

ePIC SVT INNER BARREL FPC SIGNAL INTEGRITY

Kshitij Agarwal¹, Paolo Camerini¹, Giacomo Contin¹, Laura Gonella¹, et al.

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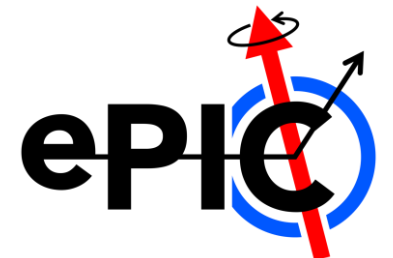
¹ University and INFN Trieste (IT)

SVT Working Meeting

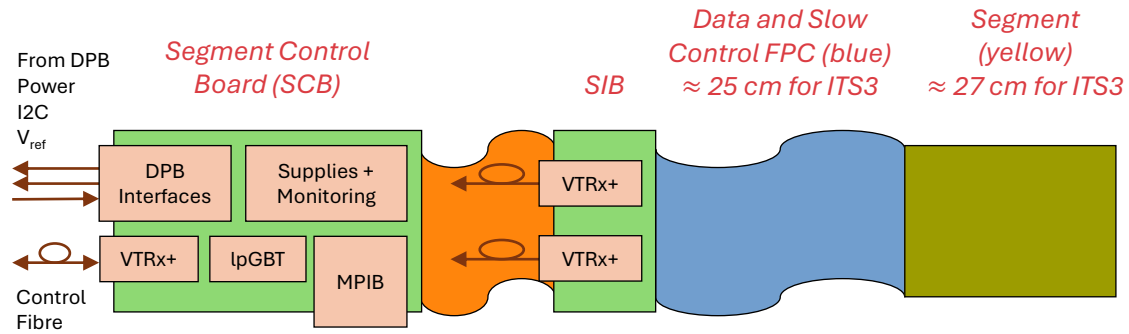
University of Oxford, 15.12.2025



**UNIVERSITÀ
DEGLI STUDI
DI TRIESTE**

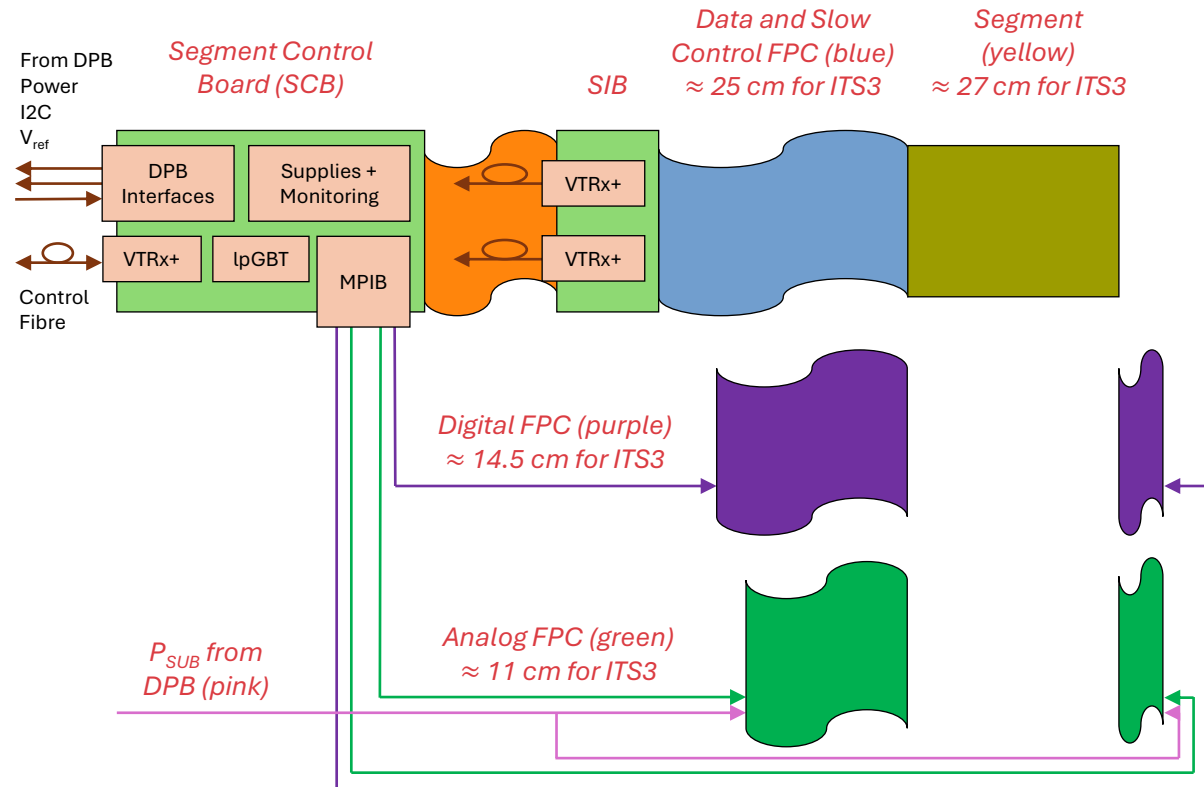


FPC: SENSOR TO SEGMENT INTERFACE BOARD (SIB)

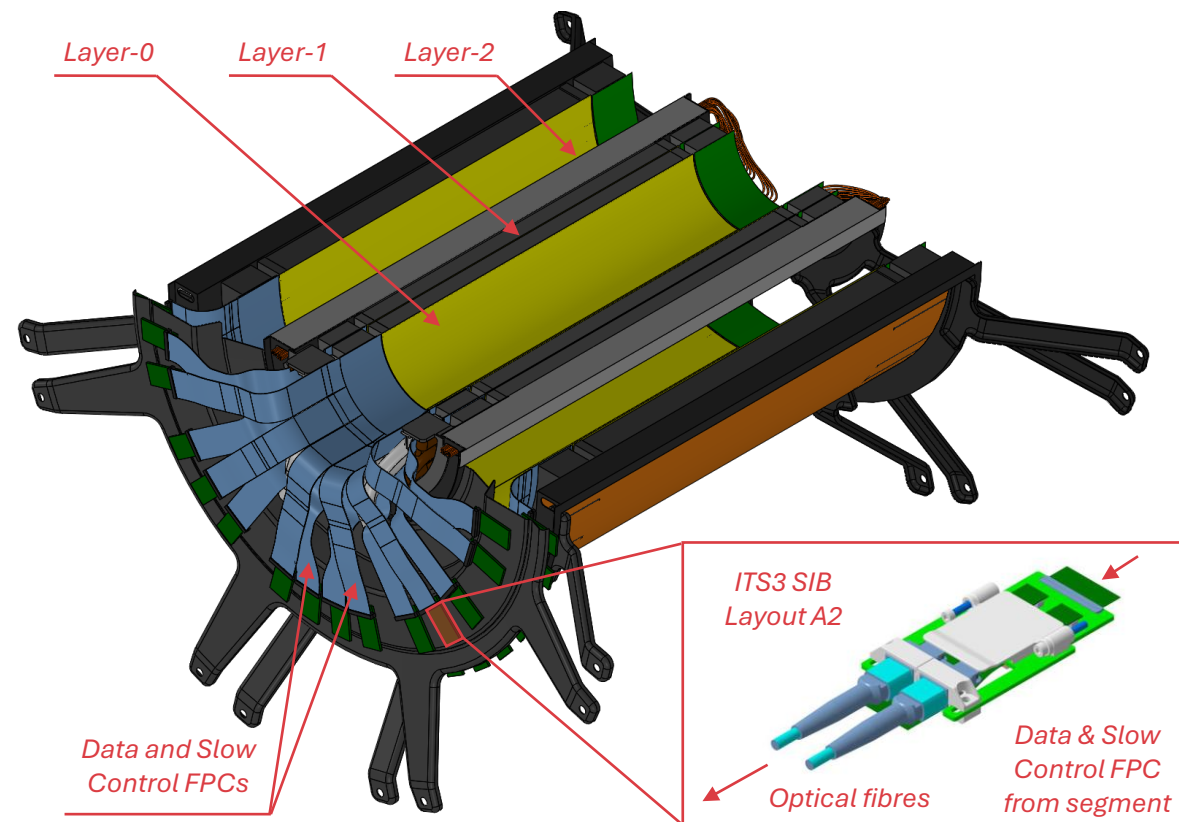


- **ITS3-MOSAIX-like sensors:** Differential data links at 10.24 Gb/s
- **Segment Interface Boards:** Electrical-to-optical data conv. & TTC

