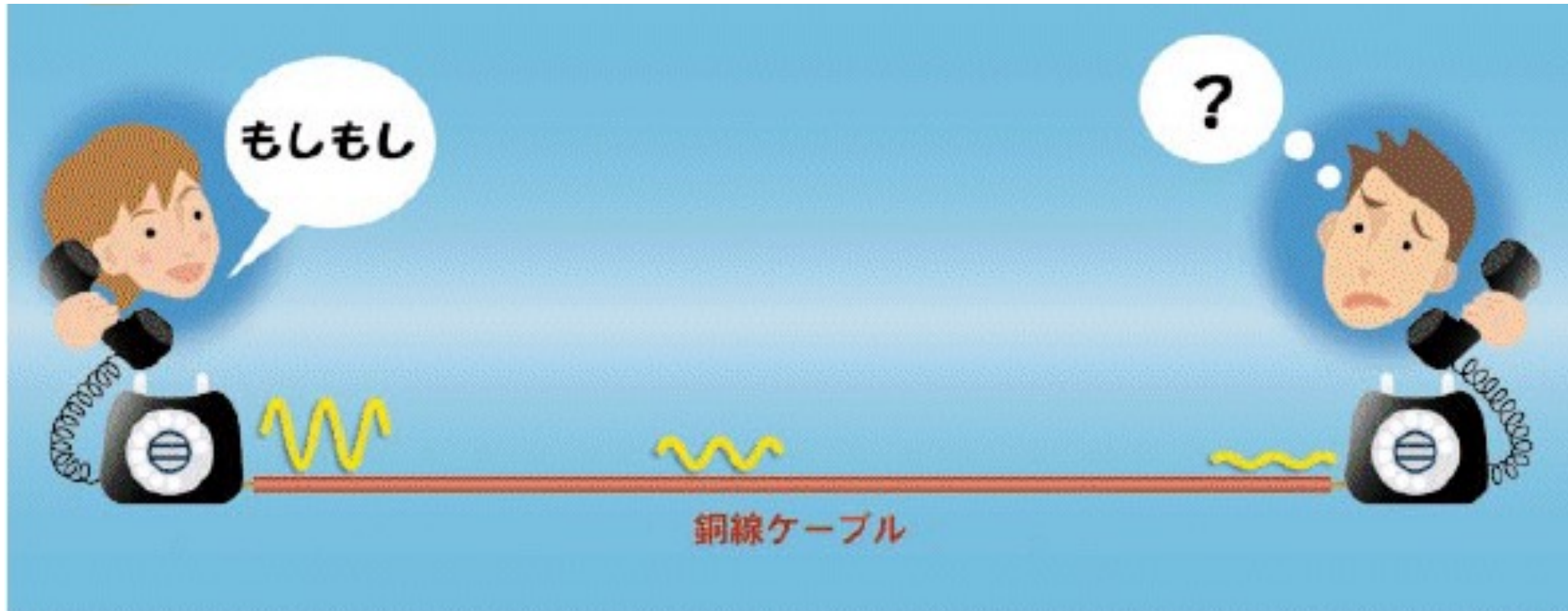


INTT Readout Cable Chain

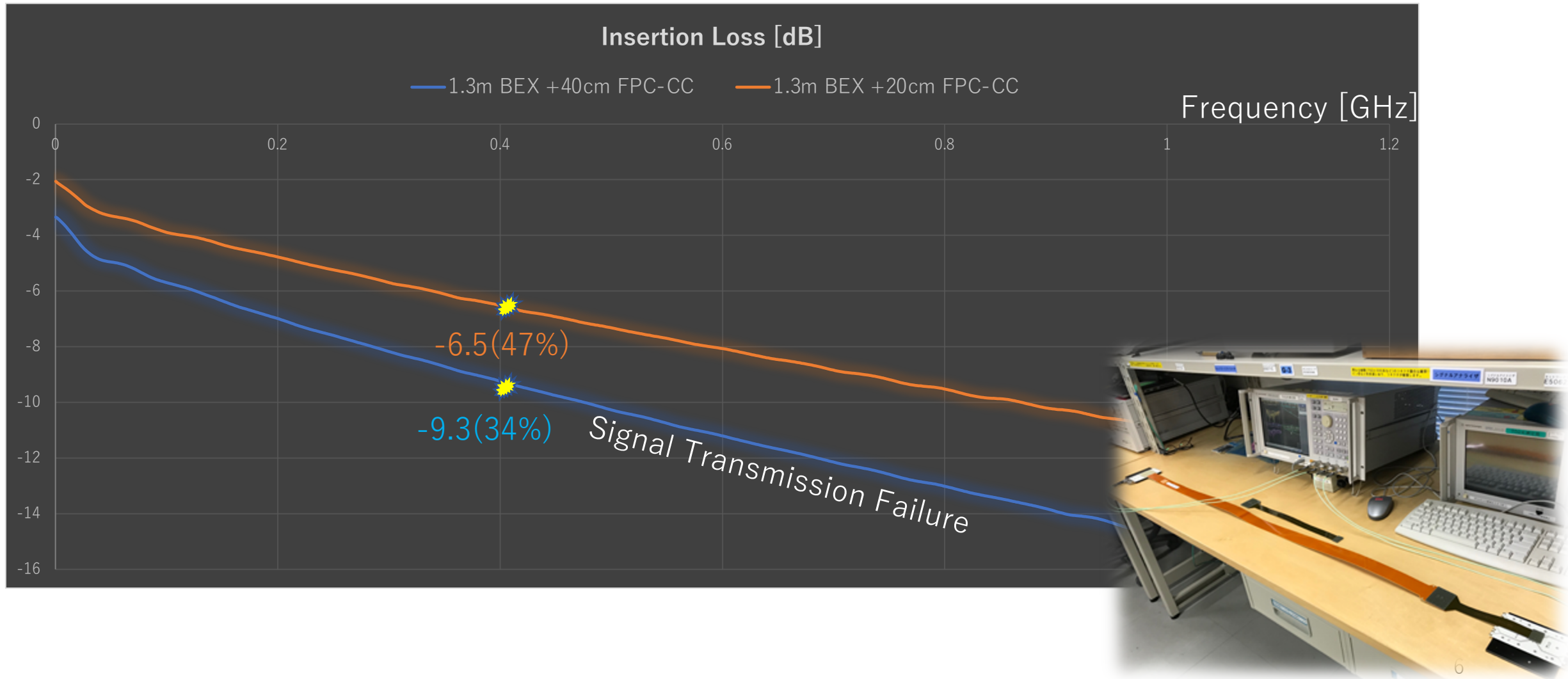
INTT ½ Ladder



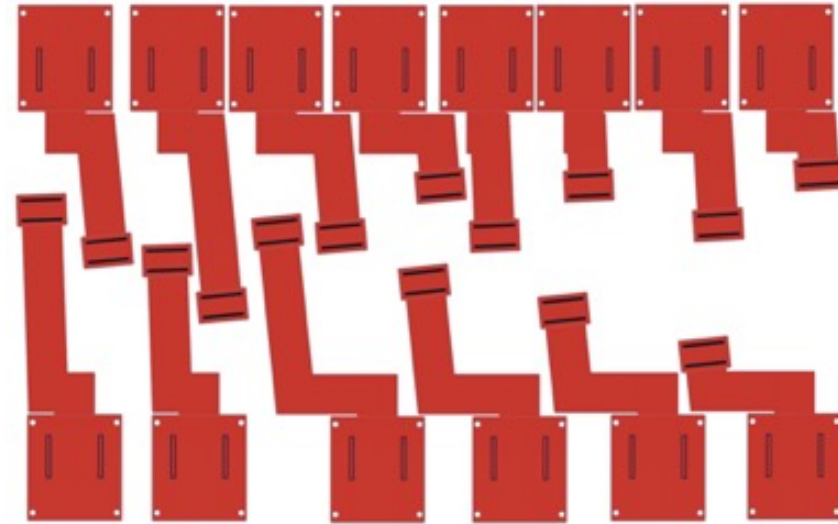
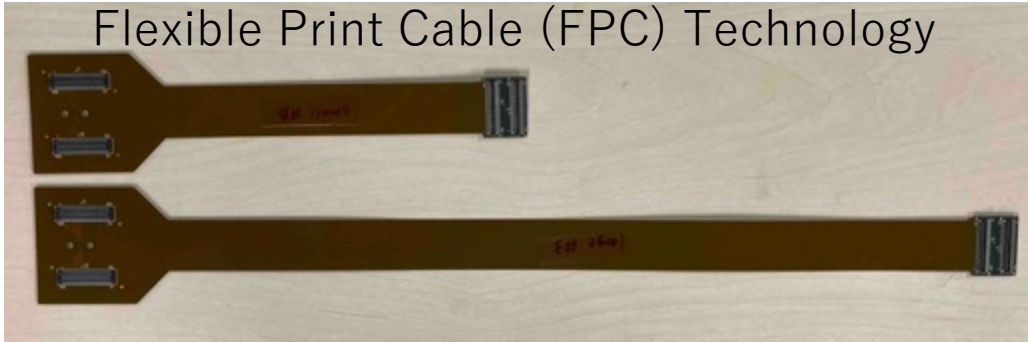
Signal Transmission Performance



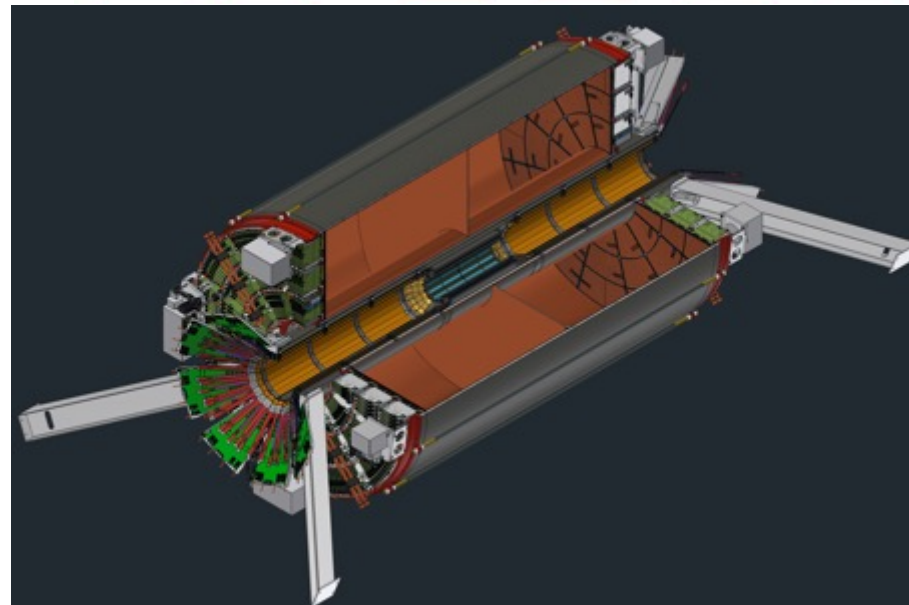
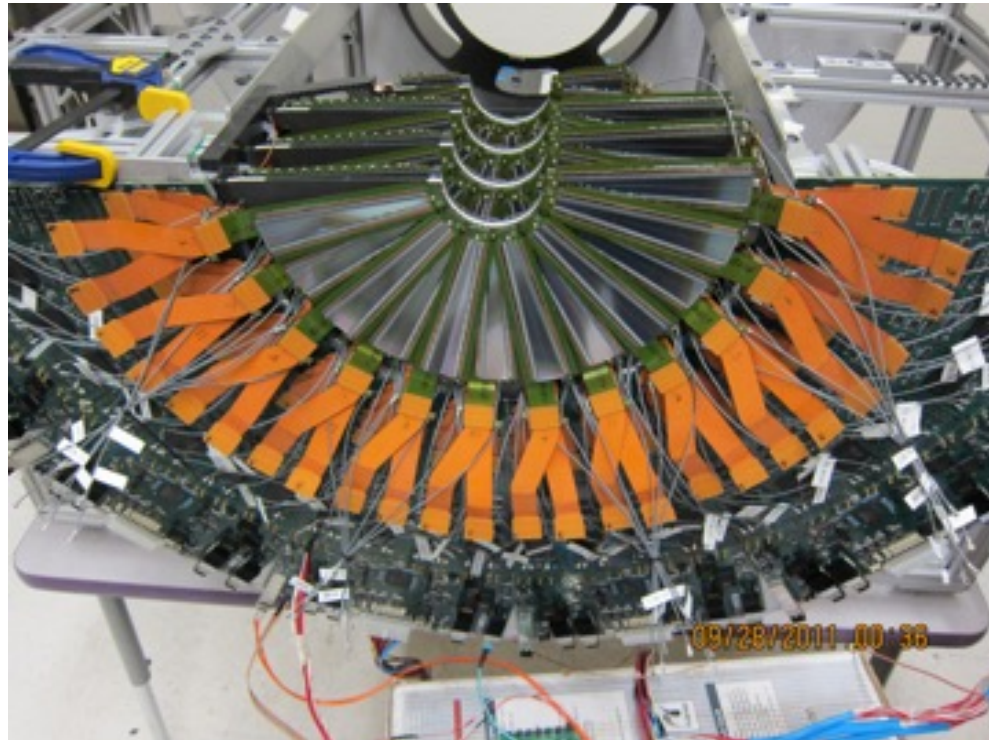
Insertion Loss Limit



Conversion Cable using FPC Technology



14 Different Types
are required for
INTT



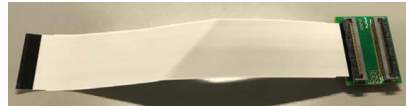
Risky in many
sense f.i. cost,
spares, mis-design,
etc.

