ePIC SVT Inner Barrel
Ongoing Activities On Signal FPCs

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SVT WP3 Meeting Meeting

11.06.2026

UNIVERSITÀ DEGLI STUDI DI TRIESTE

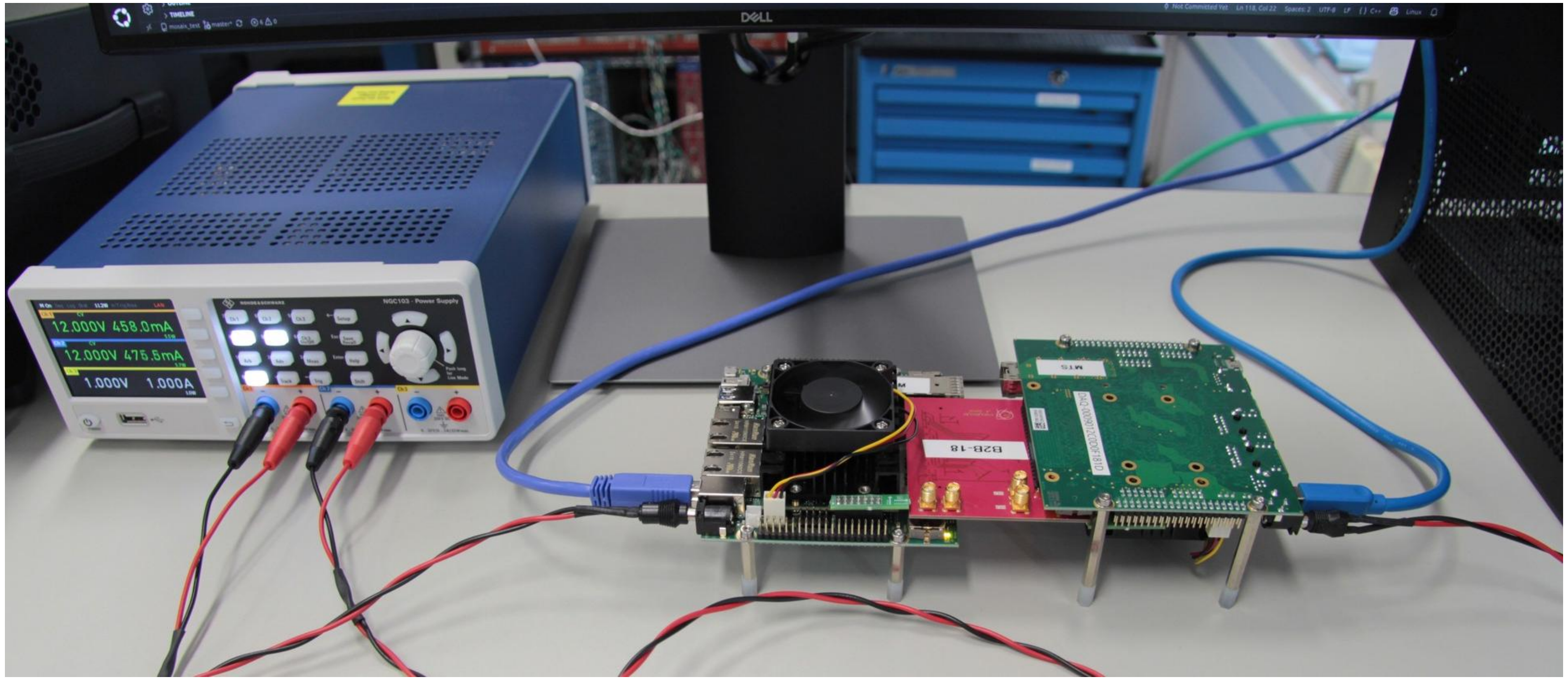
Dipartimento di Fisica

INFN TRIESTE Istituto Nazionale di Fisica Nucleare Sezione di Trieste

ePIC

Activity #1
Setups With ITS3 Components

TRANSMITTER (MOSAIX EMULATOR) + RECEIVER (DAQ)