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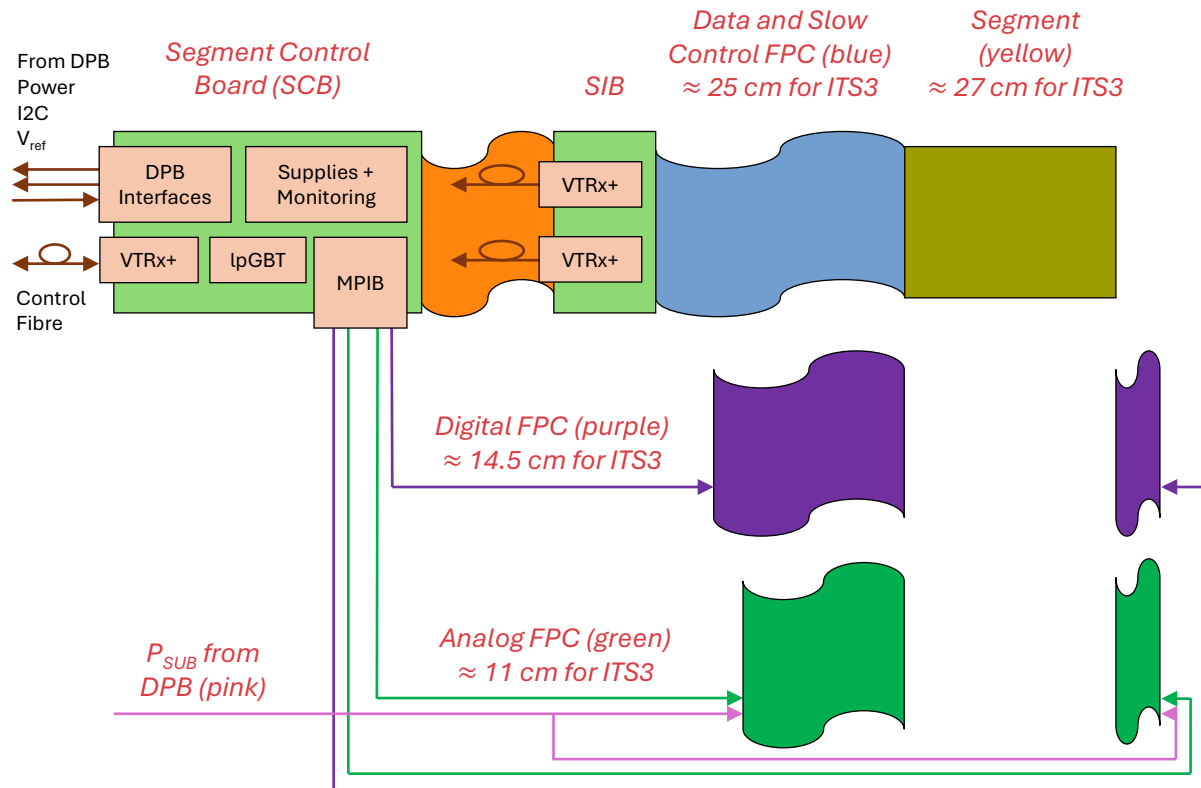


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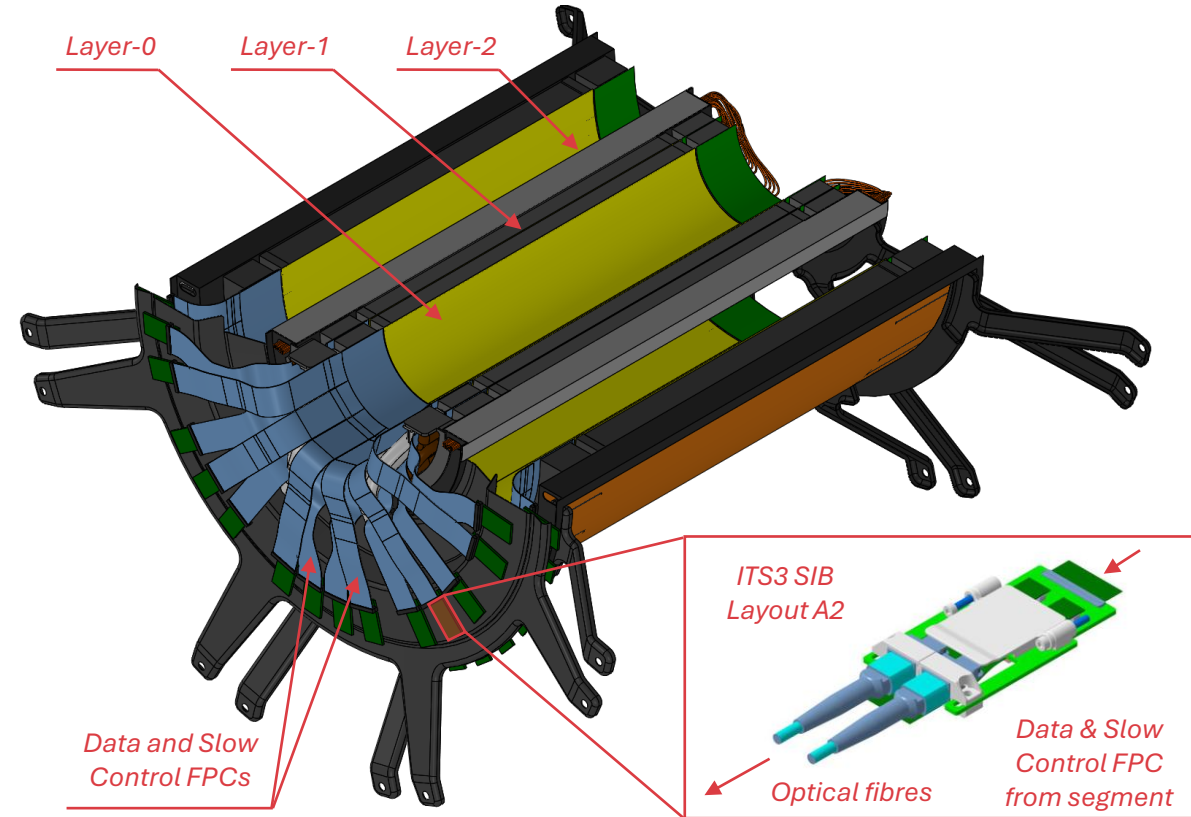


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FPC: SENSOR TO SEGMENT INTERFACE BOARD (SIB)



- **ITS3-MOSAIX-like sensors:** Differential data links at 10.24 Gb/s
- **Segment Interface Boards:** Electrical-to-optical data conv. & TTC
- **Data, Slow Control FPCs:** Diff. FPC lengths per layer (8 ... 18 cm)



This talk:

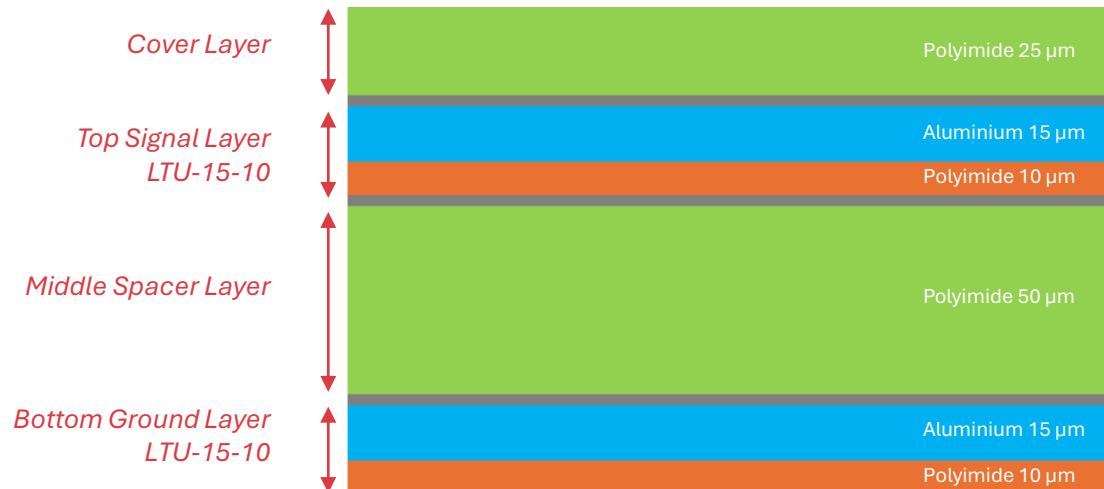
First look into the Inner Barrel's FPC prototyping, signal integrity calculations, and plans for experimental characterisation

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)

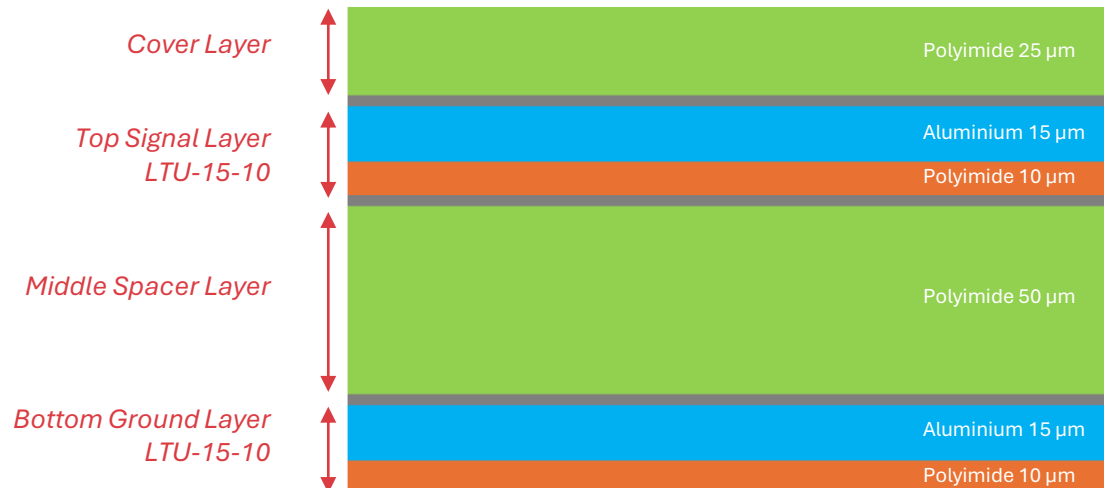
- A-1: Without cover layer, 25 μm middle spacer layer
- A-2: With cover layer, 50 μm middle spacer layer
- Diff. impedance = 100 Ω
- Trace width = 70 μm
- Trace thickness = 15 μm
- Space b/w traces = 80 μm
- Trace pitch = 150 μm

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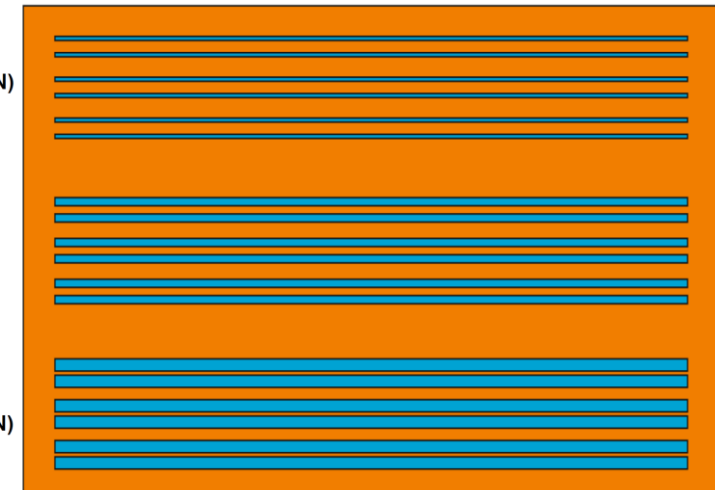
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- Further sub-variants with $\pm 10\%$ trace width
- 5 test samples of each variant (18 cm trace length)
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Group –
(- ~7 μm from N)

