Final Design and Safety Review of the INTT Ladder and Barrels

Ladder Electronic Components

WBS: 3.01

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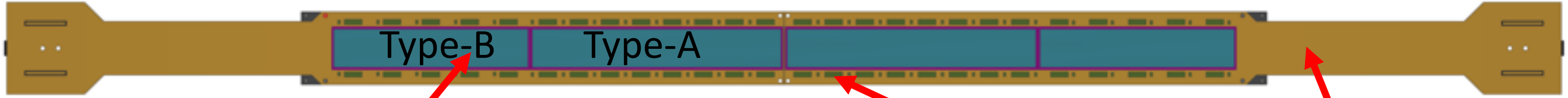
March 2, 2021

Ladder Electric Components Overview

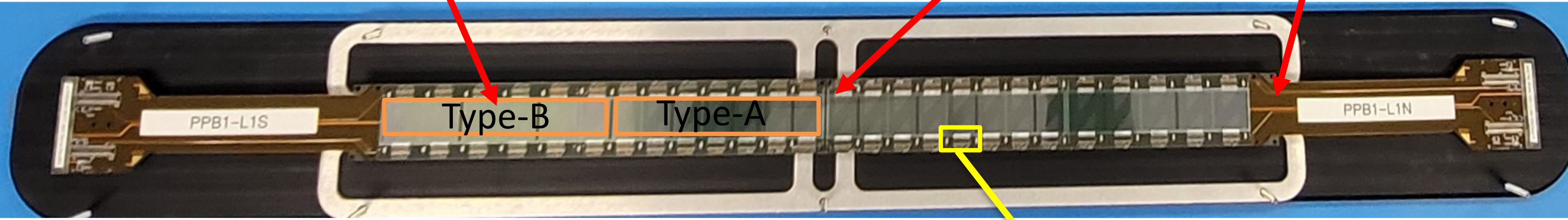
INTT Full Ladder



1. Silicon strip sensors

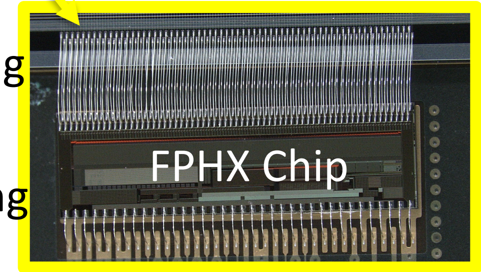
2. FPHX Chips

3. HDI Readout Cable



Wirebonding
(silicon-FPHX)

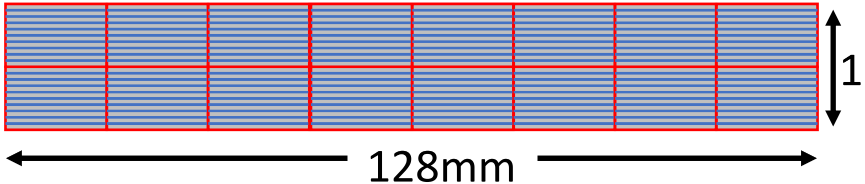
Wirebonding
(FPHX-HDI)



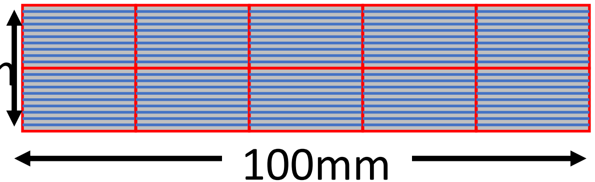
HDI

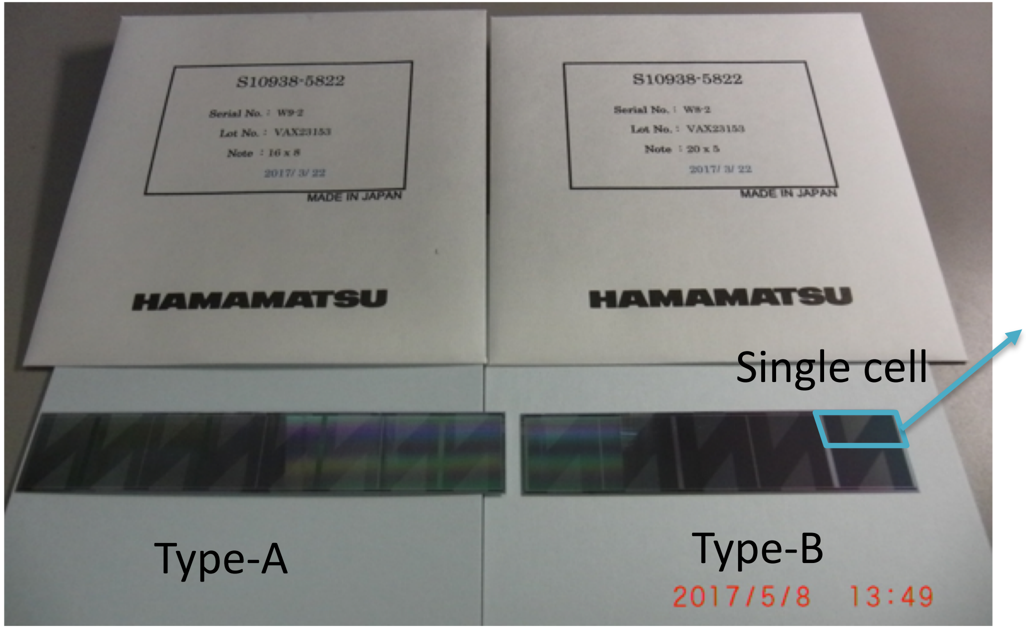
Silicon Strip Sensors (Hamamatsu)

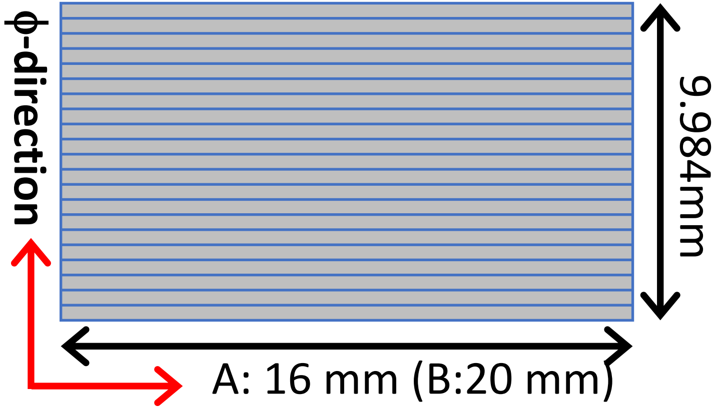
Type-A (8 x 2 cells)



Type-B (5 x 2 cells)







Single cell geometry (active region):

128 strips (better resolution in ϕ-direction)

Strip width = 78 μm

ϕ-length = 78 μm x 128 strips x 2 cells =19.97 mm

z-length = A: 16 mmx 8=128 mm

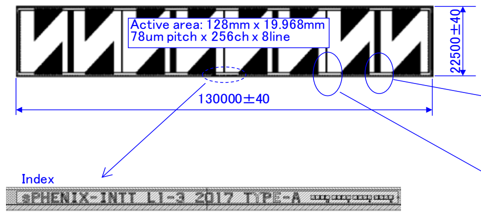
B: 20 mm x5=100 mm

Silicon Strip Sensors (Hamamatsu)

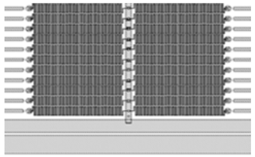
Tracking System: MVTX+INTT+TPC

Type-A

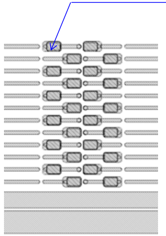
see fig.A



bias resistors



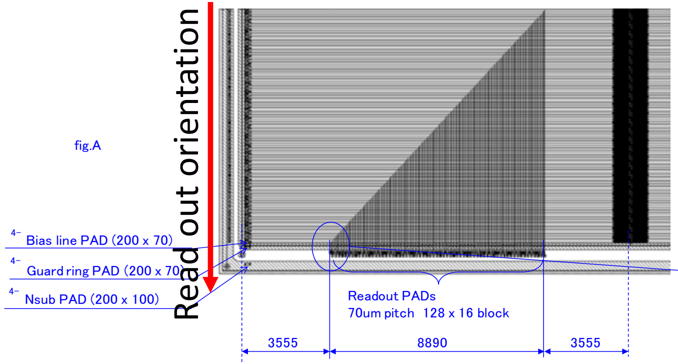
DC PADs(for Inspection)

