ePIC SVT Inner Barrel FPC Signal Integrity

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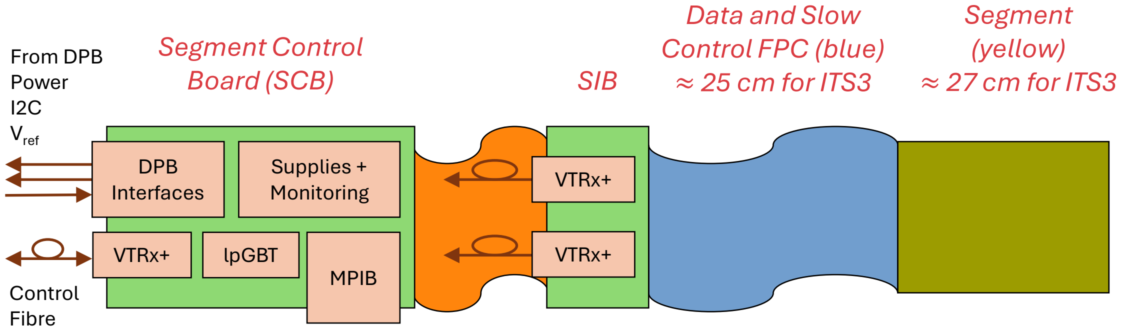
SVT Working Meeting

University of Oxford, 15.12.2025

Università degli Studi di Trieste — Dipartimento di Fisica — INFN Trieste, Istituto Nazionale di Fisica Nucleare, Sezione di Trieste — ePIC

FPC: Sensor To Segment Interface Board (SIB)



- **ITS3-MOSAIX-like sensors:** Differential data links at 10.24 Gb/s
- **Segment Interface Boards:** Electrical-to-optical data conv. & TTC

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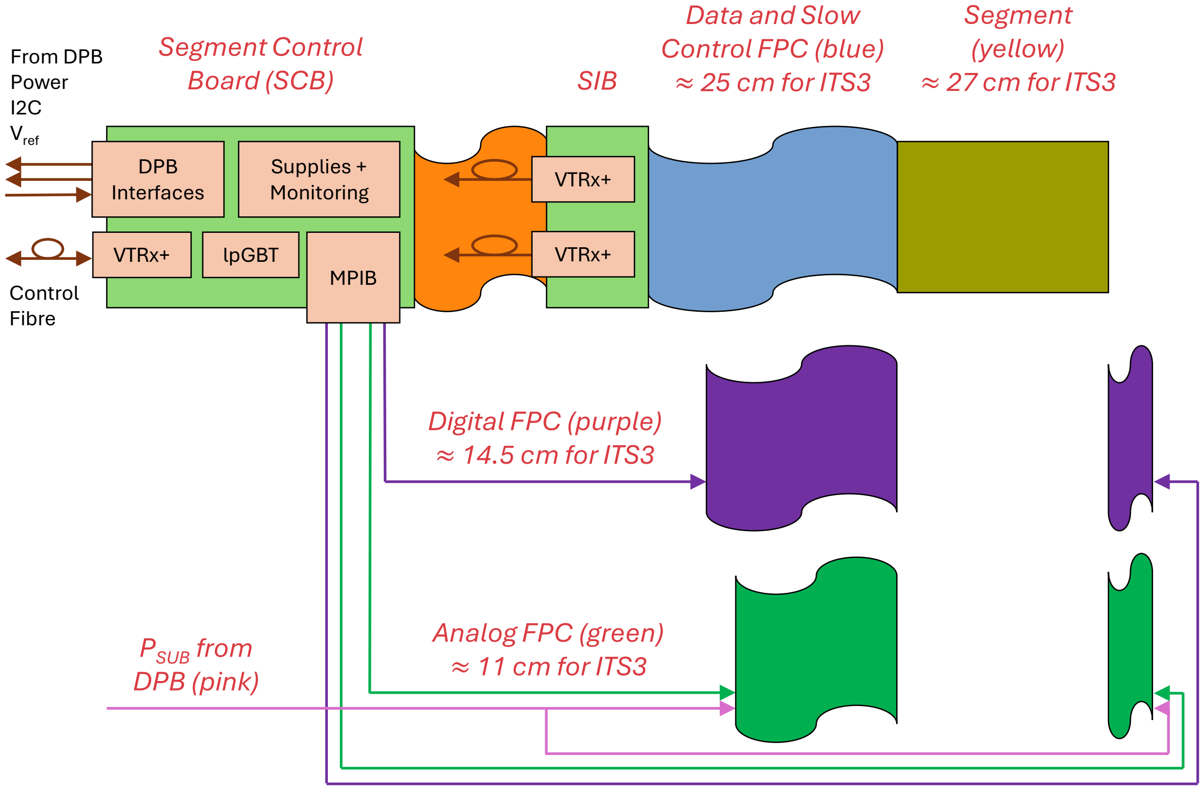

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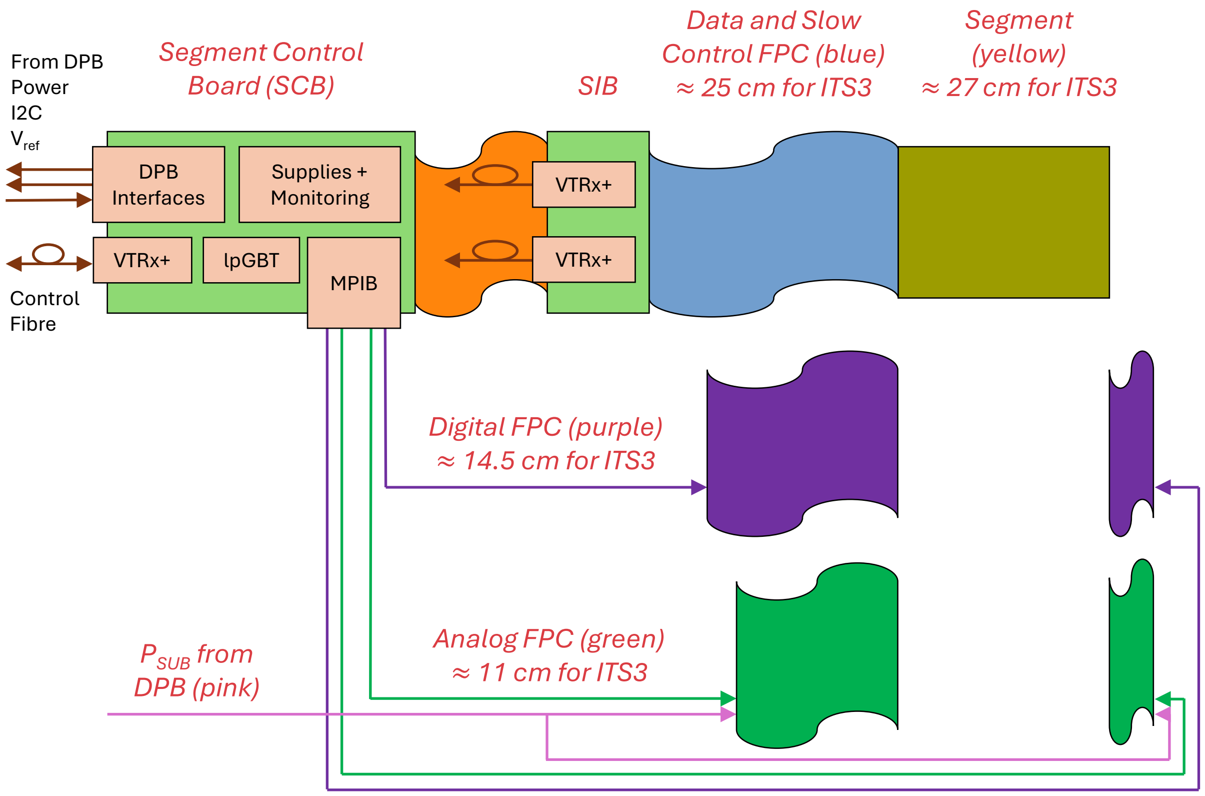