Group N
(nominal)

Group +
(+~7 μm from N)

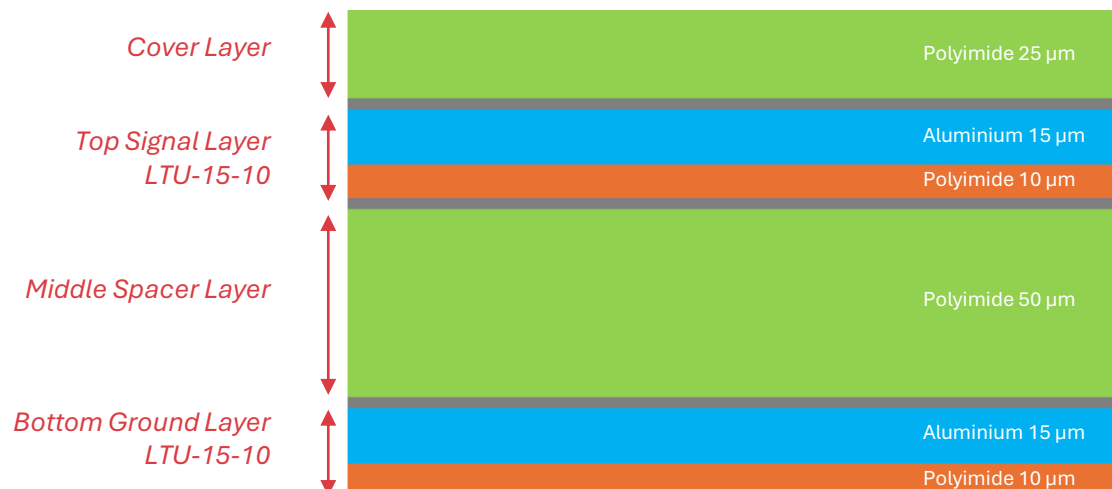


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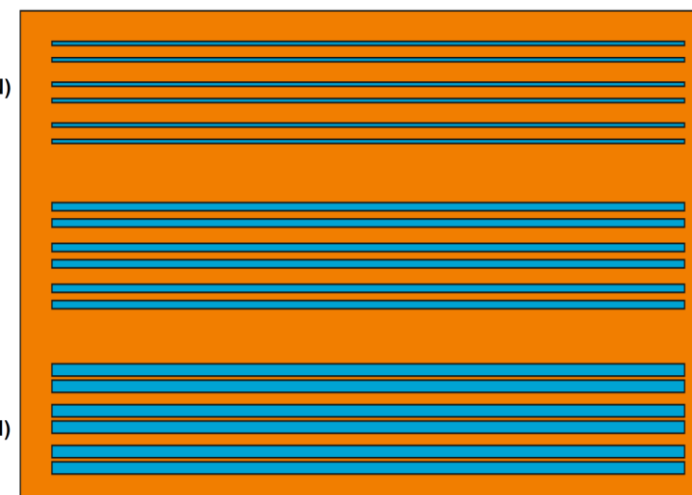
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- Ordered! Delivery in Q1-2026

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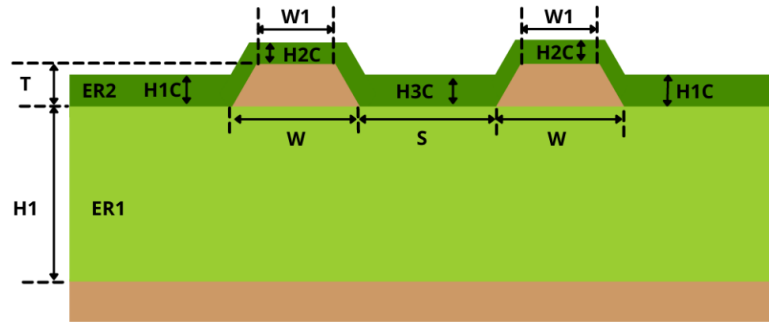
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SIGNAL INTEGRITY CALCULATIONS : BENCHMARKING

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

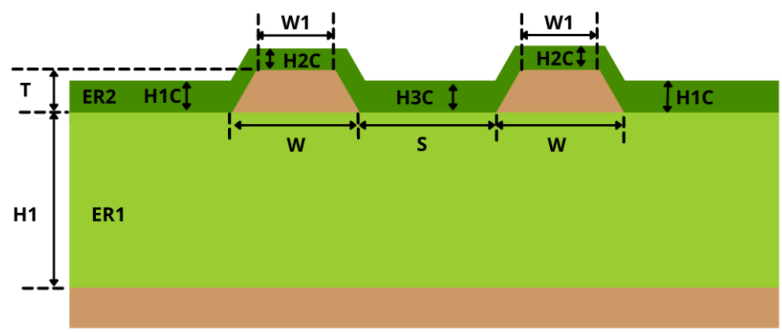


<https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL>

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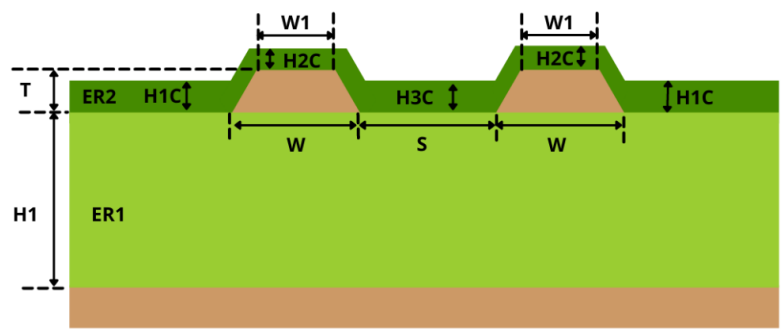
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		ALICE ITS2 IB	ALICE ITS3
Dielectric	H1 [μm]	75	150
	ER1 [-]	3.3	3.2
	DF1 [-]	0.0038	0.0030
Coating	HiC [μm]	25	75
	ER2 [-]	3.7	3.0
	DF_coat [-]	0.0290	0.0045
Trace	W [μm]	100	200
	W1 [μm]	70	200
	T [μm]	25	35
	S [μm]	100	200
	L [cm]	21.3 / 44.1	25.8

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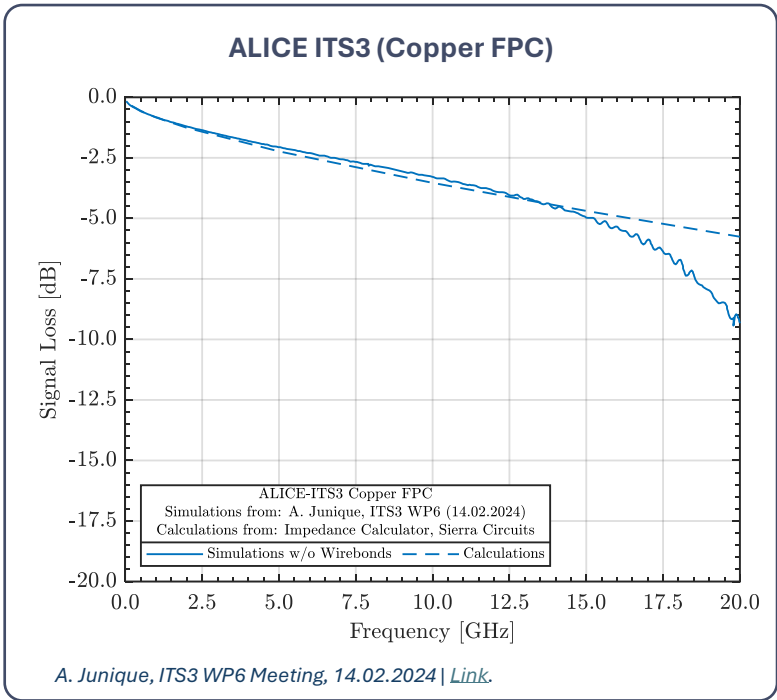


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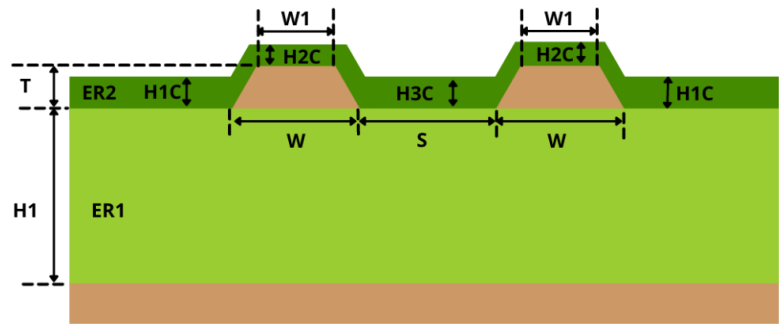
A. Junique, ITS3 WP6 Meeting, 14.02.2024 | [Link](#).

