

ePIC SVT INNER BARREL

FPC SIGNAL INTEGRITY

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

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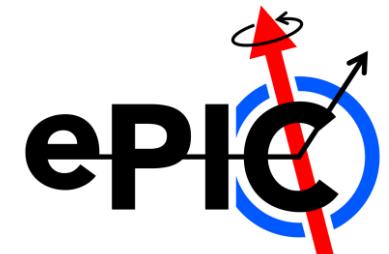
¹ University and INFN Trieste (IT)

SVT Working Meeting

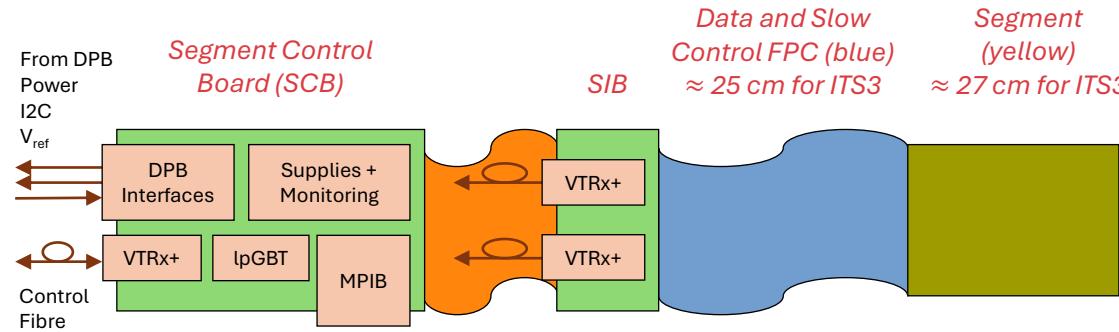
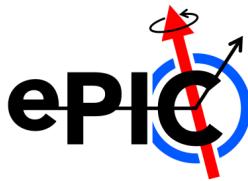
University of Oxford, 15.12.2025



**UNIVERSITÀ
DEGLI STUDI
DI TRIESTE**

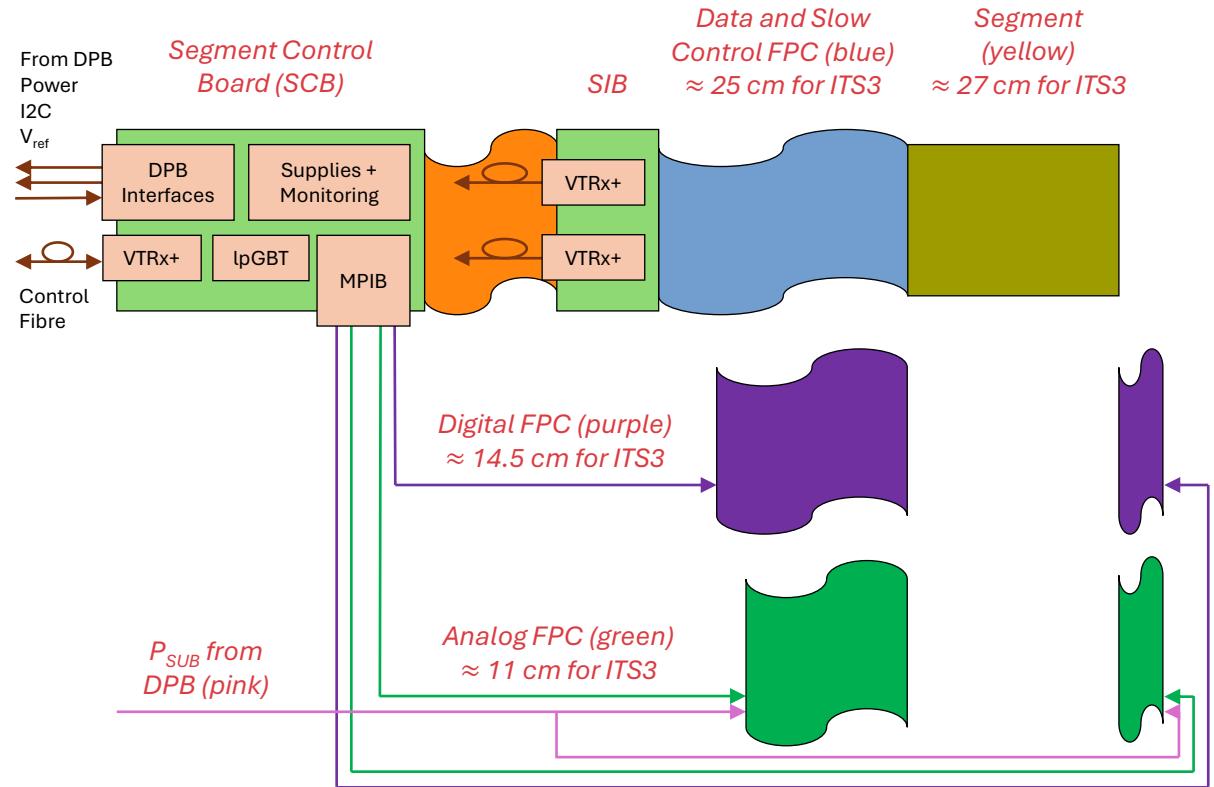


FPC: SENSOR TO SEGMENT INTERFACE BOARD (SIB)



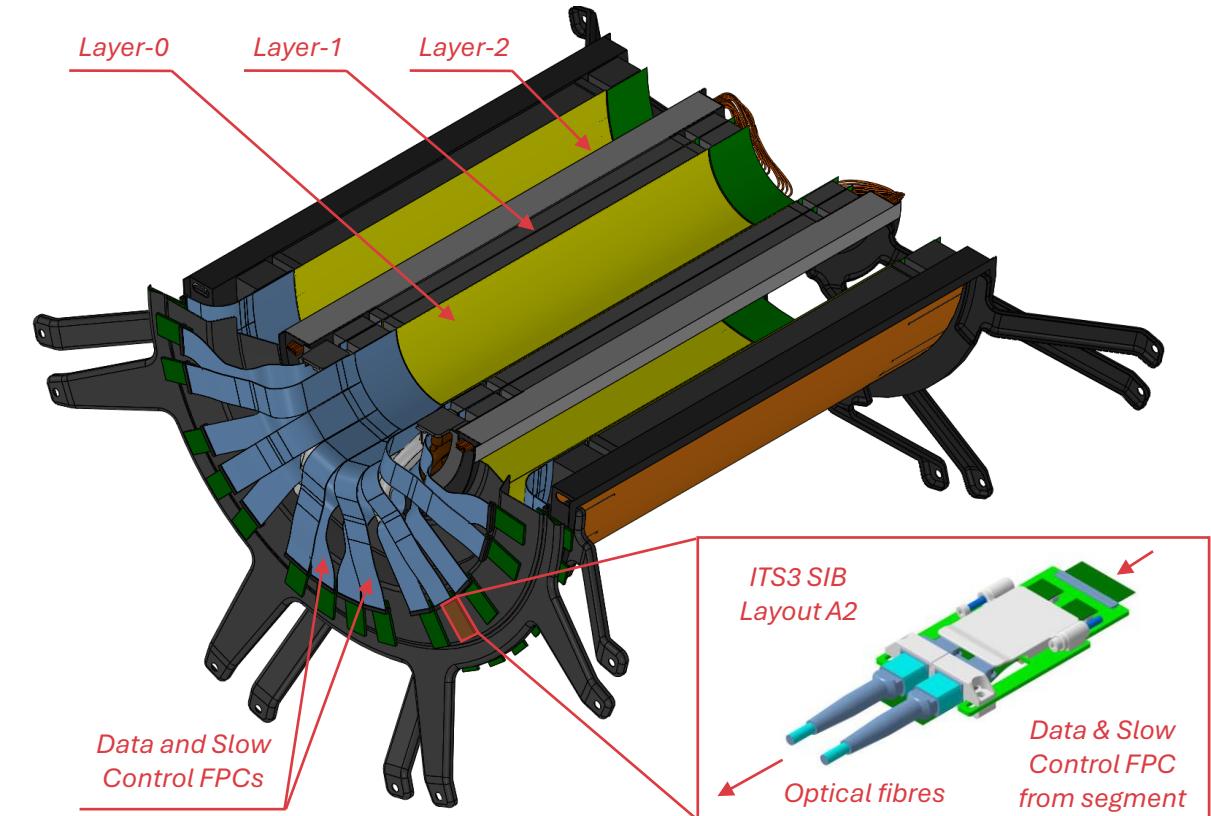
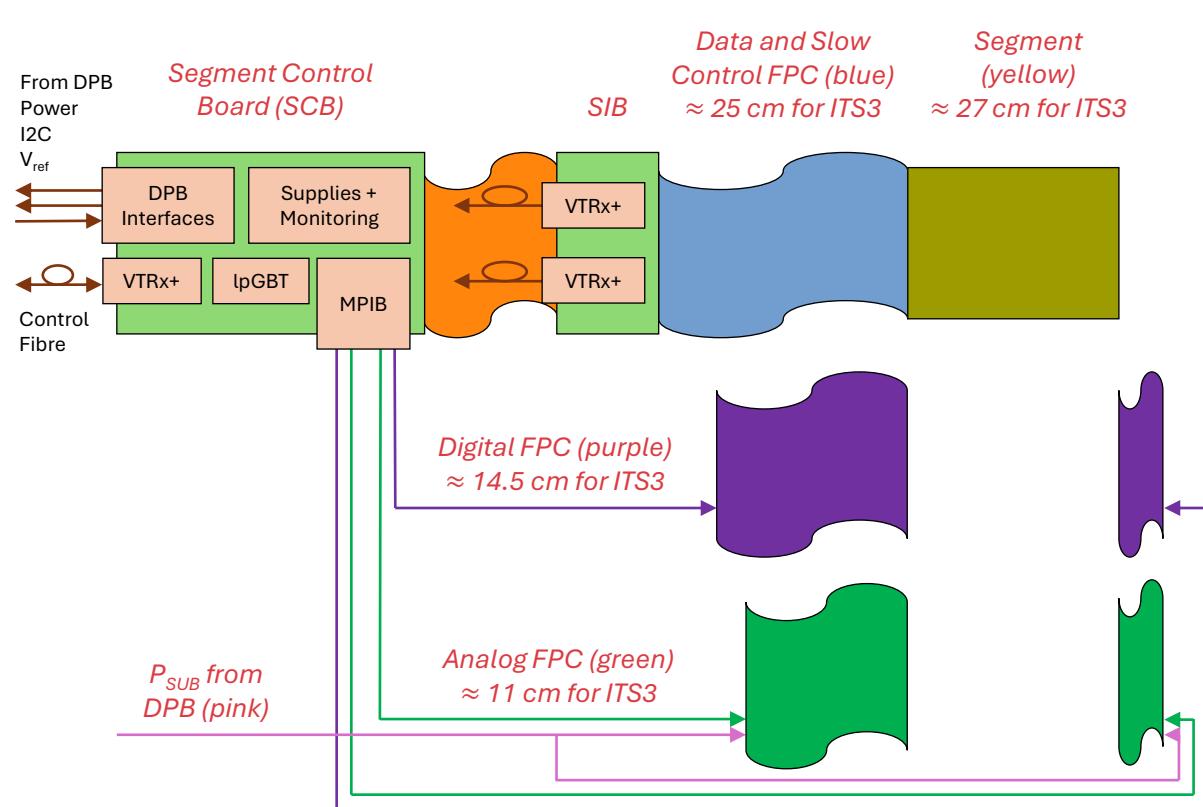
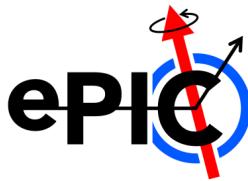
- **ITS3-MOSAIX-like sensors:** Differential data links at 10.24 Gb/s
- **Segment Interface Boards:** Electrical-to-optical data conv. & TTC