Technology Choices

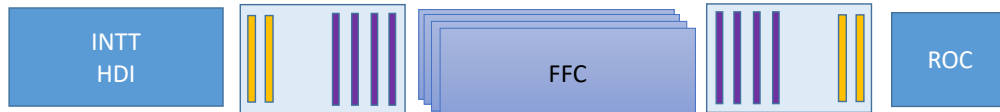
FFC option as a bus-extender for the beam test

- Consider FFC (Flexible Flat Cable) for the beam test
 - This is a test of option B for the INTT bus-extender

- FFC
 - Impedance controlled FFC ~1m
 - 500um pitch 50lines: Need 4 FFCs for 200lines
 - Cable width = 2.5cm
 - It is cheap and available in the market
 - Less-dense, larger size, heavier



- Conversion board
 - Convert the connector types and make the density less
 - Rigid PCB w/ impedance control
 - Small size (5x5cm)
 - 7 layers same as FVTX bus-extender (2 signal layers, 3 solid layers, 2 surface)



2017/9/21

INTT meeting, Takashi HACHIYA

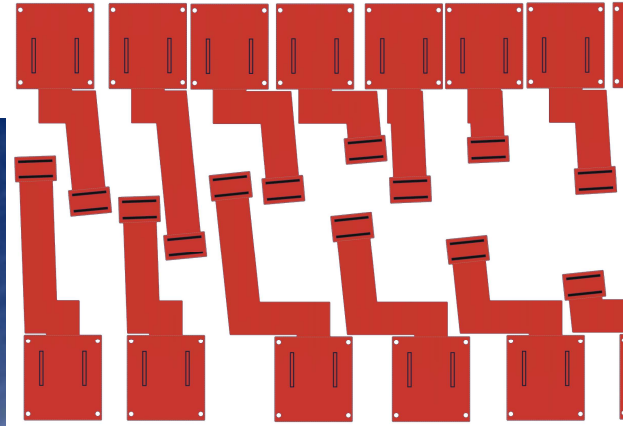
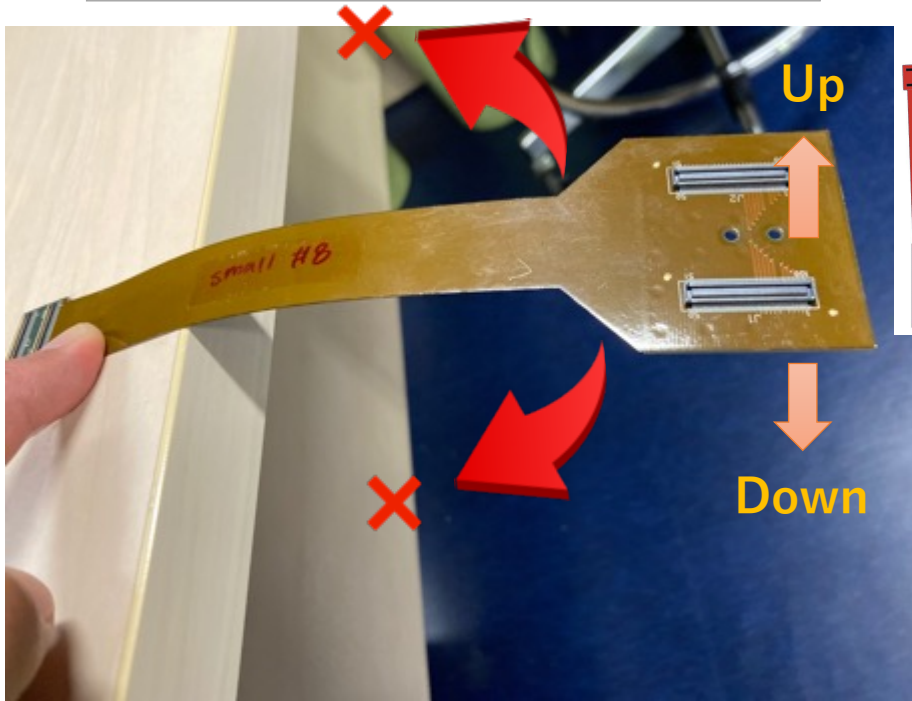
5

| | FPC | FFC | MCC |
|-----------------|----------|--------------|----------|
| Line Pitch [um] | 60 | 500 | 250 |
| Shield | Shielded | Not Shielded | Shielded |
| Flexibility | 2D | 2D | 3D |

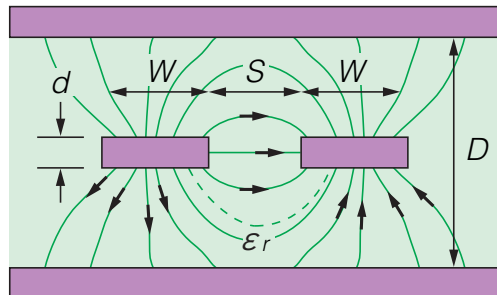
1. Flexible Print Cable (FPC)
2. Flat Flexible Cable (FFC)
3. Micro-Coaxial Cable (MCC)

Advantage in the flexibility

😞 No flexibility in left/right resulted in multiple different designs → 2 D flexibility



Micro-coaxial cable



😊 Flexible in 3 dimensions and thus only 1 simple design cable can connect any ROC port. → 3D flexibility
😊 All cables can be made in 1 single length.

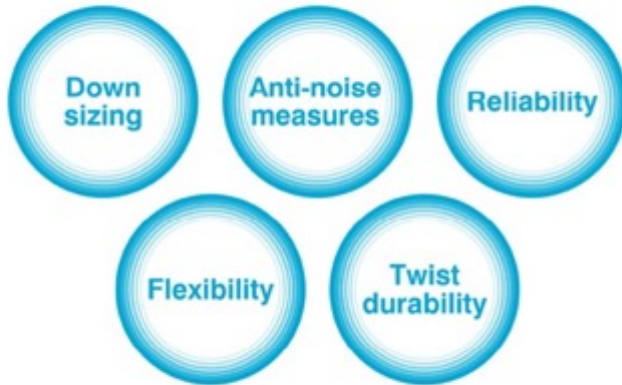
Micro-Coaxial Cable



Industry-leading small and thin connectors



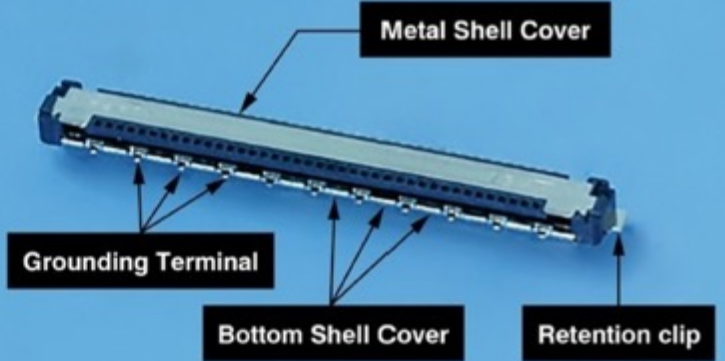
Connector for Micro Coaxial Cable



This series of connectors provide best solution for those who face some challenges in downsizing, anti-noise measures, and reliability, as well as those seeking for a cable with superior flexibility and twist durability.

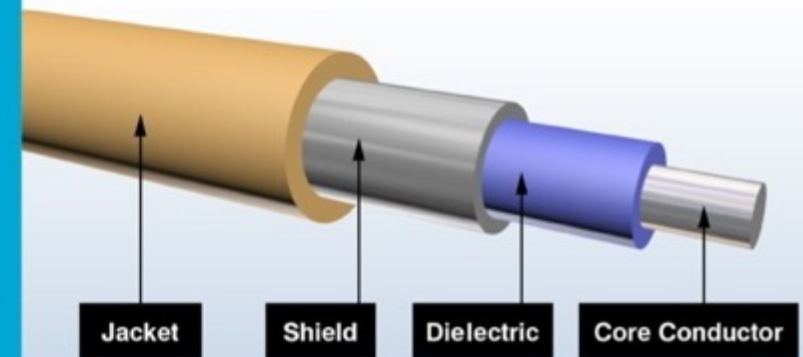
Grounding of PCB Side Connectors

Each series also provided with a ground terminal, metal shell cover and the bottom shell cover is has become a form surrounding the connector, we have to ensure the noise measures and product strength.



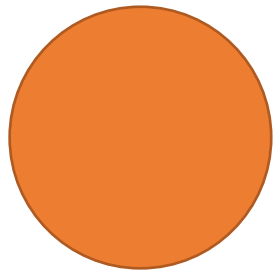
Micro Coaxial Cable Structure

In spite of the extremely thin cable, one by one has become in coaxial structure, and excellent transmission characteristics. Has a high flexibility and twist durability, repeated bending, is the cable that was blessed with strong features to twisting.



Potential Risk?