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

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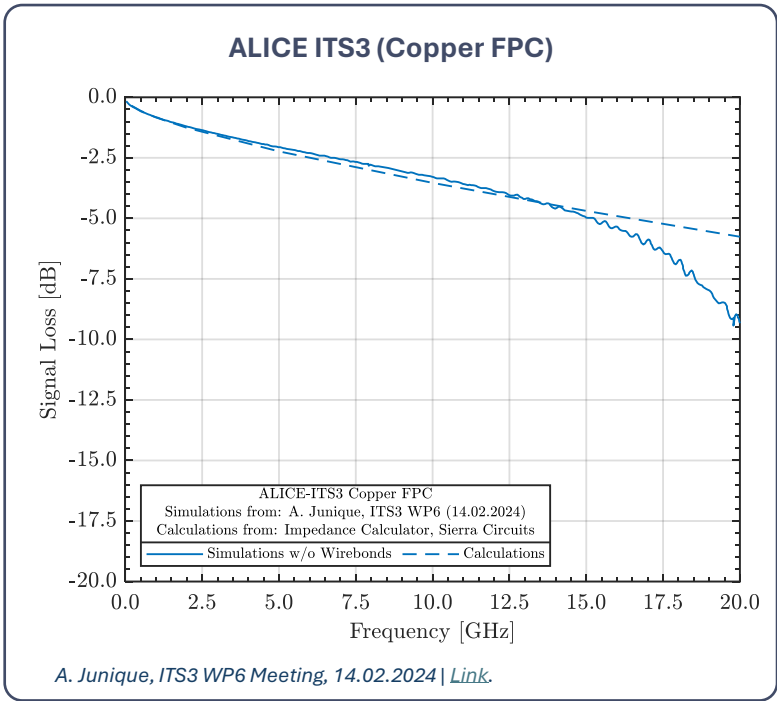


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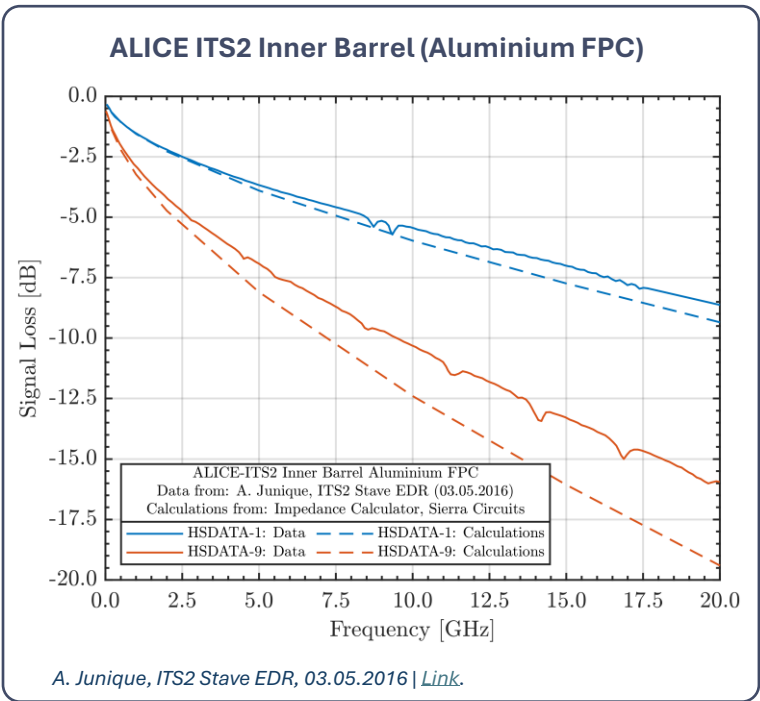


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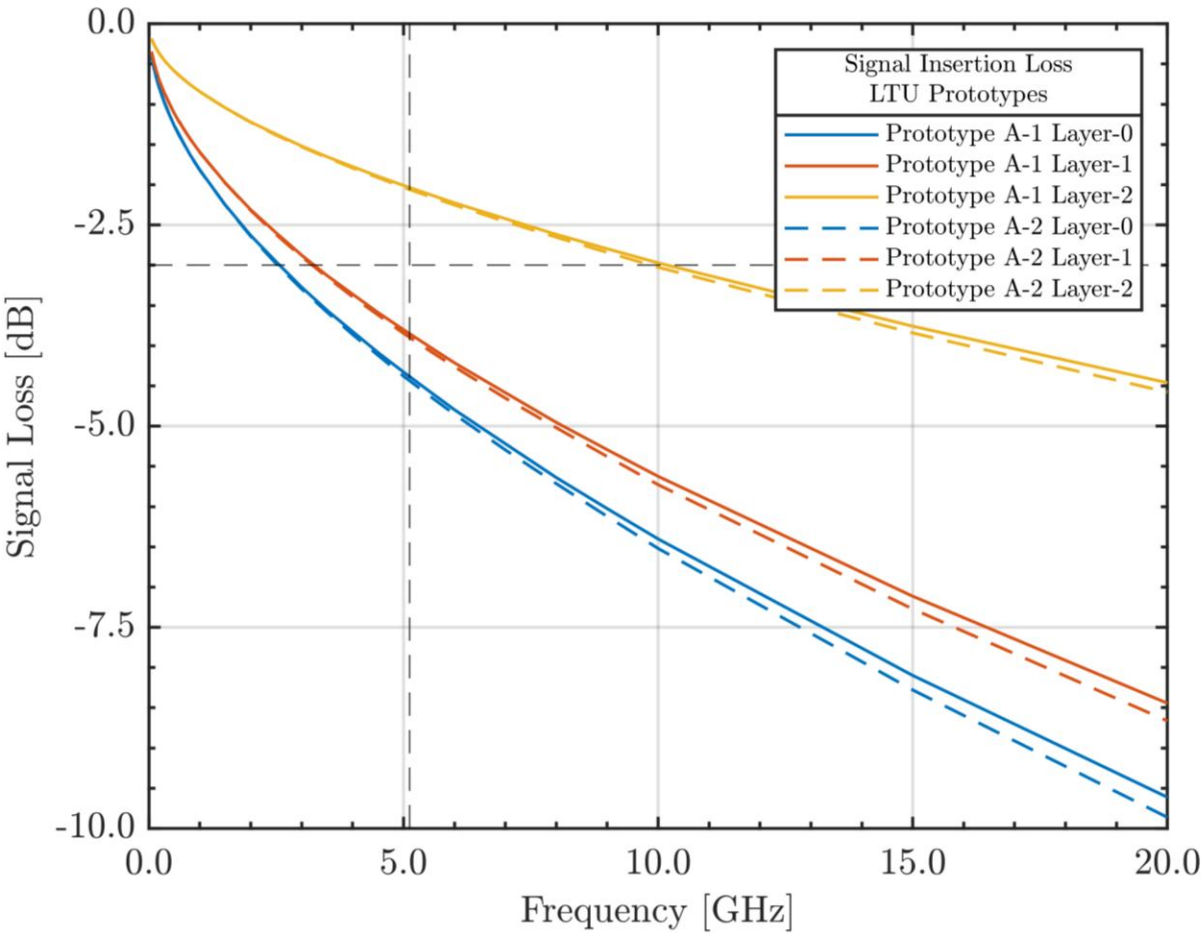
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A. Junique, ITS2 Stave EDR, 03.05.2016 | [Link](#).

- 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



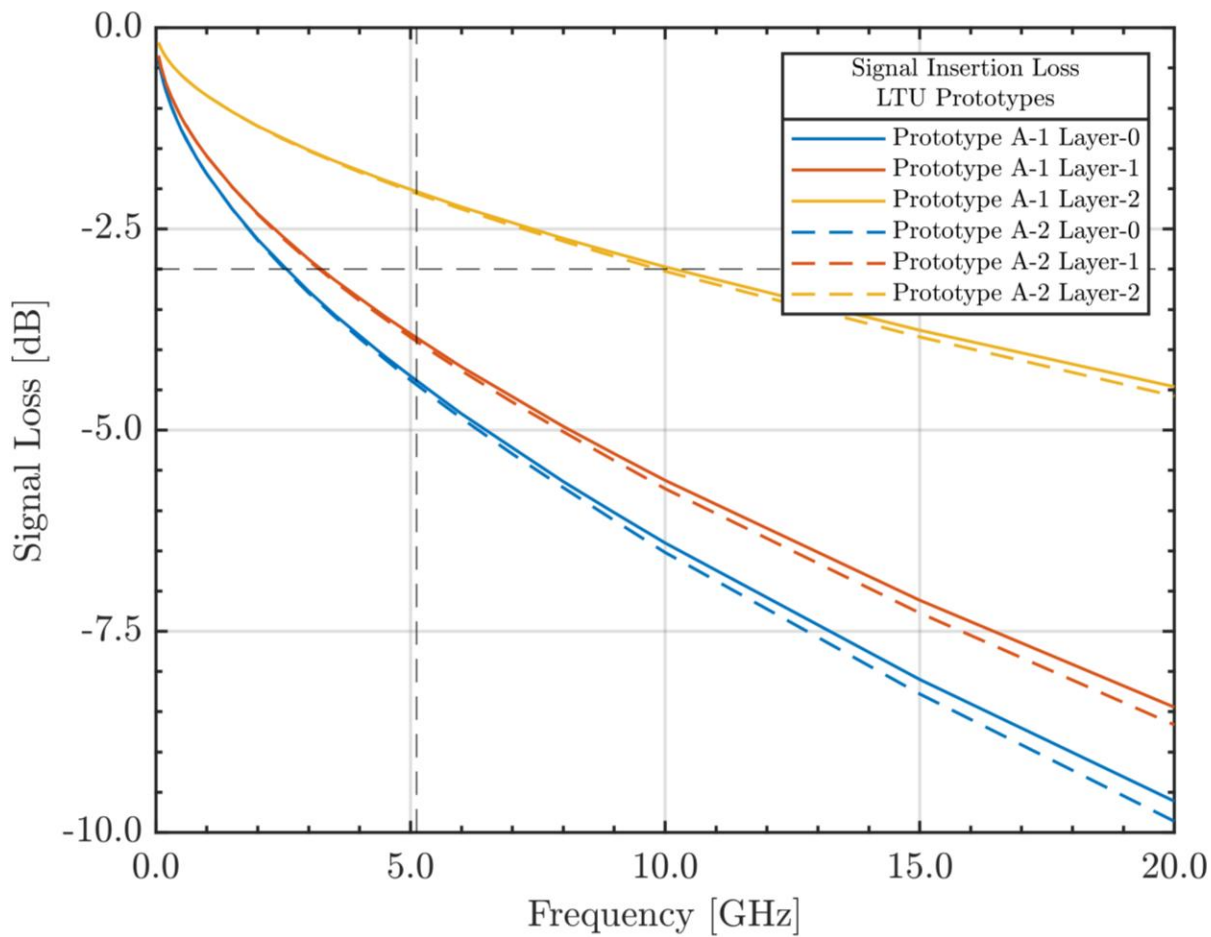
Online impedance and signal integrity calculator from Sierra Circuits
<https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL>
Calculation and setup details in the back-up slides