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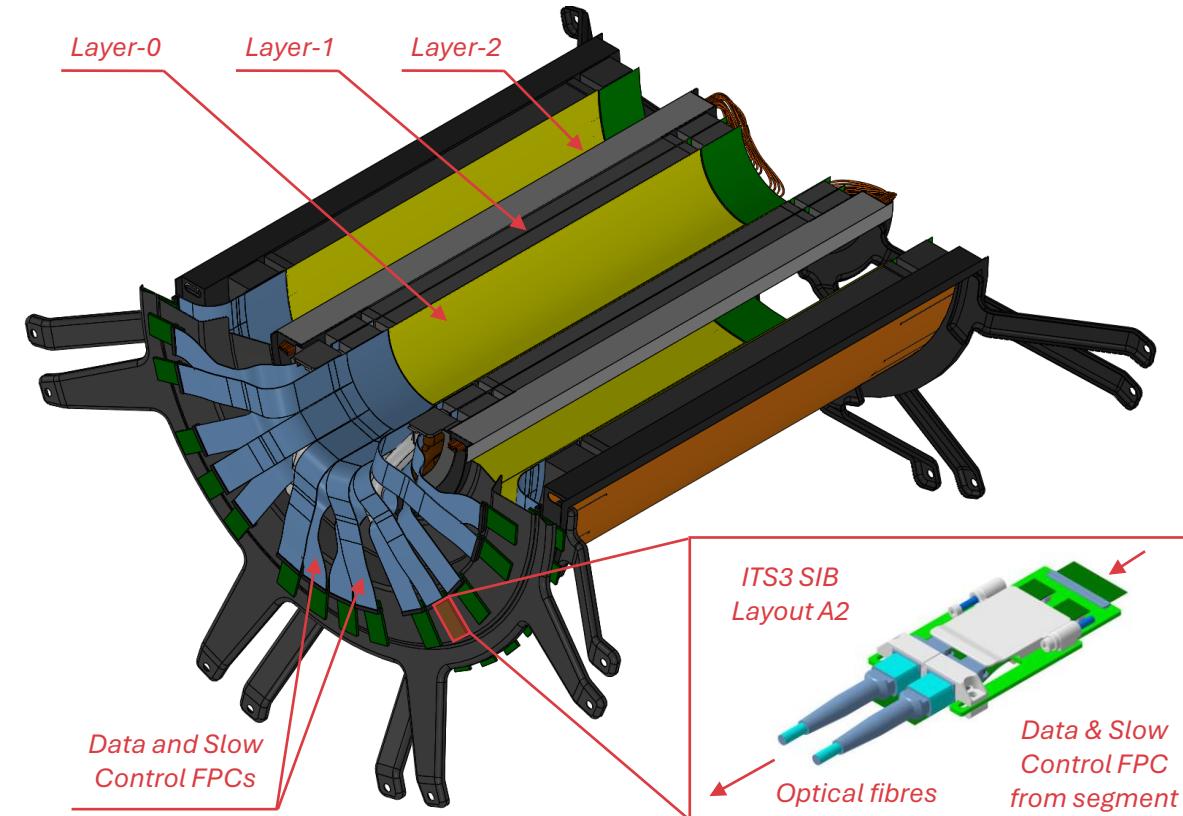
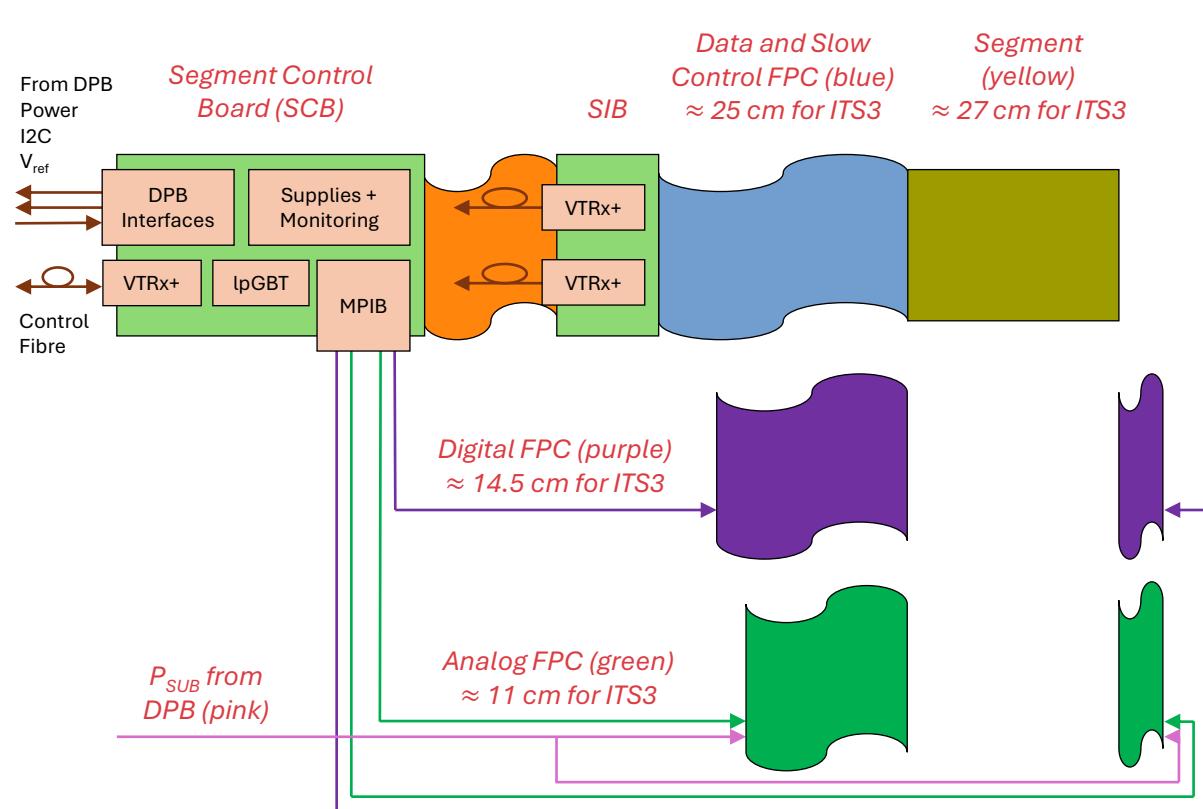
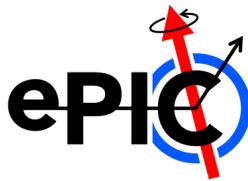
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- Data, Slow Control FPCs:** Diff. FPC lengths per layer (8 ... 18 cm)

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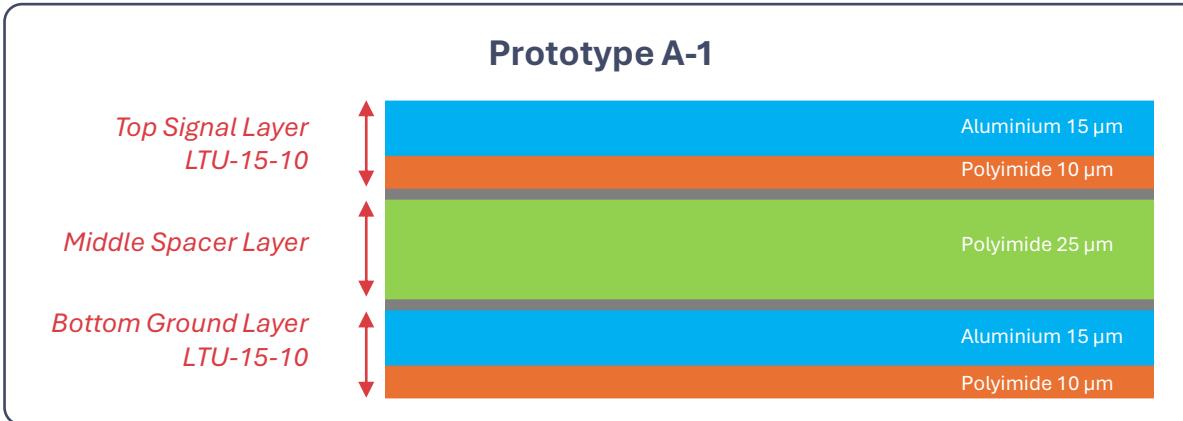


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This talk:

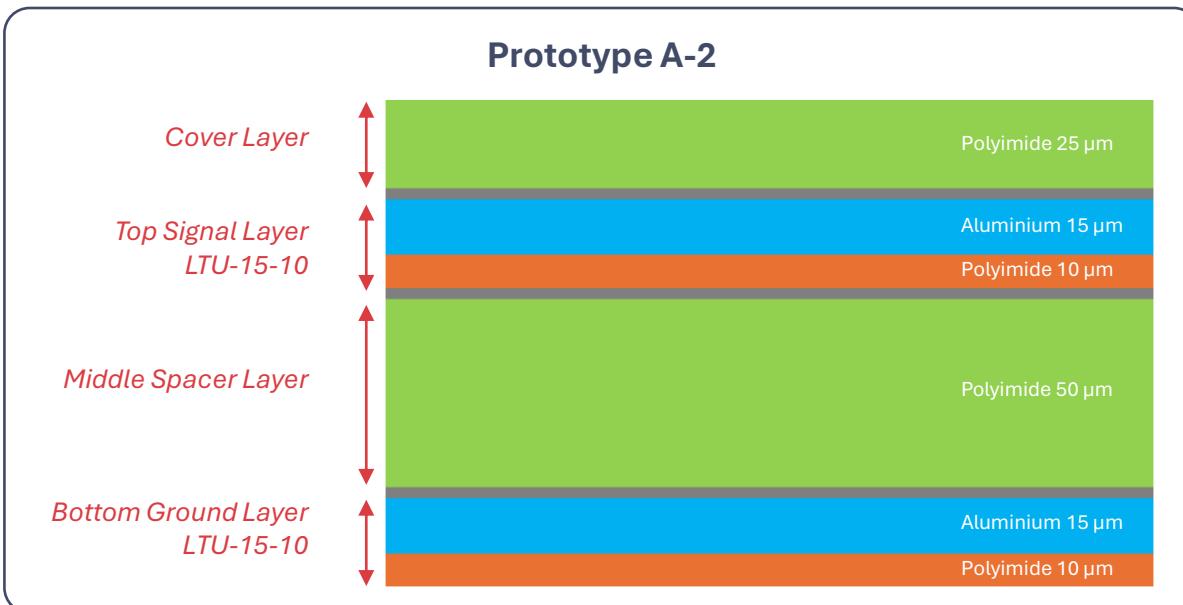
First look into the Inner Barrel's FPC prototyping, signal integrity calculations, and plans for experimental characterisation