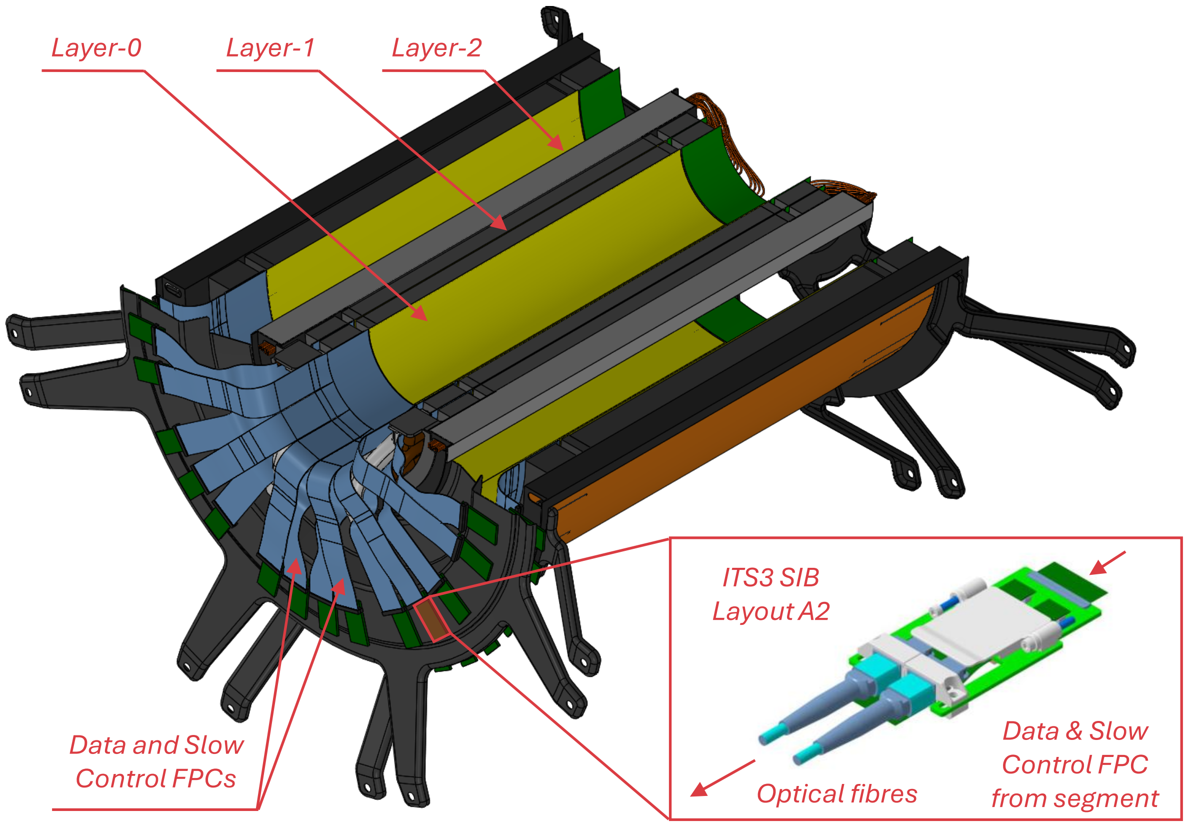

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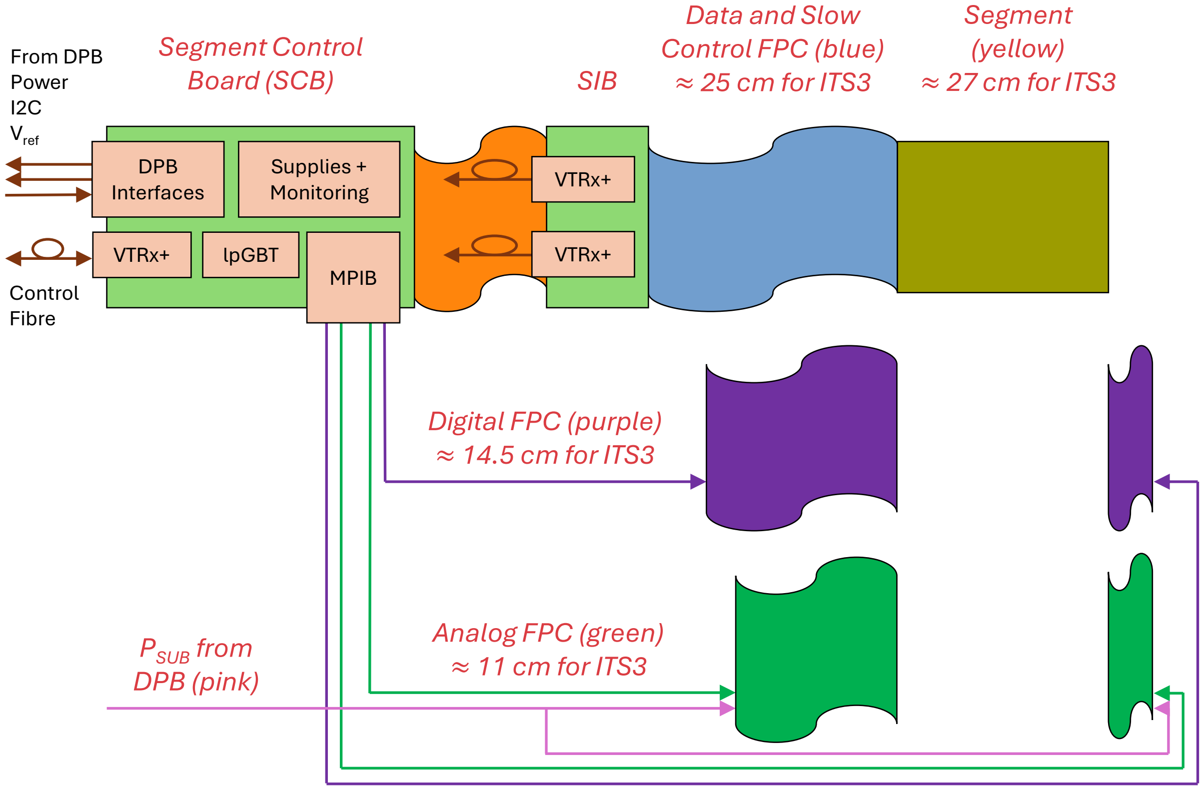

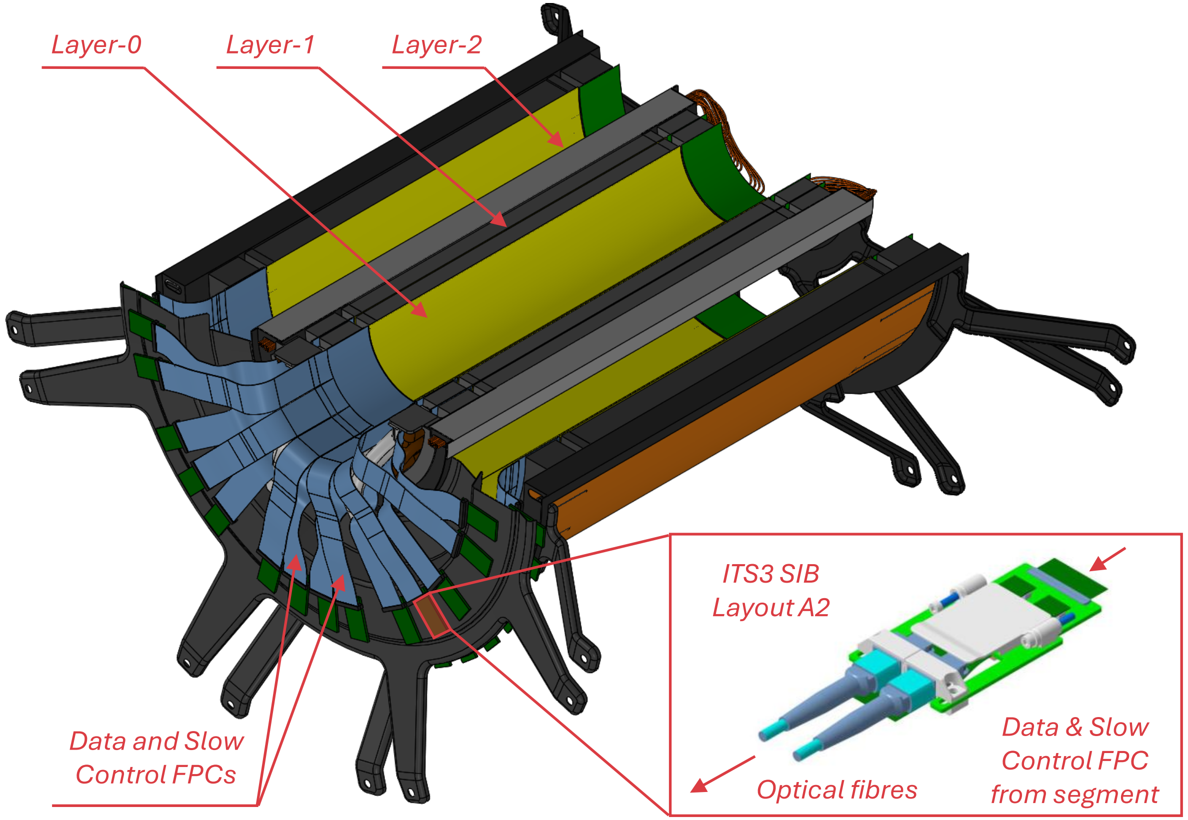

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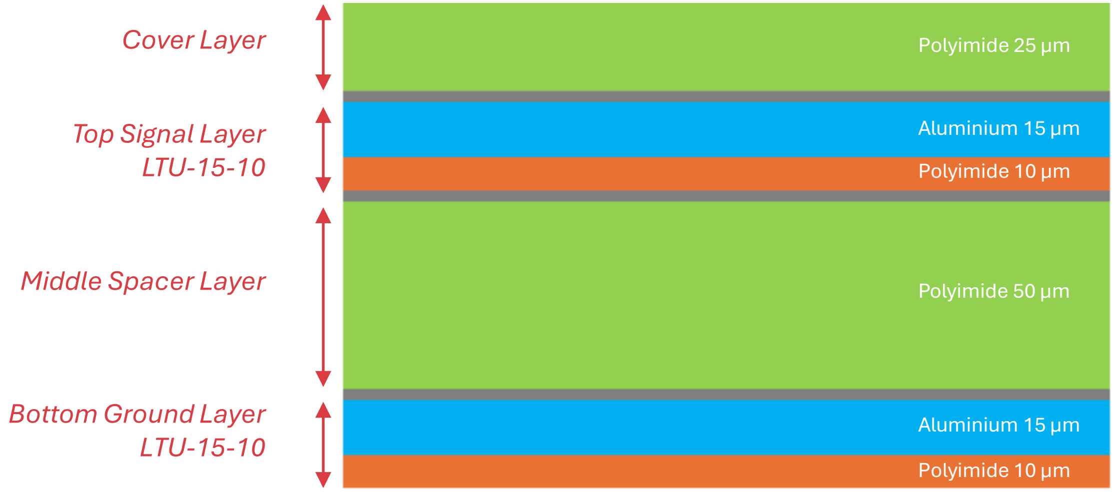
This talk:

First look into the Inner Barrel's FPC prototyping, signal integrity calculations, and plans for experimental characterisation

PROTOTYPING : PROPOSED DESIGN BY LTU

Prototype A-1

Prototype A-2



Prototypes to investigate electrical properties with thinnest "standard" aluminium-polyimide sheet from LTU (LTU-15-10)

- A-1: Without cover layer, 25 µm middle spacer layer
- A-2: With cover layer, 50 µm middle spacer layer
- Diff. impedance = 100 Ω
- Trace width = 70 µm
- Trace thickness = 15 µm
- Space b/w traces = 80 µm
- Trace pitch = 150 µm

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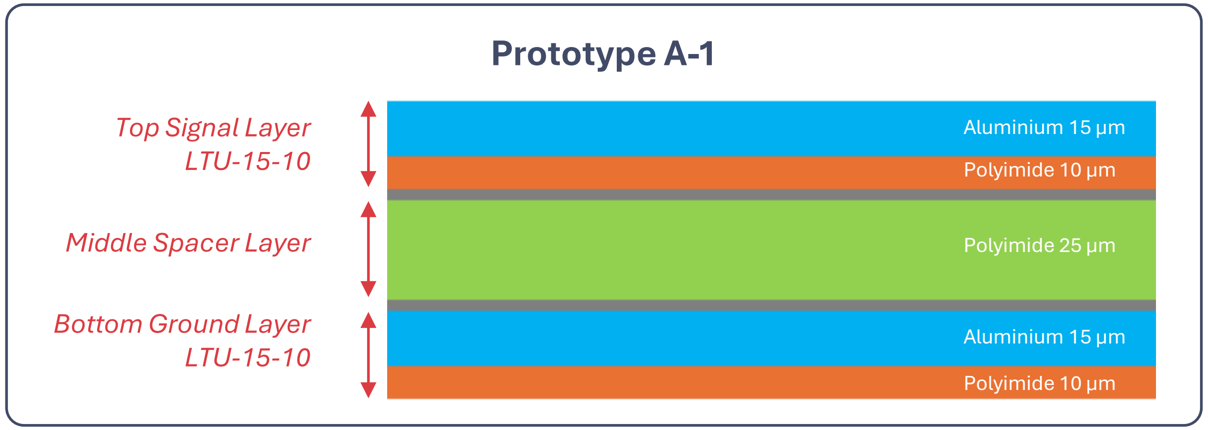