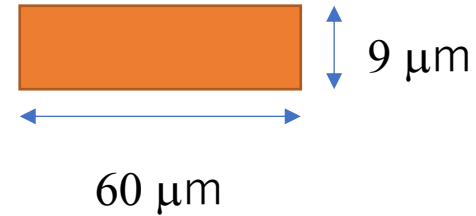
- Coaxial Cable



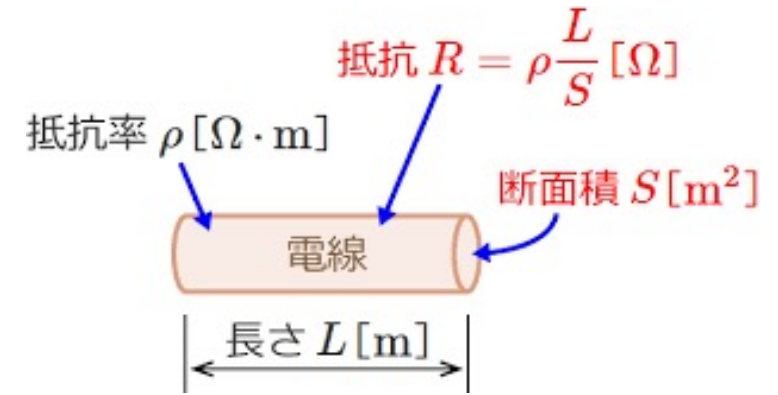
40 ~ 50 μm

Cross section $S = 1256 \sim 1962 \mu\text{m}^2$

- FPC



Cross section $S = 540 \mu\text{m}^2$

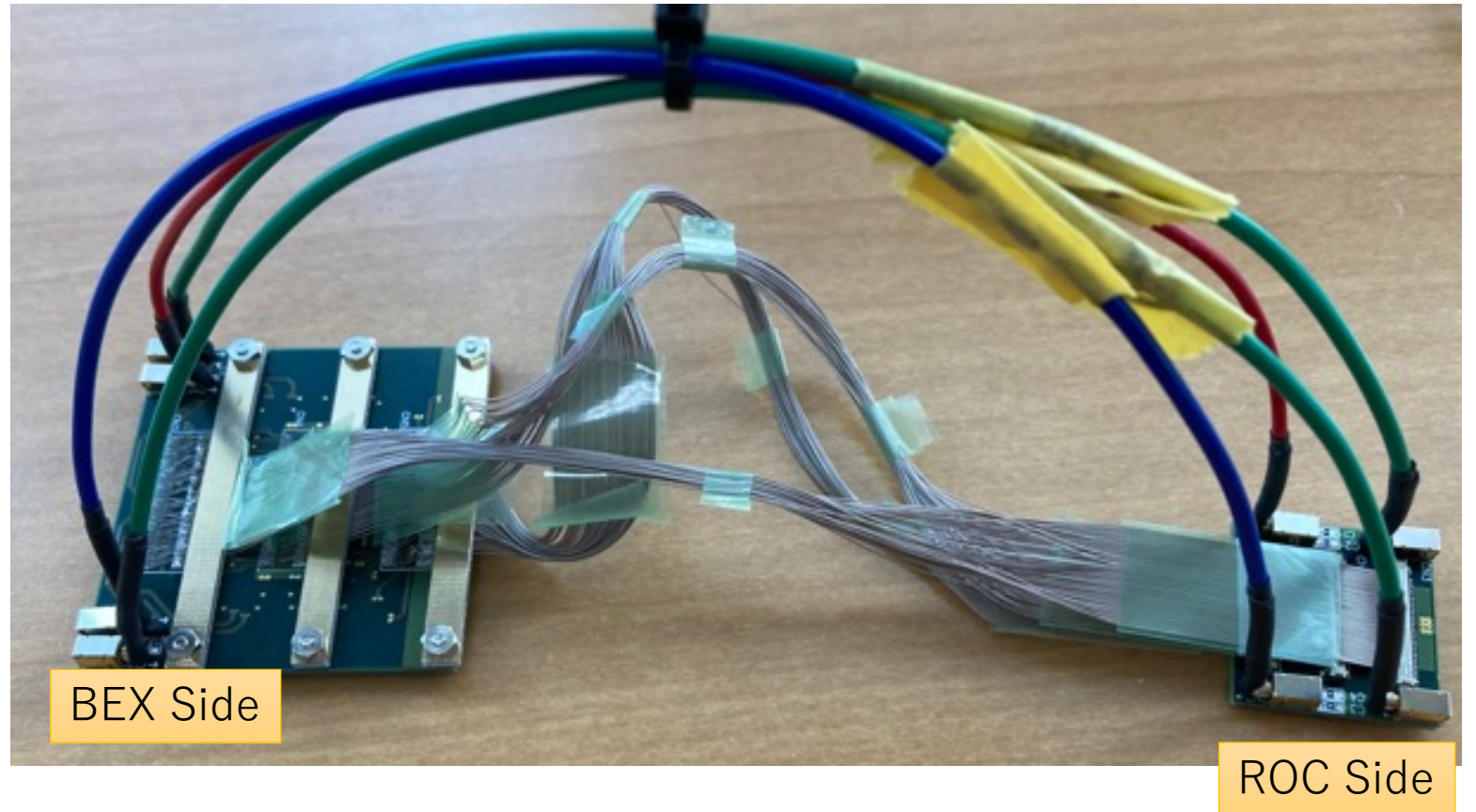


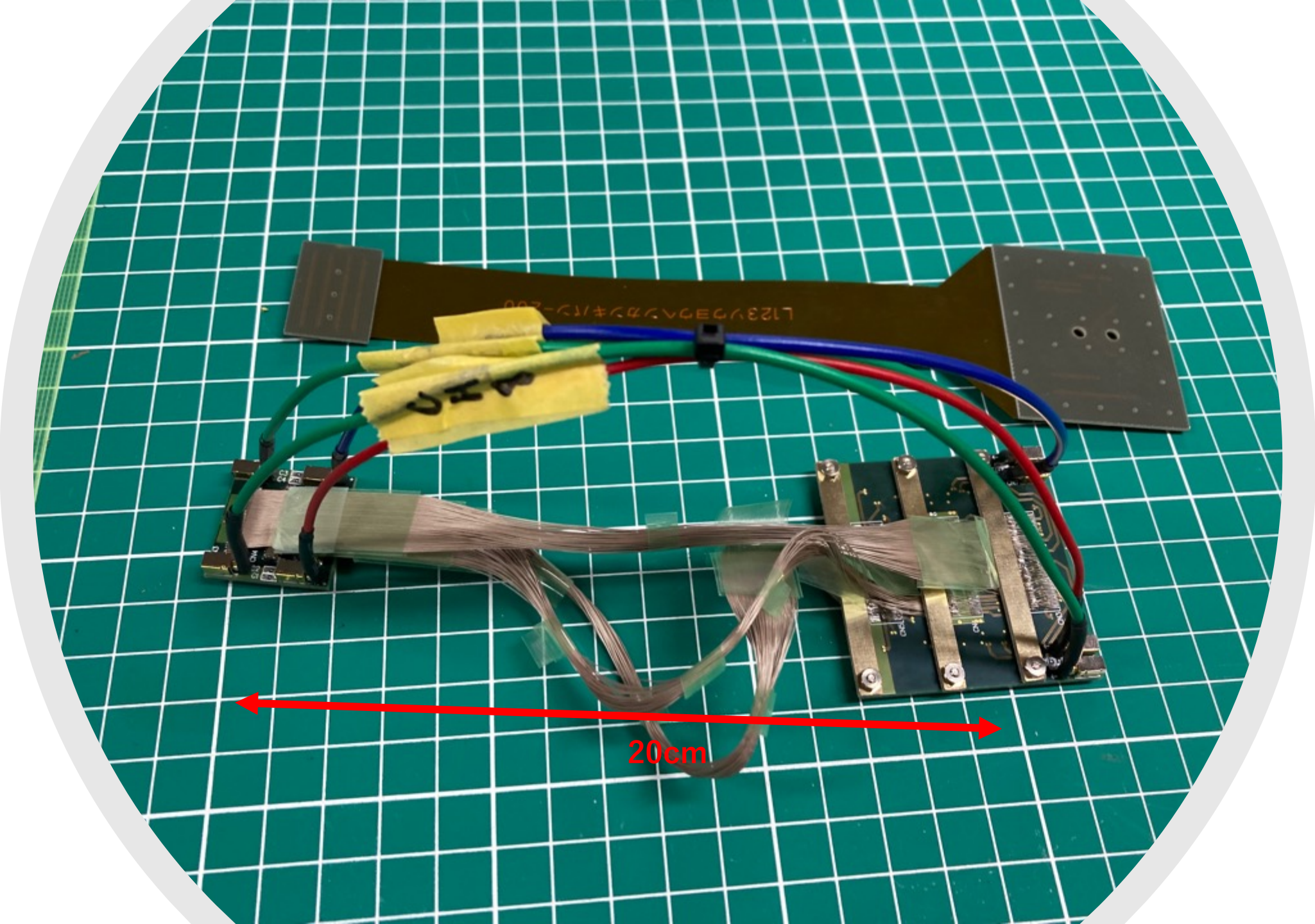
Factor of 2 to 3 larger cross section compared to FPC. Things are not complicated, but the signal attenuation can be expected to be relaxed intuitively.

m-Coax Conversion Cable Prototype-I

Delivered in December, 2021

μ -Coax Conversion Cable Prototype-1

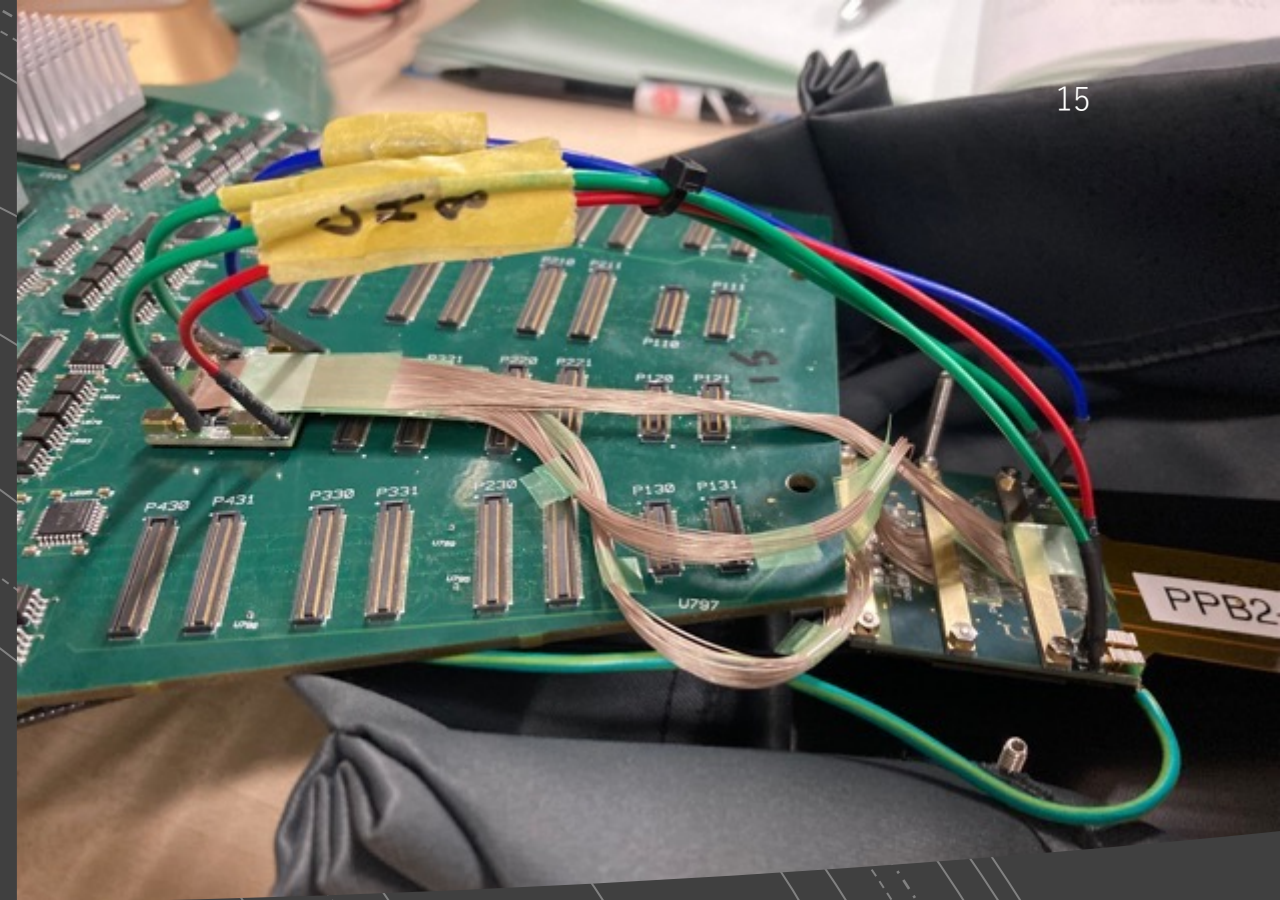
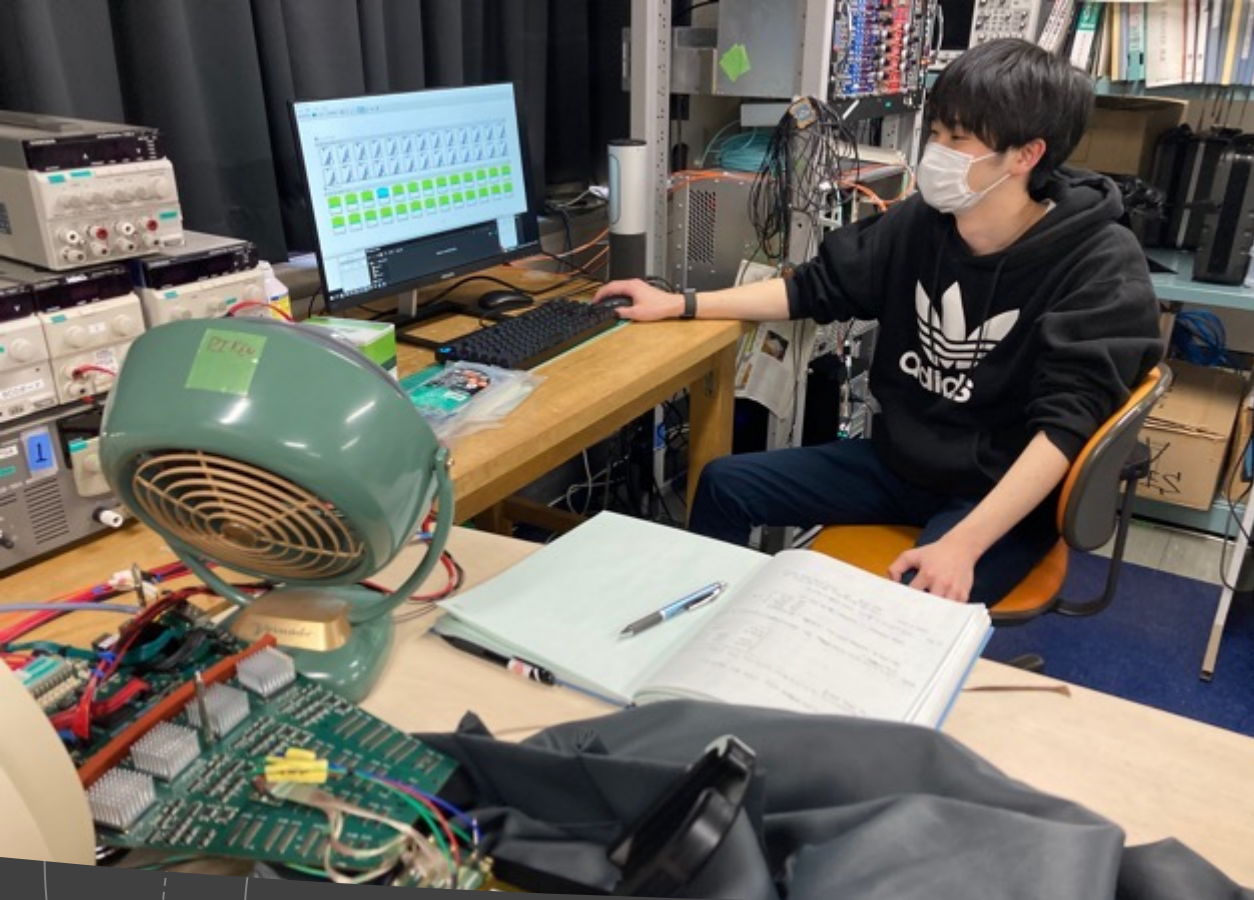