PROTOTYPING : PROPOSED DESIGN BY LTU

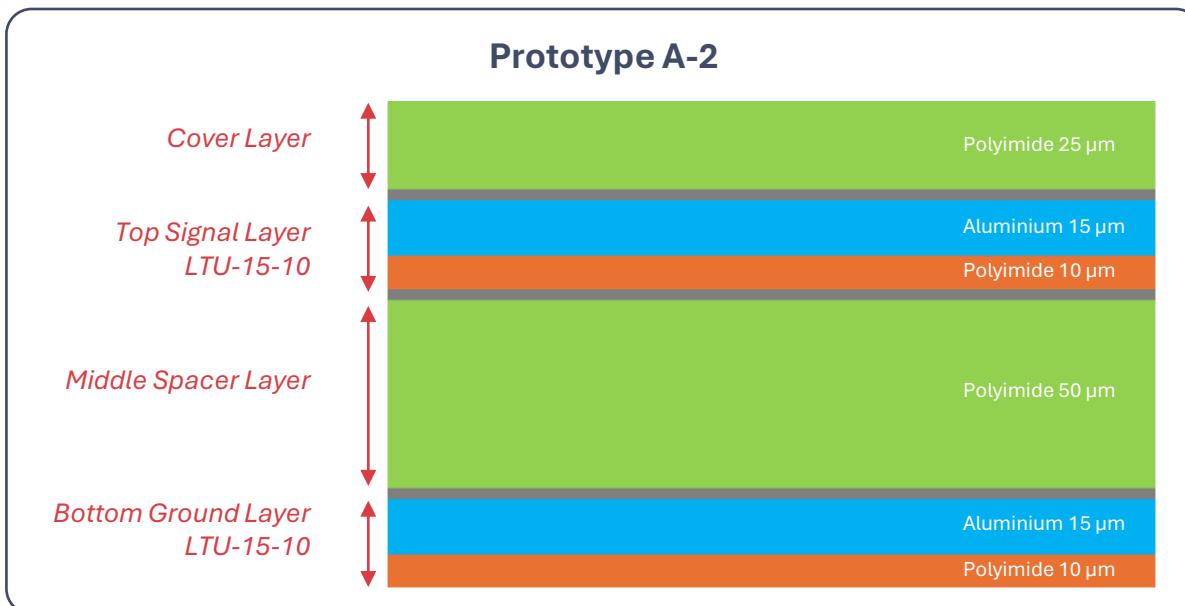
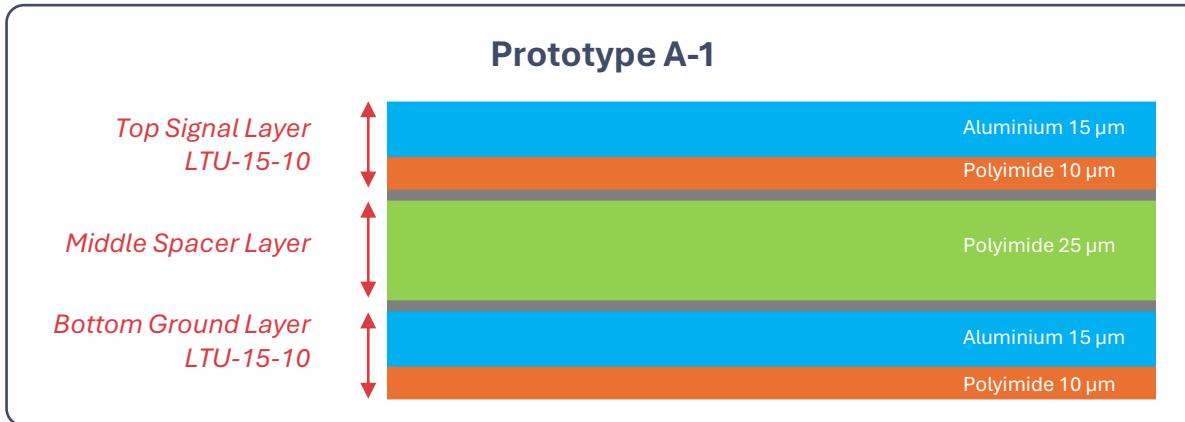


Prototypes to investigate electrical properties with thinnest “standard” aluminium-polyimide sheet from LTU (LTU-15-10)

- 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

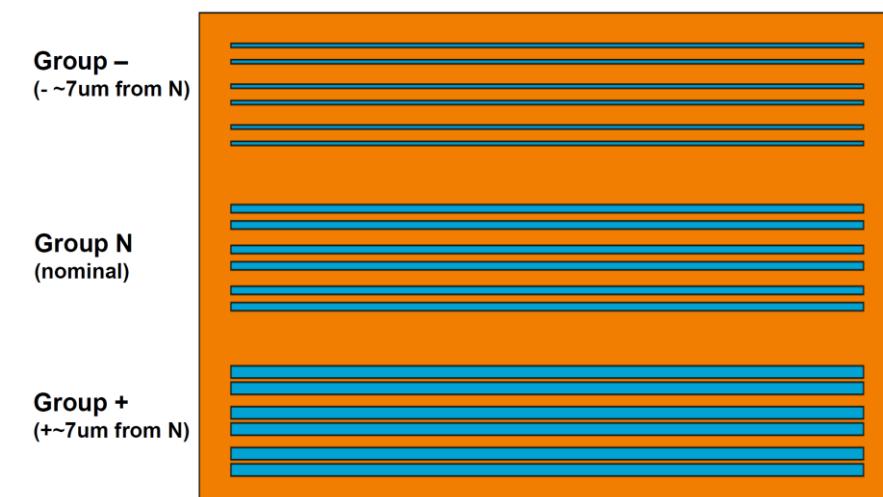


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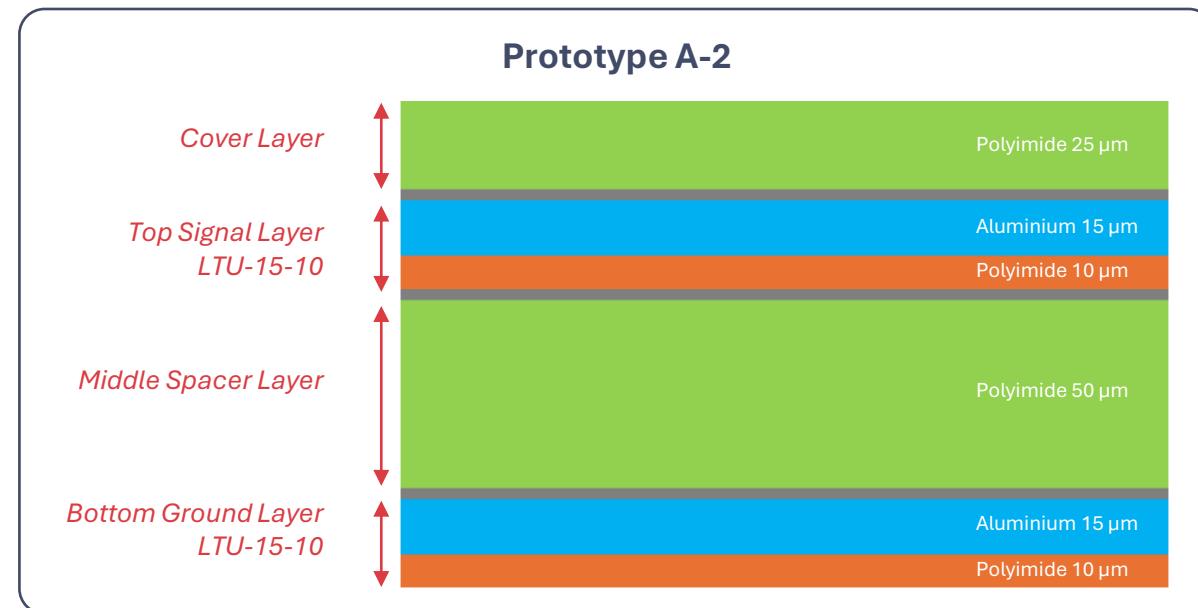
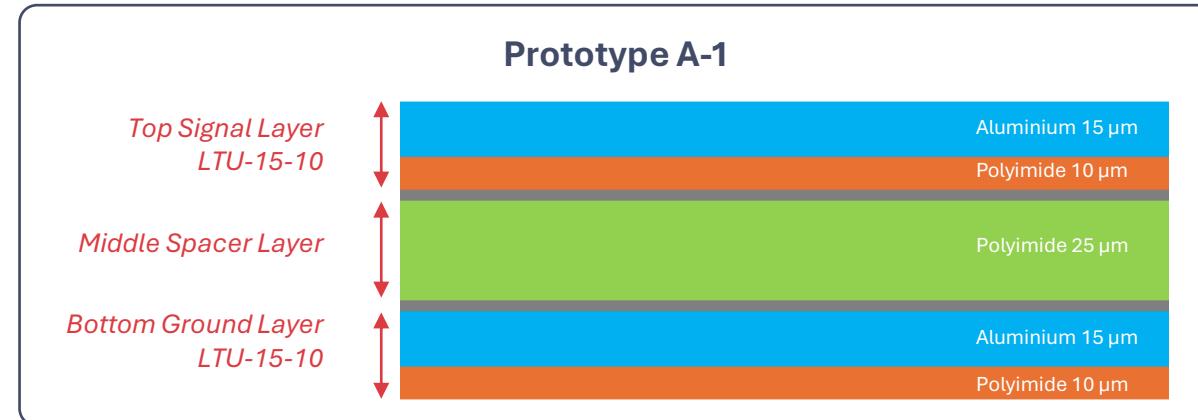


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- 5 test samples of each variant (18 cm trace length)

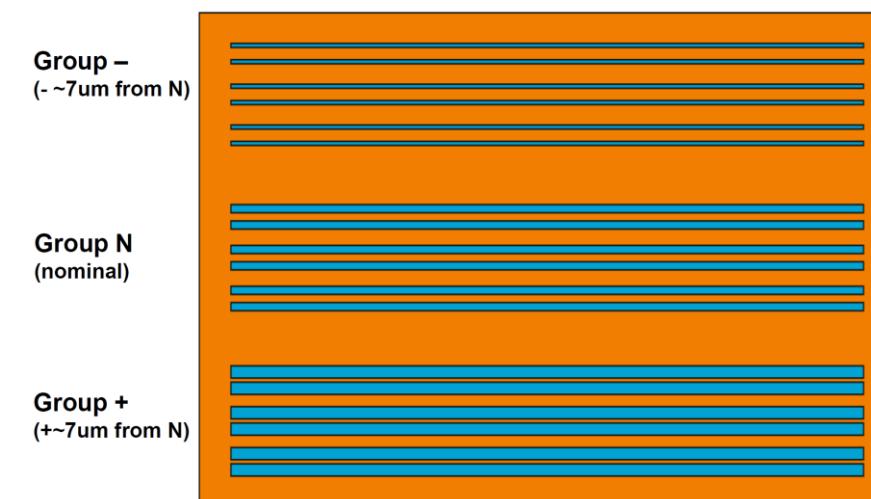


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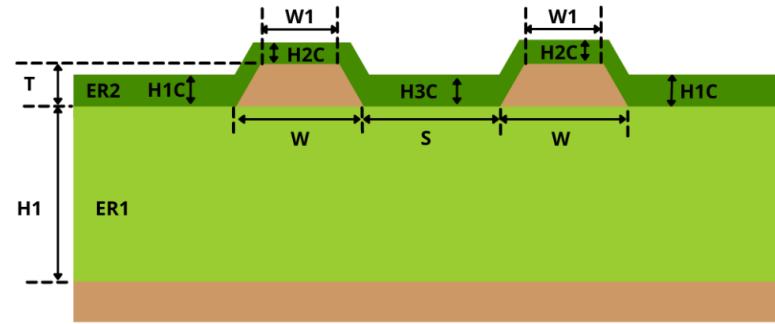
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- 5 test samples of each variant (18 cm trace length)
- Ordered! Delivery in Q1-2026