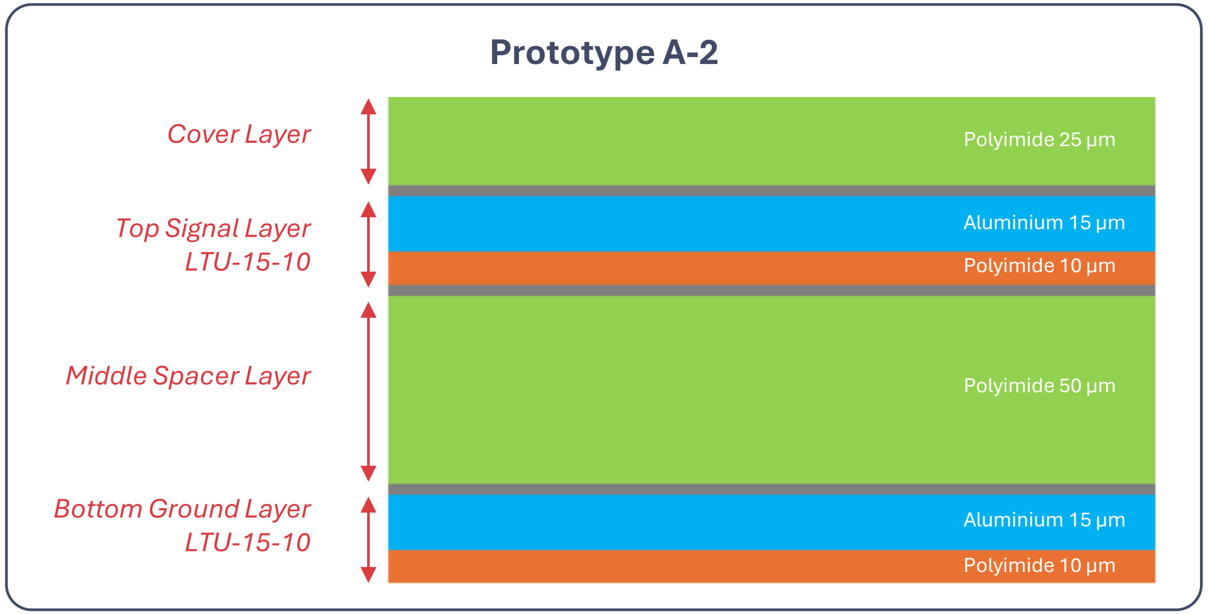

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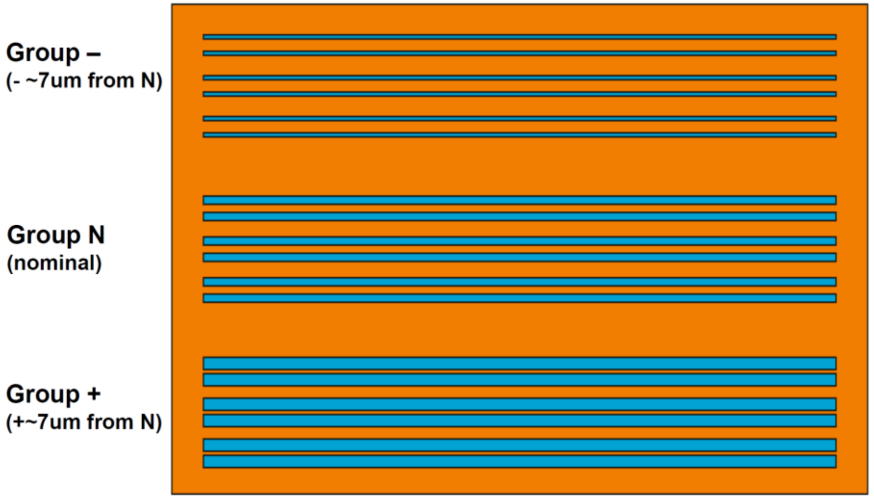
- Further sub-variants with ±10% trace width
- 5 test samples of each variant (18 cm trace length)



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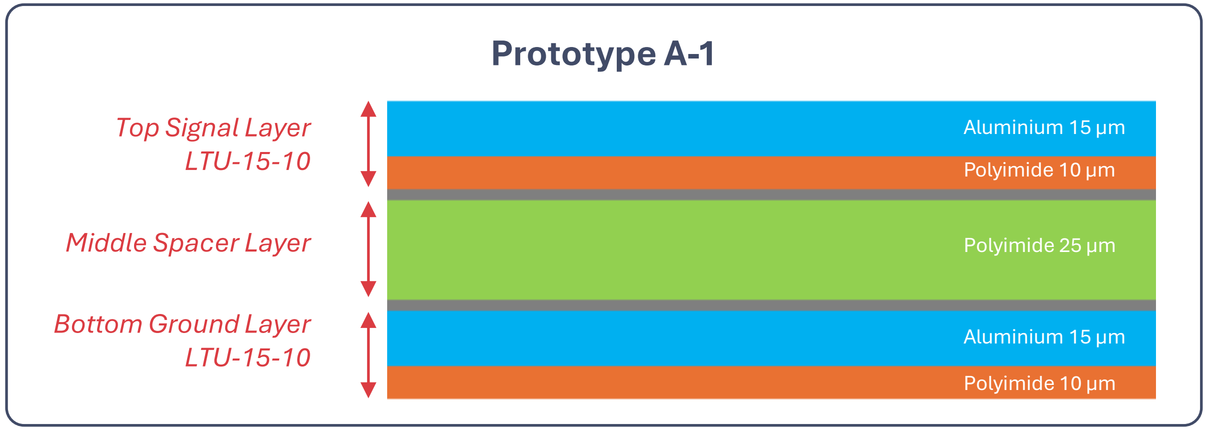

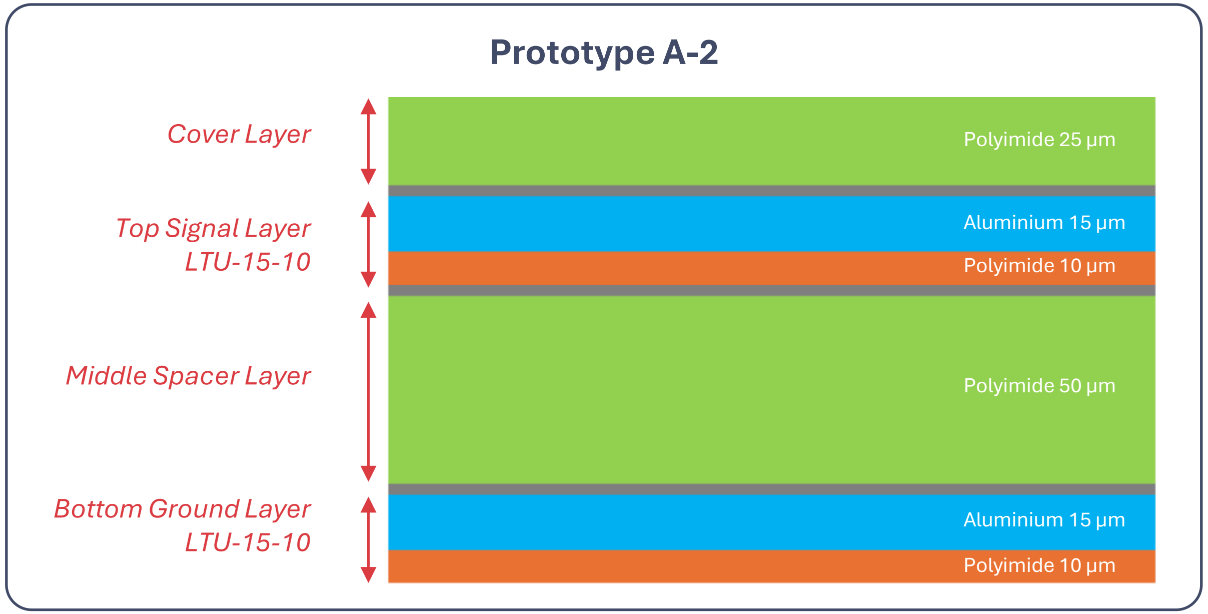

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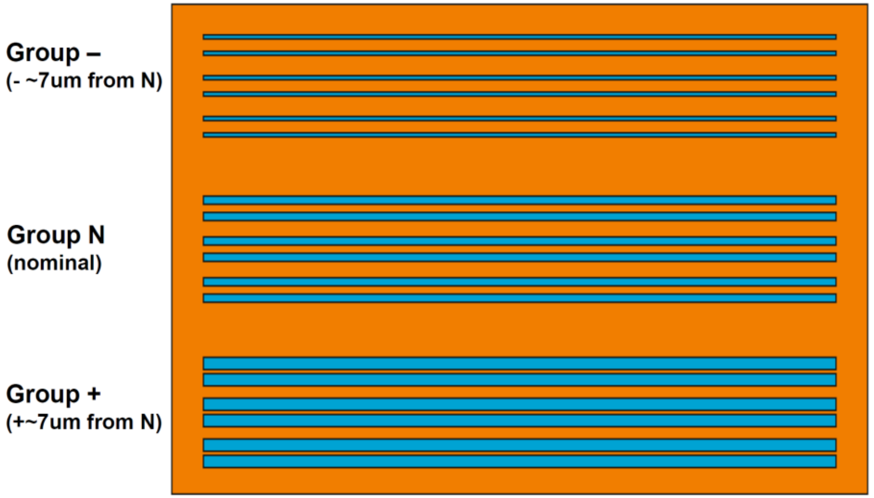
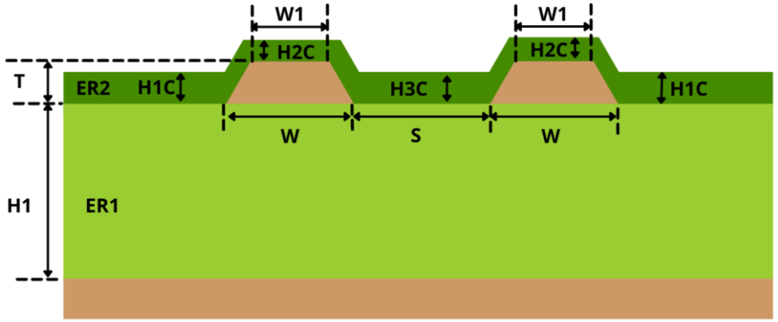
- Further sub-variants with ±10% trace width
- 5 test samples of each variant (18 cm trace length)
- Ordered! Delivery in Q1-2026