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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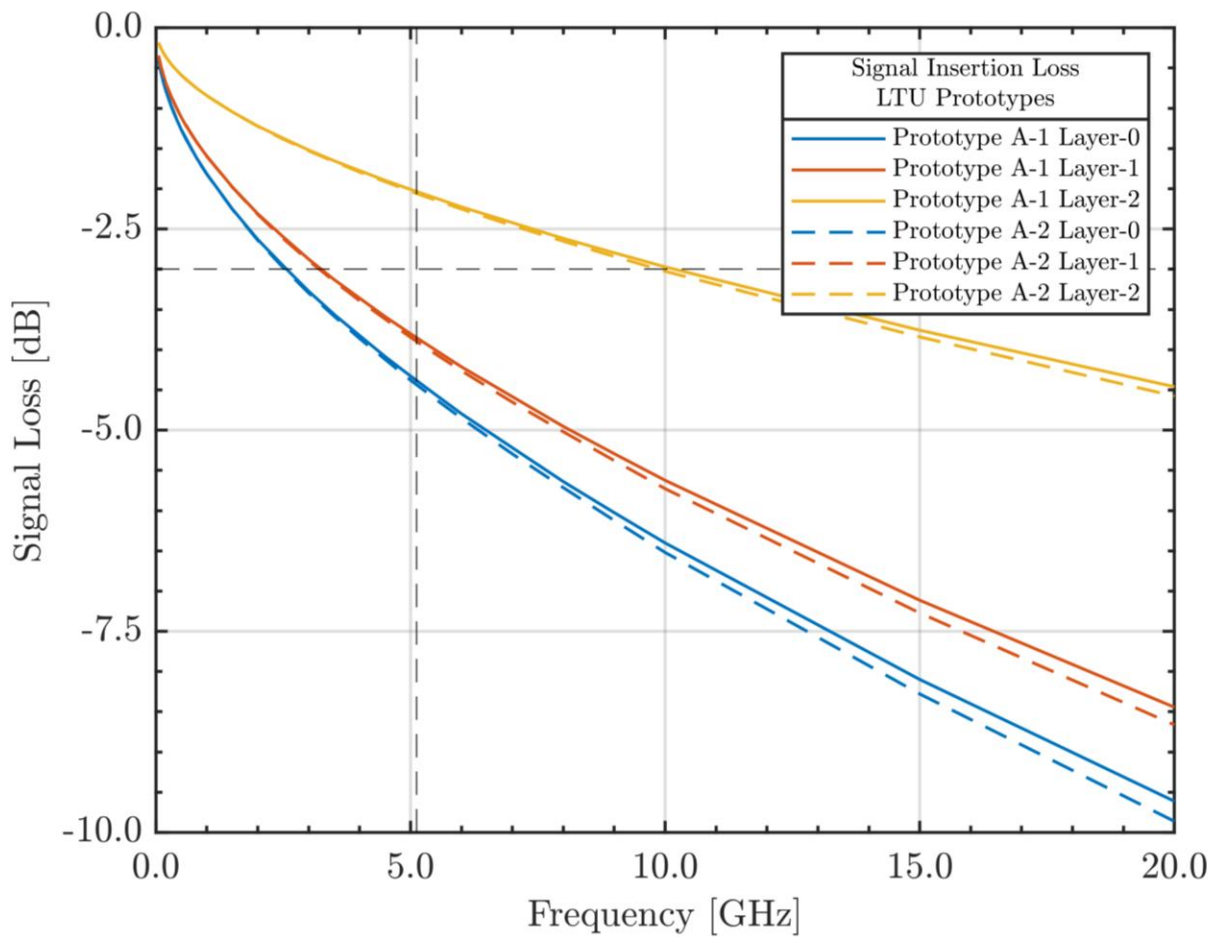
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Mitigating strategies needed for recovering signal for L0 and L1

- NKF7 pre-emphasis on MOSAIX → Exp. Characterisation is needed

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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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(POTENTIAL) MITIGATION #1 : MORE MATERIAL

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

Materials for ultra-low mass flexible single- and multilayered FPCs/FPCBs from LTU

Aluminium-polyimide adhesiveless foiled dielectrics



Now RPE LTU is able to manufacture aluminium-polyimide adhesiveless materials with various thickness of conductive foils

Material	polyimide	aluminium foil
❖ LTU-15-10	– 10 μm	– 15 μm
❖ LTU-25-10	– 10 μm	– 25 μm
❖ LTU-30-20	– 20 μm	– 30 μm
❖ LTU-10-10	– 10 μm	– 10 μm
❖ LTU-50-20	– 20 μm	– 50 μm
❖ LTU-100-20	– 20 μm	– 100 μm
❖ LTU-10-50-10	– 10 μm	– 50 μm
❖ LTU-150-20	– 20 μm	– 150 μm
❖ LTU-200-20	– 20 μm	– 200 μm

„Standard,, materials

Developed for ALICE ITS2

Developed for ALICE FoCal

Developed for further possible ultralight FPCs (ePIC SVT, ALICE 3, CBM-MVD)

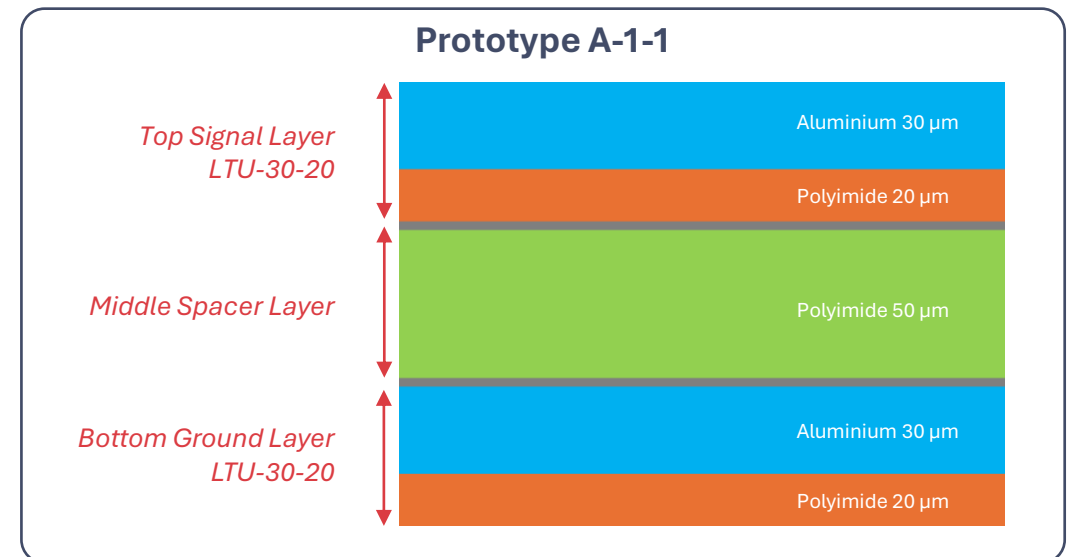
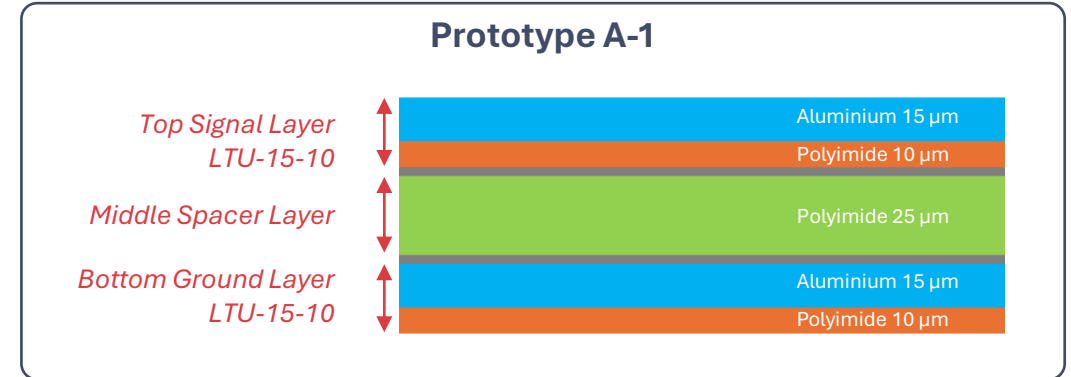
July 11, 2025 Uni Trieste - STFC DL - RPE LTU ePIC SVT IB work meeting viatcheslav.borshchov@cern.ch, lhor.tymchuk@cern.ch

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

	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)



Materials for ultra-low mass flexible single- and multilayered FPCs/FPCBs from LTU