003-6114646V0E0A3217

V12

20cm



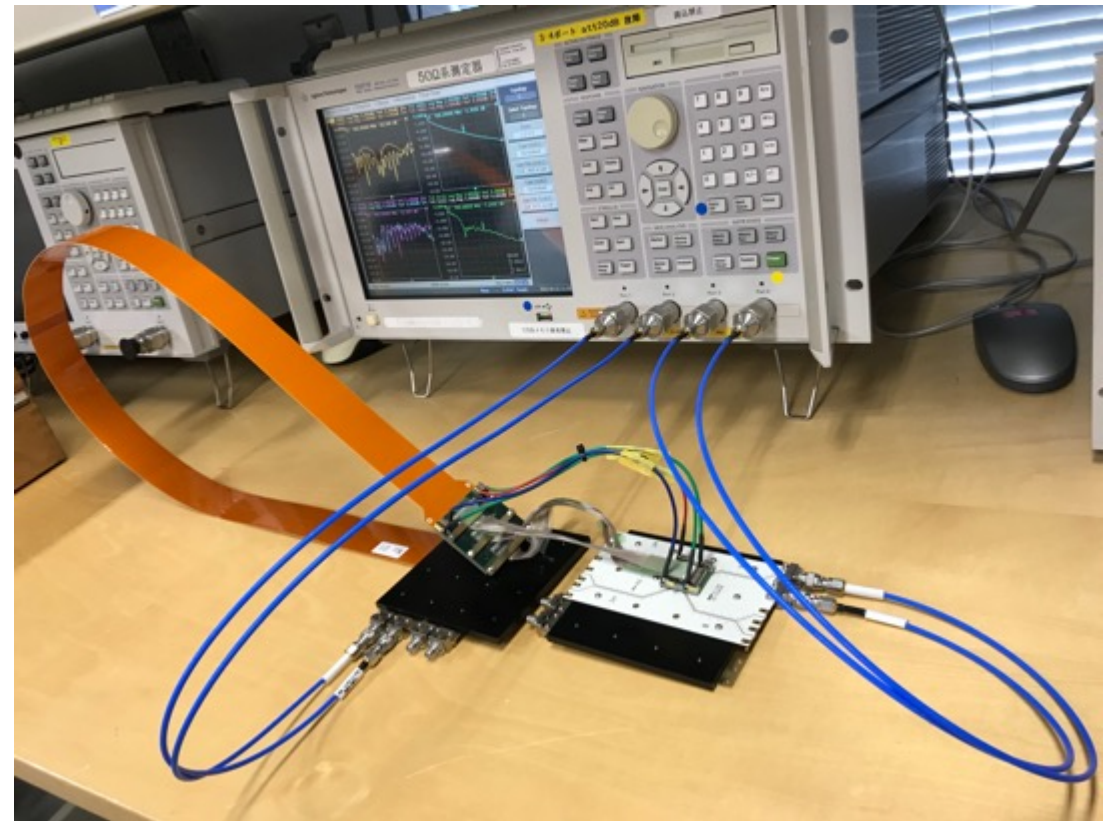
Performance Check

- After some iteration between Hayashi-REPIC to fix mixed up channels, we confirmed satisfactory data taking.

Bus Extender + Conversion Cable Chain

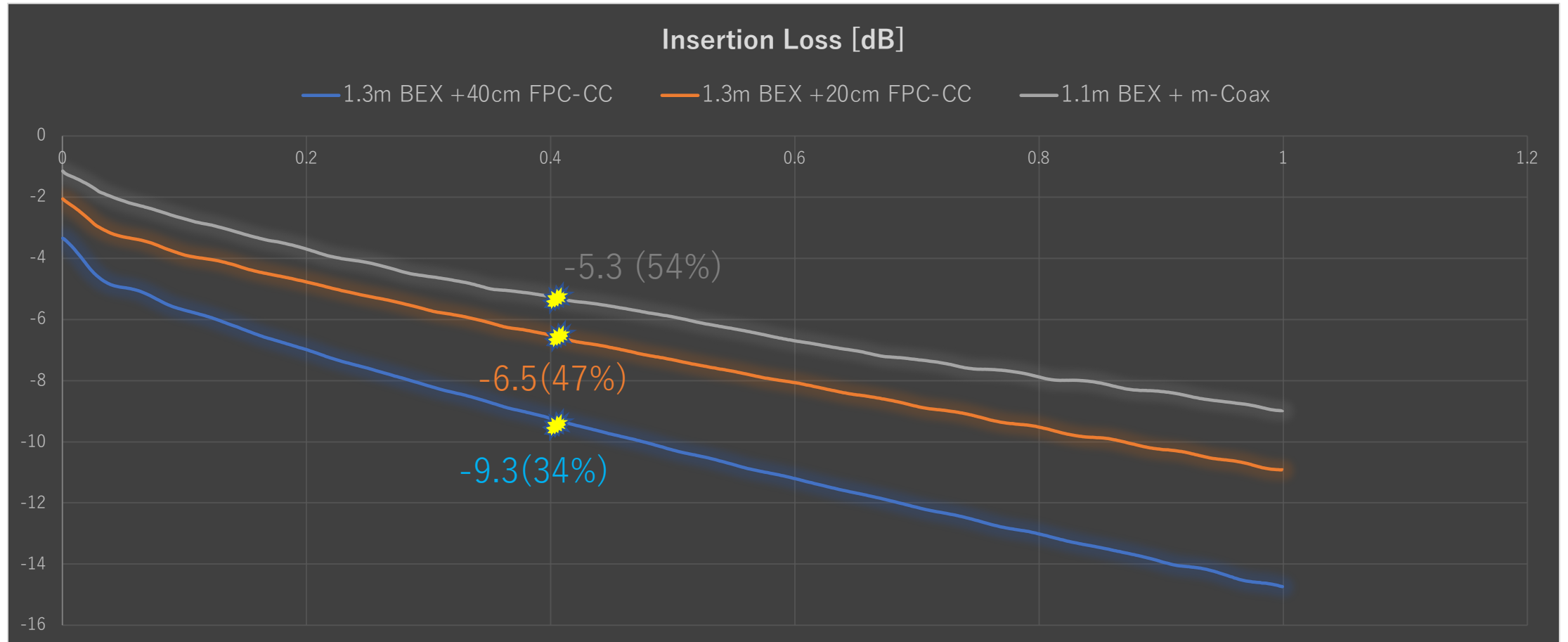


2021/8/4
1.3m Bus Extender + FPC Conversion Cable



2022/2/21
1.1m Bus Extender + μ -Coax Conversion Cable

Insertion Loss

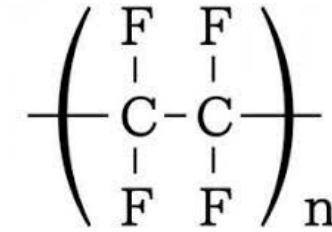


OK, the insertion loss is moderate than FPC as intuitively expected.

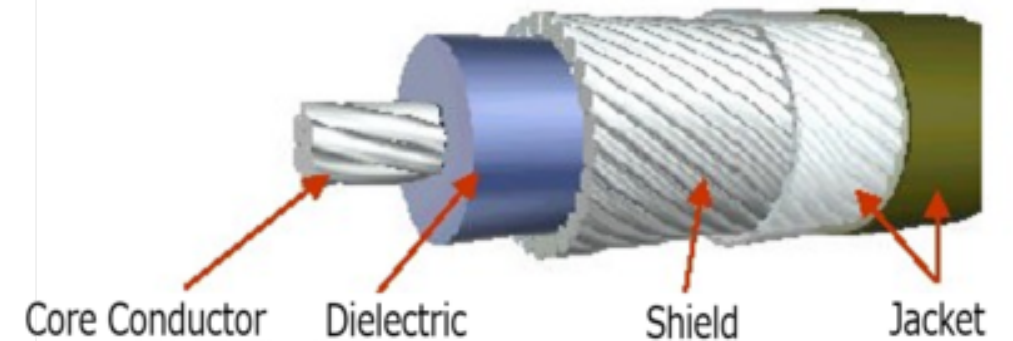
μ-Coax Cable Structure and Material

2. Construction and material Material Breakdown of micro-Coax

| Item | Unit | Specified Value |
|-----------------|-----------------------|---------------------------------|
| Inner conductor | Material | Silver plated Copper Alloy wire |
| | AWG size | 44 |
| | Stranding | No./mm |
| | Dia. (approx.) | mm |
| Insulation | Material | PFA |
| | Thick. (nom.) | mm |
| | Dia. (approx.) | mm |
| | Color | - |
| Outer Conductor | Material | Tinned copper alloy wire |
| | Type | Wrap(Right-hand lay) |
| | Strand Dia. (approx.) | mm |
| | Material | PFA |
| Jacket | Thick. (nom.) | mm |
| | Dia. (Max.) | mm |
| | Color | - |
| | | |



PTFE 化学式



PFA (フッ素樹脂) =パーフルオロアルコキシアルカン
 四フッ化エチレン・パーフルオロアルコキシエチレン共重合樹脂

Radiation Hardness of Fluoropolymer

<https://www.osti.gov/servlets/purl/1467983>

Dielectric material

Radiation Effects on Teflon Wires

LeRoy Whimery, Alexis Abelow, Wei-Yang Lu, Karla Reyes, Donald Ward, Dustin Murtagh, Zachary Meinhart, Nathalie Le Galloudec, Al Ver Berkmoes, Raymond Friddle

Problem

- Nuclear Safety Assurance asked a question along the lines of... "given that Teflon is the most radiation sensitive polymer used in NW, how do we know that the Teflon insulation of the wires exposed to radiation for decades is not flaking off leaving the conductors without adequate insulation?"
- Given the context, a quick study to find a preliminary answer was needed.

Approach

- Perform electrical testing to ensure wires are behaving normally
- Remove cables from MCF501
- Remove the outer sheath from the cable
- Examine the cable/wires for discoloration
- Band the wire(s), look for cracks and record images
- Cut and prepare sample for nano-indentation
- Strip wire(s) and tensile test Teflon only

Radiation Damage Mechanism

The mechanism of Teflon degradation by radiation has been well studied. No C-C peaks observed in FTIR

Polymer Radiation Sensitivity

Teflon is one of the most radiation sensitive polymers

Teflon Wire Bend Test

No cracks were observed when put in tension.

Nano-indentation

The hardness is calculated as the maximum load divided by the actual contact area made between the indenter tip and the material. Hardness is essentially the flow resistance a material is to deformation (elastic + plastic). The Modulus is the slope of the load-displacement curve upon unloading, divided by the rest of the contact area. So modulus is the ratio of elastic stress to strain.

Results

Tensile testing showed ~25% reduction in strength and a significant reduction in elongation to failure. Substantial variability was observed, particularly in the elongation. This variability may be due to flaws introduced during sample preparation. Additional testing is underway to provide better statistics.

| Sample | Material | Modulus (MPa) | Elongation (%) |
|--------|----------|---------------|----------------|
| PTFE 1 | PTFE | 1,250 | 2.35 |
| PTFE 2 | PTFE | 2,500 | 14.57 |
| PTFE 3 | PTFE | 5,000 | 23.15 |
| PTFE 4 | PTFE | 10,000 | 34.72 |
| PTFE 5 | PTFE | 30,000 | 68.44 |
| Empty | Empty | 5,000 | 23.15 |

Additional Dose Testing

Dosimeter Locations

Additional Radiation Exposure

- Expose the Teflon coated wires to additional radiation and examine their physical/mechanical properties.
- Determine how much additional exposure is needed to compromise their ability to provide electrical isolation.
- Samples are irradiated at the GJF using a Co-60 source.
- Dose rates from 10^3 rad/s to over 10^7 rad/s.
- Samples irradiated in an inert atmosphere (N_2).

Future Work

- High voltage breakdown and insulation resistance will be performed
- Additional radiation to look for a shift in the properties
- Vessels irradiated at GJF (AEG) (gamma)
 - 5mm/second (0.412 krad/hr)

Summary

- No discoloration was observed
- No cracking was observed upon bending (1/4" radius)
- Additional radiation did not show any differences in hardness or modulus
- Elongation of Teflon appears to be sensitive to radiation
- Need to perform more tensile testing for better statistics

Tensile Testing of Insulation Only

Conductor removal for tensile testing - a possible source of variability (flaws)

- Wire strippers were used to remove a small amount of insulation.
- Files were then used to grab the copper conductors.
- Sliding my grip down the wire many times allowed it to slowly release from the insulation and be removed.
- Gloves helped with gripping the Teflon.
- Care was taken to not pull too hard or too fast.