SIGNAL INTEGRITY CALCULATIONS : BENCHMARKING

Online impedance calculator produces fairly accurate results for signal loss by using 2D numerical solution of Maxwell's equations



https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL

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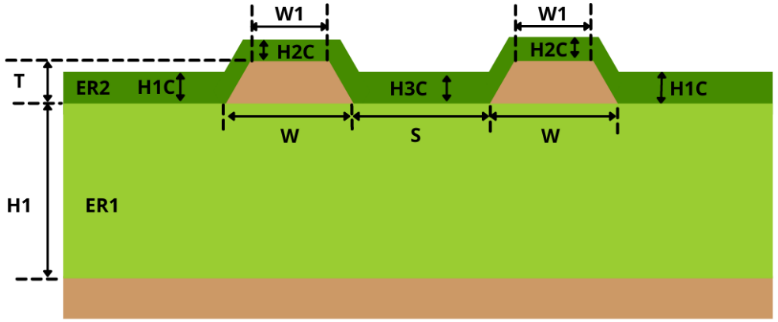

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		ALICE ITS2 IB	ALICE ITS3
Dielectric	H1 [µm]	75	150
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Coating	HiC [µm]	25	75
	ER2 [-]	3.7	3.0
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Trace	W [µm]	100	200
	W1 [µm]	70	200
	T [µm]	25	35
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	L [cm]	21.3 / 44.1	25.8

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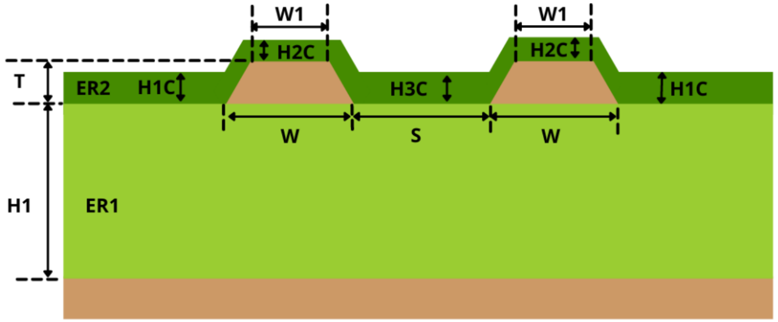

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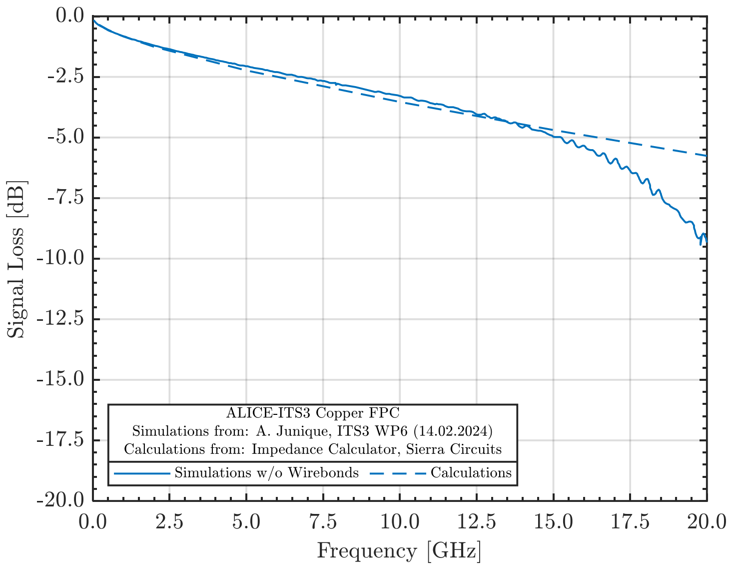
ALICE ITS3 (Copper FPC)



A. Junique, ITS3 WP6 Meeting, 14.02.2024 | Link.

- Results are broadly in agreement
- Discrepancy is substantial at higher frequencies

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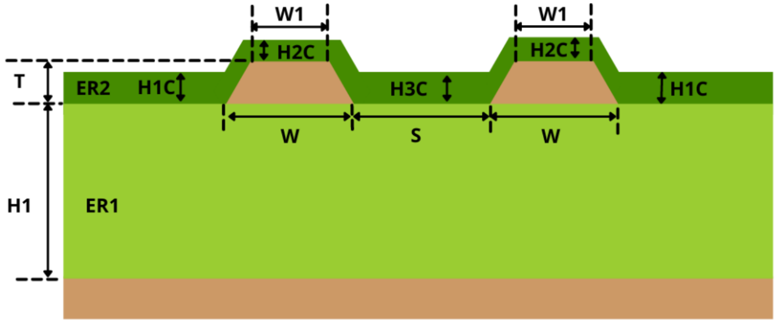

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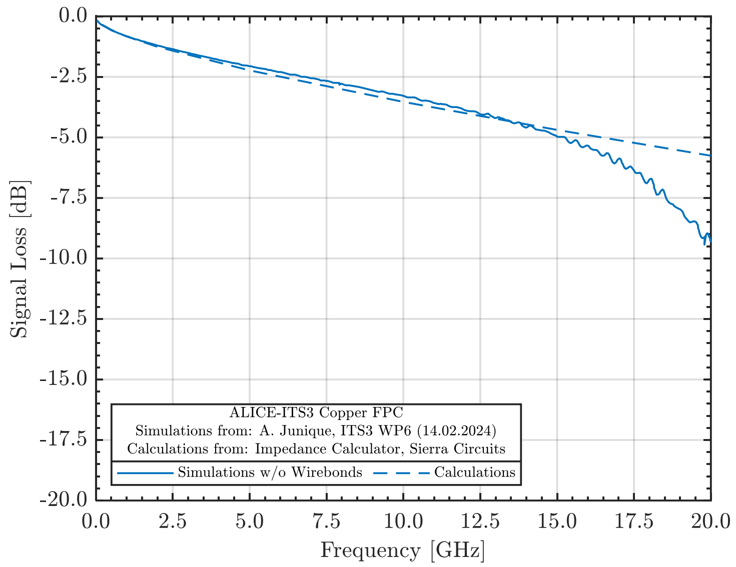
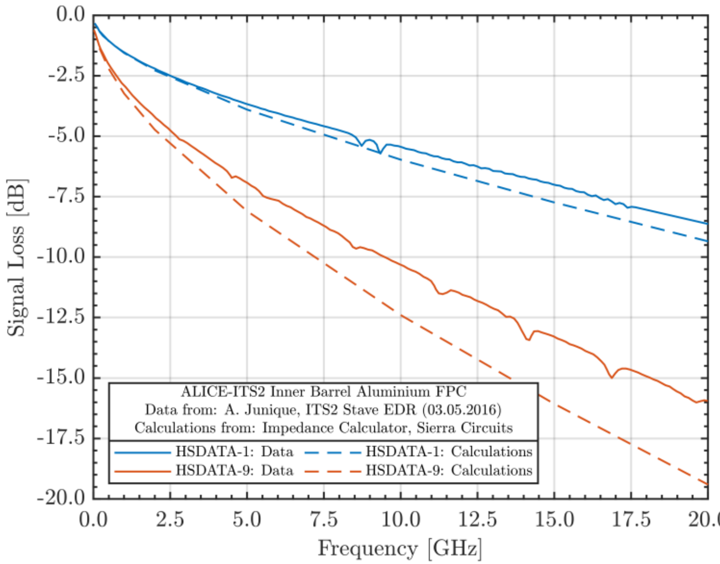


A. Junique, ITS3 WP6 Meeting, 14.02.2024 | Link.

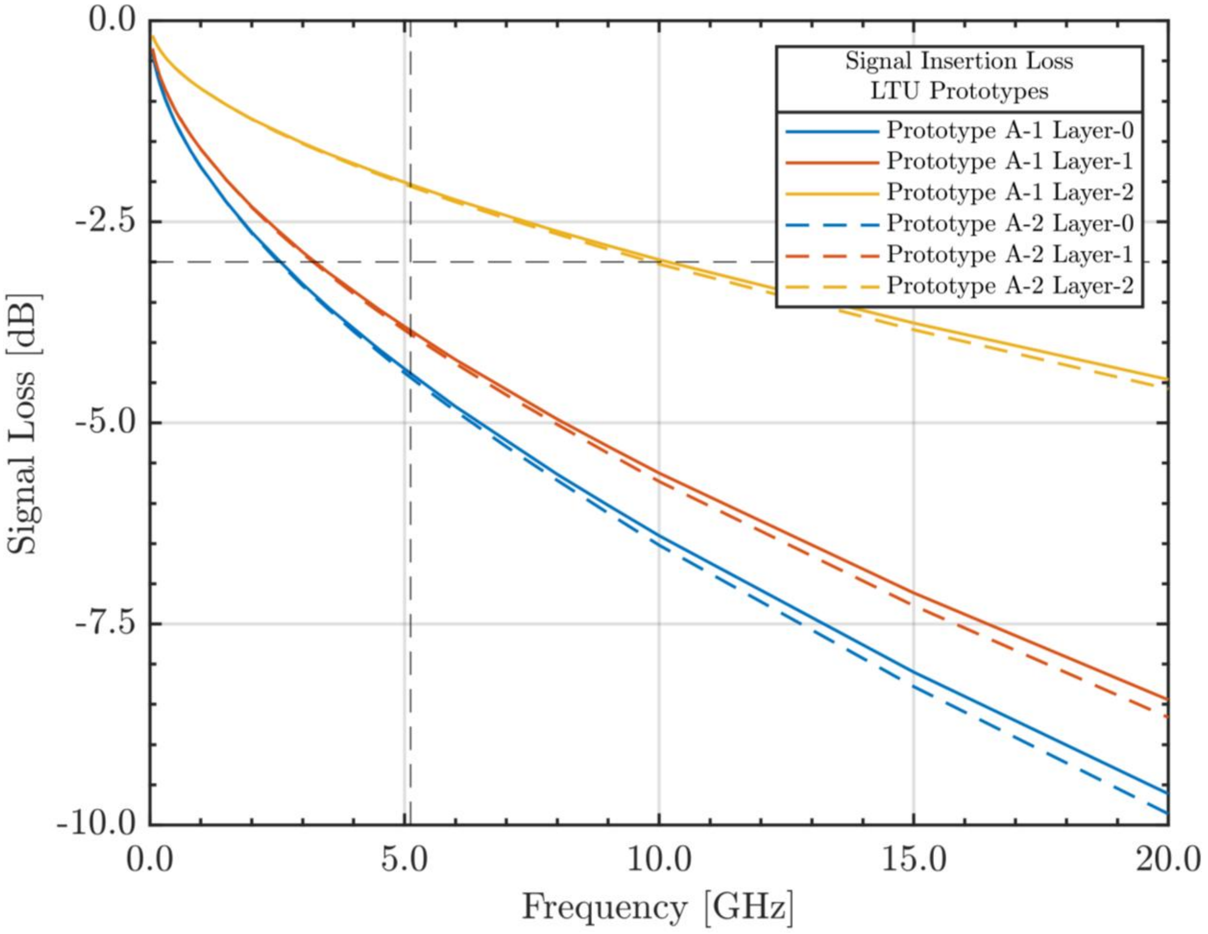
ALICE ITS2 Inner Barrel (Aluminium FPC)