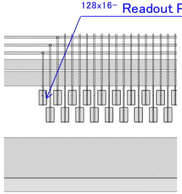


Strip orientation

Read out orientation

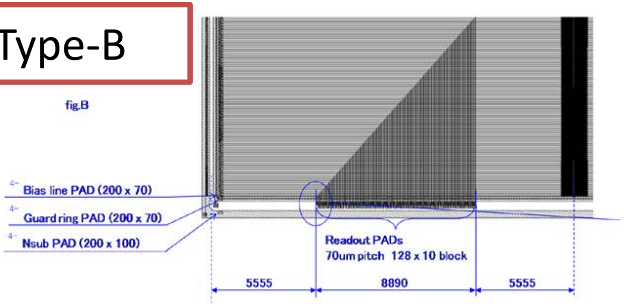
fig.A

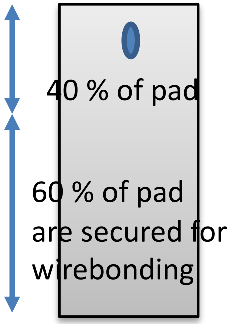




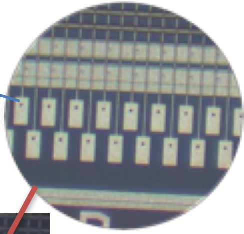
Type-B

fig.B

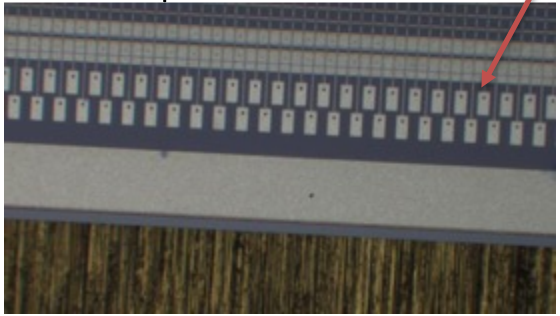




probe trace



AC readout pads

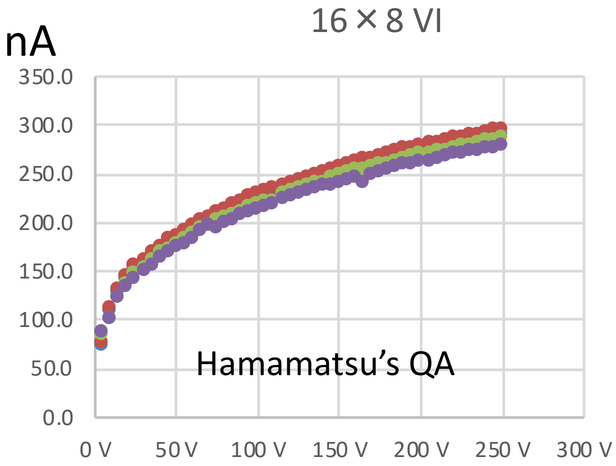


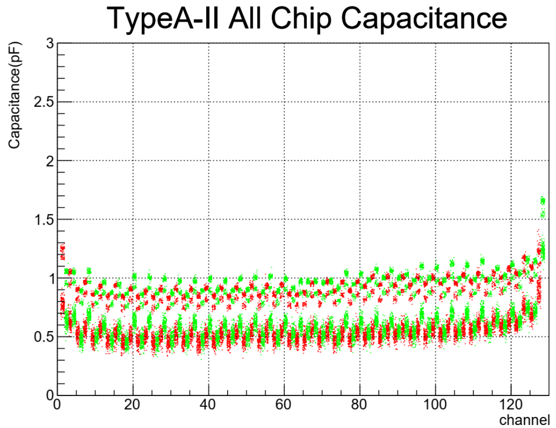
Silicon Quality Assurance (HPK/NCU)

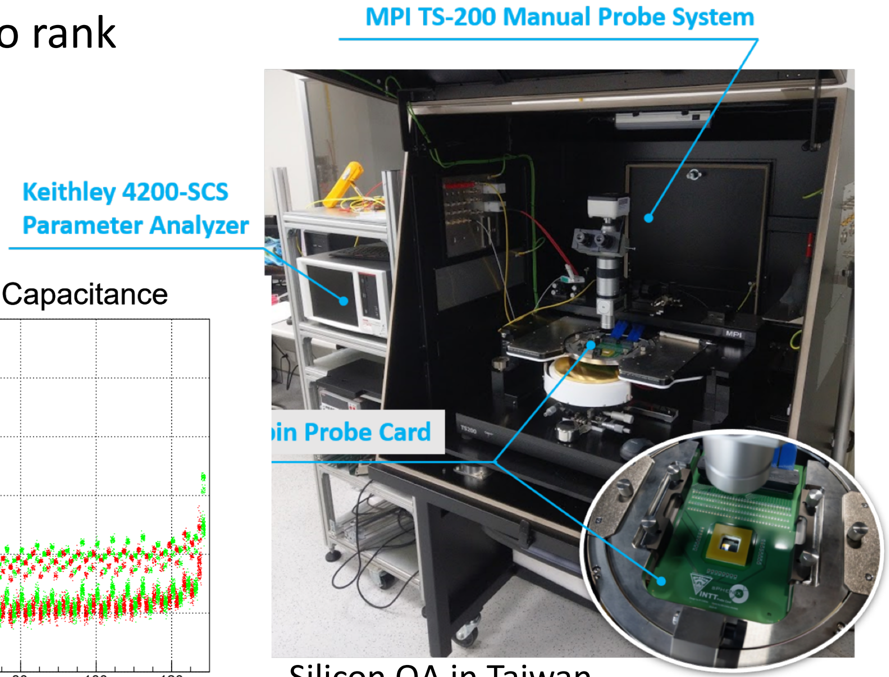
STEP1 Sensor by sensor performances (IV, CV) are measured Hamamatsu co. before delivery.

STEP2 Strip by strip performances are further evaluated in Taiwan for 20% fraction of silicon sensors

STEP3 QA results are kept in DB to be referred to rank ladder performance. So far most of silicons are confirmed to be good quality.







Silicon QA in Taiwan

FPHX Chip/Produced by FNAL

Developed for Forward Vertex Detector for PHENIX at Fermi Lab.

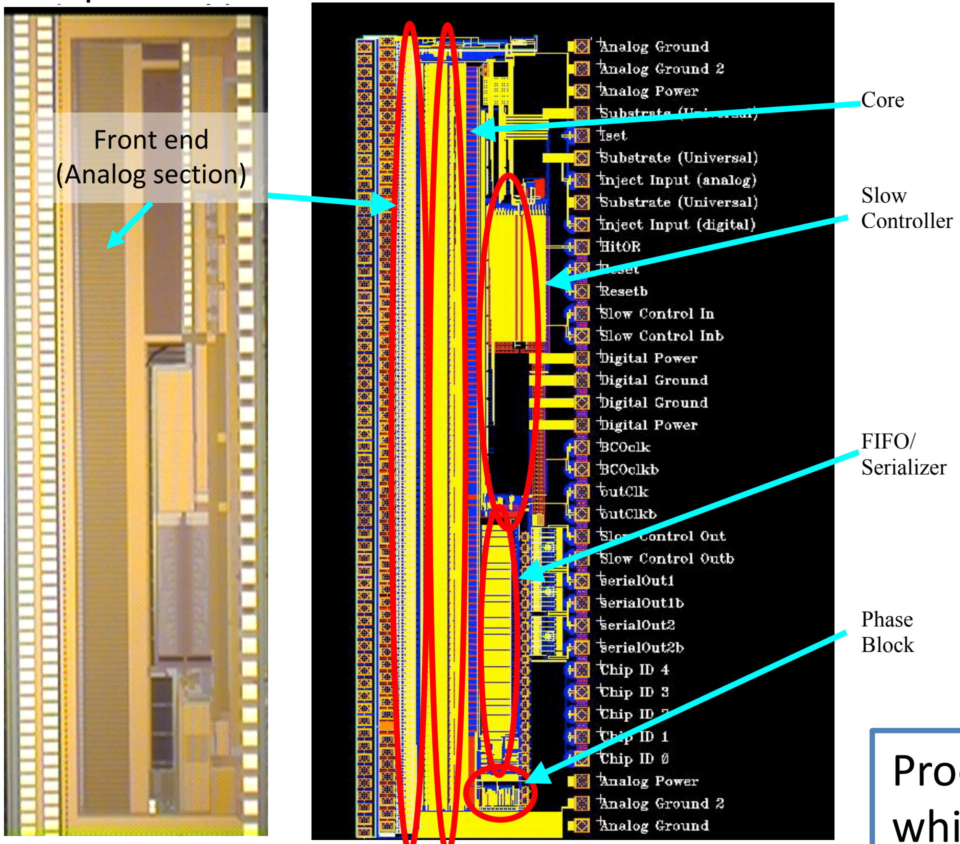


Figure 3 - The FPhx Layout

Specification	FPHX
ADC/channel	3 bits
Operation Voltage	2.5V
Power Consumption	64 mW
Number of channels	128
Data Transmission	200Mbps

Each FPHX chip integrates and shapes (CR-RC) signals, digitizes and sparsifies the hit channels each beam crossing (106ns beam clock), and serially pushes out the digitized data.