6

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❖ LTU-100-20	20 μm	100 μm
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❖ LTU-150-20	20 μm	150 μm
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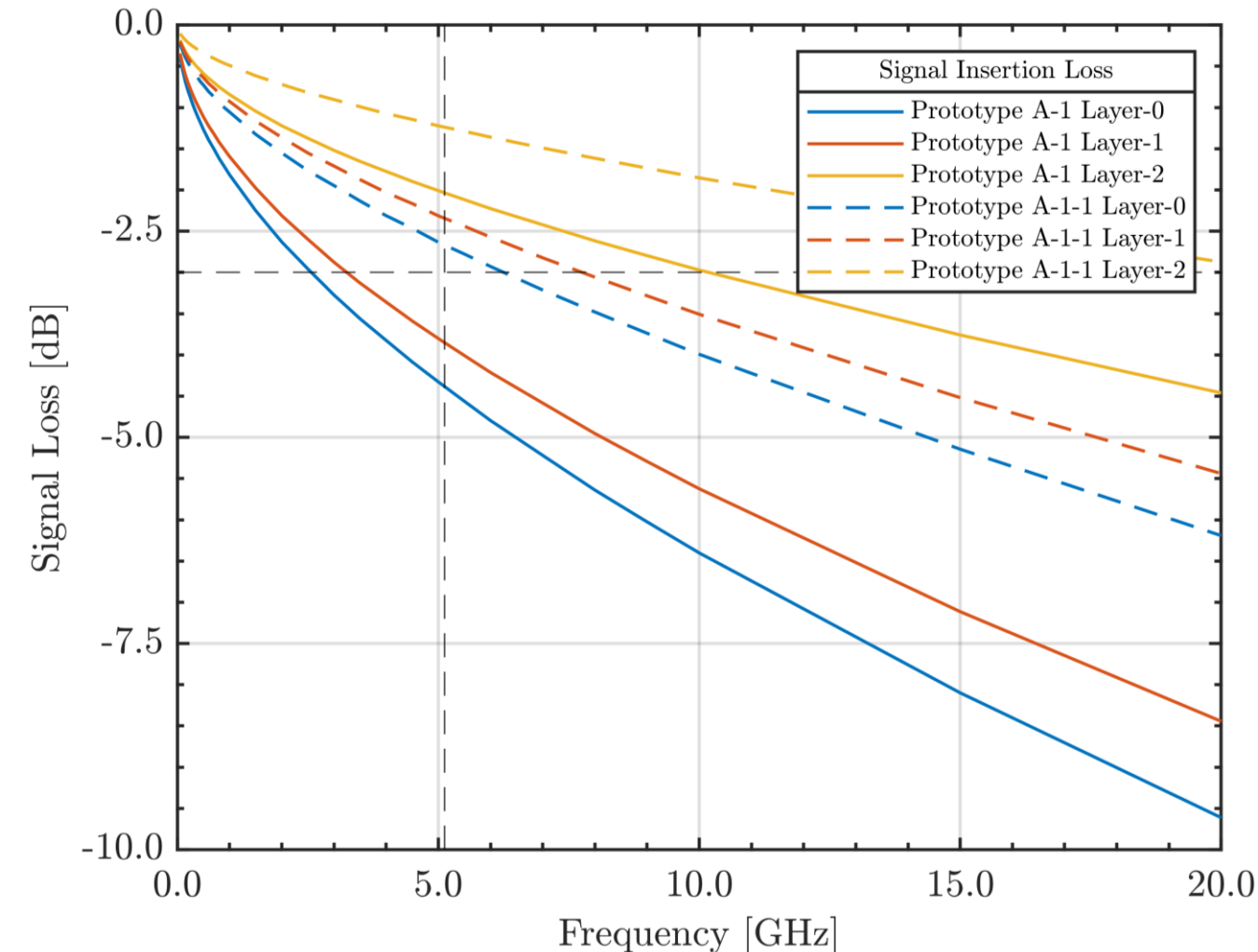
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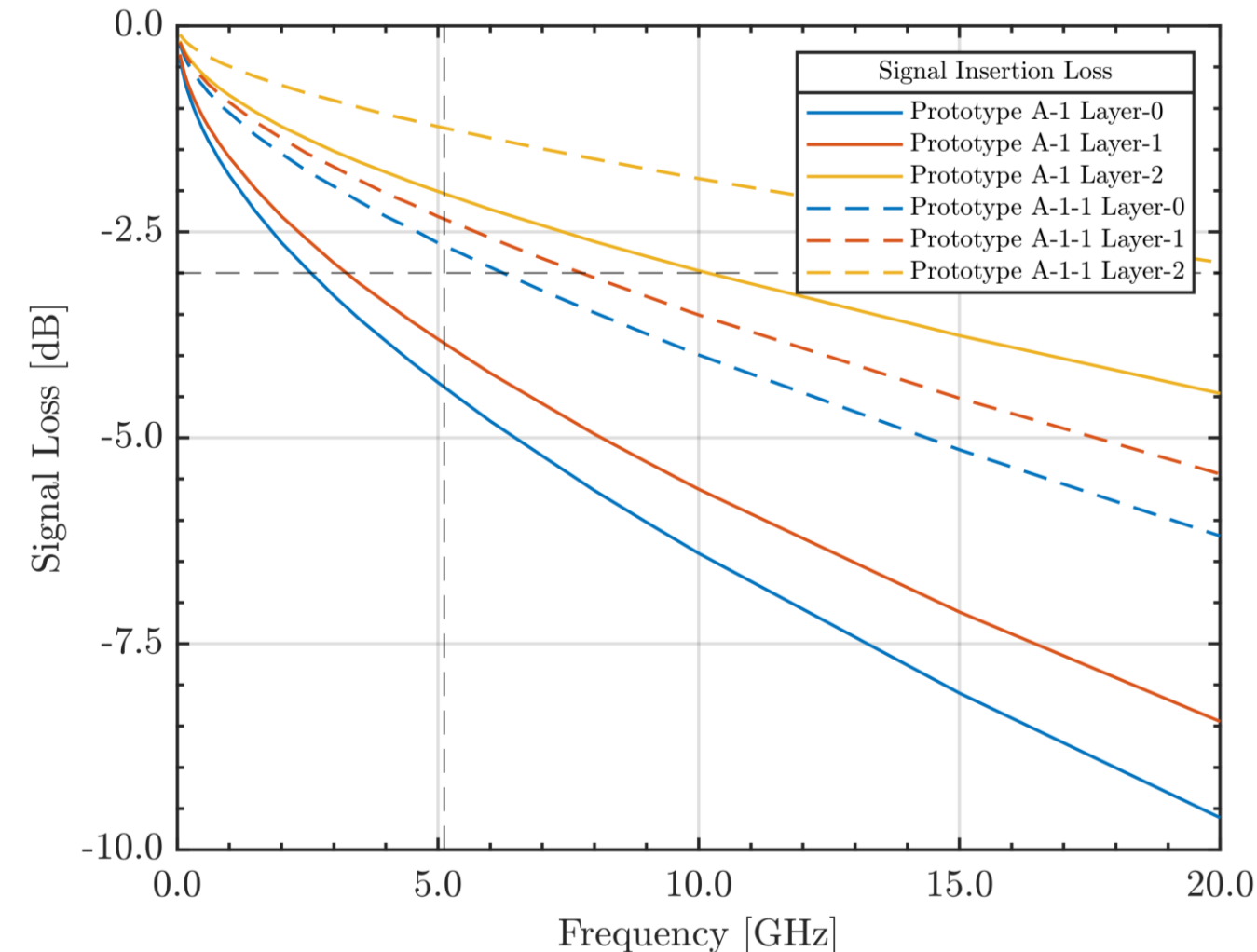
Estimated < 3 dB signal loss at 5 GHz for L0 and L1

- A-1-type FPC based on LTU-30-20
- Conductor loss reduced by > 2x (still dominating contributor)
- Material budget increased by $\approx 2x$

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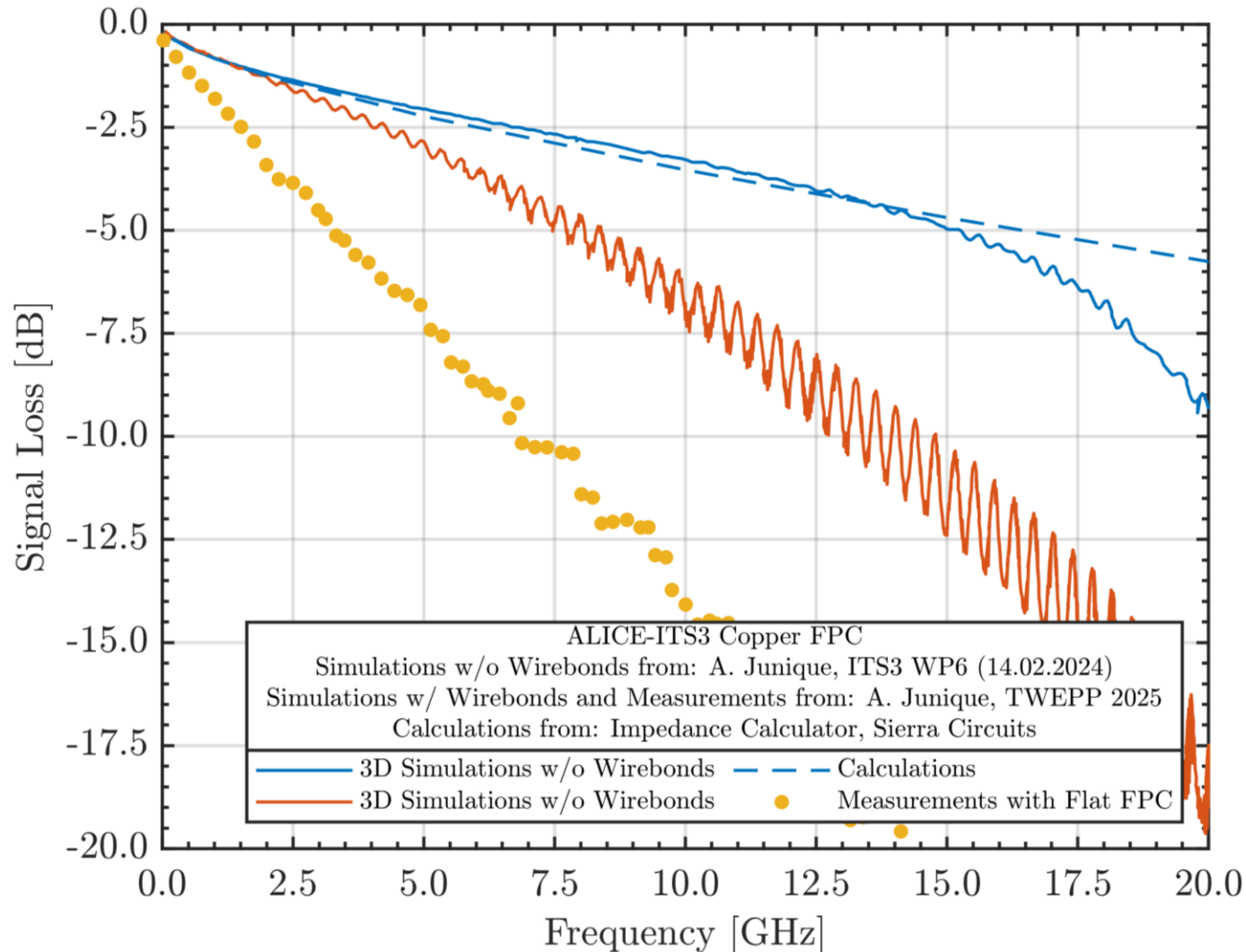
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Further room for optimization by opting for intermediate aluminium thicknesses from the LTU catalogue (20 μm , 25 μm)