SIGNAL INTEGRITY CALCULATIONS : BENCHMARKING

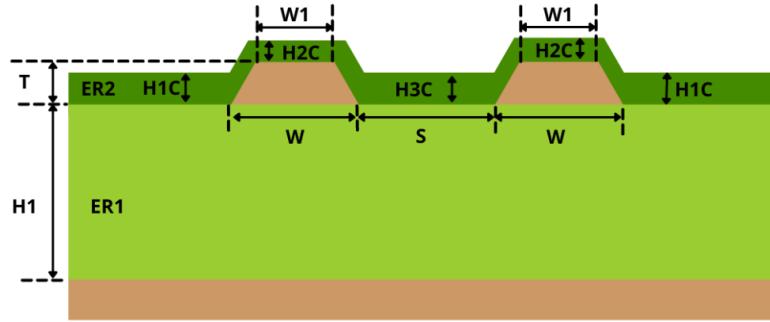
Online impedance calculator produces fairly accurate results for signal loss by using 2D numerical solution of Maxwell's equations



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

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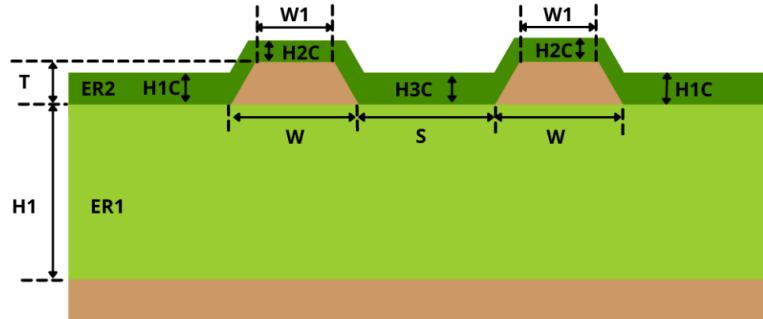


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	ALICE ITS2 IB	ALICE ITS3	
Dielectric	H1 [μm]	75	150
	ER1 [-]	3.3	3.2
	DF1 [-]	0.0038	0.0030
Coating	HiC [μm]	25	75
	ER2 [-]	3.7	3.0
	DF_coat [-]	0.0290	0.0045
Trace	W [μm]	100	200
	W1 [μm]	70	200
	T [μm]	25	35
	S [μm]	100	200
	L [cm]	21.3 / 44.1	25.8

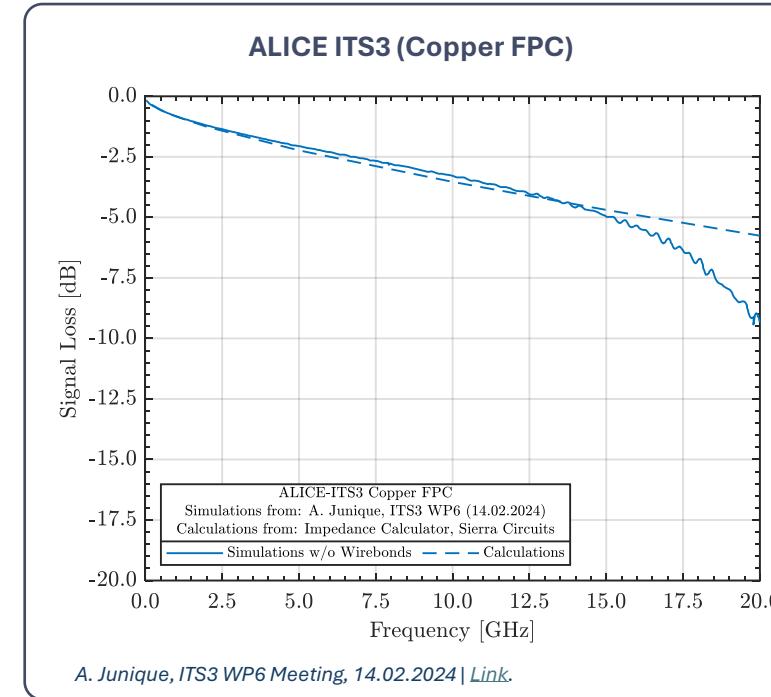
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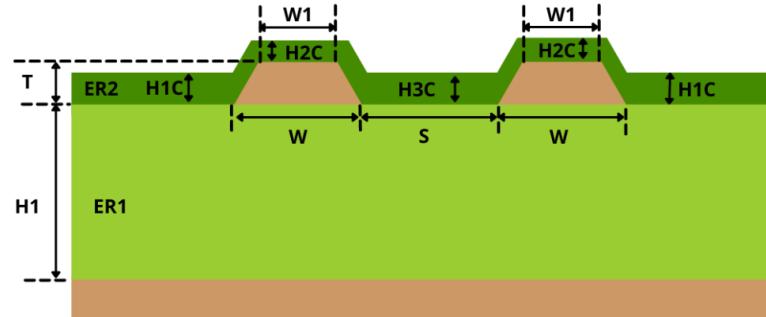


- Results are broadly in agreement
- Discrepancy is substantial at higher frequencies

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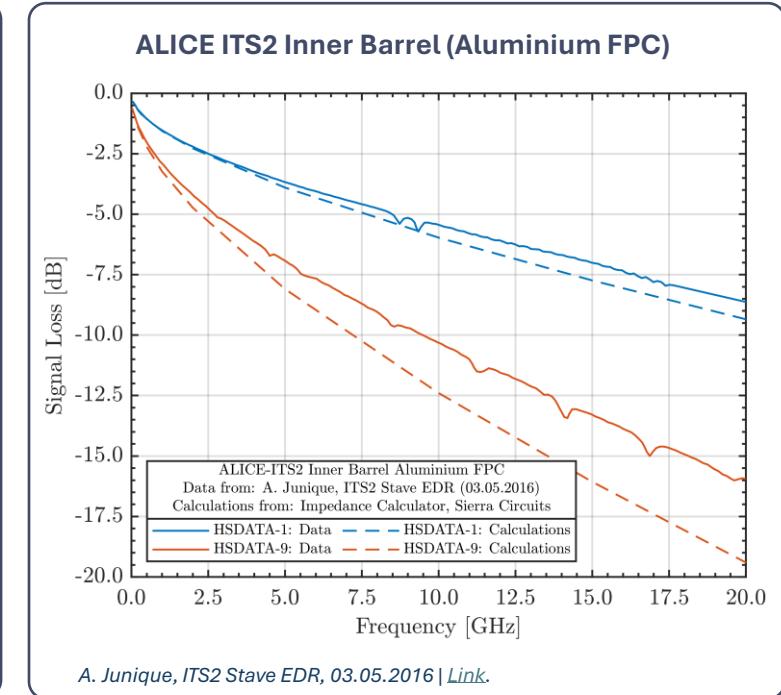
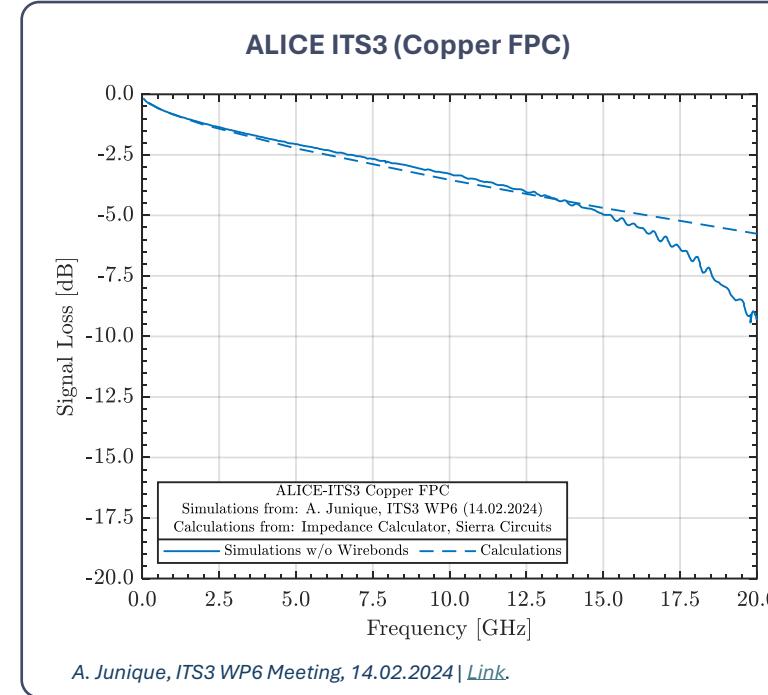


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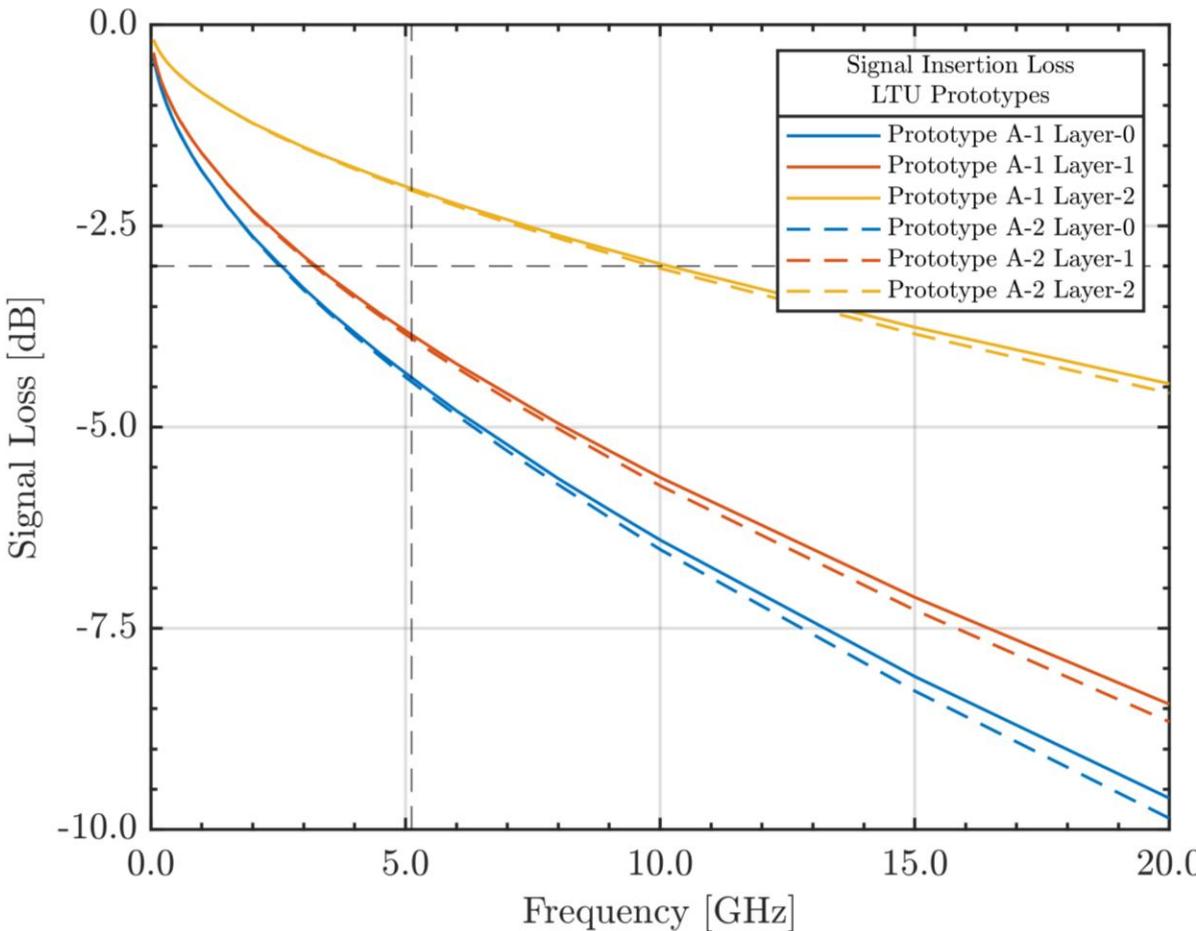
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- Discrepancy is substantial at higher frequencies
- Online calculator uses copper as the default trace material, therefore ITS2 IB's conductor loss must be corrected for aluminium (conductor loss $\propto \sqrt{\text{resistivity}}$)