Production 13k FPHX Chips in 2018&2019 while 3k needed for 56 ladders.

FPHX Chip (Analog Section)

Tracking System: MVTX+INTT+TPC

128 channel

46, 50, 60, 67, 85, 100, 150, or 200 mV/fC

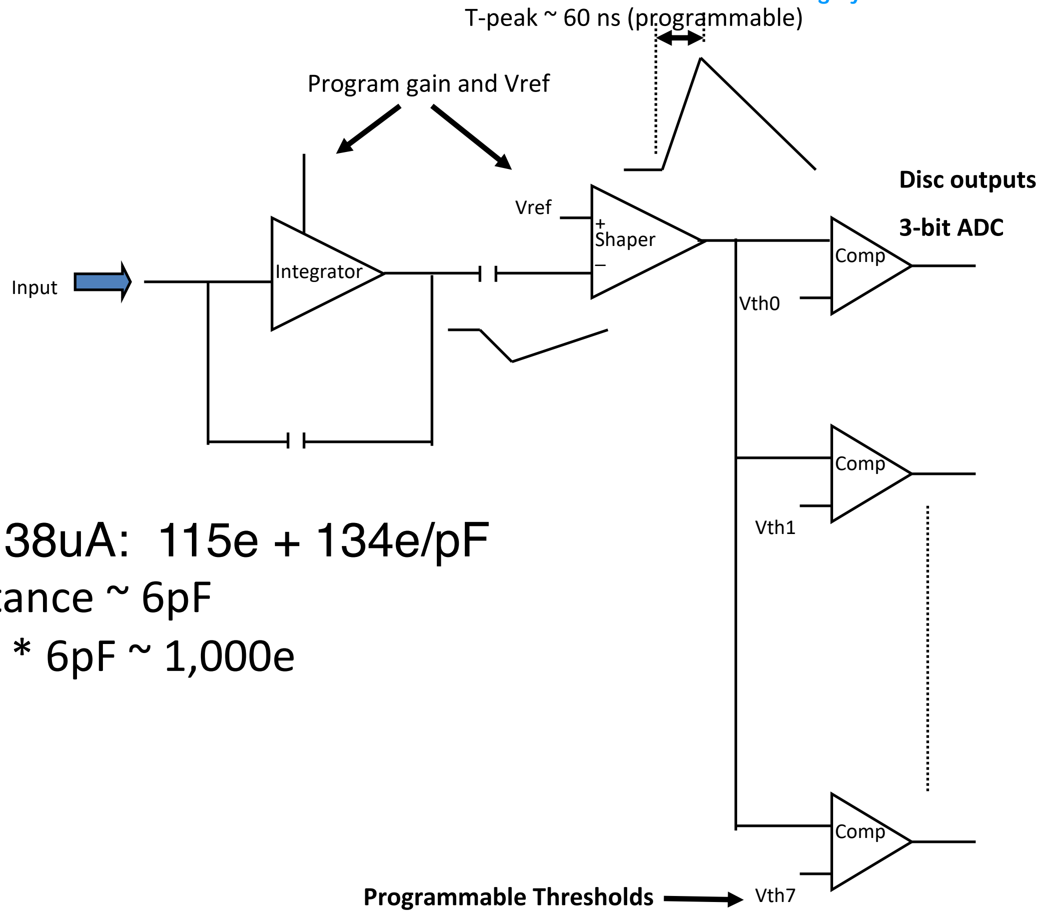
60 ns peak time (rt- pgmbl)

3—bit ADC (th-pgmbl)

Optimized to 1 to 2.5 pf input

115e + 134e/pf

~ 70 to 140 μW/ch (dep. gain)



At max. input transistor bias of 38uA: 115e + 134e/pF

Silicon strip + readout line capacitance ~ 6pF

Predicted noise ~ 115e + 134e/pF * 6pF ~ 1,000e

Signal ~ 20,000e

Expected S/N ~ 20/1

FPHX Chip (Digital Section)

Data push architecture

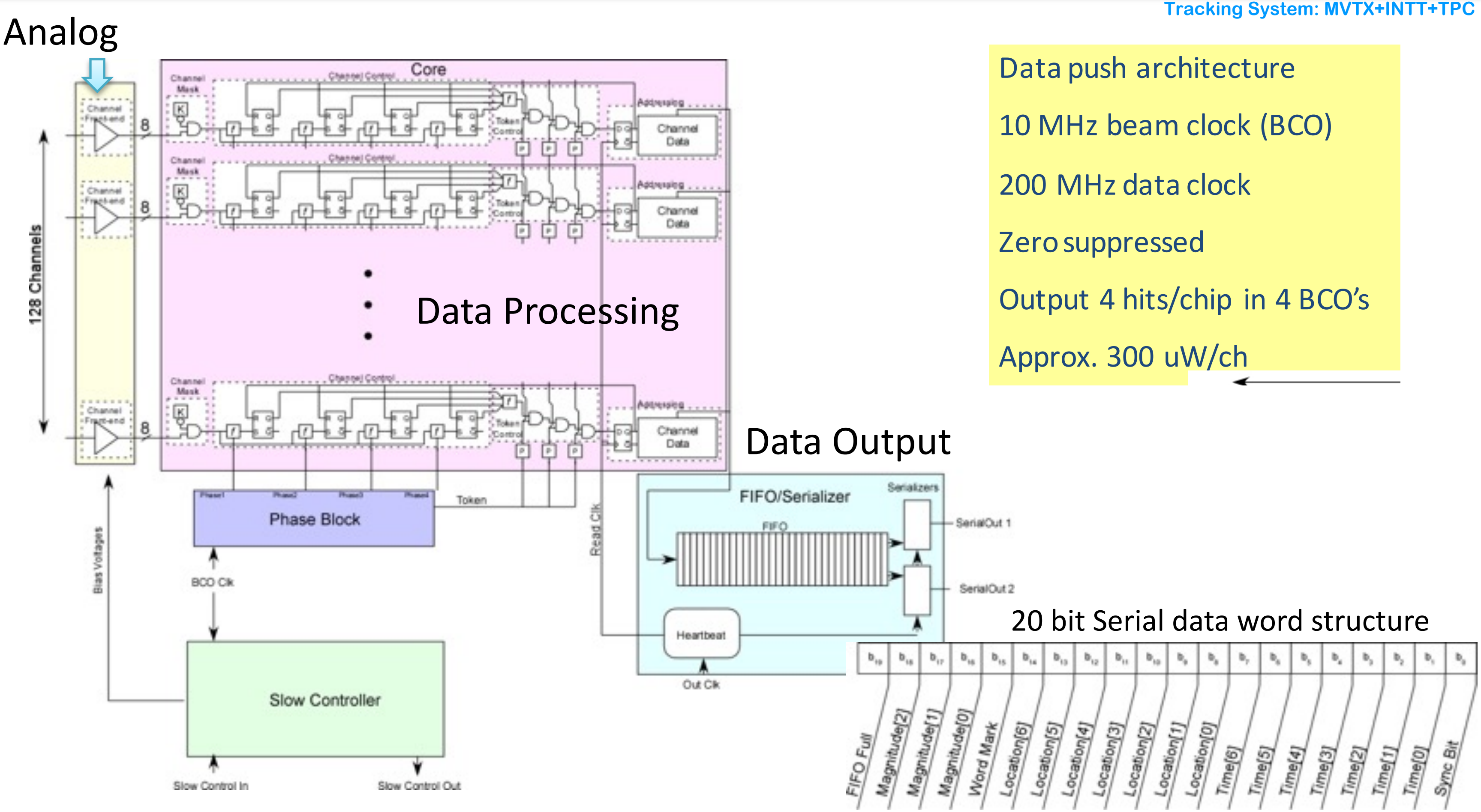
10 MHz beam clock (BCO)