A. Junique, ITS2 Stave EDR, 03.05.2016 | Link.

- Results are broadly in agreement
- Discrepancy is substantial at higher frequencies
- Online calculator uses copper as the default trace material, therefore ITS2 IB's conductor loss must be corrected for aluminium (conductor loss $\propto \sqrt{\text{resistivity}}$)

Signal Integrity Calculations : Results



Online impedance and signal integrity calculator from Sierra Circuits
https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL
Calculation and setup details in the back-up slides

Estimated > 3 dB signal loss at 5 GHz for L0 and L1

- Minor difference between the two variants (A-1 and A-2)
- Conductor loss is the dominating contributor

Variants		Differential Impedance [Ω]	Signal Loss @ 5 GHz			Material Budget [% X/X_0]
			Total [dB]	Conductor [dB/cm]	Dielectric [dB/cm]	
A-1	L0	101.07	4.33	0.212	0.026	0.0512
	L1		3.80			
	L2		2.01			
A-2	L0	101.93	4.38	0.211	0.031	0.0695
	L1		3.85			
	L2		2.03			

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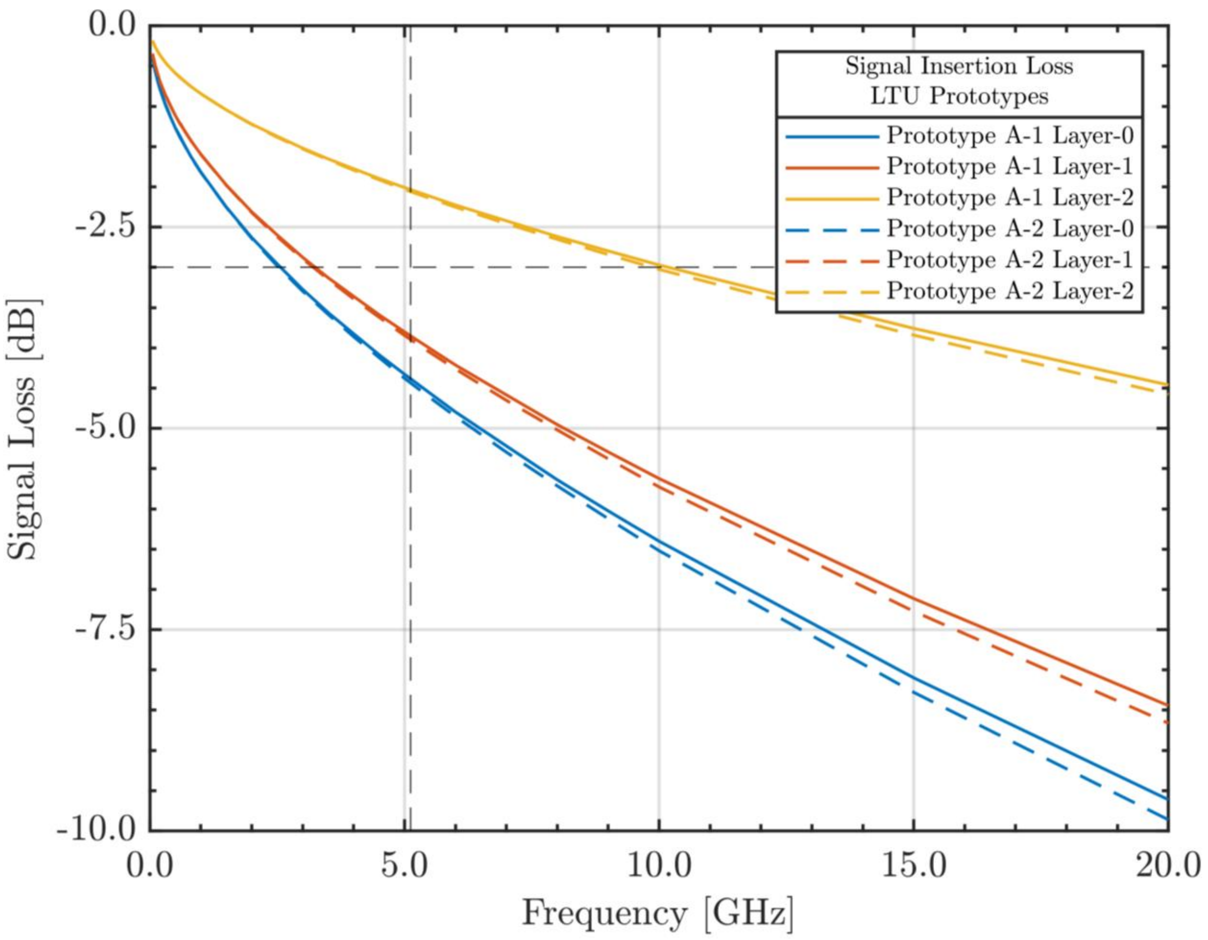

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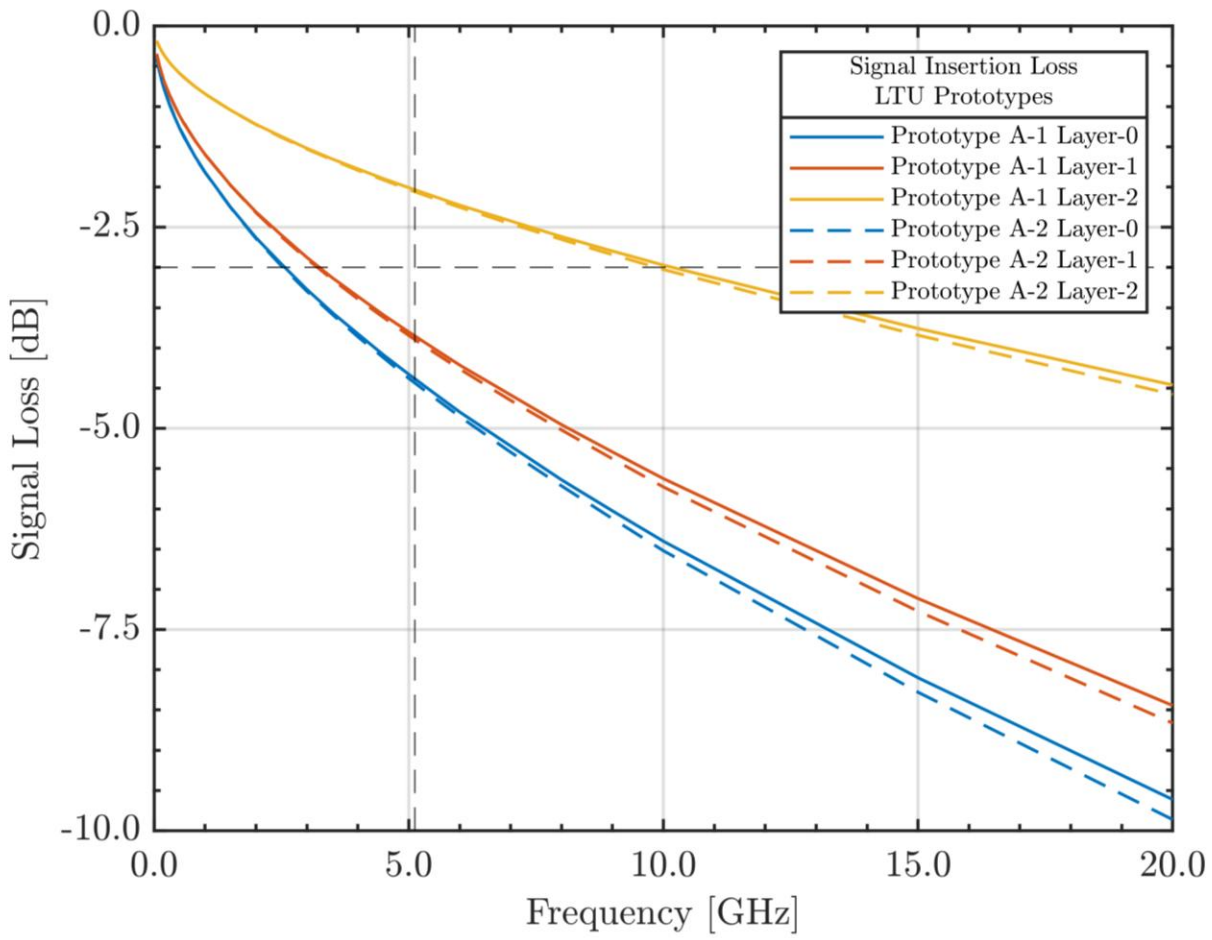

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- NKF7 pre-emphasis on MOSAIX → Exp. Characterisation is needed
- Lower conductor loss (α_C) by reducing trace resistance (R)
  - Lower electrical resistivity (ρ) → ~~copper~~
  - Increase trace width (W)
  - Increase trace thickness (T)

$$\alpha_C \propto R \propto \frac{\sqrt{\rho}}{W + T}$$

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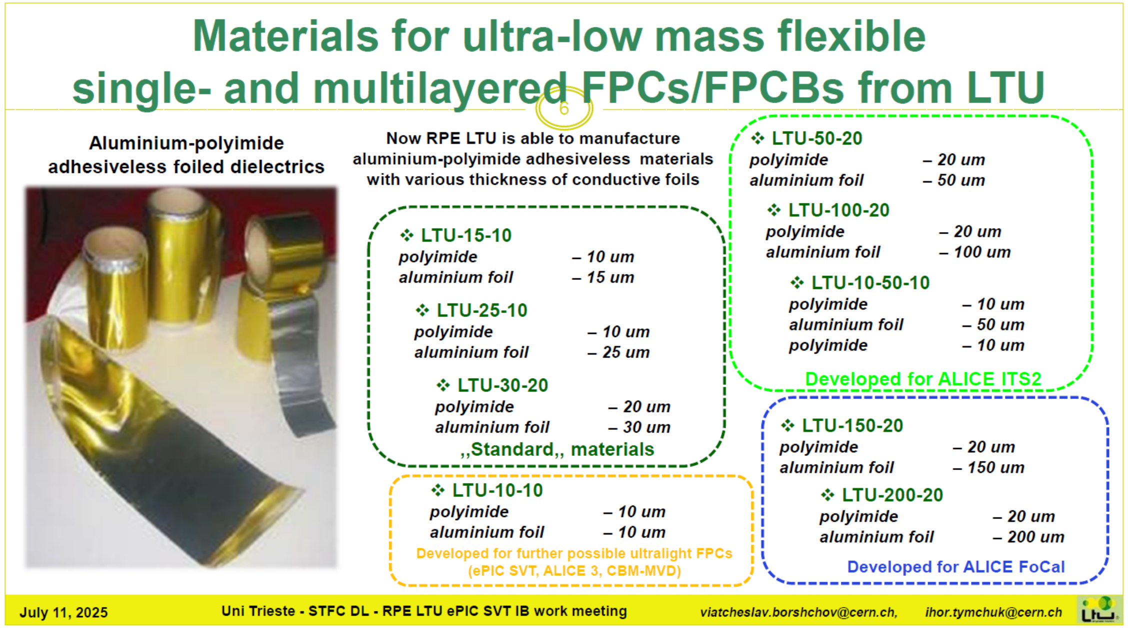
Opting for thicker and wider traces with "standard" aluminium-polyimide sheet from LTU, while keeping diff. impedance of 100 Ω