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Expose the Teflon coated wires to additional radiation and examine their physical/mechanical properties.

Determine how much additional exposure is needed to compromise their ability to provide electrical isolation.

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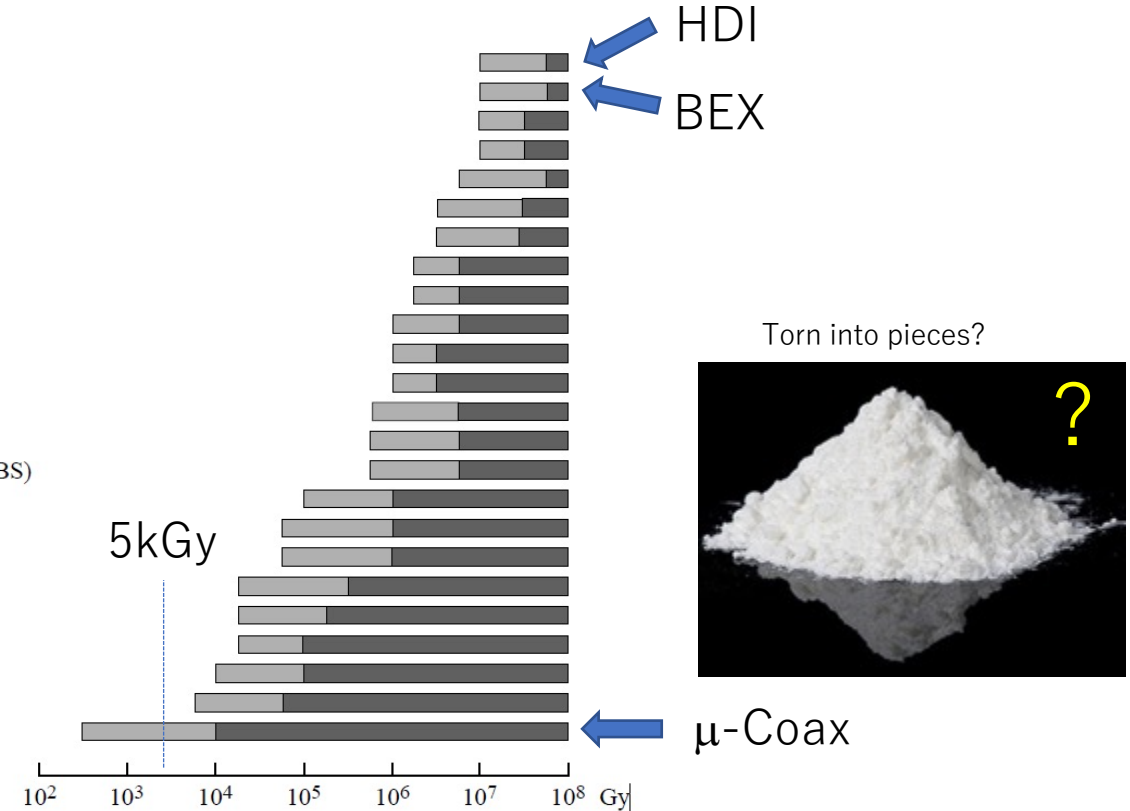
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hard

- Polyimide (PI)
- Liquid Crystal Polymer (LCP)
- Polyetherimide (PEI)
- Polyamideimide (PAI)
- Polyphenylsulfide (PPS)
- Polyetheretherketone (PEEK)
- Polystyrene (PS)
- Copolymer PI + siloxane
- Polyarylate (PAR)
- Polyarylamide (PAA)
- Polyethersulfide (PES)
- Polysulfone (PSU)
- Polyamide 4.6
- Polyphenyloxyde (PPO)
- Acrylonitrile-butadiene-styrene (ABS)
- Polyethylene (PE)
- Polyethyleneterephthalate (PETP)
- Polycarbonate (PC)
- Polyamide 6.6 (PA)
- Cellulose acetate
- Polypropylene (PP)
- Polymethylmethacrylate (PMMA)
- Polyoxymethylene (POM)
- Polytetrafluoroethylene (PTFE)



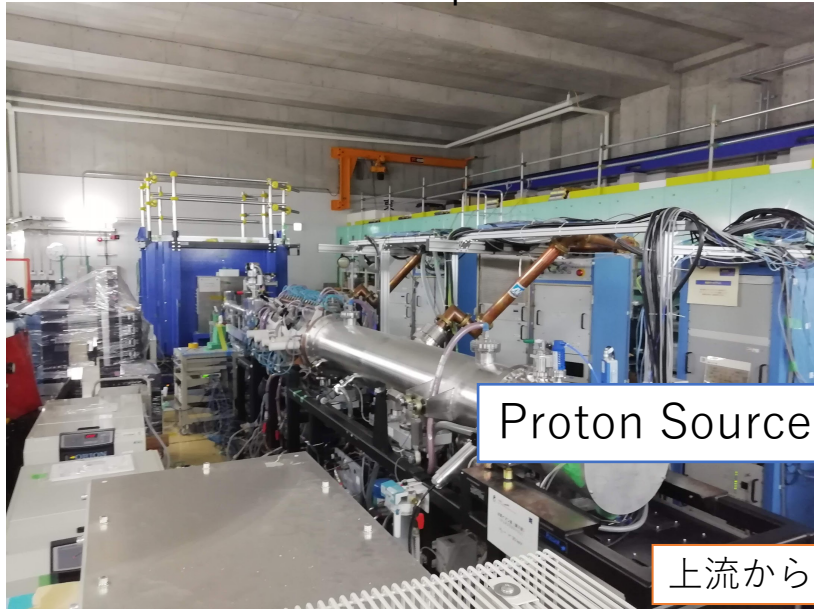
mild to moderate damage, utility is often satisfactory
 moderate to severe damage, use not recommended

In general, fluoropolymer is known to to be weak against the radiation

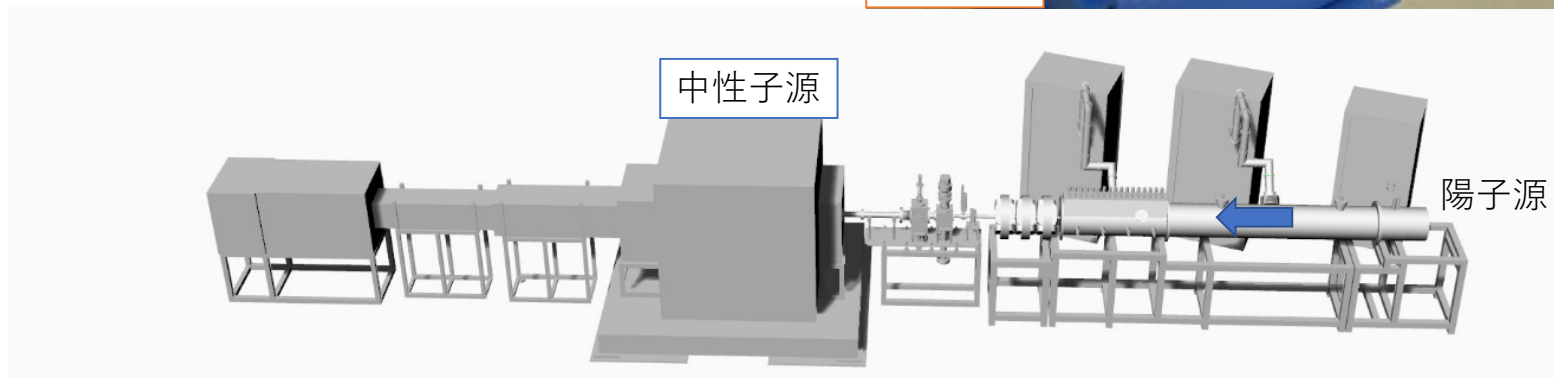
Radiation Test of μ -Coax

RIKEN Accelerator-driven compact Neutron Source: RANS

View from Upstream

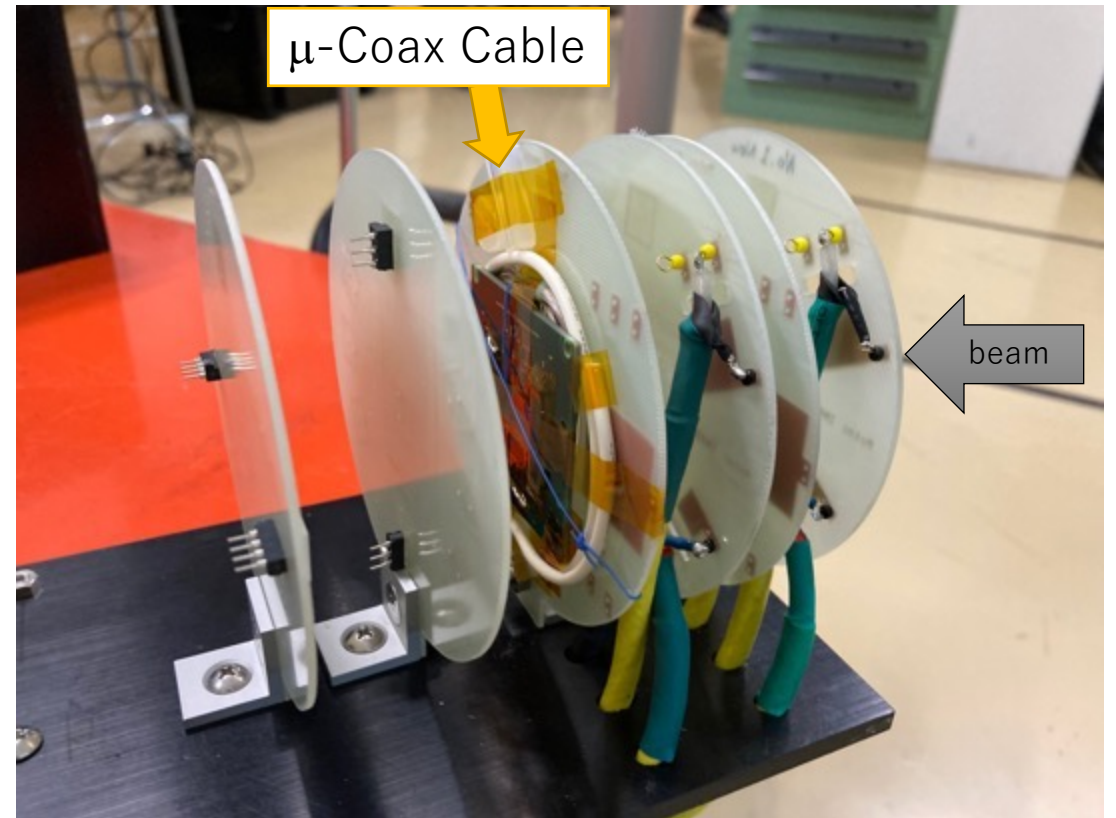
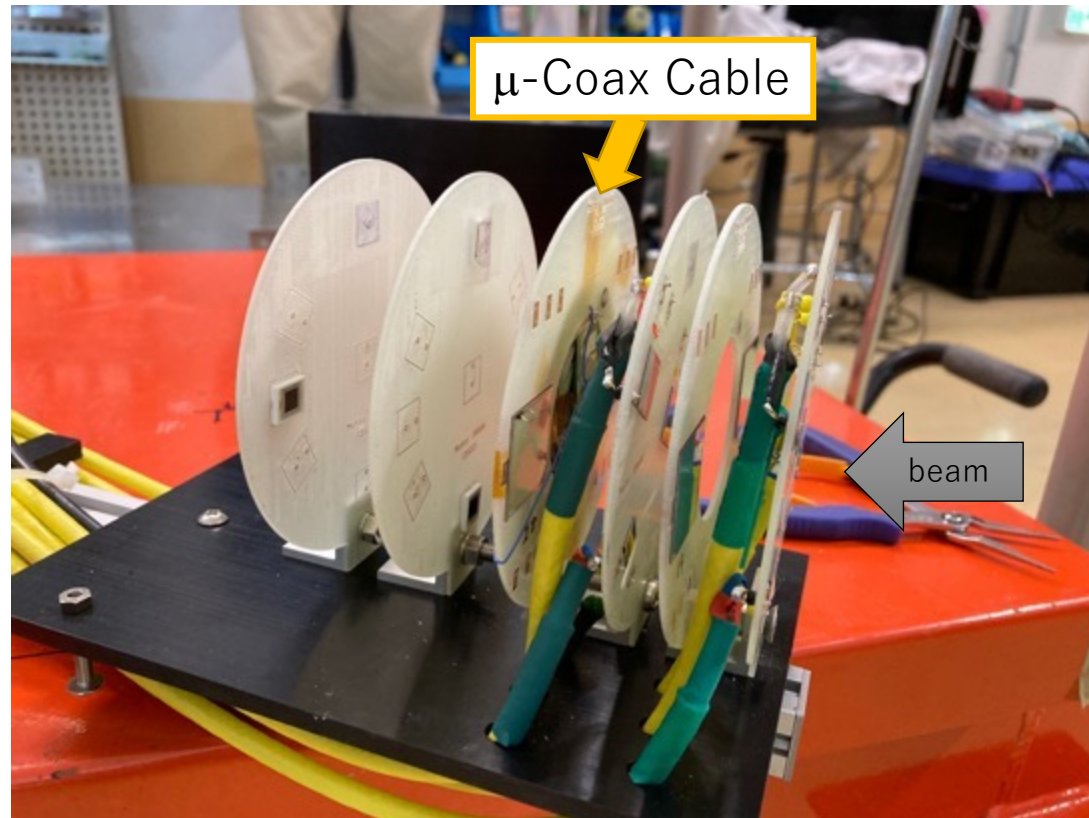