200 MHz data clock

Zero suppressed

Output 4 hits/chip in 4 BCO's

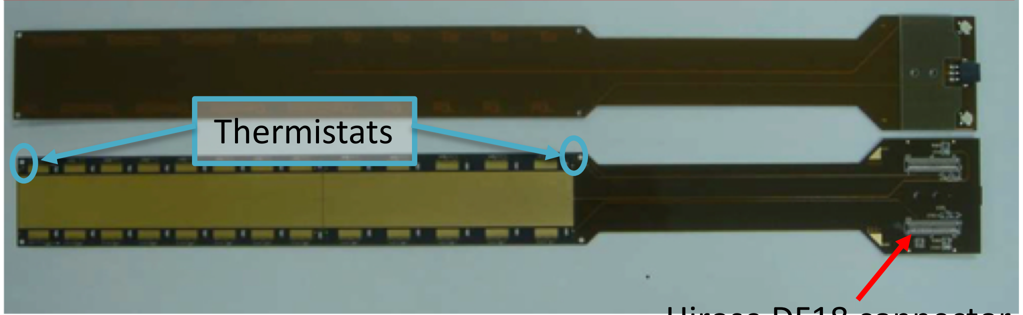
Approx. 300 uW/ch



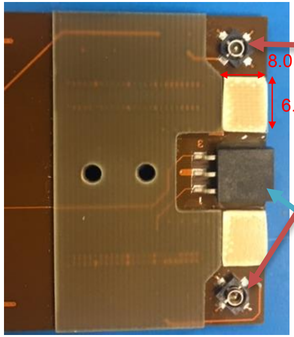
High Density Interconnect (HDI) Cable

Tracking System: MVTX+INTT+TPC

INTT HDI (Manufactured by Yamashita co., Japan)



Hirose DF18 connector
Data, slow control, FPHX power



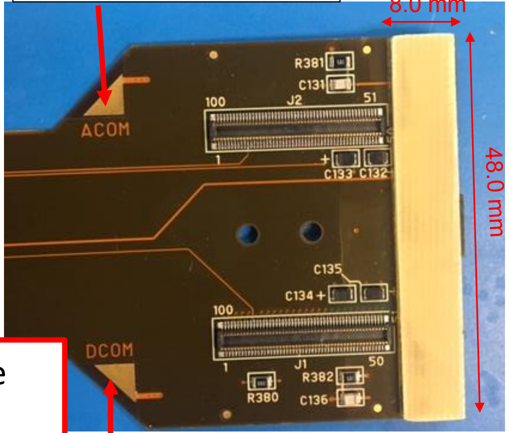
Dedicated Bias connectors each side

M20-7910342R
2 Thermistats 3pin readout

	FVTX	INTT
# Layers	7	7
Length [cm]	~20	40
Pitch [µm]	40	60

The design is based on HDI's of FVTX. The cable length is longer, but the pitch of the signal line is somewhat relaxed 60 [µm] instead of 40 [µm].

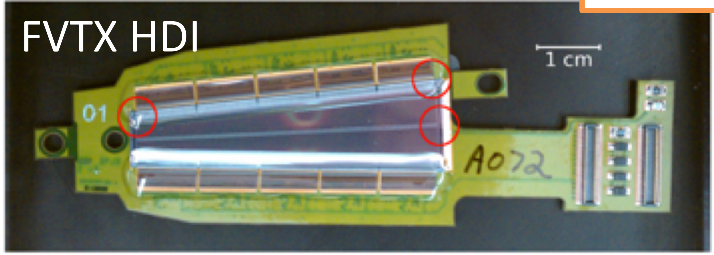
Analog GND pad



Digital GND pad

Analog and digital pads are used for grounding in case we need them.

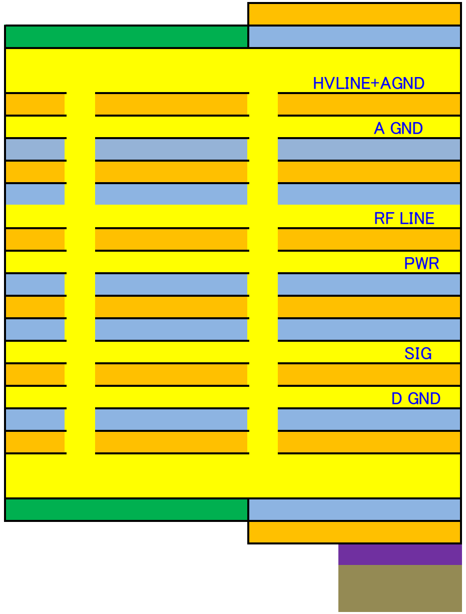
FVTX HDI



High Density Interconnect (HDI) Cable

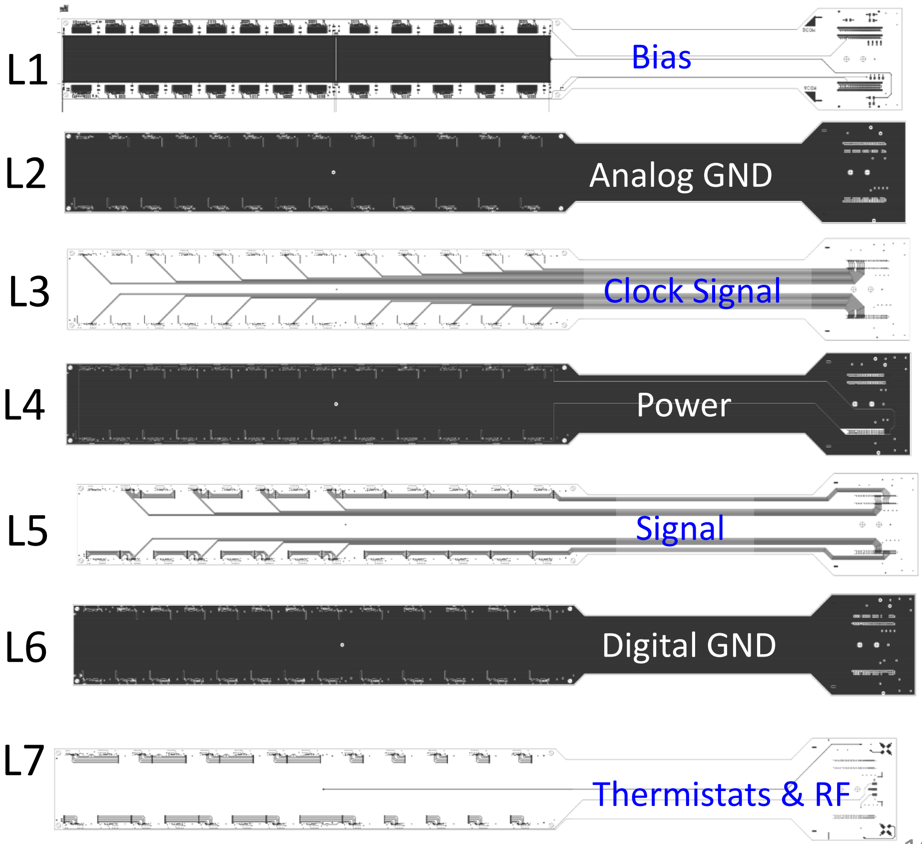
Tracking System: MVTX+INTT+TPC

- 7 cupper layers
- High signal line density in 2 layers
- Solid ground outer layers to shield signal layers