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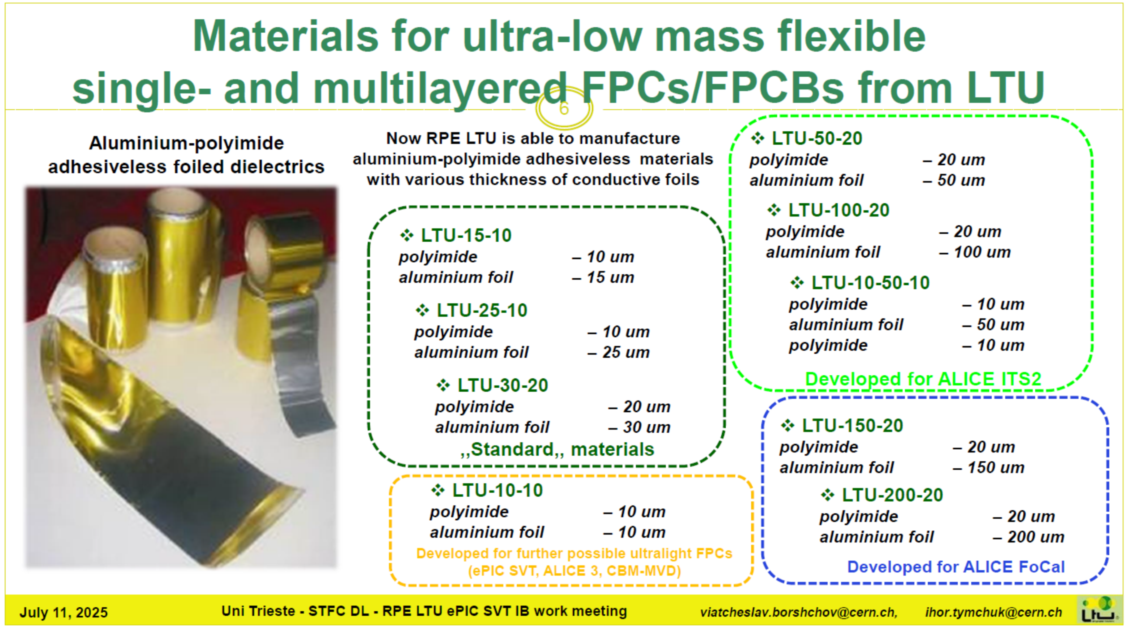
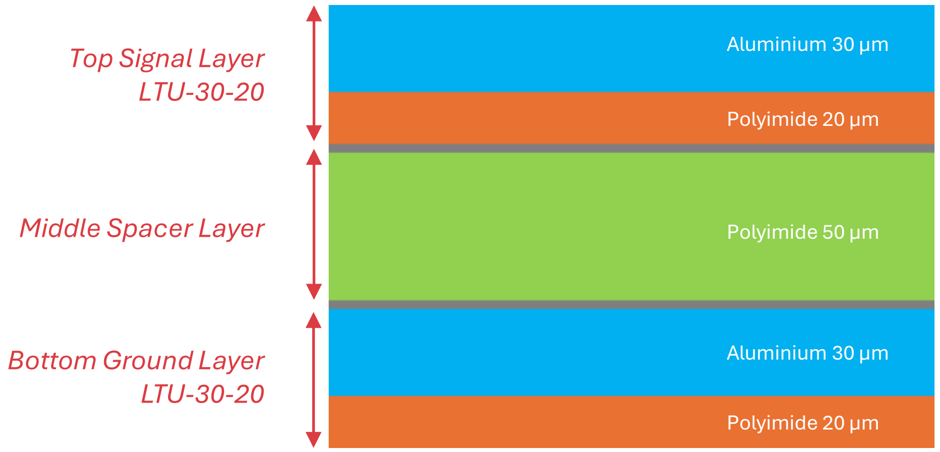
		Prot. A-1	→	Prot. A-1-1
▪ Trace thickness	=	15 µm	→	30 µm
▪ Trace width	=	70 µm	→	125 µm
▪ Space b/w traces	=	80 µm	→	125 µm
▪ Trace pitch	=	150 µm	→	250 µm

} Variation of A-1 (w/o cover layer)



Prototype A-1

Prototype A-1-1



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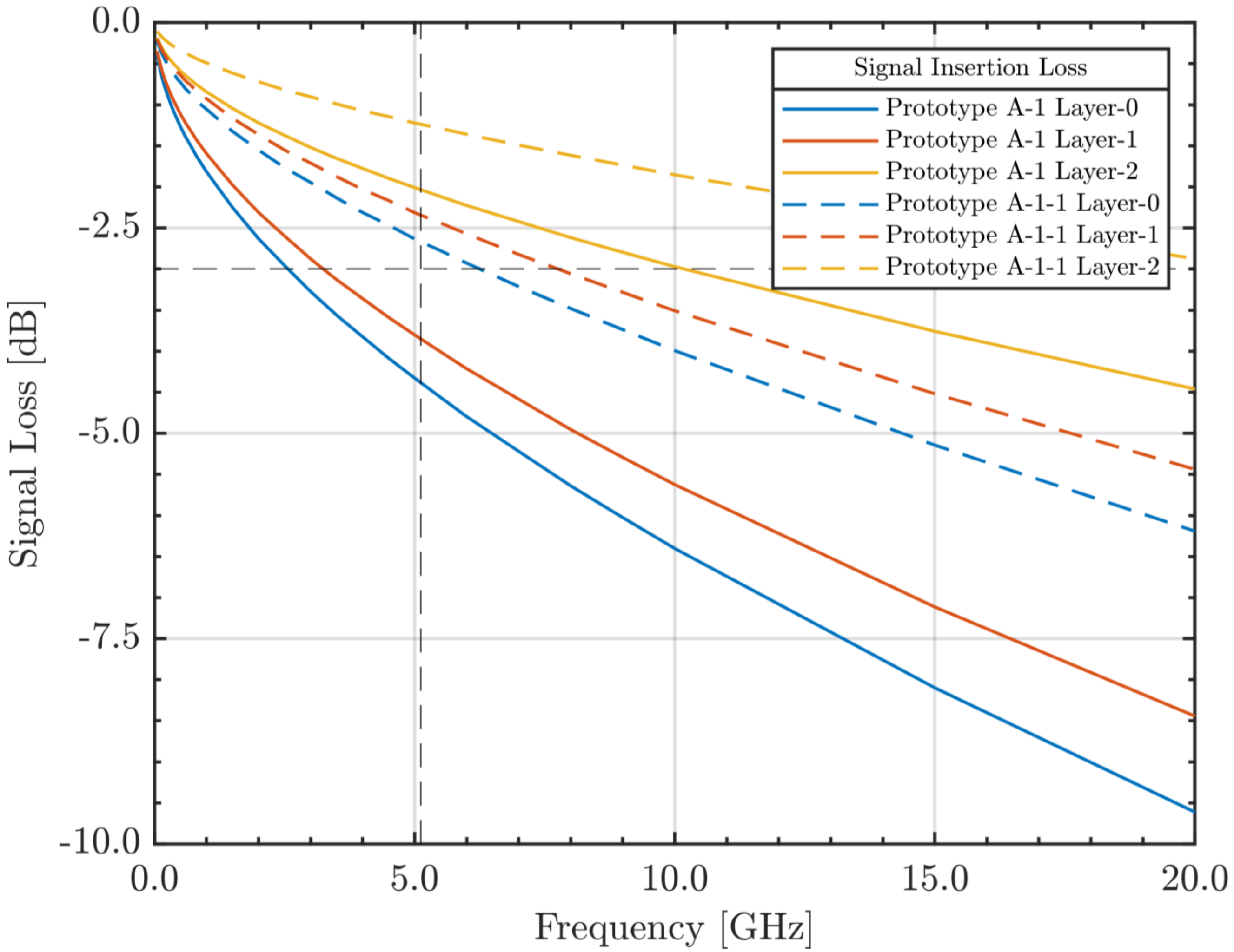

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- Conductor loss reduced by > 2x (still dominating contributor)
- Material budget increased by ≈ 2x

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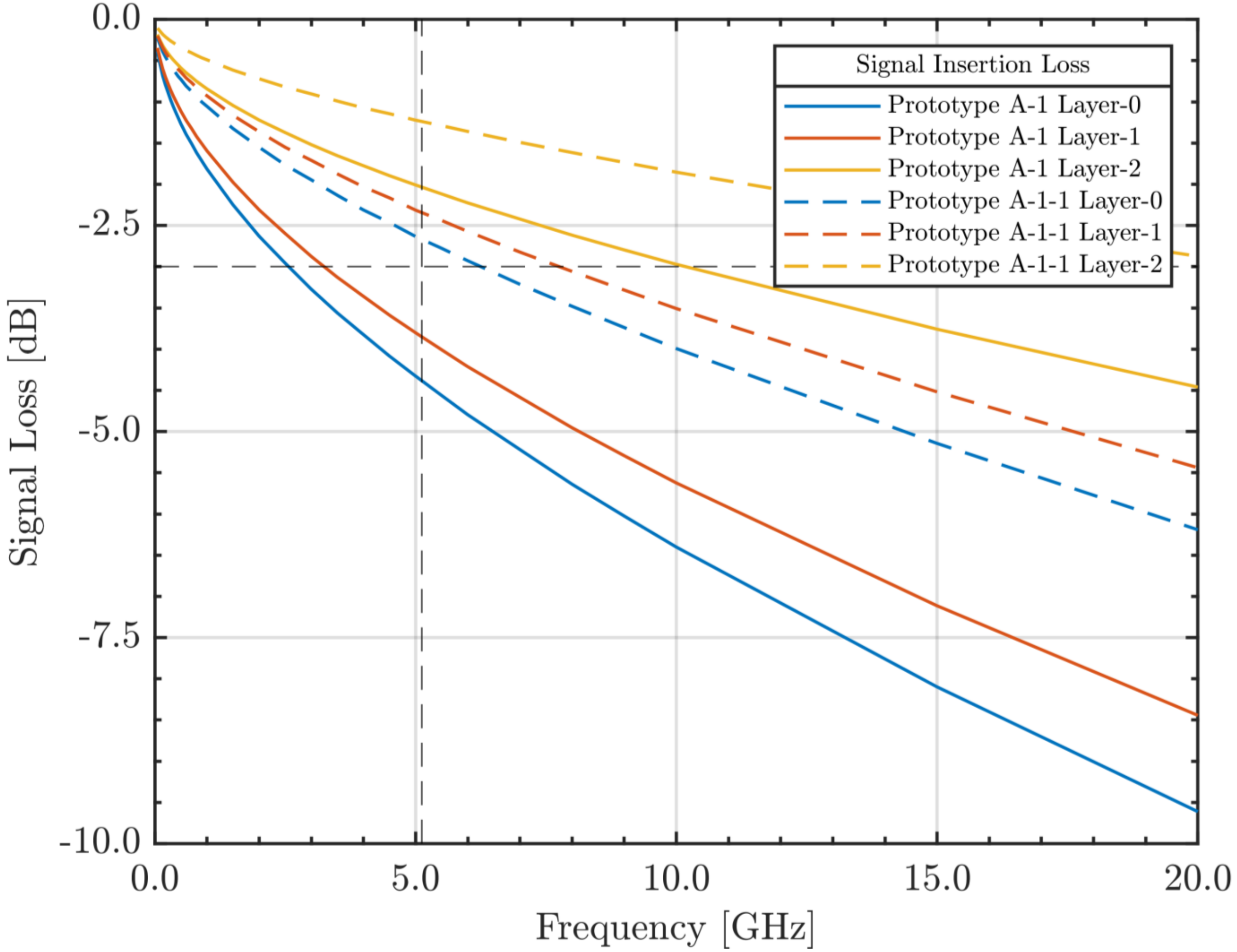