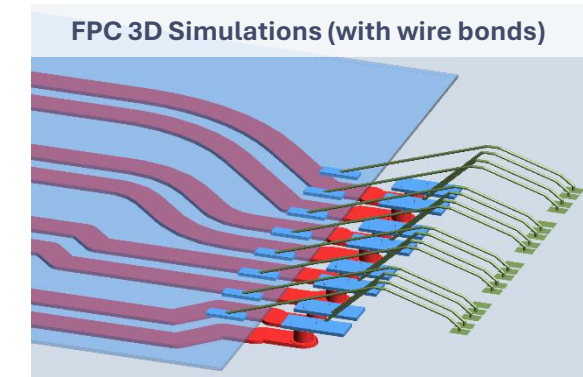
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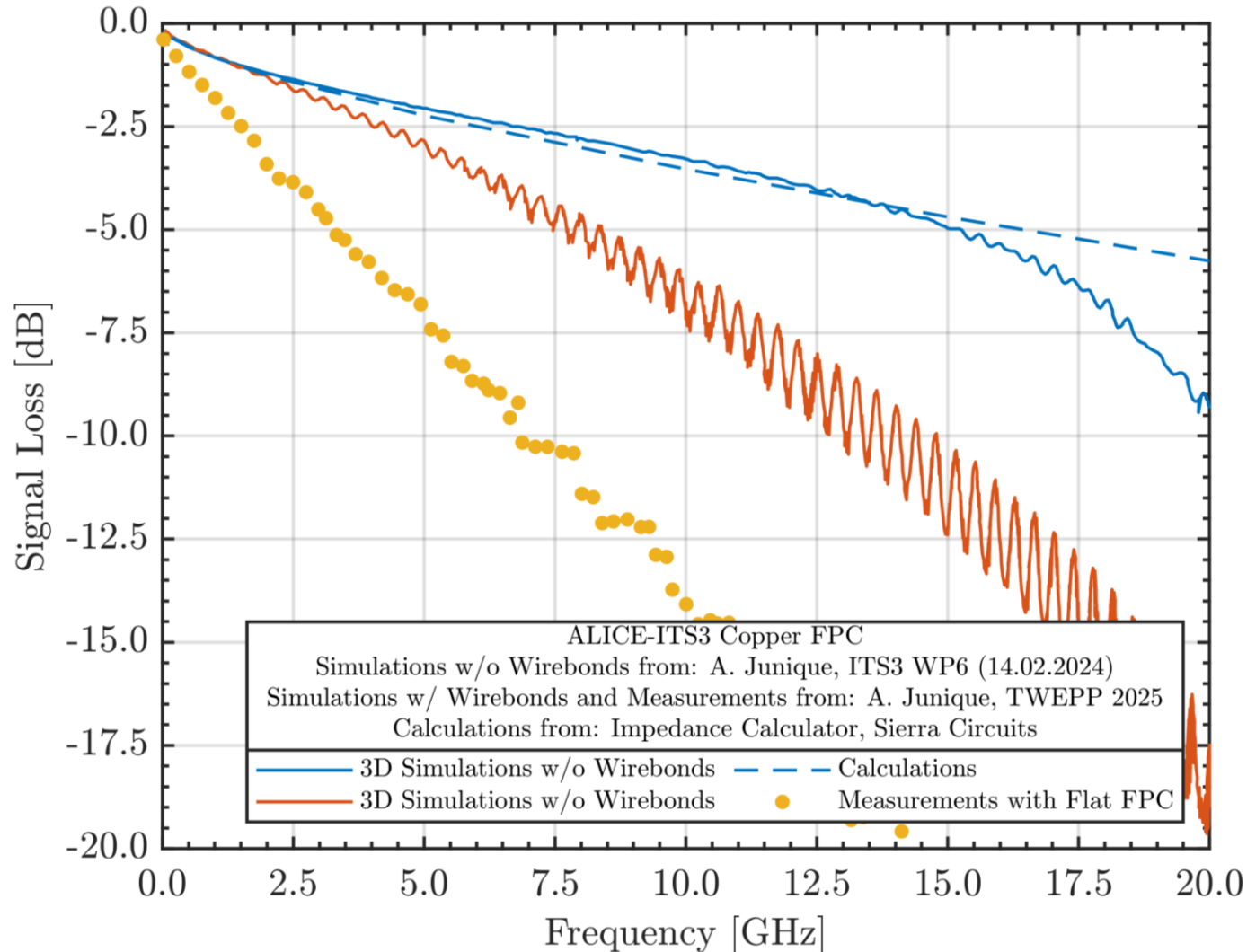
(NECESSARY) MITIGATION #2 : EXP. CHARACTERISATION



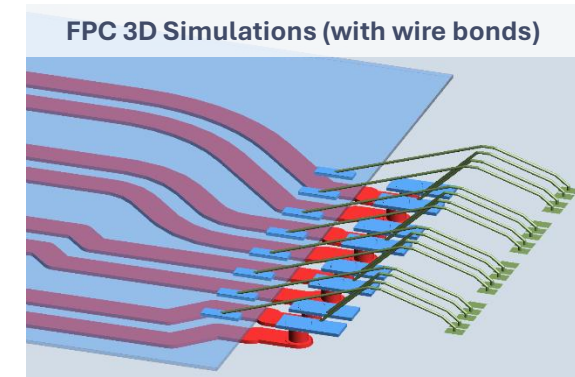
Latest signal integrity measurements with ITS3 FPCs at CERN indicate higher signal loss (wire bonds, text fixtures)



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

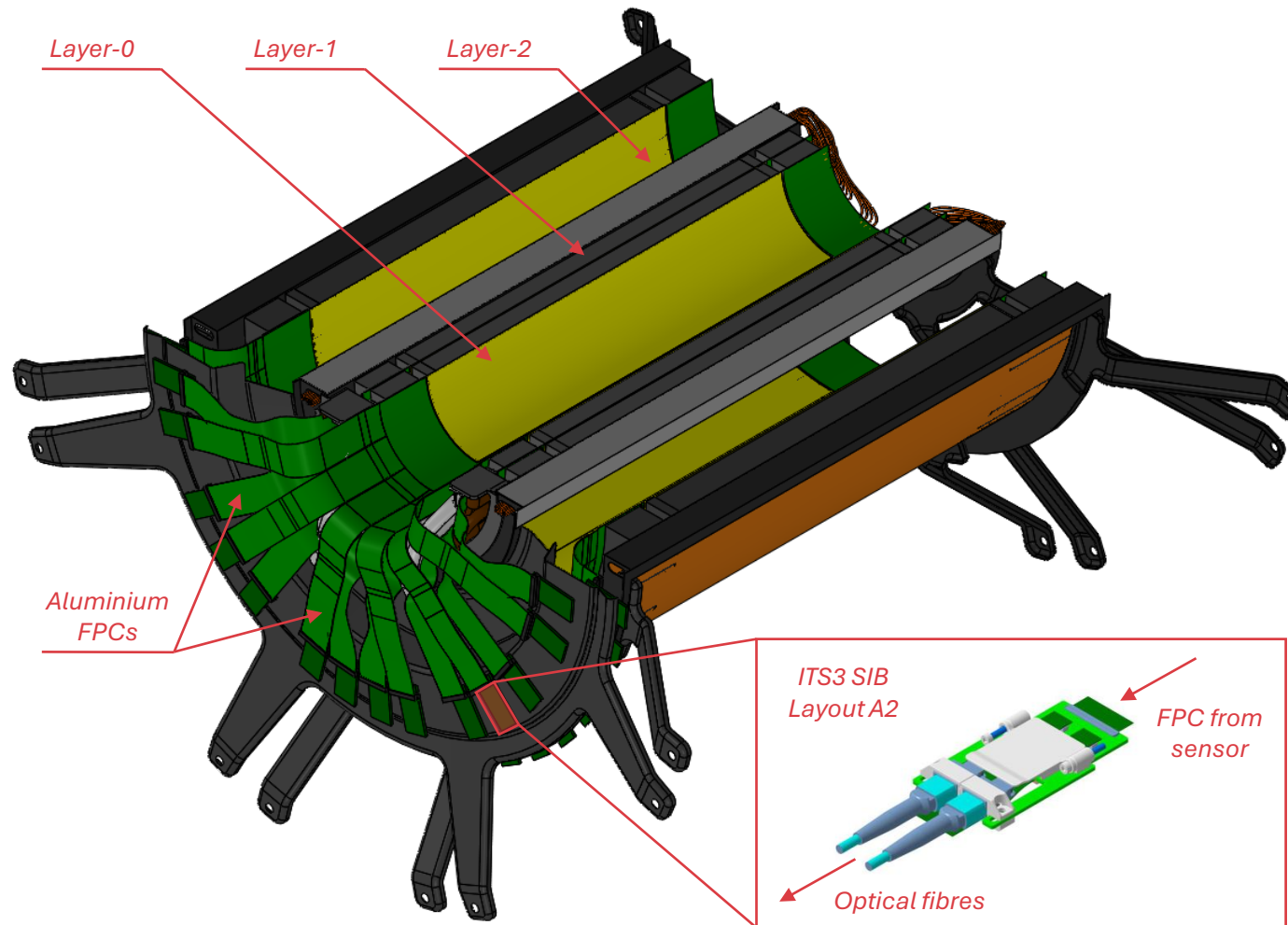


Similar setup currently under preparation at UniTS.
Expected to be up-and-running in January!
Mechanical prototypes also ordered. Expected in Q1-26.