	Coverlay Polyide	12.5	μm
	Coverlay Glue	25	μm
	Copper plated	15	μm
L1	Electrolytic copper foil	9	μm
	Base Polyimide	50	μm
L2	Electrolytic copper foil	9	μm
	Glue	25	μm
	Base Polyimide	12.5	μm
	Glue	15	μm
L3	Electrolytic copper foil	9	μm
	Base Polyimide	50	μm
L4	Electrolytic copper foil	9	μm
	Glue	25	μm
	Base Polyimide	12.5	μm
	Glue	15	μm
L5	Electrolytic copper foil	9	μm
	Base Polyimide	50	μm
L6	Electrolytic copper foil	9	μm
	Glue	25	μm
	Base Polyimide	25	μm
L7	Electrolytic copper foil	9	μm
	Copper plated	15	μm
	Coverlay Glue	25	μm
	Coverlay Polyimide	12.5	μm
Glue for support plate		40	μm
Support Plate FR-4 1.0t		1000	μm

Cross Section of HDI



High Density Interconnect (HDI) Cable

- 7 cupper layers
- High signal line density in 2 layers
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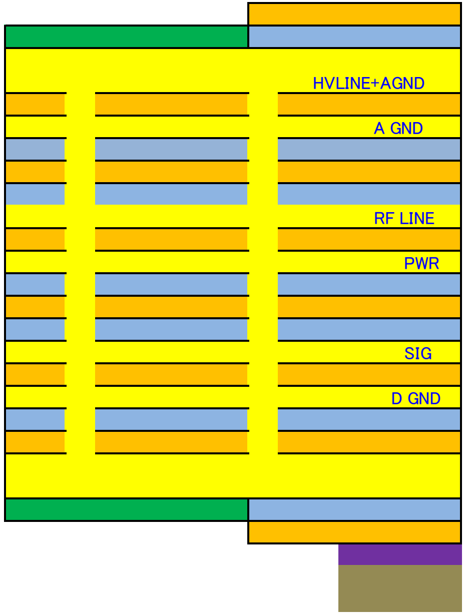
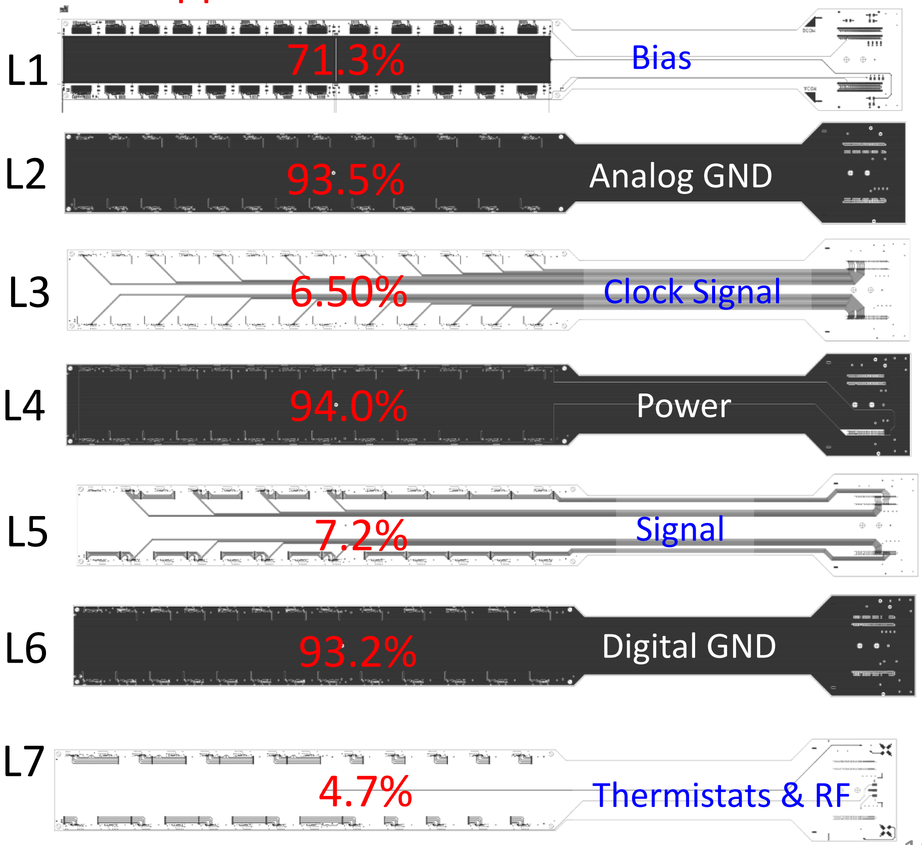


	Coverlay Polyide	12.5 μm
	Coverlay Glue	25 μm
	Copper plated	15 μm
L1	Electrolytic copper foil	9 μm
	Base Polyimide	50 μm
L2	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	12.5 μm
	Glue	15 μm
L3	Electrolytic copper foil	9 μm
	Base Polyimide	50 μm
L4	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	12.5 μm
	Glue	15 μm
L5	Electrolytic copper foil	9 μm
	Base Polyimide	50 μm
L6	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	25 μm
L7	Electrolytic copper foil	9 μm
	Copper plated	15 μm
	Coverlay Glue	25 μm
	Coverlay Polyimide	12.5 μm
Glue for support plate		40 μm
Support Plate FR-4 1.0t		1000 μm

Copper Fraction



High Density Interconnect (HDI) Cable

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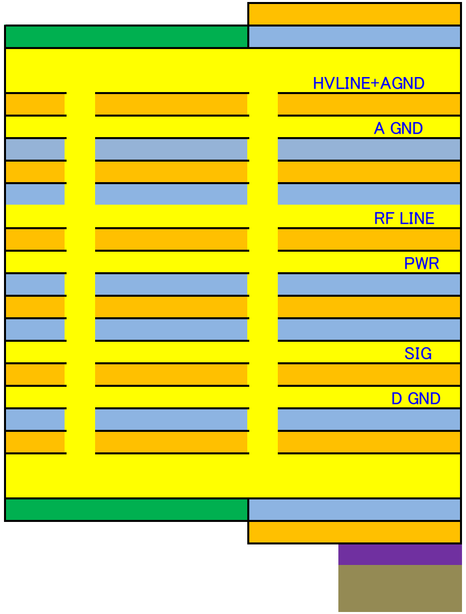
Tracking System: MVTX+INTT+TPC

Material Budget of HDI Cable



Layer	Material	Thickness	Unit	Copper Fraction	Effective Thickness [μm]
	Coverlay Polyide	12.5	μm		
	Coverlay Polyide	12.5	μm		
	Coverlay Glue	25	μm		
	Copper plated	15	μm	71.3%	10.69
L1	Electrolytic copper foil	9	μm		0.00
	Base Polyimide	50	μm		
L2	Electrolytic copper foil	9	μm	93.5%	8.42
	Glue	25	μm		
	Base Polyimide	12.5	μm		
	Glue	15	μm		
L3	Electrolytic copper foil	9	μm	6.50%	0.59
	Base Polyimide	50	μm		
L4	Electrolytic copper foil	9	μm	94.0%	8.46
	Glue	25	μm		
	Base Polyimide	12.5	μm		
	Glue	15	μm		
L5	Electrolytic copper foil	9	μm	7.20%	0.65
	Base Polyimide	50	μm		
L6	Electrolytic copper foil	9	μm	93.2%	8.38
	Glue	25	μm		
	Base Polyimide	25	μm		
L7	Electrolytic copper foil	9	μm	4.68%	0.42
	Copper plated	15	μm		0.00
	Coverlay Glue	25	μm		
	Coverlay Polyimide	12.5	μm		
	Glue for support plate	40	μm		
	Support Plate FR-4 1.0t	1000	μm		
	TOTAL厚	473	μm	Total	37.6053
				Radiation Length [cm]	1.435
				X/Xrad [%]	0.26206

HDI	Thickness [μm]	X/X_0 [%]
Copper	38	0.26
Polymide	380	0.14
Total	432	**0.40**

- Major contribution to the radiation length comes from 7 copper layers
- Signal layers are effectively thin.
- Total radiation length is 0.40%.

Successful Performance

- INTT Ladders have been tested extensively in NWU/BNL/NTU test benches and beam tests at FNAL in 2018 and 2019.
- Calibration responses are confirmed to be very similar to those of FVTX's. We understood by now minor difference in response from the design difference between FVTX and INTT.
- Overall satisfactory performance was confirmed from INTT ladders.

Summary

- The INTT Ladder consisted of Silicon strip sensors, FPHX chips, HDIs and stave.