SIGNAL INTEGRITY CALCULATIONS : RESULTS



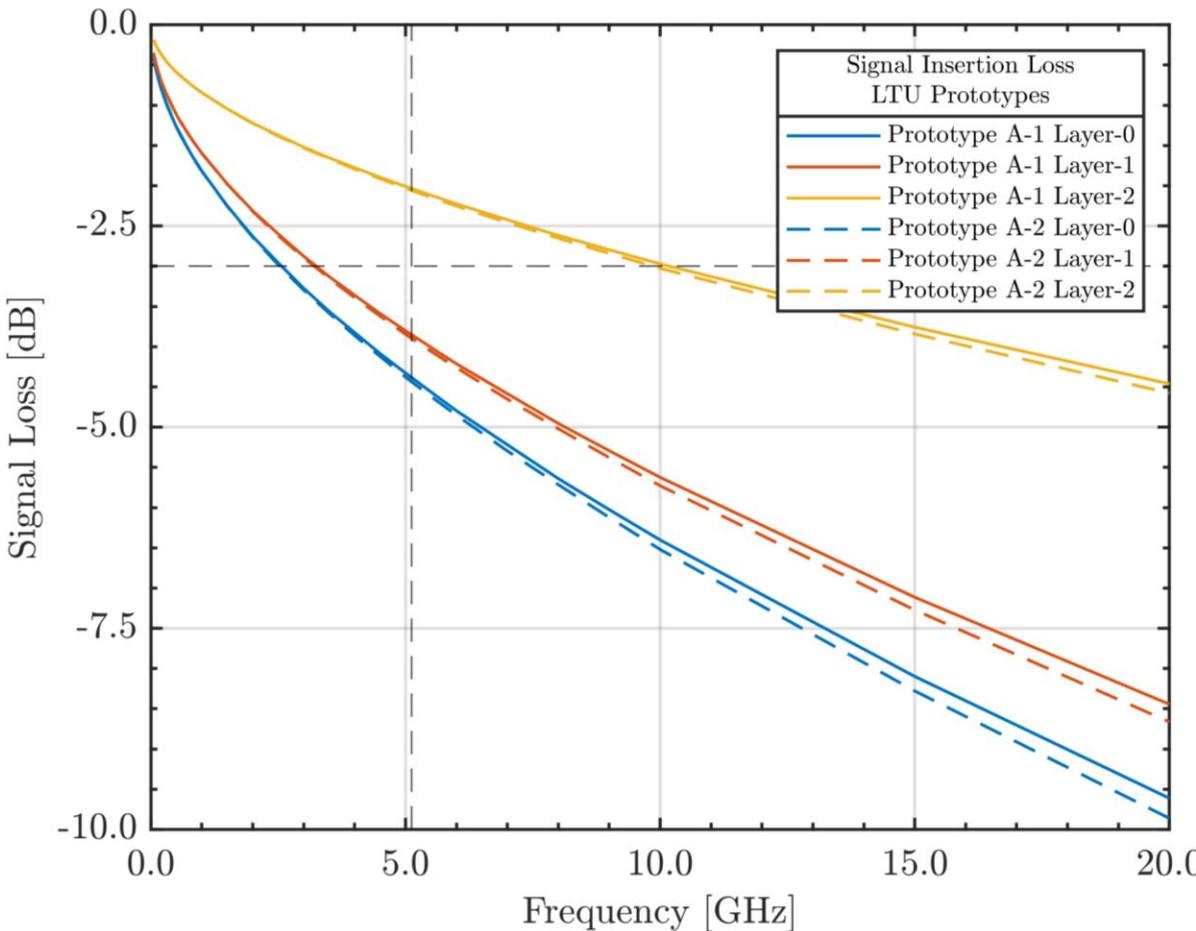
Online impedance and signal integrity calculator from Sierra Circuits
<https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL>
Calculation and setup details in the back-up slides

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	101.07	4.33			
		3.80	0.212	0.026	0.0512
		2.01			
A-2	101.93	4.38			
		3.85	0.211	0.031	0.0695
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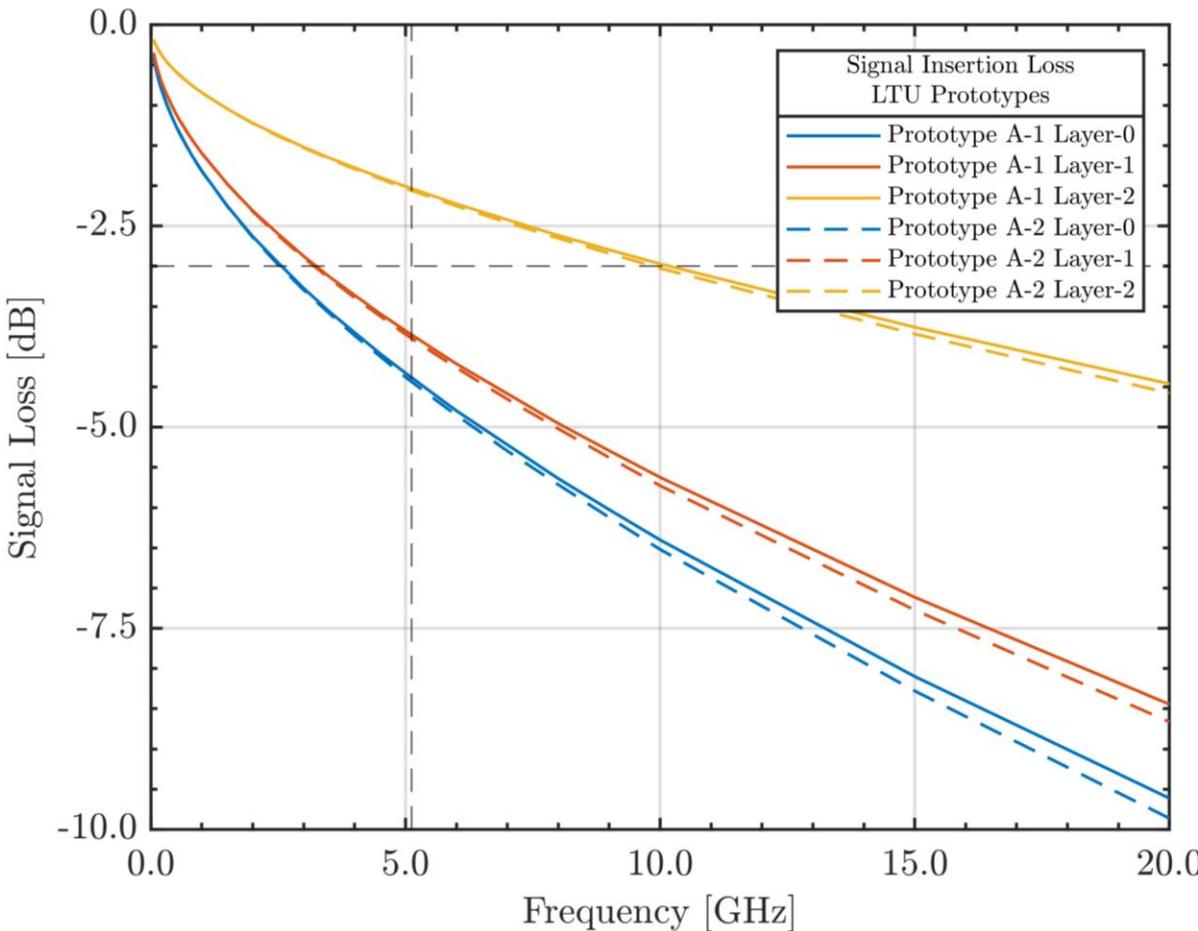
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Mitigating strategies needed for recovering signal for L0 and L1

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

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

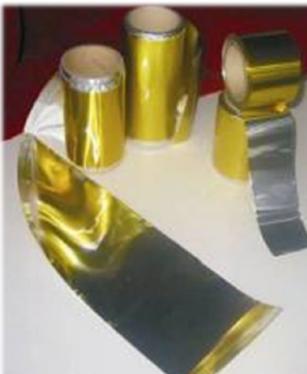
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(POTENTIAL) MITIGATION #1 : MORE MATERIAL

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

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

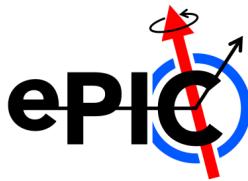


- ❖ LTU-15-10 polyimide aluminium foil – 10 μm – 15 μm
- ❖ LTU-25-10 polyimide aluminium foil – 10 μm – 25 μm
- ❖ LTU-30-20 polyimide aluminium foil – 20 μm – 30 μm
„Standard„ materials
- ❖ LTU-10-10 polyimide aluminium foil – 10 μm – 10 μm
Developed for further possible ultralight FPCs (ePIC SVT, ALICE 3, CBM-MVD)
- ❖ LTU-50-20 polyimide aluminium foil – 20 μm – 50 μm
- ❖ LTU-100-20 polyimide aluminium foil – 20 μm – 100 μm
- ❖ LTU-10-50-10 polyimide aluminium foil – 10 μm – 50 μm – 10 μm
- ❖ LTU-150-20 polyimide aluminium foil – 20 μm – 150 μm
- ❖ LTU-200-20 polyimide aluminium foil – 20 μm – 200 μm
Developed for ALICE FoCal