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Further room for optimization by opting for intermediate aluminium thicknesses from the LTU catalogue (20 µm, 25 µm)

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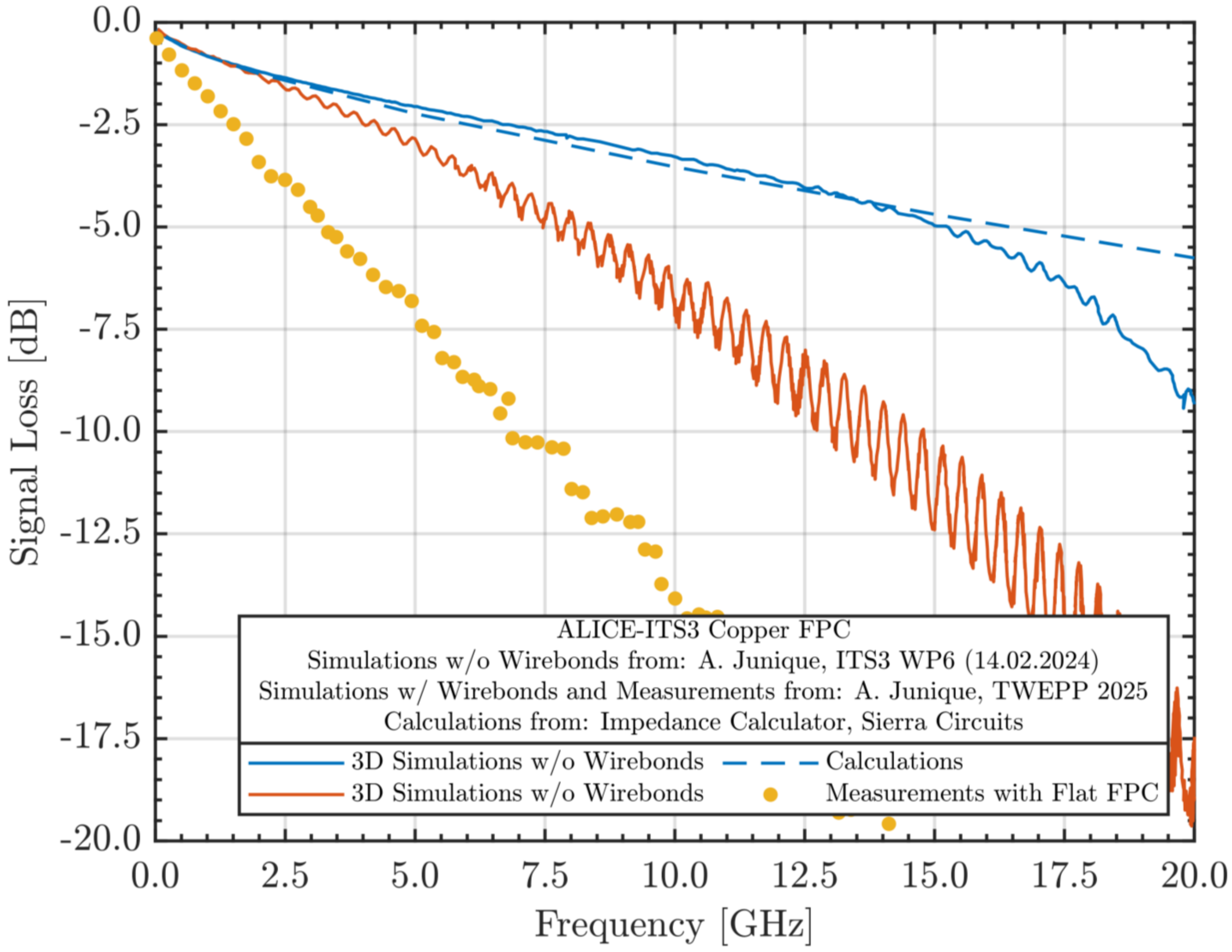
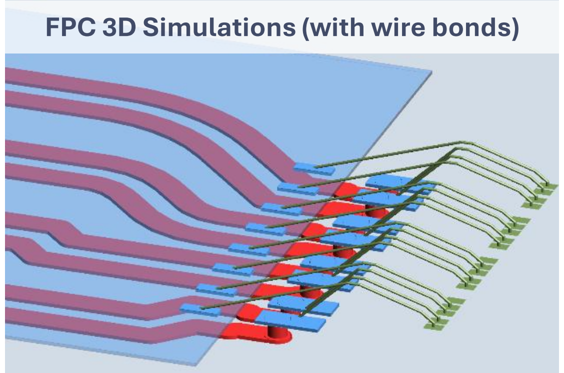
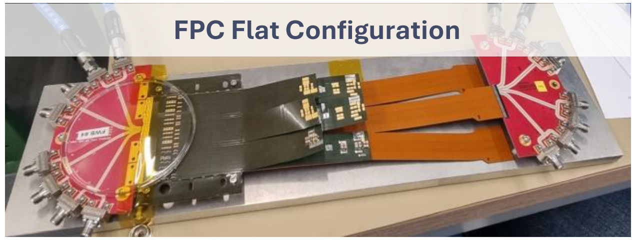
(NECESSARY) MITIGATION #2 : EXP. CHARACTERISATION



Latest signal integrity measurements with ITS3 FPCs at CERN indicate higher signal loss (wire bonds, text fixtures)





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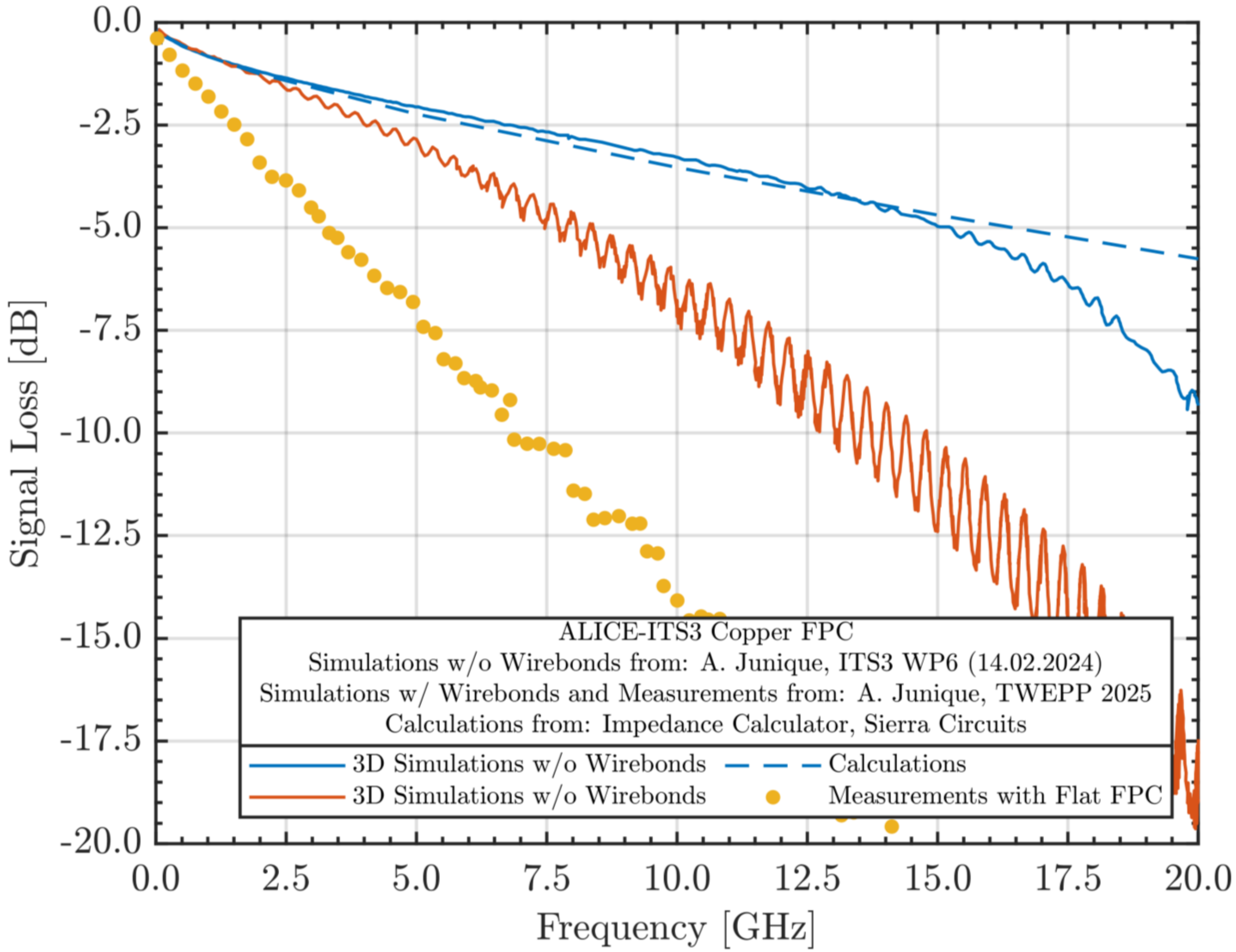