- **The INTT Silicon strip sensors** are manufactured by Hamamatsu photonics. Basic design is based on FVTX silicon strip sensors. The primary difference is the dimension of the strip and sensors. The thickness is standard 320μm. → **Ready**

- The **HDI** cable is also designed based on the one of FVTX and manufactured in Yamashita co in Japan. The cable consisted of 7 layers and signal layers are kept inner layers to be shielded by ground or bias layers. The radiation length is kept to be as low as 0.40%. Demonstrated good performance through two beam tests in 2018 and 2019. → **Ready**

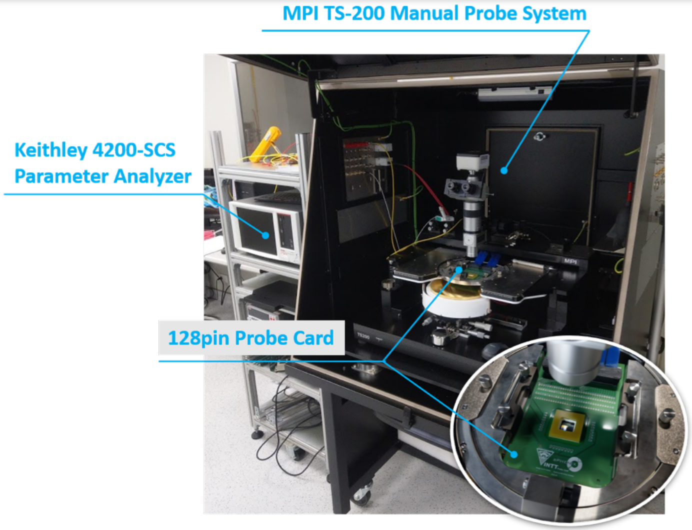
- **FPHX chips** are developed by Fermi lab for FVTX detector for PHENIX. Sufficient enough FPHX chips are produced for INTT needs. Some programmable parameters will be uniquely optimized for INTT. → **Ready**

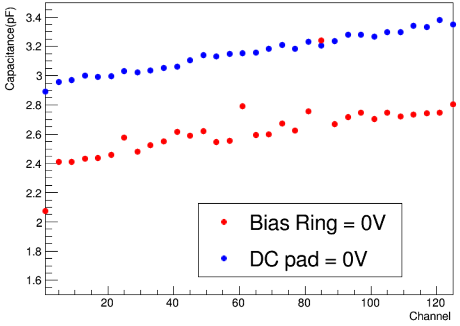
We are ready for the ladder mass production.

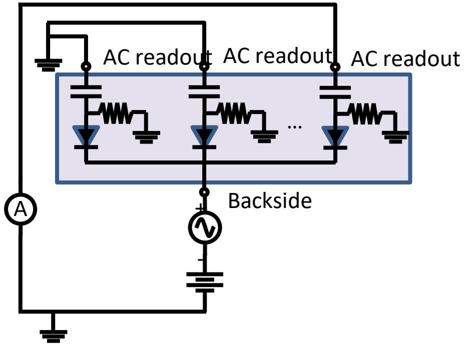
Back Up

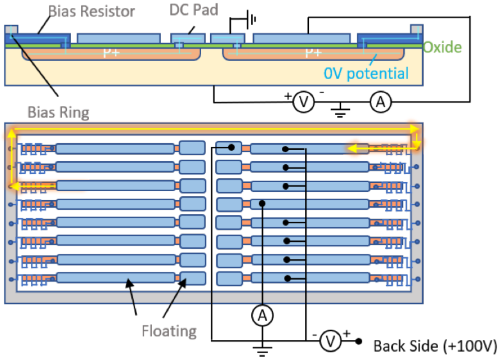
The CV Measurement Circuit of INTT Sensor Testing

- Measure the capacitance of single channel from AC readout pad to check the status of each channels.
- Supply bias voltage to the backside of sensor. The AC signal also send to backside and measure current variety form AC pad on front side. To sure we only measure the single channel capacitance, relay matrix will ground all channels except target channel. The system and circuit are showed in right plots.
- Ground the DC pad to sure the sensors are full depletion, because grounding bias ring are difficult during all chips measurement. The bottom left plot shows the difference between grounding bias ring and DC pads. The value of DC pad situation is little higher, but the trend are the same, so ground some DC pads to supply same voltage is expedient method.