Developed for ALICE ITS2

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

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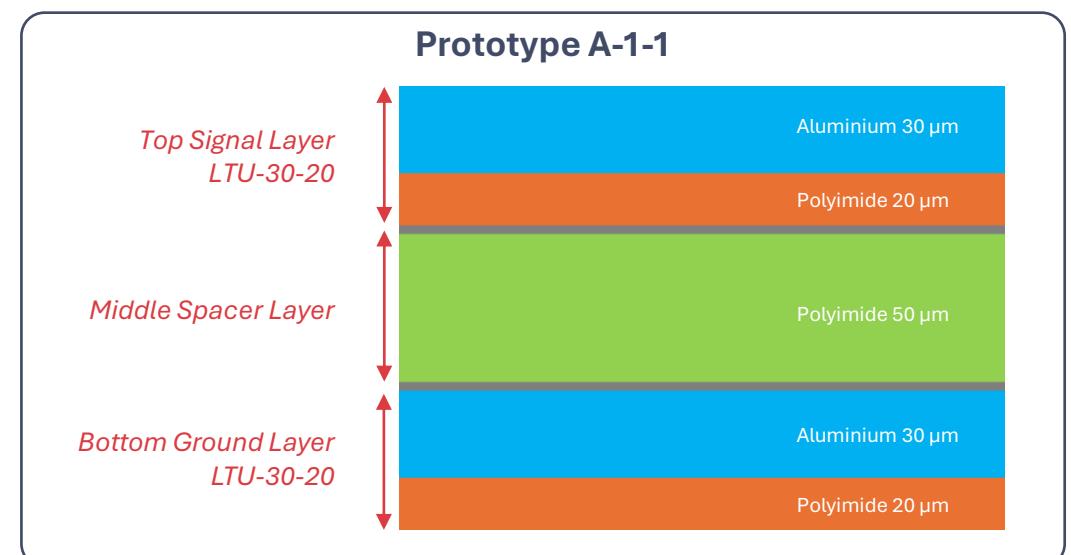
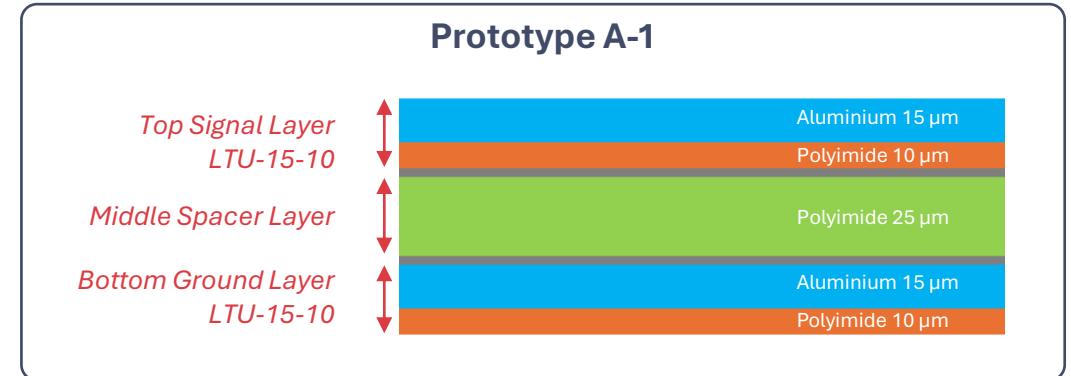
	Prot. A-1	→	Prot. A-1-1	Variation of A-1 (w/o cover layer)
▪ Trace thickness	= 15 μm	→	= 30 μm	
▪ Trace width	= 70 μm	→	= 125 μm	
▪ Space b/w traces	= 80 μm	→	= 125 μm	
▪ Trace pitch	= 150 μm	→	= 250 μm	

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

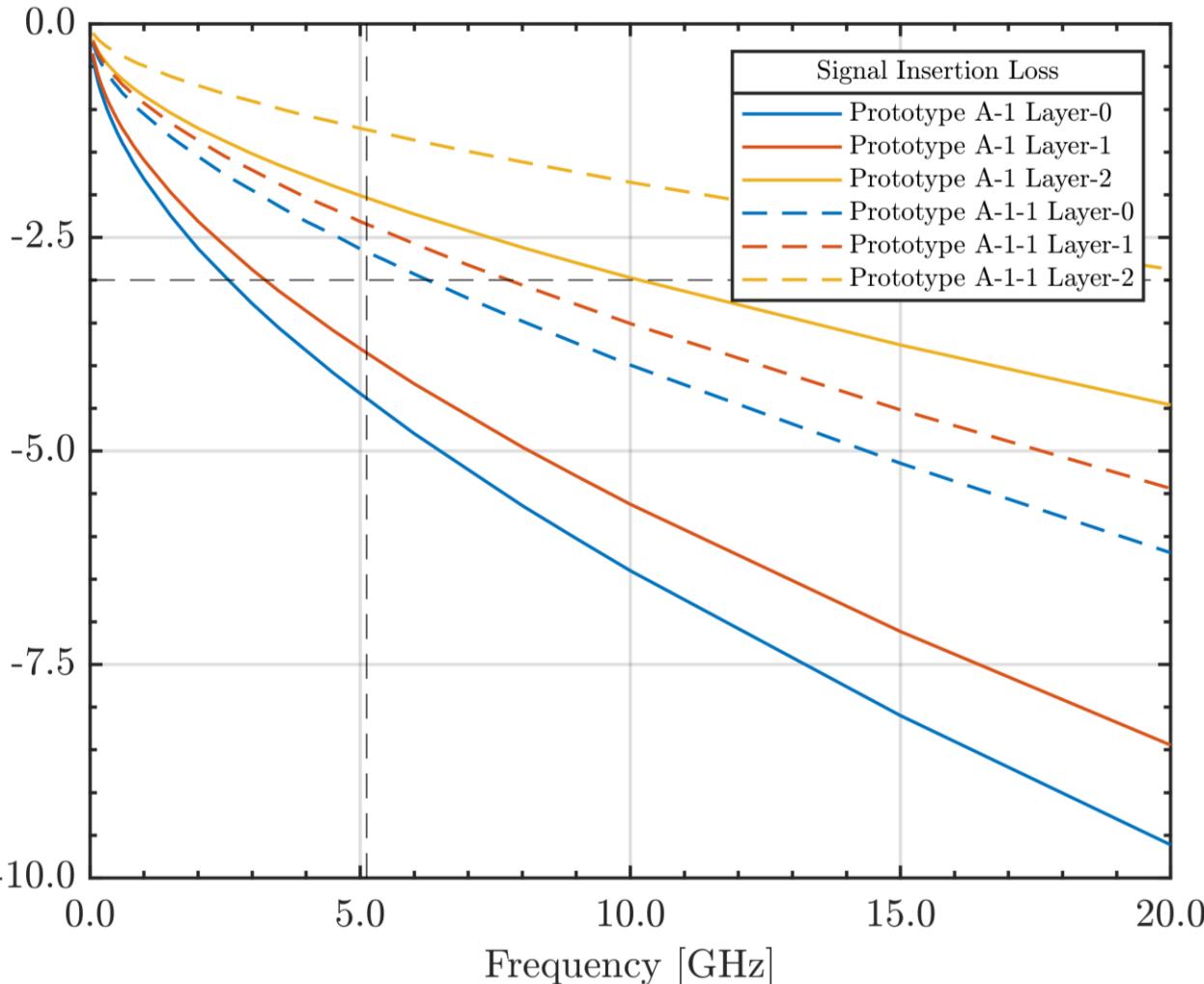
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Aluminium-polyimide adhesiveless foiled dielectrics	Developed for ALICE ITS2
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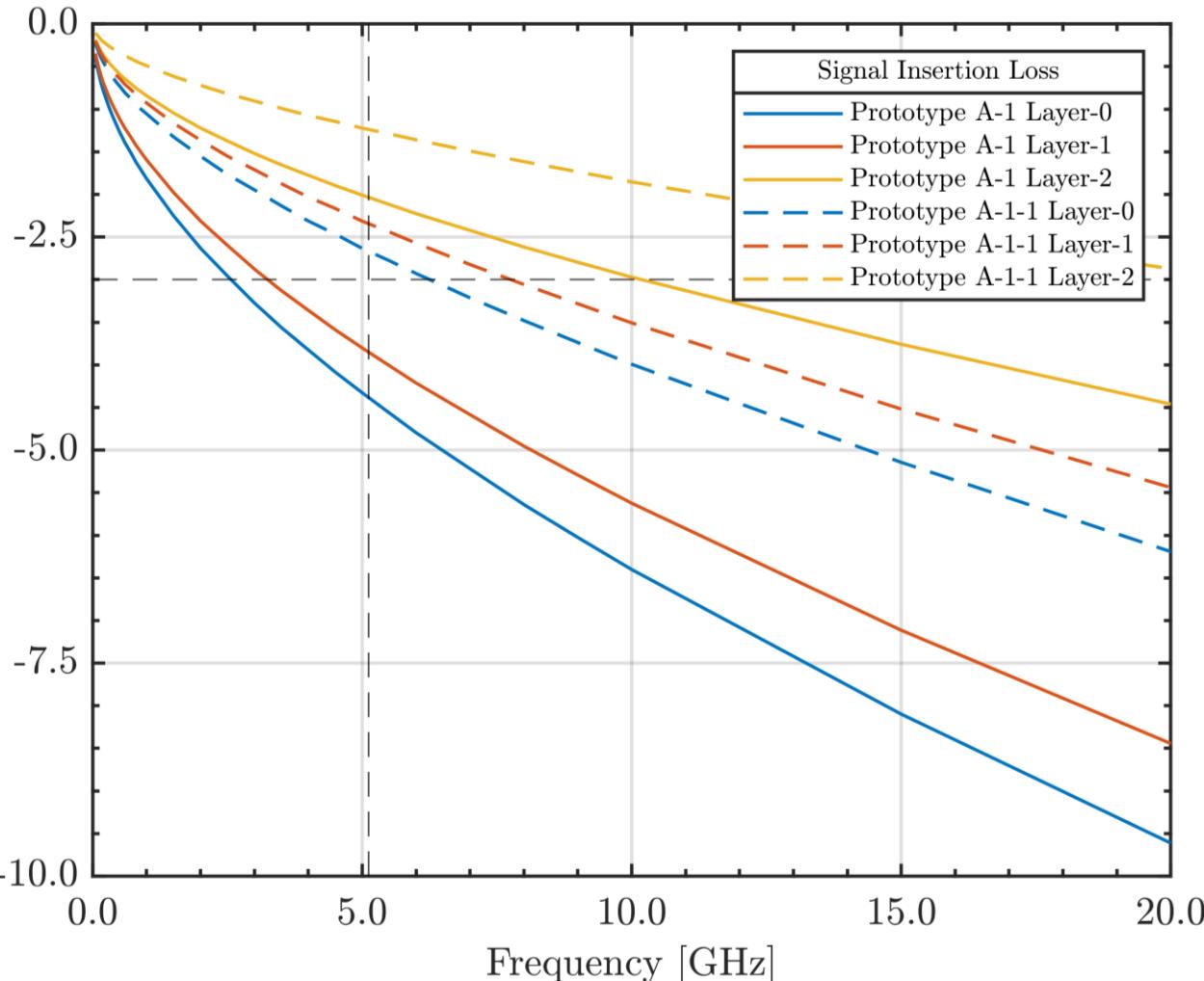
Estimated < 3 dB signal loss at 5 GHz for L0 and L1

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

Variants	Differential Impedance [Ω]	Signal Loss @ 5 GHz			Material Budget [% X/X_0]
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	L1	101.07	3.80	0.212	0.0512
	L2	2.01			
A-1-1	L0	2.63			
	L1	99.44	2.31	0.093	0.1007
	L2	1.22			

Online impedance and signal integrity calculator from Sierra Circuits
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 Calculation and setup details in the back-up slides