View from Downstream



Beam Time for FoCAL@ALICE project in March 3-4, 2022. (10 hours)

Disk Mount Setup with FoCAL Sensors



Irradiated 9 hours total.
Total Neutron Flux = 1.7×10^{13} neutrons

To be checked its performance afterword

INTT Production Schedule

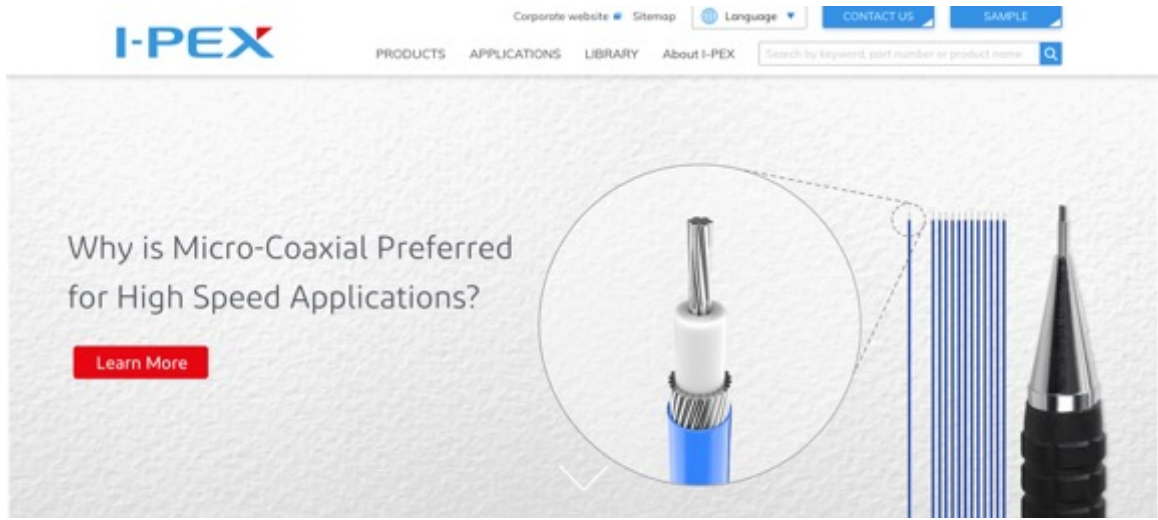
* Beyond 112 are spares

| 2022 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Qty* | Status |
|------------------|-------------|-------------|----------|---|-------------|---|-------------|------------------|------|------------|
| Silicon | | | | | | | | | 135 | Done |
| HDI | | | | | | | | | 176 | Done |
| Stave | | | | | | | | | 204 | Done |
| Bus Extender | | Batch-1(20) | | | Batch-2(40) | | | | 130 | Production |
| Conversion Cable | Prototype-1 | | Contract | | | | Batch-3(70) | | 130 | Prototype |
| | | | Contract | | Prototype-2 | | | | | |
| | | | | | | | | Production (130) | | |
| Barrel Assembly | | | | | | | | | 1008 | INSTALL |



Due to the supply chain crisis these days, KEL's lead time is at least 6 months. This is not gonna fit with out INTT construction schedule.

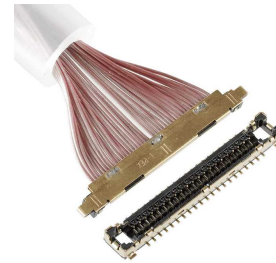
Alternative μ -Coax Model



| | |
|-------------------------|--|
| Trade Name | I-PEX Inc. |
| Date of Incorporation | July 10th, 1963 History |
| President | Takaharu Tsuchiyama Top Message Board Members |
| Head Office | 12-4 Negoro, Momoyama-cho, Fushimi-ku, Kyoto, JAPAN 612-8024 |
| Paid-in Capital | 10.968 billion yen (as of December 31, 2021) |
| Consolidated Net Sales | 66.8 billion yen (ended December 31, 2021) |
| Stock Exchange Listings | 1st Sec., Tokyo Stock Exchange (Code: 6640) Investor Relations |
| Head Count | Consolidated: 5,667 (as of December 31, 2021) Non-Consolidated: 1,972 (as of December 31, 2021) |
| Group Companies | Japan: 4 (Including I-PEX Inc.) Overseas: 17 Network |
| Business Operation | Connectors & Electronics Components Business Automotive Electronics & Associated Components Business Semiconductor Mfg. Equipment and Other Business |

CABLINE[®]-UX II

Slim design suitable for through-hole solution, narrow pitch (0.25 mm), Right angle vertical mating type micro-coaxial connector



- ✓ Suitable for small connector spaces.
- ✓ Slim plug design, suitable for through-hinge assemblies.
- ✓ EMI shielding and multi-point ground design.

Pin counts:

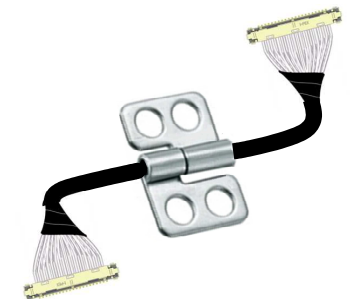
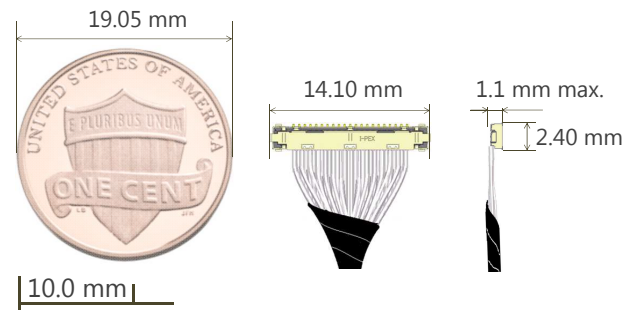
| | |
|-----------|----------------|
| Range | Up to 50 |
| Available | 30, 34, 40, 50 |

*Please inquire for pin counts not listed or outside of the pin count range.

| | | |
|------------------------------|------------------------|--|
| Mating type | Right angle vertical | |
| Wire (FPC) pitch (mm) | 0.25 | |
| Board pitch (mm) | 0.5 | |
| Mated size (mm) | Height | 1.0 +/- 0.1 |
| | Width Formula | 4.1 + (0.25*p) |
| | Depth | 2.40 |
| Wiping length (mm) | 0.20 | |
| Applicable wire (AWG#) | Micro-coax for signals | 45ohm : #44 or smaller 50ohm : #46 or smaller |
| | Twincoax | - |
| | Discrete | #39 or smaller |
| Contact point | - | |
| Performance (Reference only) | | USB 3.1 Gen 1 (5 Gbps) |
| | | V-By-One HS 1.4 (4 Gbps) |
| | | HDMI 1.3 (3.4 Gbps) |

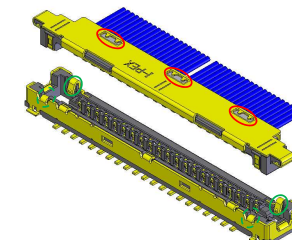
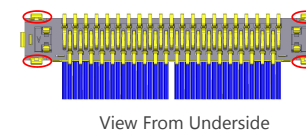
Suitable for Small Connector Spaces

CABLINE-UX II 40p size is smaller than a one-cent coin.



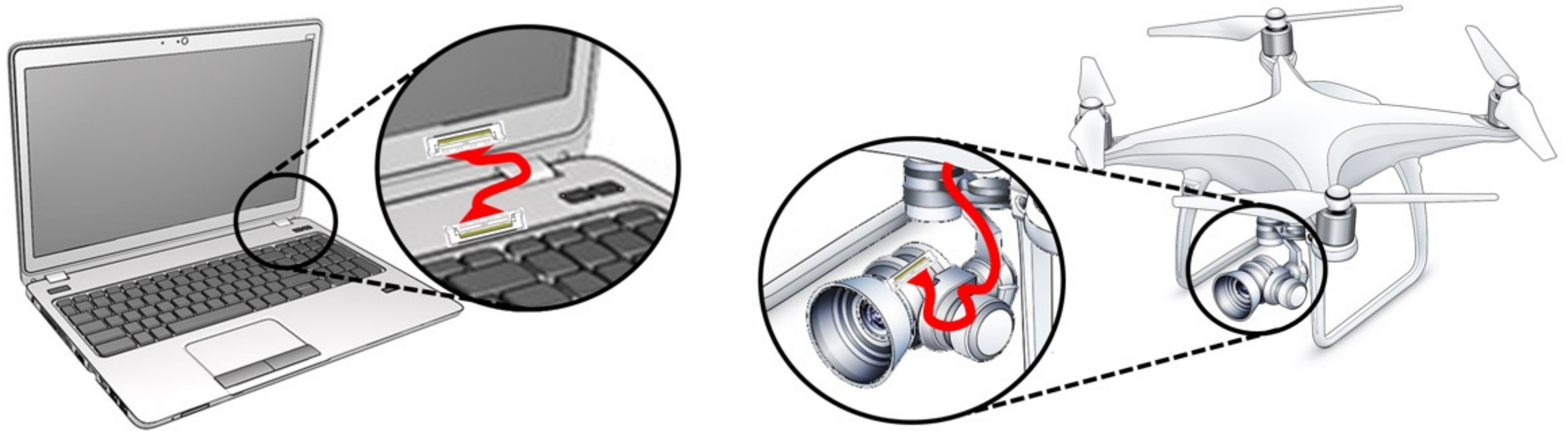
Flexible micro-coaxial cable harness is suitable for small applications with a hinge design.

EMI Shielding and Multi-point Ground Design



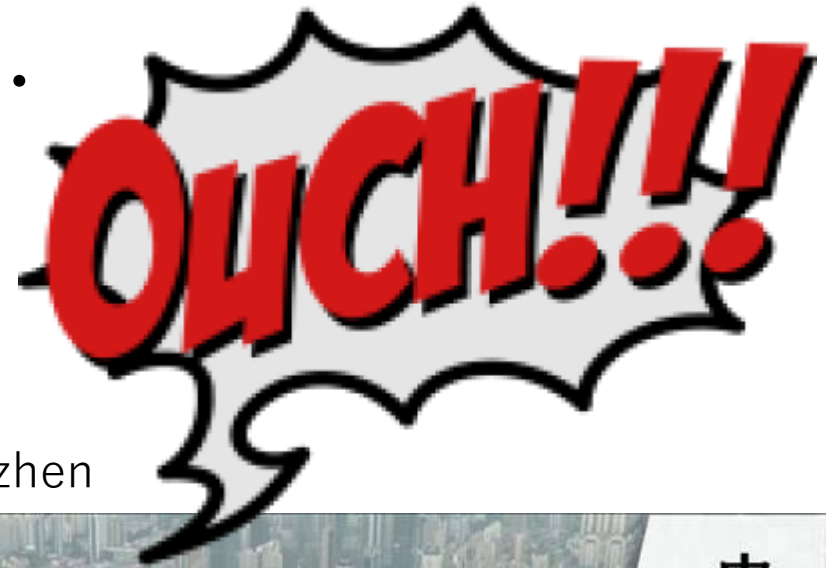
Lead time is 1 month

Market Share of I-PEX μ -Coax Product



I-PEX Dominates world's market

Catching Up Schedule, but ...