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

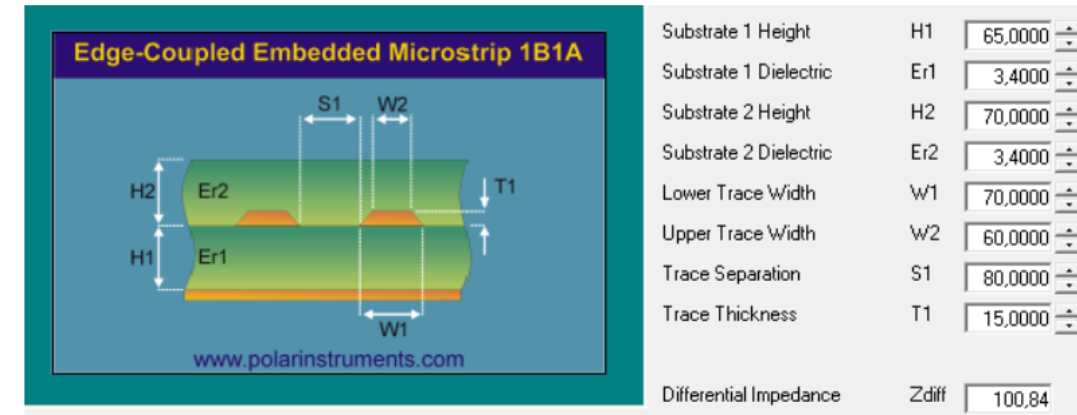
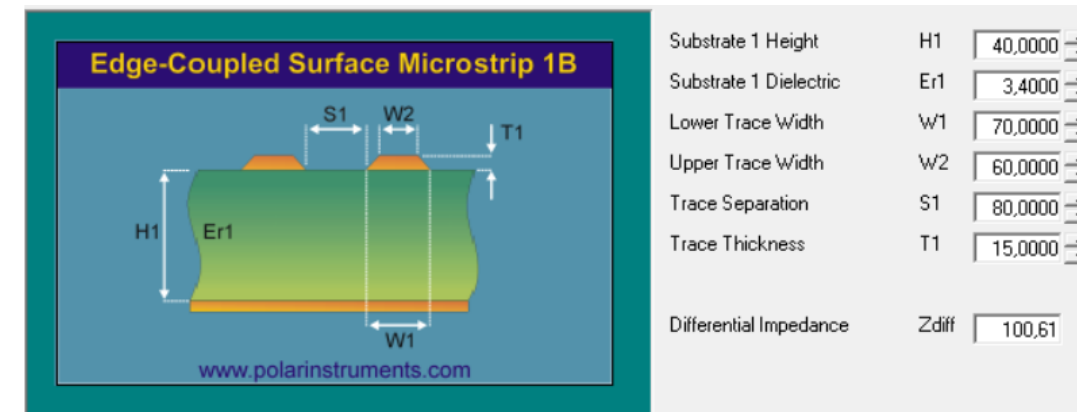
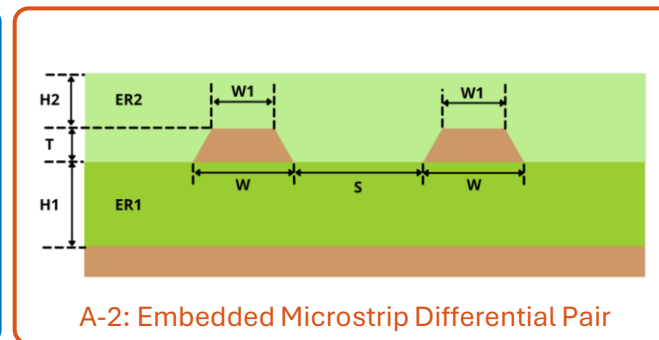
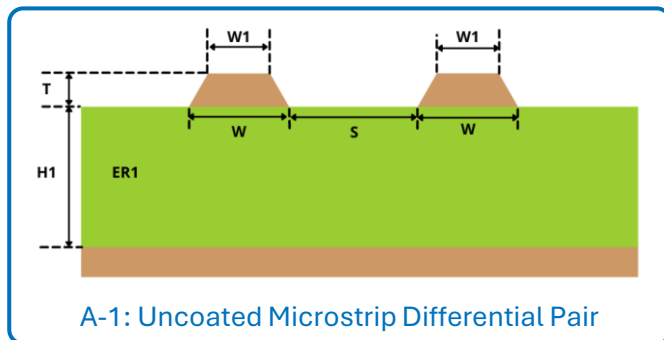
- Different FPC lengths per layer (8 ... 18 cm)
- Aluminium-based FPCs from LTU Kharkiv

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						



Online impedance and signal integrity calculator from Sierra Circuits
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Calculations from:
 I. Tymchuk et al., Uni Trieste - STFC DL - RPE LTU
 ePIC SVT IB work meeting, July 11, 2025

POTENTIALLY REVISED VERSIONS



Uncoated Microstrip Differential Pair Impedance Calculator

Impedance | Signal Loss | S Parameter | Crosstalk

Geometry Information

UNCOATED MICROSTRIP DIFFERENTIAL PAIR

Units (μm)

μm

Show PCB Dielectric Material Construction Table

Dielectric Information

Dielectric Height (H1) (μm) 75

Dielectric Constant (ER1) 3.4

Trace Information

Trace Width (W) (μm) 125 **Calculate W**

ΔW = (W - W1) (μm) 10

Trace Thickness (T) (μm) 30

Trace Separation (S) (μm) 125

Trace + Separation = (W + S) (μm) 250

Impedance Output

Target Diff. Impedance (Zd) Ω 100

Calculated Diff. Impedance (Zd) Ω 99.43646 **Calculate Zd**

Coupling Coefficient (K %) 10.83025

Odd Mode Impedance (Zodd) Ω 49.71823

Even Mode Impedance (Zeven) Ω 61.79544

Propagation Delay (PdEven) (ps/cm) 54.33142

Propagation Delay (Pdodd) (ps/cm) 49.92612

Embedded Microstrip Differential Pair Impedance Calculator

Impedance | Signal Loss | S Parameter | Crosstalk

Geometry Information

EMBEDDED MICROSTRIP DIFFERENTIAL PAIR

Units (μm)

μm

Show PCB Dielectric Material Construction Table

Dielectric Information

Dielectric Height (H1) (μm) 125

Dielectric Constant (ER1) 3.4

Dielectric Height (H2) (μm) 45

Dielectric Constant (ER2) 3.4

Trace Information

Trace Width (W) (μm) 125 **Calculate W**

ΔW = (W - W1) (μm) 10

Trace Thickness (T) (μm) 30

Trace Separation (S) (μm) 125

Trace + Separation = (W + S) (μm) 250

Impedance Output

Target Diff. Impedance (Zd) Ω 100

Calculated Diff. Impedance (Zd) Ω 100.51389 **Calculate Zd**

Coupling Coefficient (K %) 22.58372

Odd Mode Impedance (Zodd) Ω 50.25695

Even Mode Impedance (Zeven) Ω 79.57866

Propagation Delay (PdEven) (ps/cm) 57.9172

Propagation Delay (Pdodd) (ps/cm) 57.41975

Impedance | Signal Loss | S Parameter | Crosstalk

Dielectric Dissipation Factor Information

Dissipation Factor (DF1) 0.0038

Signal Loss Input

Frequency (GHz) 5 GHz

Surface Roughness (Rz) (μm) 0

Length (cm) 25

Calculate Loss

Signal Loss Output Odd Mode

Conductor Loss (Odd Mode) (dB/cm) 0.09291

Dielectric Loss (Odd Mode) (dB/cm) 0.02598

Insertion Loss (Odd Mode) (dB/cm) 0.1185

Total Insertion Loss (Odd Mode) (dB) 2.966

Signal Loss Output Even Mode

Conductor Loss (Even Mode) (dB/cm) 0.09764

Dielectric Loss (Even Mode) (dB/cm) 0.02835

Insertion Loss (Even Mode) (dB/cm) 0.12598

Total Insertion Loss (Even Mode) (dB) 3.147

Impedance | Signal Loss | S Parameter | Crosstalk

Dielectric Dissipation Factor Information

Dissipation Factor (DF1) 0.0038

Dissipation Factor (DF2) 0.0038

Signal Loss Input

Frequency (GHz) 5 GHz

Surface Roughness (Rz) (μm) 0

Length (cm) 25

Calculate Loss

Signal Loss Output Odd Mode

Conductor Loss (Odd Mode) (dB/cm) 0.09173

Dielectric Loss (Odd Mode) (dB/cm) 0.02992

Insertion Loss (Odd Mode) (dB/cm) 0.12165

Total Insertion Loss (Odd Mode) (dB) 3.038

Signal Loss Output Even Mode

Conductor Loss (Even Mode) (dB/cm) 0.06969

Dielectric Loss (Even Mode) (dB/cm) 0.02992

Insertion Loss (Even Mode) (dB/cm) 0.09961

Total Insertion Loss (Even Mode) (dB) 2.494