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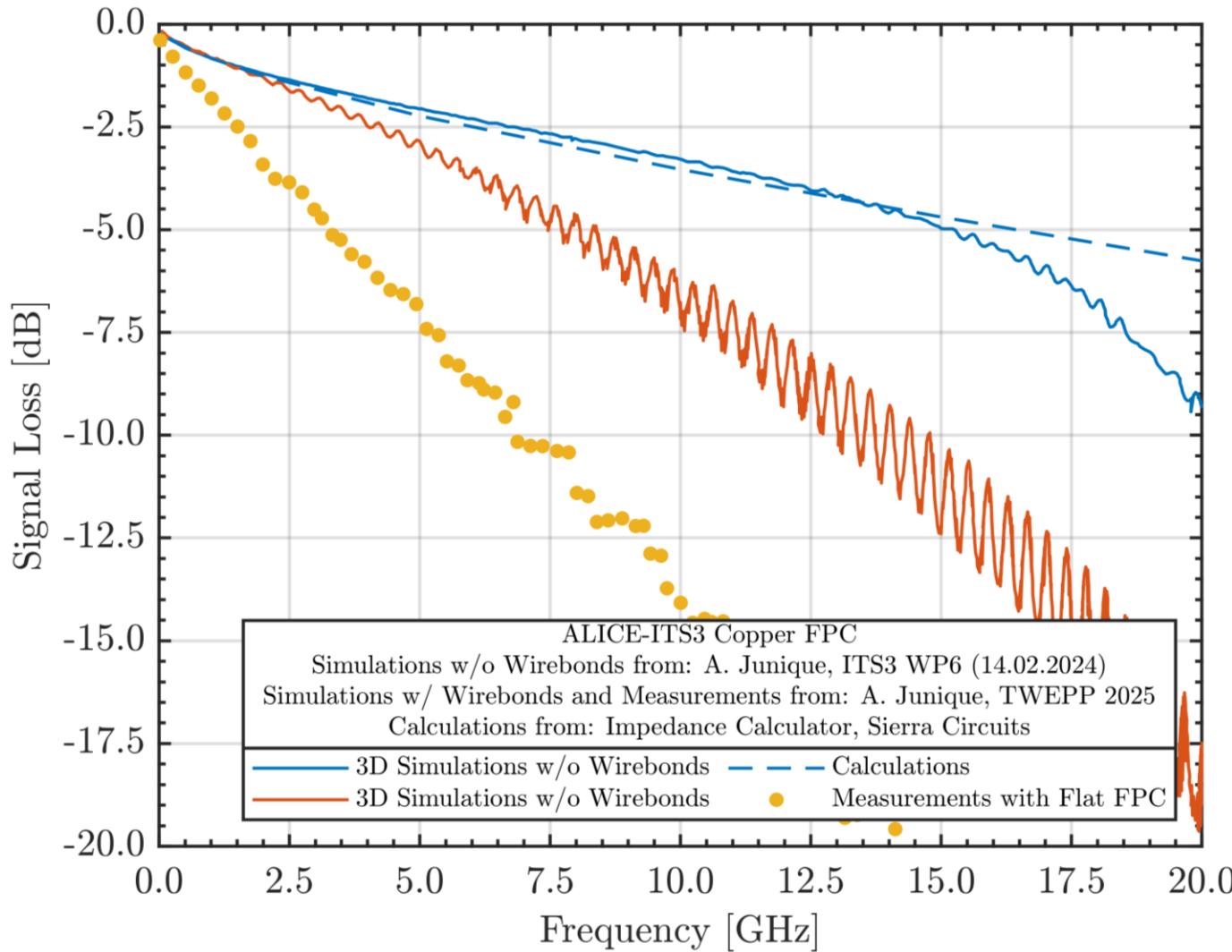
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Further room for optimization by opting for intermediate aluminium thicknesses from the LTU catalogue (20 μm , 25 μm)

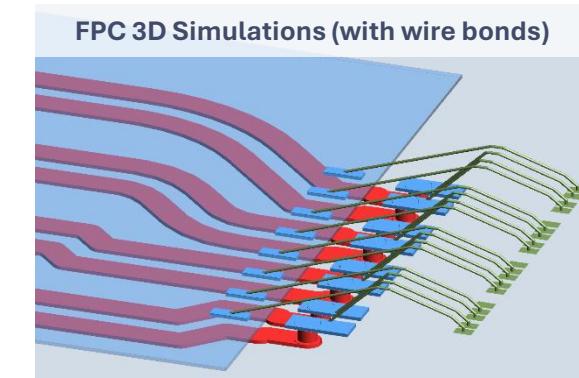
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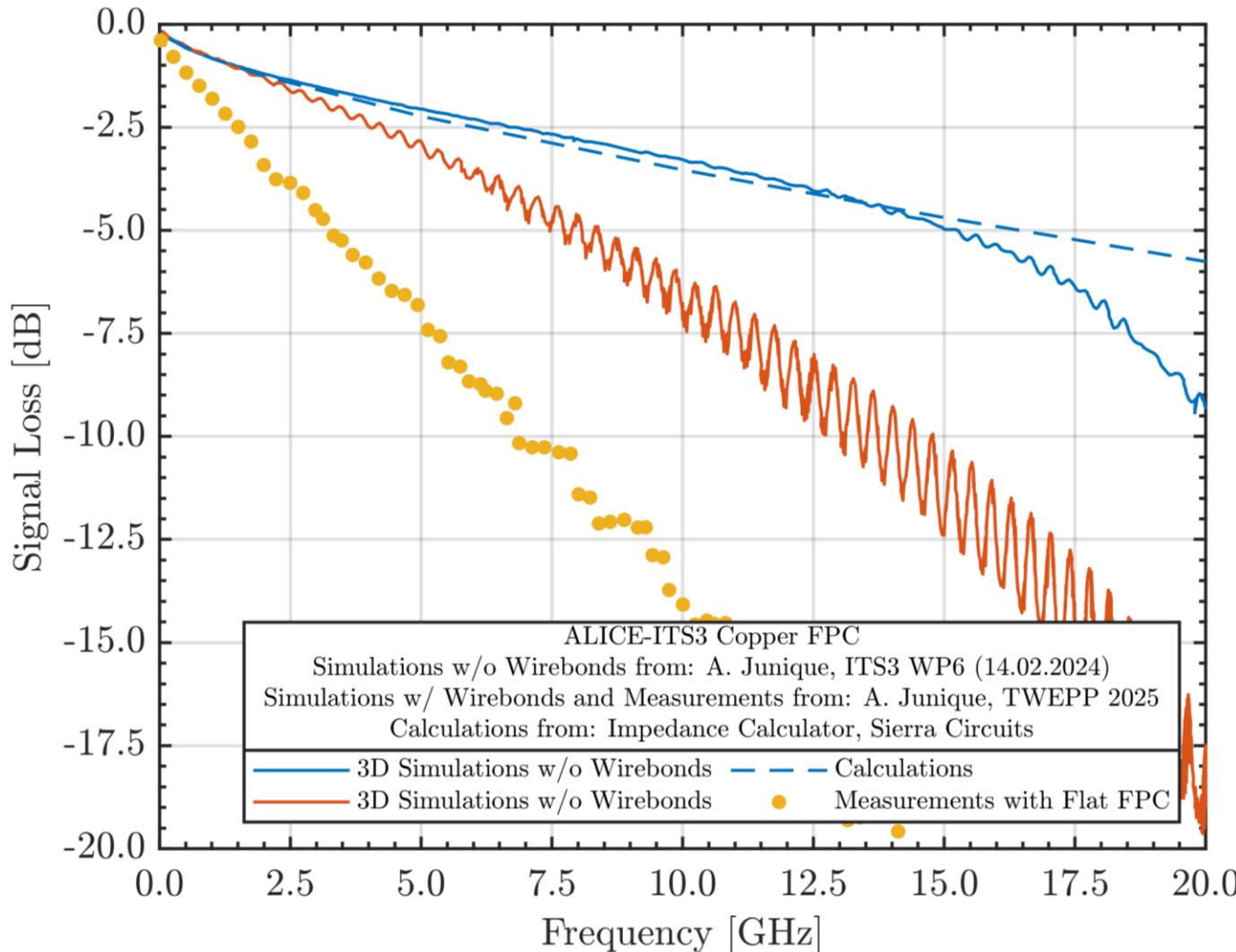
(NECESSARY) MITIGATION #2 : EXP. CHARACTERISATION



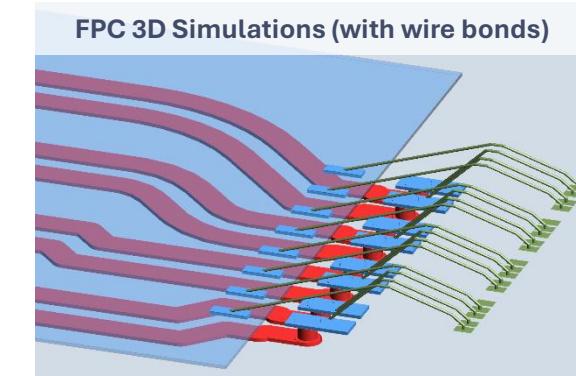
Latest signal integrity measurements with ITS3 FPCs at CERN indicate higher signal loss (wire bonds, test fixtures)



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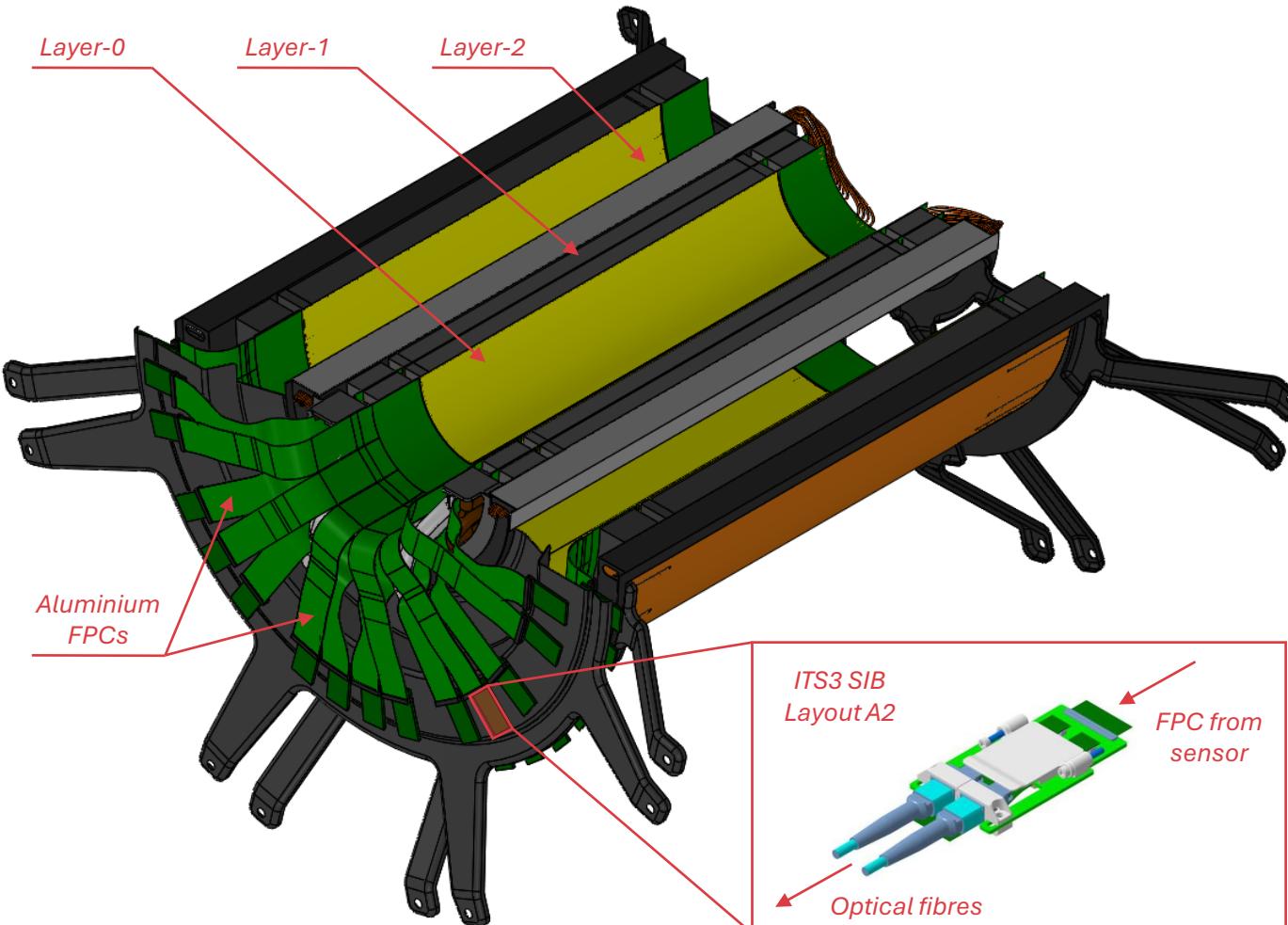


Similar setup currently under preparation at UniTS.
Expected to be up-and-running in January!
Mechanical prototypes also ordered. Expected in Q1-26.