Factory is in Shenzhen

★ 中文版 | ★ English

神宇股份 SHEN YU COMMUNICATION

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PRODUCT 产品中心

High-end stationary phase cables

Microwave low loss cable

Semi rigid cable

Fine coaxial radio frequency cable

Very thin radio frequency coaxial cable

High speed data line

Radio frequency cable components customized

Fine coaxial radio frequency cable

- 1.中心导体: 神宇电缆使用的中心导体为铜镀银, 表面电镀的银确保了最佳的长期高频传输性能和耐高温特性
- 2.介质: 神宇电缆使用了聚四氟乙烯 (PTFE) 或氟化乙丙烯 (FEP) 作为绝缘体, 相比聚乙烯是一种有更好的高频性能、更佳的可弯曲性、更高耐温的绝缘材料
- 3.外导体: 神宇电缆的外导体采用了镀银铜线或镀锡铜线编织, 特点是柔软, 加工方便, 耐温高也满足了连接器安装时压接和焊接的需要
- 4.护套: 神宇电缆的护套选择氟化乙丙烯 (FEP) 具有耐温200°C, 表面光滑耐磨, 适合于狭小空间的通过, 天生的抗紫外线、不降解、防盐雾、等优异特性。

RF radio frequency coaxial cable

RG & MICRO-COAXIAL SERIES

- SFF-75-1.5-2
- SFF-75-1.5-1
- SFF-50-7-2
- SFF-50-3-1

+More

RG radio frequency coaxial cable

RG & MICRO-COAXIAL SERIES

- RG400 (50Ω)
- RG316 (50Ω)
- RG302 (75Ω)
- RG180 (50Ω)

+More



March 2022

Still unclear if we can be in time ...

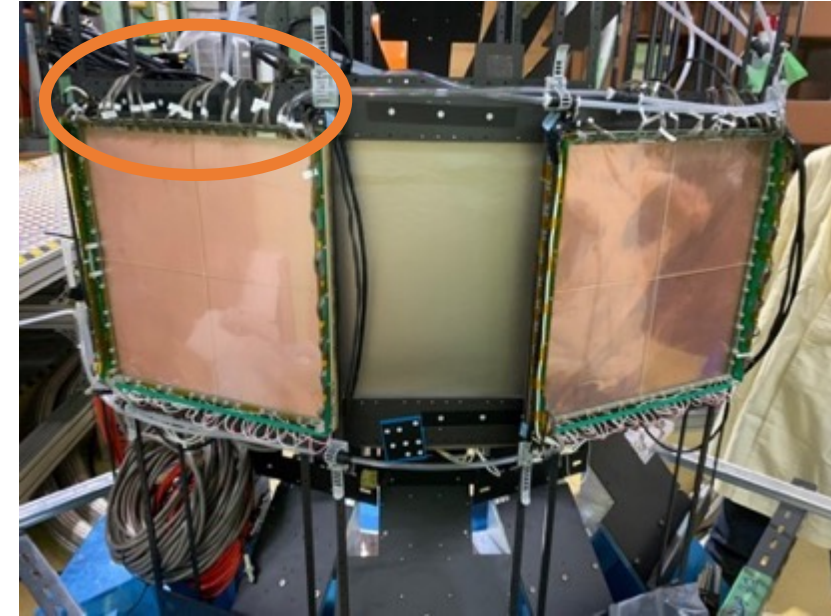
Summary

- The conversion cable was re-designed with μ -coax cable technology from FPC.
- The prototype-I demonstrated reasonable performance compared to FPC.
- Radiation test is ongoing.
- Switched the model from KEL's XSL to IPEX's UX-II to avoid severe delay of the mass production.

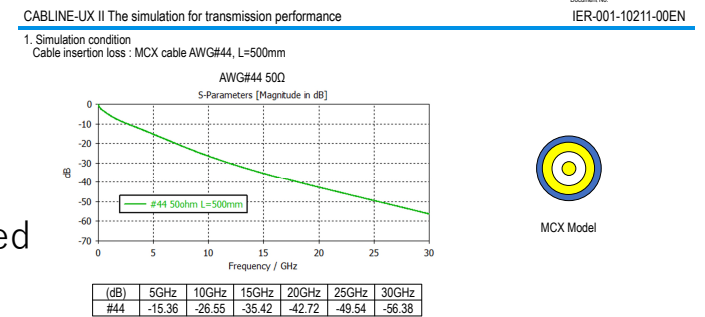
backup

The reason of XSL(KEL) as the first choice

1. It was used in E16 experiment at J-Parc and survives radiation (7.2Gray)
2. Fabrication experience of connector boards in Hayashi Repic.
3. Free samples were available.
4. KEL was willing to provide detailed signal transmission performance data.

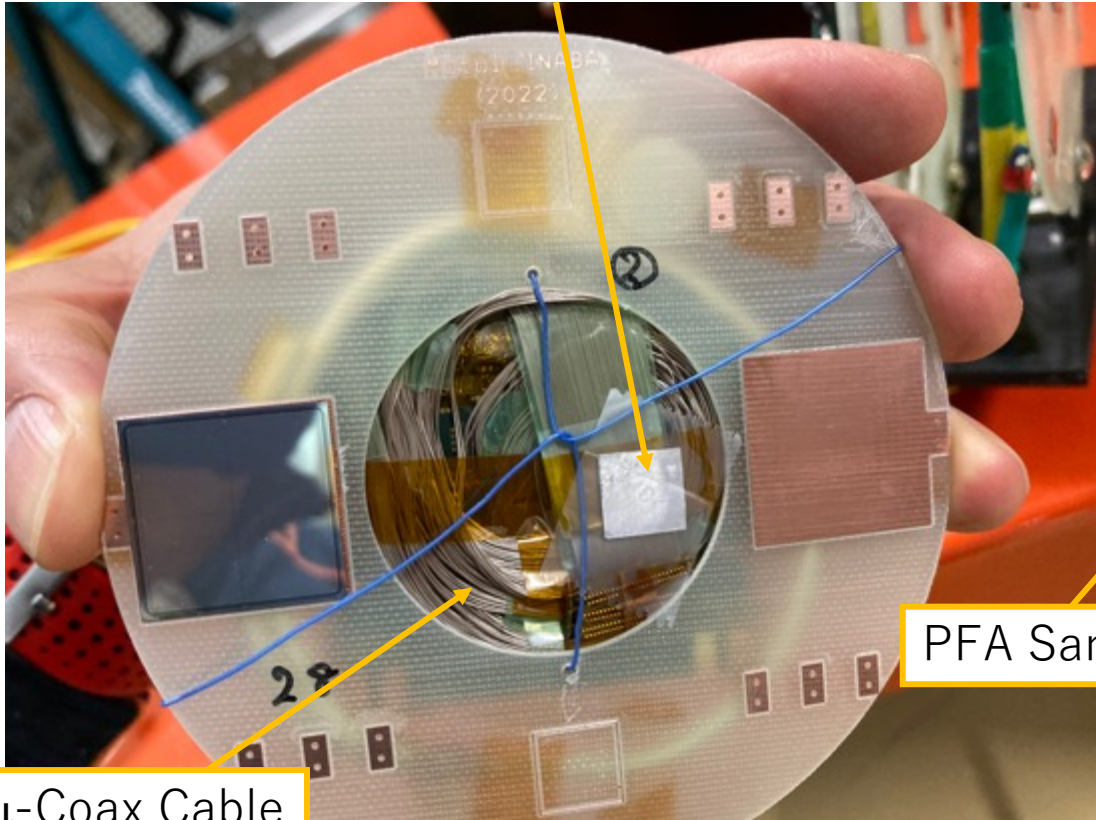


The performance data provided by I-PEX was too coarse



Prototype-1 Cable Setup

Indium foil for absolute neutron flux measurement

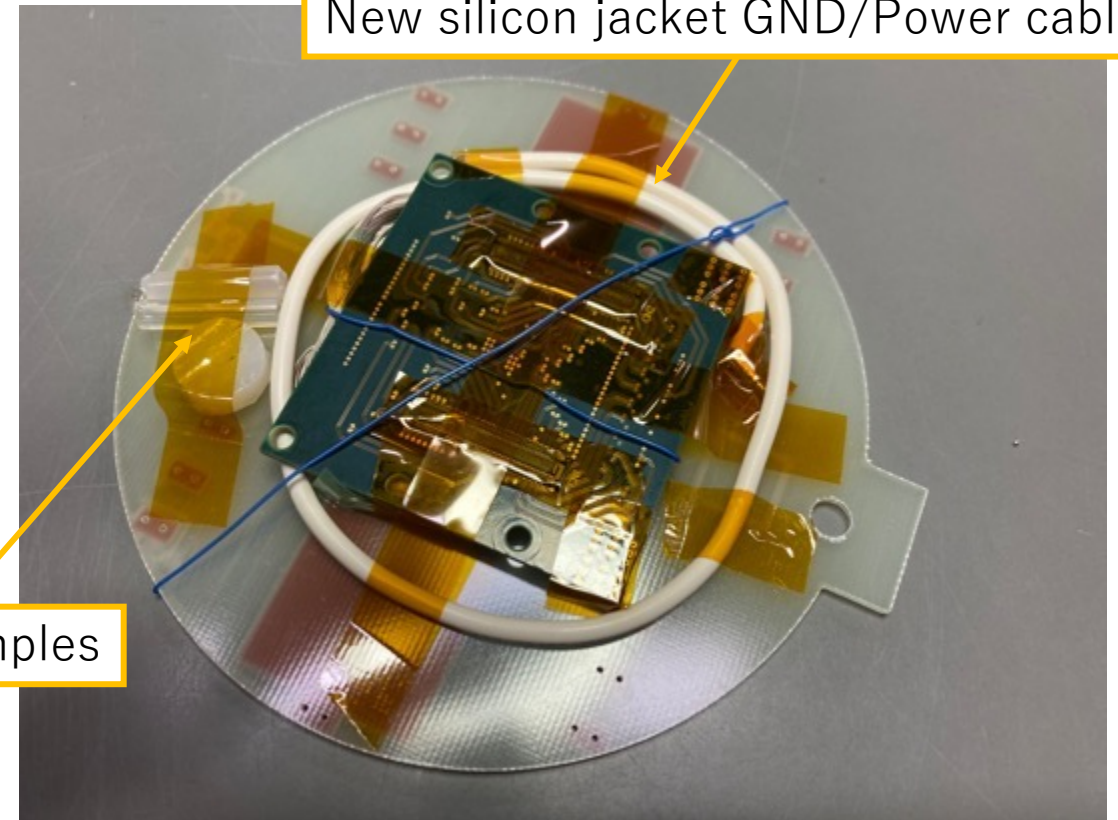


PFA Samples

μ-Coax Cable

Attached to the disk (Front View)