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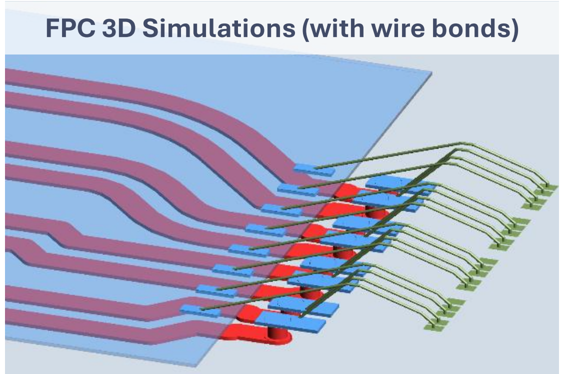
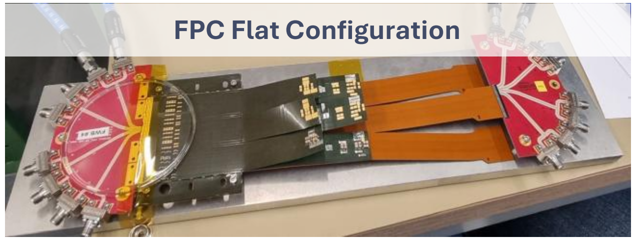


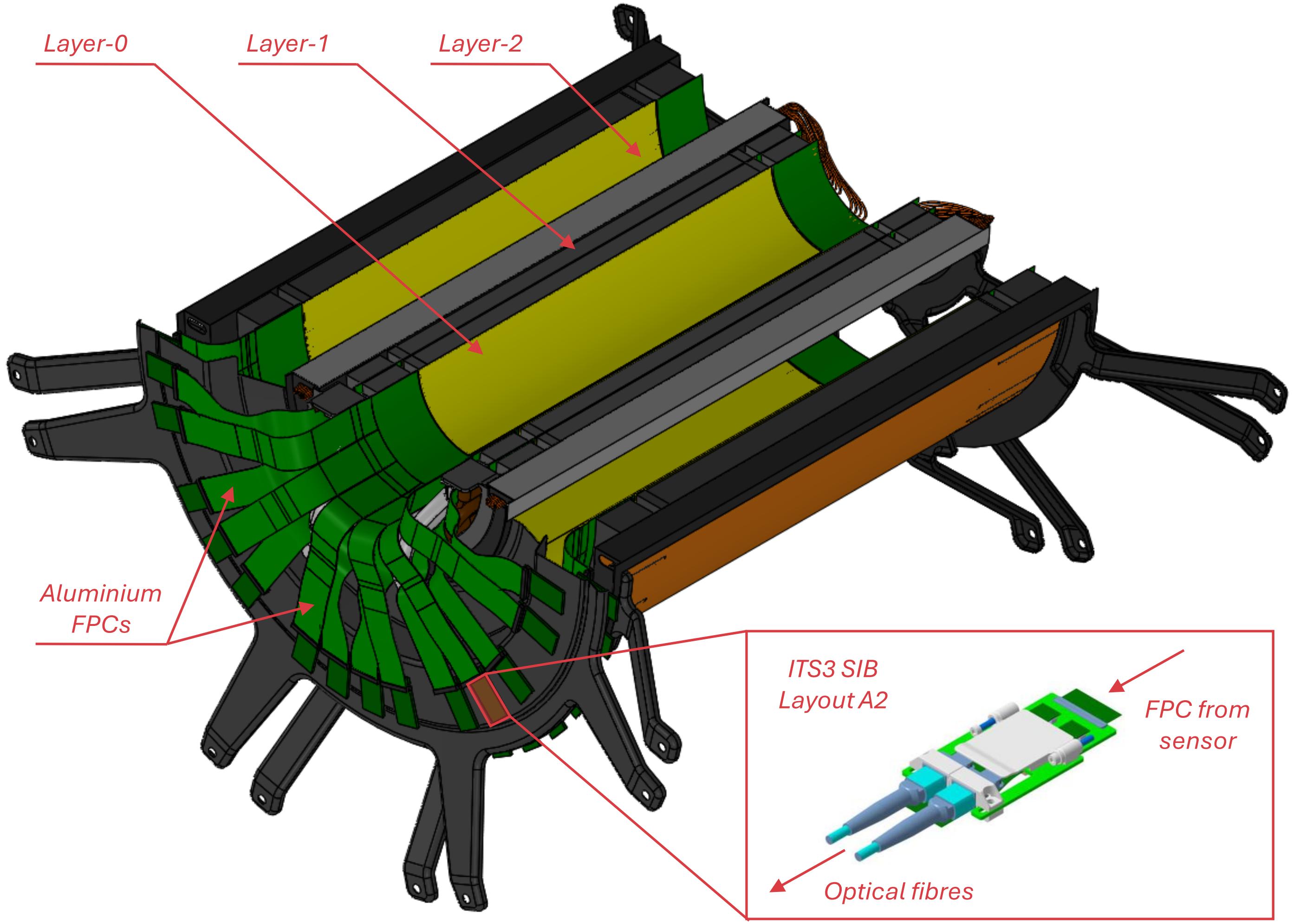


Similar setup currently under preparation at UniTS.
Expected to be up-and-running in January!
Mechanical prototypes also ordered. Expected in Q1-26.

THANK YOU

Extra Slides

FPC: Sensor To Segment Interface Board (SIB)



ITS3-MOSAIX-like sensors
- Differential data links at 10.24 Gb/s (lpGBT encoded)
- 8 differential pairs per segment

Segment Interface Boards
- Electrical-to-optical conversion
- 2 VTRx+ and slow control (clock, trigger, control)

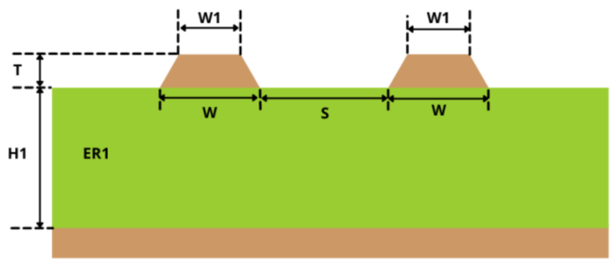
Flexible Printed Circuits
- Different FPC lengths per layer (8 … 18 cm)
- Aluminium-based FPCs from LTU Kharkiv

Layer	Radius [mm]	FPC Length [cm]	# Segments # SIBs
L0	38	18.1	12
L1	50	15.9	16
L2	126	8.4	40

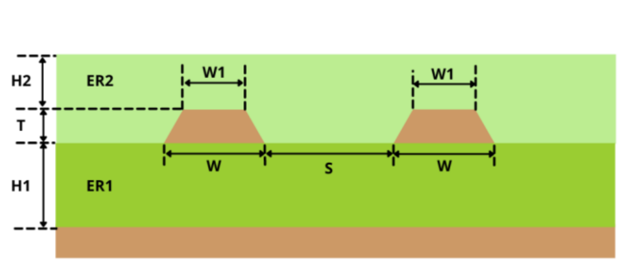
(First) Prototypes : Signal Integrity Calculations

All geometrical for both variants are taken to match the initial LTU calculations, albeit with different commercial calculators

Variants		Substrate and Coating				Aluminium Trace			
		H1 [µm]	H2 [µm]	ERi [-]	DFi [-]	W [µm]	W1 [µm]	T [µm]	S [µm]
A-1	Nominal	40	-	3.4	0.0038	70	60	15	80
A-2	Nominal	65	70	3.4	0.0038	70	60	15	80



A-1: Uncoated Microstrip Differential Pair



A-2: Embedded Microstrip Differential Pair

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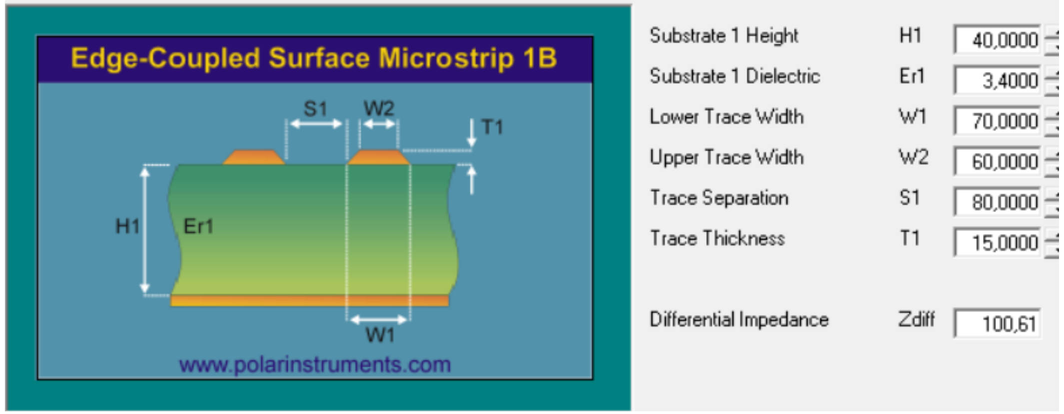
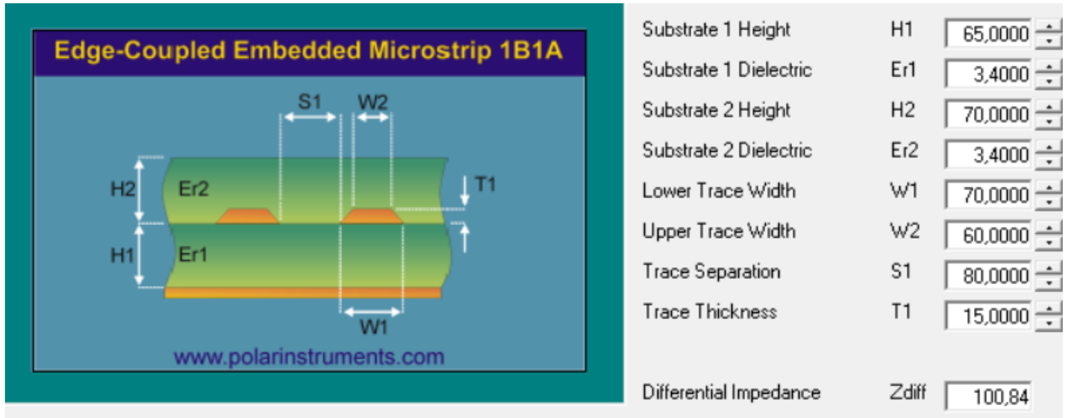
https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL





Calculations from:
I. Tymchuk et al., Uni Trieste - STFC DL - RPE LTU
ePIC SVT IB work meeting, July 11, 2025

Potentially Revised Versions