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

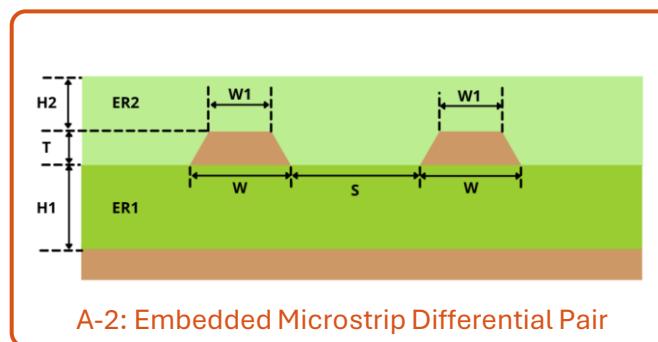
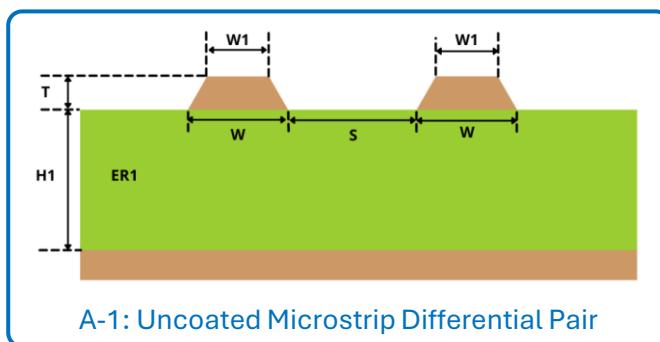
- Different FPC lengths per layer (8 ... 18 cm)
- Aluminium-based FPCs from LTU Kharkiv

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

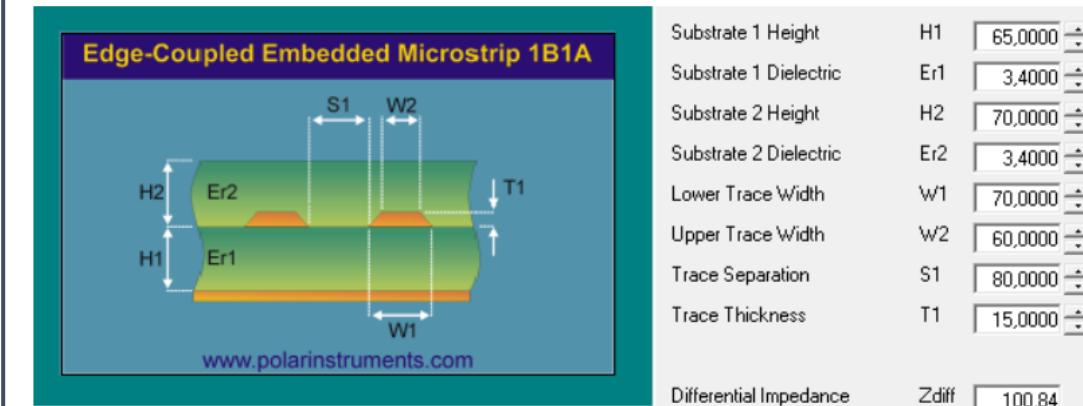
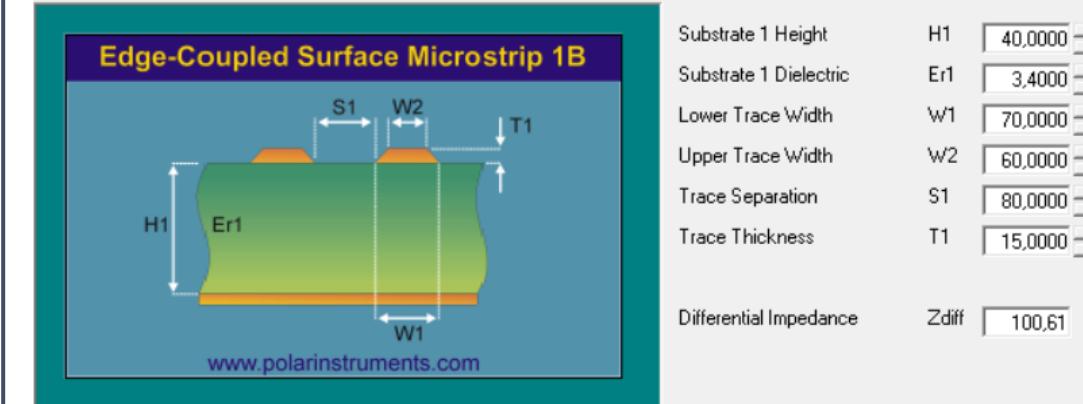
(FIRST) PROTOTYPES : SIGNAL INTEGRITY CALCULATIONS

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						

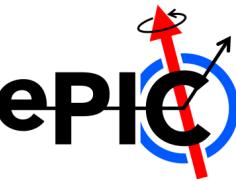


Online impedance and signal integrity calculator from Sierra Circuits
<https://impedance.app.protoexpress.com/?appid=CTDPIMPCAL>



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

POTENTIALLY REVISED VERSIONS



Uncoated Microstrip Differential Pair Impedance Calculator

Impedance		Signal Loss		S Parameter		Crosstalk	
Geometry Information		Dielectric Information		Trace Information		Impedance Output	
		Dielectric Height (H1) (μm) <input type="text" value="75"/> ?		Trace Width (W) (μm) <input type="text" value="125"/> ? Calculate W		Target Diff. Impedance (Zd) Ω <input type="text" value="100"/> ?	
		Dielectric Constant (ER1) <input type="text" value="3.4"/> ?		ΔW = (W-W1) (μm) <input type="text" value="10"/> ?		Calculated Diff. Impedance (Zd) Ω <input type="text" value="99.43646"/> ? Calculate Zd	
				Trace Thickness (T) (μm) <input type="text" value="30"/> ?		Coupling Coefficient (K %) <input type="text" value="10.83025"/> ?	
				Trace Separation (S) (μm) <input type="text" value="125"/> ?		Odd Mode Impedance (Zodd) Ω <input type="text" value="49.71823"/> ?	
				Trace + Separation = (W + S) (μm) <input type="text" value="250"/> ?		Even Mode Impedance (Zeven) Ω <input type="text" value="61.79544"/> ?	
						Propagation Delay (PdEven) (ps/cm) <input type="text" value="54.33142"/> ?	
						Propagation Delay (Pdodd) (ps/cm) <input type="text" value="49.92812"/> ?	

Embedded Microstrip Differential Pair Impedance Calculator

Impedance		Signal Loss		S Parameter		Crosstalk	
Geometry Information		Dielectric Information		Trace Information		Impedance Output	
		Dielectric Height (H1) (μm) <input type="text" value="125"/> ?		Trace Width (W) (μm) <input type="text" value="125"/> ? Calculate W		Target Diff. Impedance (Zd) Ω <input type="text" value="100"/> ?	
		Dielectric Constant (ER1) <input type="text" value="3.4"/> ?		ΔW = (W-W1) (μm) <input type="text" value="10"/> ?		Calculated Diff. Impedance (Zd) Ω <input type="text" value="100.51589"/> ? Calculate Zd	
				Trace Thickness (T) (μm) <input type="text" value="30"/> ?		Coupling Coefficient (K %) <input type="text" value="22.58372"/> ?	
				Trace Separation (S) (μm) <input type="text" value="45"/> ?		Odd Mode Impedance (Zodd) Ω <input type="text" value="50.25695"/> ?	
				Trace + Separation = (W + S) (μm) <input type="text" value="250"/> ?		Even Mode Impedance (Zeven) Ω <input type="text" value="79.57866"/> ?	
						Propagation Delay (PdEven) (ps/cm) <input type="text" value="57.9172"/> ?	
						Propagation Delay (Pdodd) (ps/cm) <input type="text" value="57.41975"/> ?	

Impedance

Signal Loss		S parameter		Crosstalk	
Dielectric Dissipation Factor Information		Signal Loss Input		Signal Loss Output Odd Mode	
Dissipation Factor (DF1) <input type="text" value="0.0038"/> ?		Frequency (GHz) <input type="text" value="5"/> GHz ?		Conductor Loss (Odd Mode) (dB/cm) <input type="text" value="0.09291"/> ?	
		Surface Roughness (Rz) (μm) <input type="text" value="0"/> ?		Conductor Loss (Even Mode) (dB/cm) <input type="text" value="0.09764"/> ?	
		Length (cm) <input type="text" value="25"/> ?		Dielectric Loss (Odd Mode) (dB/cm) <input type="text" value="0.02598"/> ?	
				Dielectric Loss (Even Mode) (dB/cm) <input type="text" value="0.02835"/> ?	
				Insertion Loss (Odd Mode) (dB/cm) <input type="text" value="0.1185"/> ?	
				Insertion Loss (Even Mode) (dB/cm) <input type="text" value="0.12598"/> ?	
				Total Insertion Loss (Odd Mode) (dB) <input type="text" value="2.966"/> ?	
				Total Insertion Loss (Even Mode) (dB) <input type="text" value="3.147"/> ?	

Impedance

Signal Loss		S Parameter		Crosstalk	
Dielectric Dissipation Factor Information		Signal Loss Input		Signal Loss Output Odd Mode	
Dissipation Factor (DF1) <input type="text" value="0.0038"/> ?		Frequency (GHz) <input type="text" value="5"/> GHz ?		Conductor Loss (Odd Mode) (dB/cm) <input type="text" value="0.09173"/> ?	
		Surface Roughness (Rz) (μm) <input type="text" value="0"/> ?		Conductor Loss (Even Mode) (dB/cm) <input type="text" value="0.06969"/> ?	
		Length (cm) <input type="text" value="25"/> ?		Dielectric Loss (Odd Mode) (dB/cm) <input type="text" value="0.02992"/> ?	
				Dielectric Loss (Even Mode) (dB/cm) <input type="text" value="0.02992"/> ?	
				Insertion Loss (Odd Mode) (dB/cm) <input type="text" value="0.12165"/> ?	
				Insertion Loss (Even Mode) (dB/cm) <input type="text" value="0.09961"/> ?	
				Total Insertion Loss (Odd Mode) (dB) <input type="text" value="3.038"/> ?	
				Total Insertion Loss (Even Mode) (dB) <input type="text" value="2.494"/> ?	