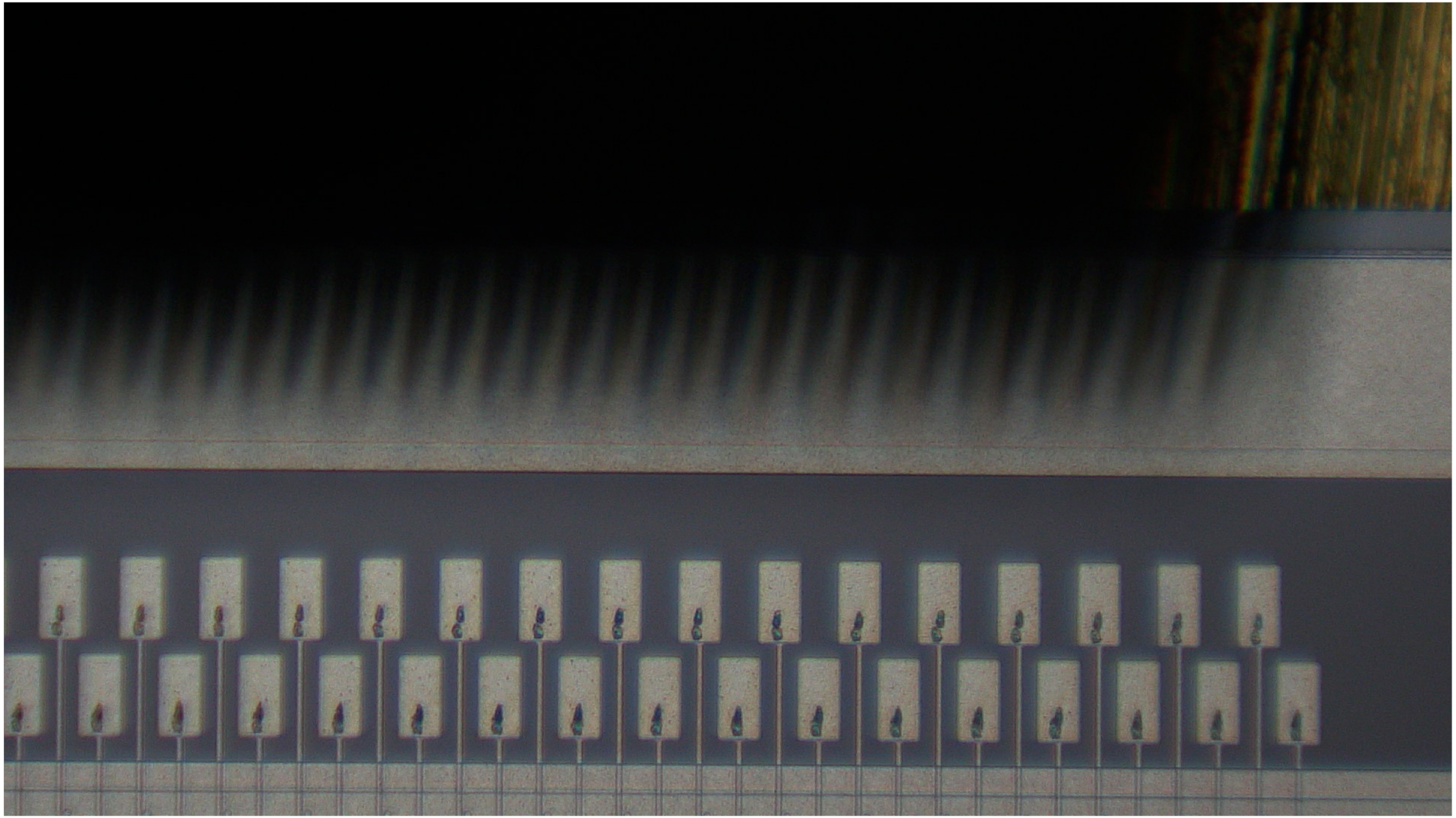






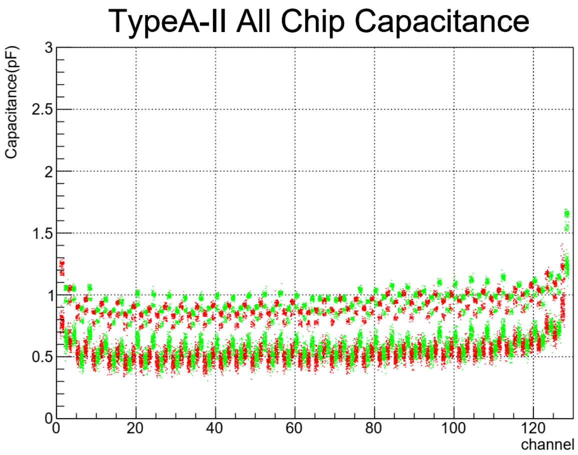


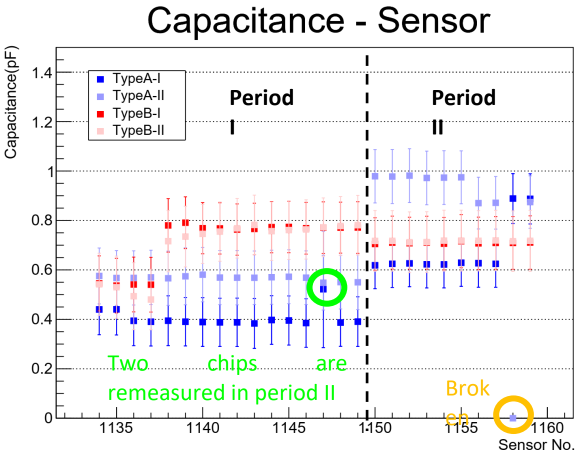
Scratch by Probing Pads

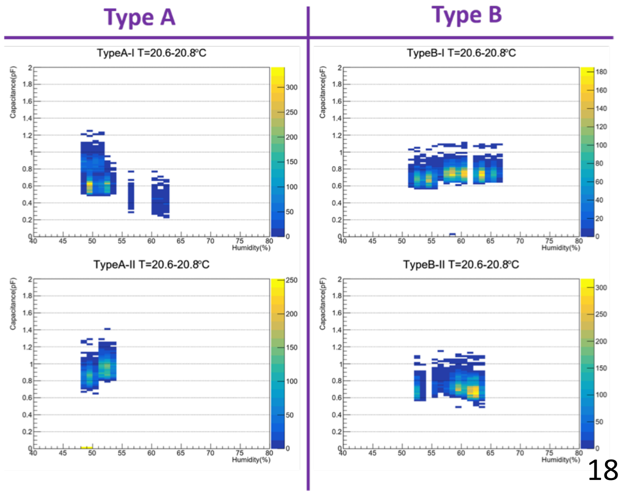


The Measurement Result of INTT Sensor Testing

- Because the layout of sensor, each module is divided into four parts in the measurement. The left plot show one part result of sensor 1133-1159. All capacitance of channels are gaussian distribution, so we can identify the broken and functional channels from measurement. The left plot obviously show there are two different distributions. These differences could match to measuring period that be showed in middle plot.
- The capacitance of signal channel showed in left plots is about 0.5pF, so total capacitance is about 1000pF. Compared with total sensor from HAMAMATSU's inspection only has 7% difference. Therefore, this method could measure the capacitance of single channel.
- To check why capacitances are different in periods, we analyze the relation between environment and measurement. The right plots shows the variety of capacitance with humidity at same temperature. The result shows the measurement is not obviously affected by humidity, so maybe this effect come from the status of sensor or measure system.







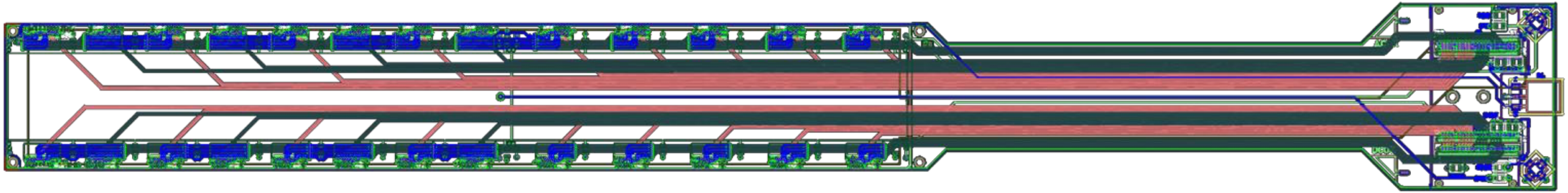
Summary

- Even if can’t ground bias ring during whole measurement, grounding from the DC pads also could get single channel capacitance to check status od each channels.
- However, the capacitance of single channel is too fine (<1.5pF), so the value could be affected by environment. From humidity study, the humidity didn’t has obvious effect, so maybe this effect come from the status of sensor or measure system.
- If the capacitance are measured in short period, the values is stable. The RMS of gaussian distribution in same channel is about 0.05. Therefore, we still can use data that come from same measurement period to identify character of channels.
- In first branch, all channels in sensor 1131-1159 are good. We don’t see any channel has very strange value.
- The secondary branch check had started.

HDI Material Budget

HDI	Thickness [μm]	X/X_0 [%]
Copper*	38	0.26
Polymide	380	0.14
Total**	432	0.40

*Copper thickness is not physical thickness, but average thickness.
**Total thickness is not 473μm, because of the copper average thickness.



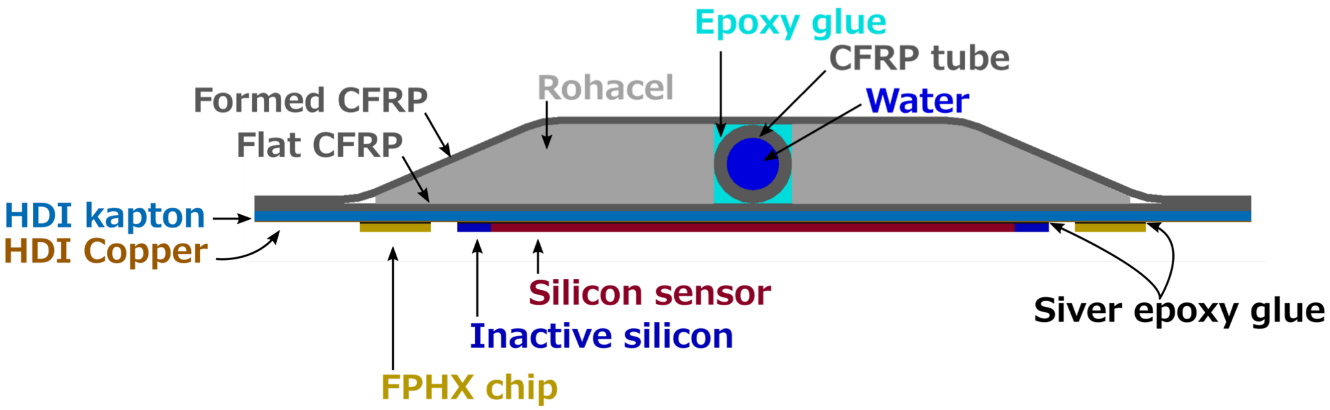
Radiation length of each layer.

Ladder Material Budget

Material	Thickness [μm]	X/X_0 [%]
Silicon Sensor	320	0.34
HDI	473	0.39
Stave	600	0.33
Total		1.06

HDI	Thickness [μm]	X/X_0 [%]
Copper*	38	0.26
Polymide	380	0.14
Total**	432	0.40

*Copper thickness is not physical thickness, but average thickness.
**Total thickness is not 473μm, because of copper average thickness.