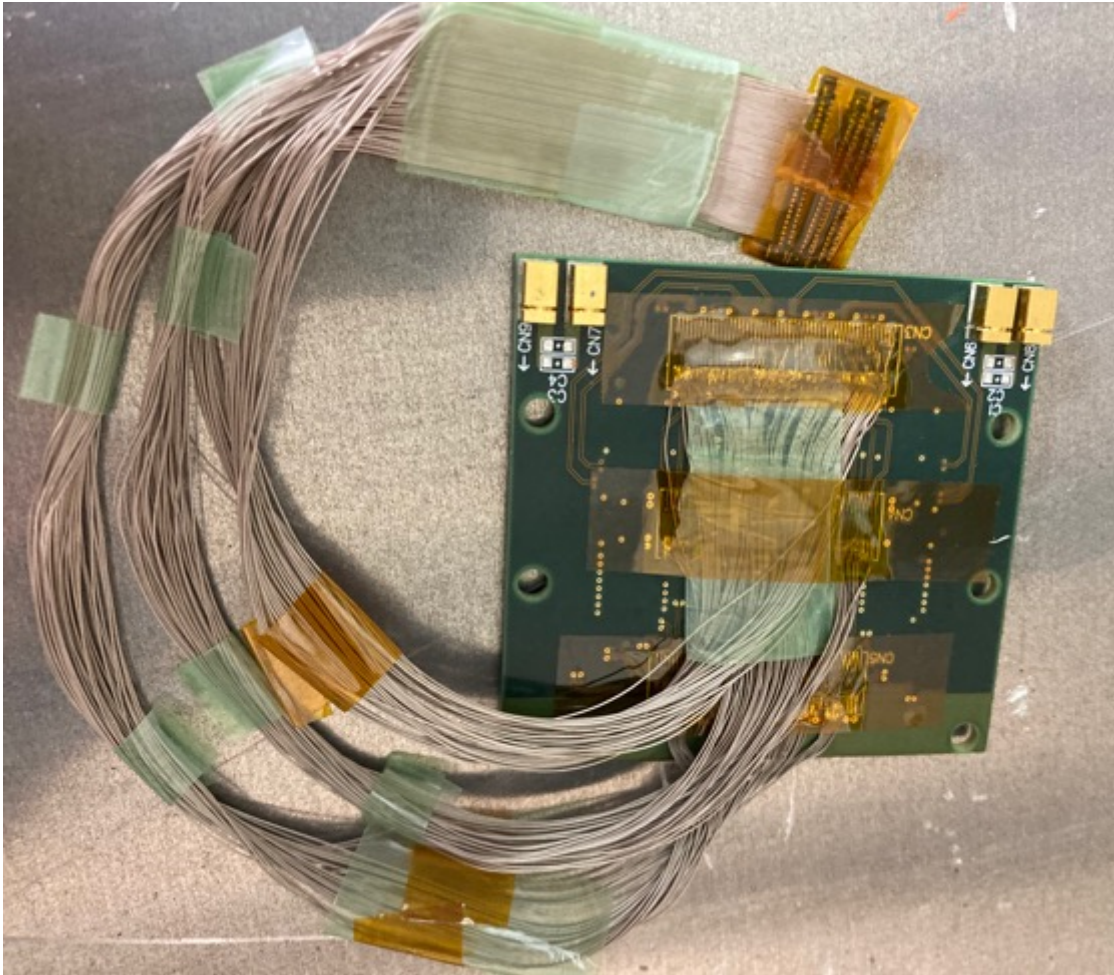
New silicon jacket GND/Power cable



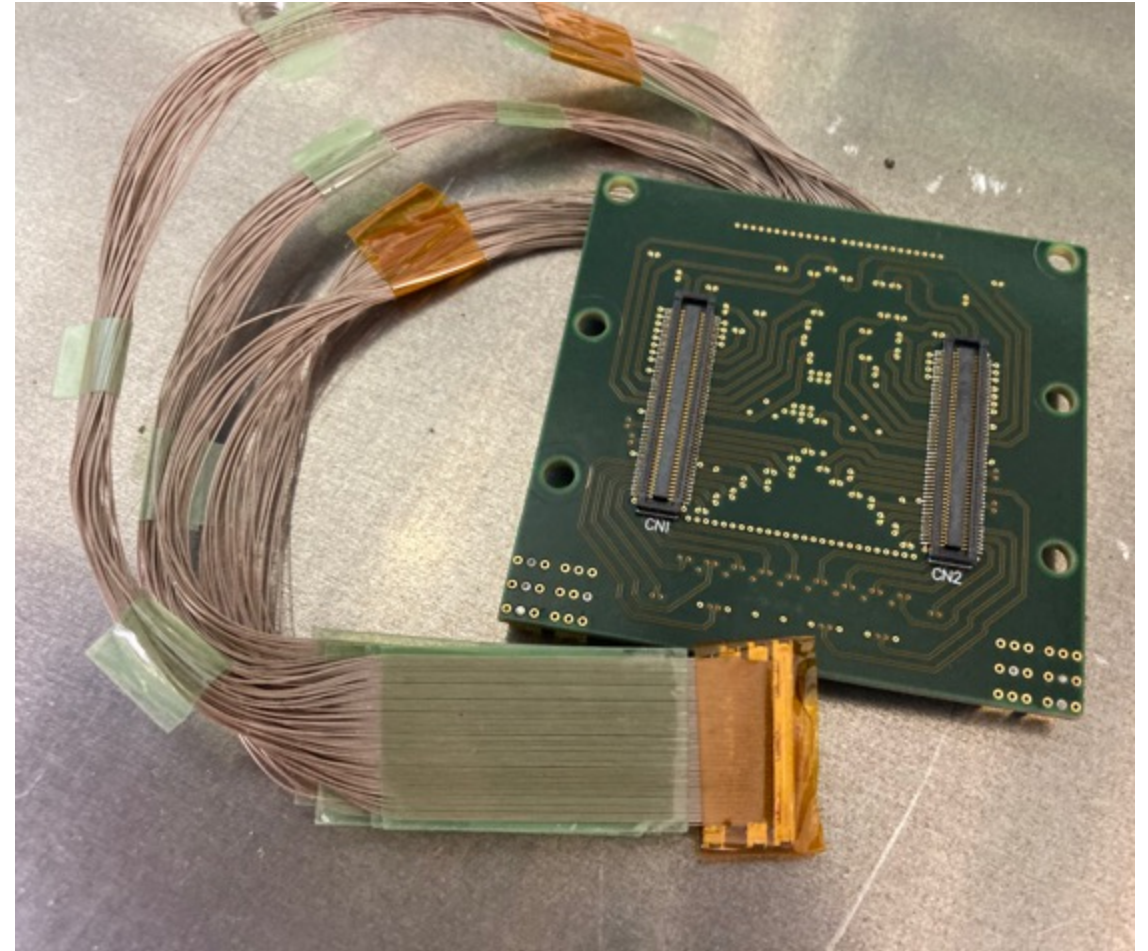
Attached to the disk (Back View)

Radiation Damage

After



After



No visible damage is observed after the irradiation.

Summary

- Prototype-I μ -coax conversion cable was irradiated for 1.7×10^{13} neutrons.
- No obvious damage has been observed after the irradiation at least visibly.
- The prototype-I cable is planned to be taken out from the radiation area and be tested again its performances.
 - sParameter and TDR in TIRI (April)
 - Stability data acquisition test with 1.1m BEX + μ -Coax at RIKEN (March ~ April)

Radioactivity Measurements

- March 4th : End of Neutron Exposure
- March 14th : 2.6 kcpm
- April 8th : 370 cpm

Requirement < 100 cpm

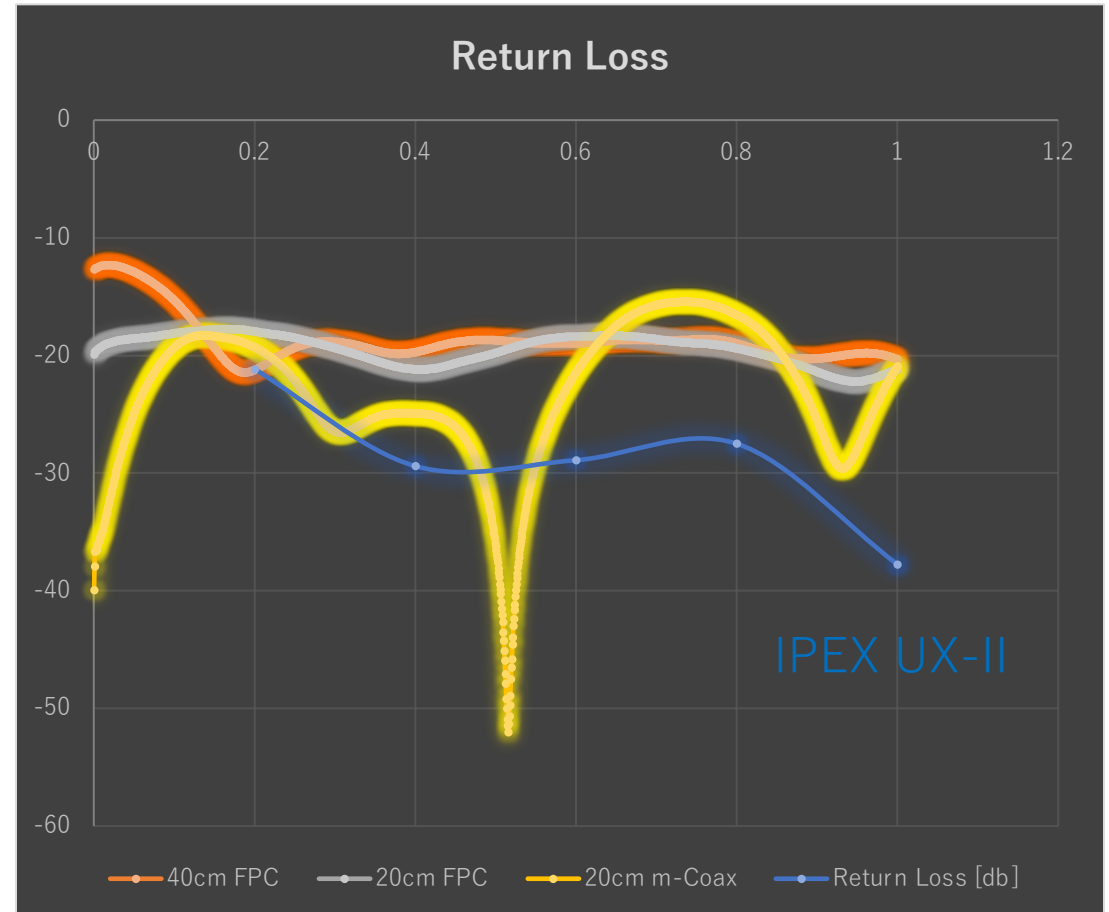
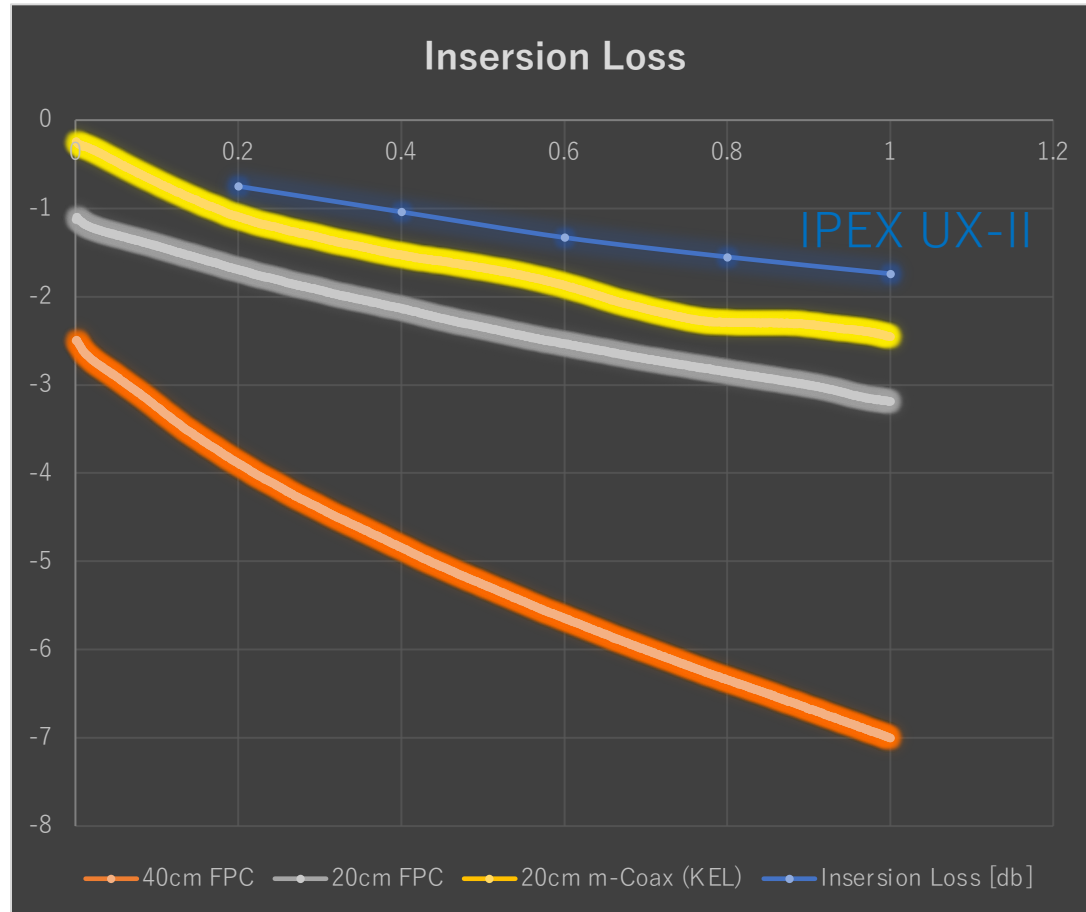


Another 1 ~ 2 weeks before we can take the prototype-I out of RANS experimental site.

いつまでも管理区域内に安置できない。ケーブルの材質の材質毎に放射化については調べてくださいますとの要請が来ています。



sParameter Comparison



Specification Comparison (Executive Summary)

High Frequency Signal Transmission Performance @400MHz

| | FPC | | KEL XSL | | | | IPEX UX-II |
|-----------------------------|----------------|-----|---------|------------|----|----|------------|
| Length [cm] | 20 | 40 | 10 | 10 | 20 | 30 | 50 |
| AWG | N/A | N/A | 46 | 44 | | | 44 |
| Impedance [Ω] | 50 | 50 | 50 | 45 \pm 3 | | | 50 |
| Diff Impedance [Ω] | 110 | 110 | 93 | 83 | | | |
| Insertion Loss [%] | 80 | 56 | 84 | 90 | 84 | 80 | 88 |
| Return Loss [%] | 10 | 20 | 25 | 18 | | | 3 |
| Cross Talk [%] | <12* | | 1 | | | | |
| Eye Diagram | similar | | similar | | | | |

*20cm conversion cable with bus extender

Conclusion

There is no data available for the exactly same condition between FPC and μ Coax cables. Presumably 20cm FPC can be compared to XSL-AWG46-10cm and XSL-AWG44-20cm. Resulting performances look similar within 20cm. To be executed actual measurement once prototype is made. Hard to extrapolate the performance to 1.41m, need to wait for the actual measurement.