High Density Interconnect (HDI) Cable

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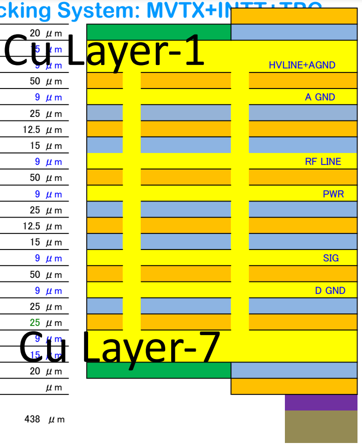
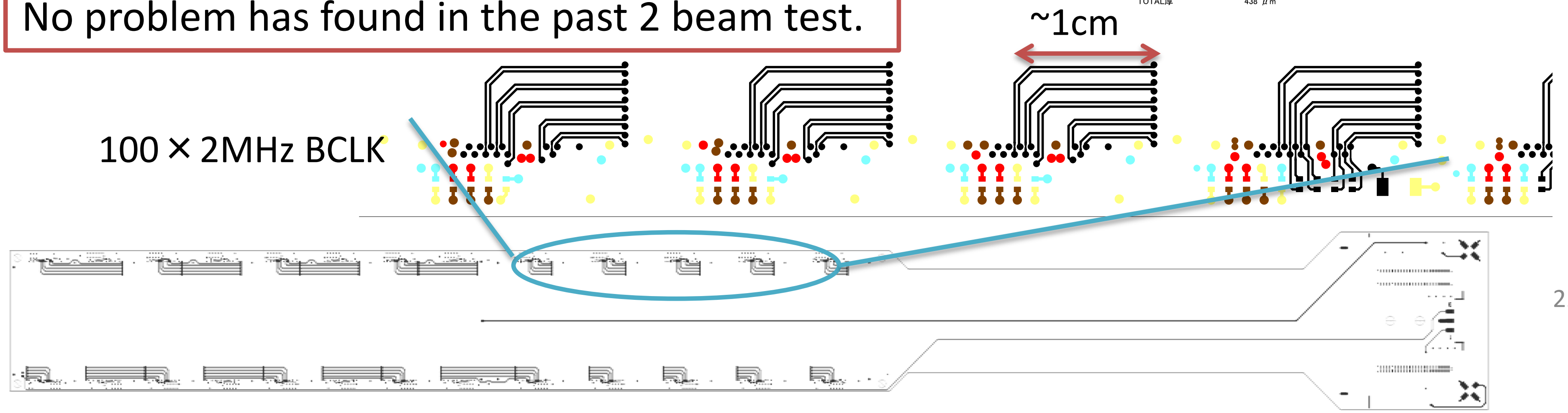
Due to spatial limit of signal layers, some part of signal lines have to run unshielded layer-7 for a few cm.

The corresponding frequency is 10 – 30GHz, which is at least an order of magnitude higher frequency than the highest frequency (100×2MHz BCLK) signal transmits layer-7.

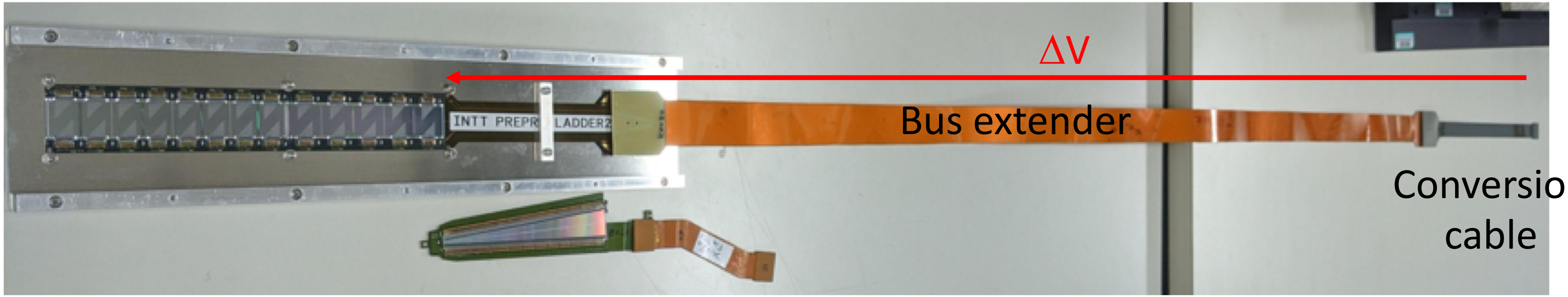
No problem has found in the past 2 beam test.

	Regist	20 μm
	Copper plated	5 μm
L1	Electrolytic copper foil	[illegible] μm
	Base Polyimide	50 μm
L2	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	12.5 μm
	Glue	15 μm
L3	Electrolytic copper foil	9 μm
	Base Polyimide	50 μm
L4	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	12.5 μm
	Glue	15 μm
L5	Electrolytic copper foil	9 μm
	Base Polyimide	50 μm
L6	Electrolytic copper foil	9 μm
	Glue	25 μm
	Base Polyimide	25 μm
L7	Electrolytic copper foil	9 μm
	Copper plated	15 μm
	Regist	20 μm
		μm
		438 μm
	TOTAL厚	438 μm





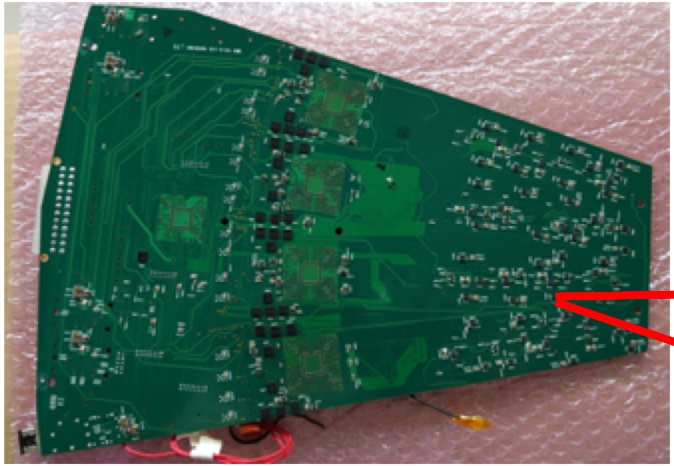
Voltage Drop for FPHX Power



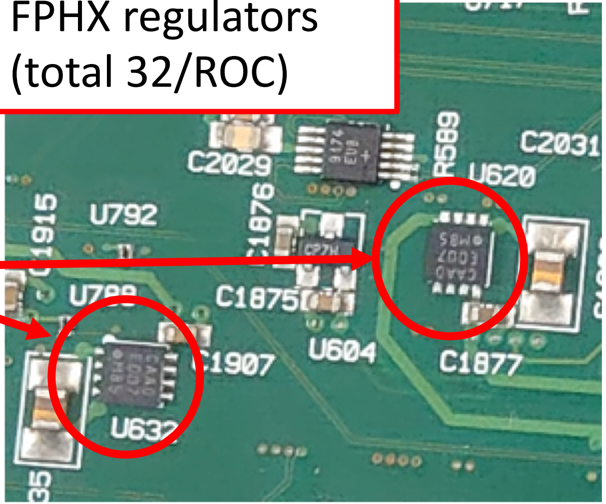
	V@ROC	HDI [mW]	Bus Extender [mW]	Conversion Cable [mW]	ΔV [V]	V@FPHX
INTT	2.5V	135 ~ 185	145	185	0.20~0.25	2.30~2.25V
FVTX	2.5V	70	70	N/A	~0.1	2.4V

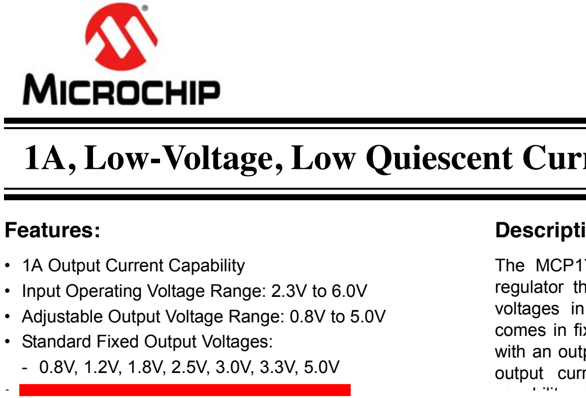
Due to the long readout cable chain of INTT, the voltage drop for FPHX power line is rather severe compared to FVTX. The FPHX is designed to be operated at 2.5V.

ΔV for FPHX Power Solution



FPHX regulators (total 32/ROC)





MICROCHIP

1A, Low-Voltage, Low Quiescent Curr

Features:

- 1A Output Current Capability
- Input Operating Voltage Range: 2.3V to 6.0V
- Adjustable Output Voltage Range: 0.8V to 5.0V
- Standard Fixed Output Voltages:
  - 0.8V, 1.2V, 1.8V, 2.5V, 3.0V, 3.3V, 5.0V

Descripti

The MCP1 regulator th voltages in comes in fi with an outp output curr

	V@ROC	ΔV [V]	V@FPHX
INTT	**3.0V**	**0.20~0.25**	**2.80~2.75V**
FVTX	2.5V	~0.1	2.4V

The plan is to replace all 2.5V regulators by 3.0V ones on the backplane of the ROC. Further voltage drop is expected due to higher LVDS current operation (To be discussed by Takashi).