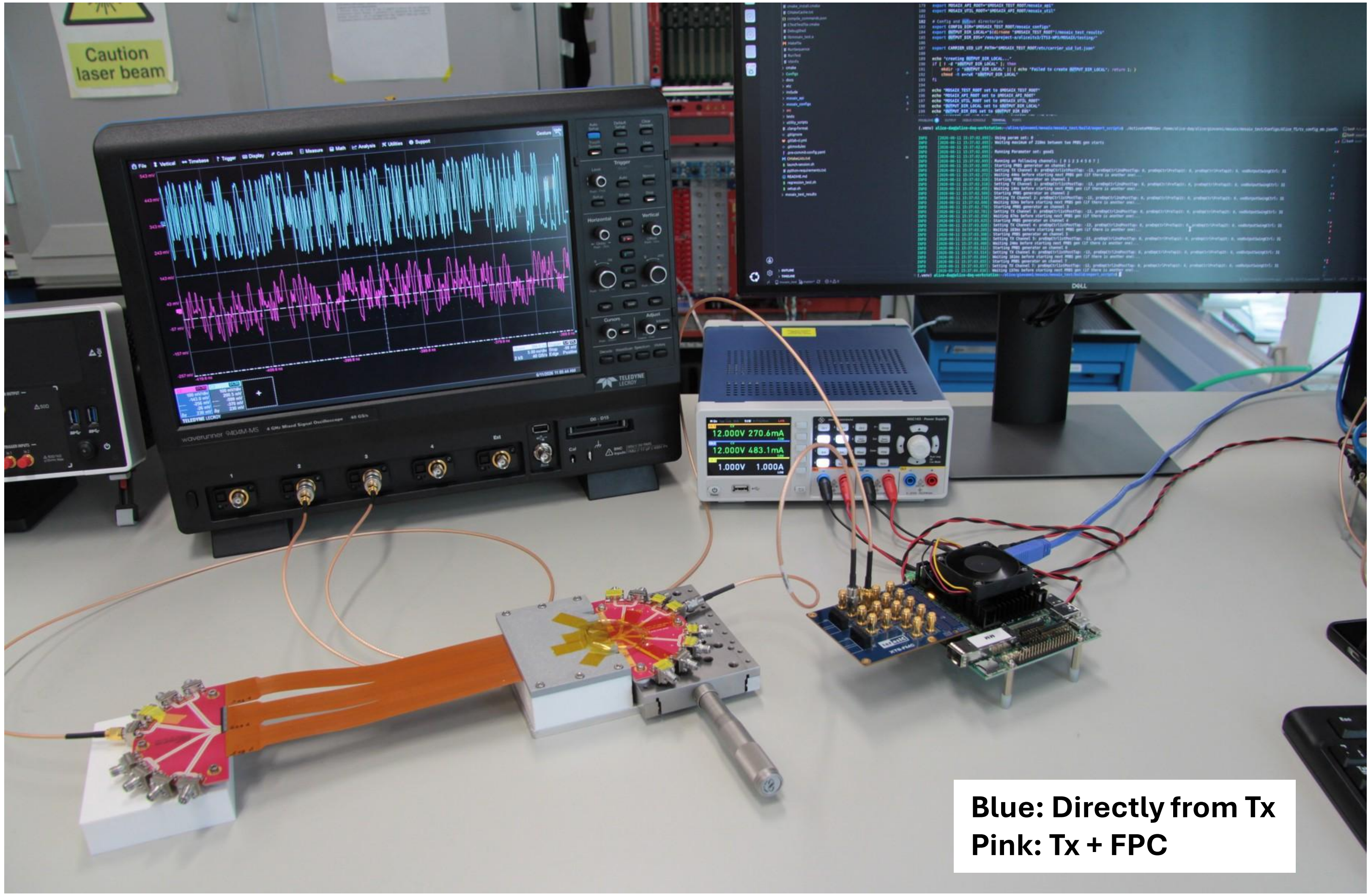


Transmitter and receiver FPGA boards are working with ≈ 0 BER

https://gitlab.cern.ch/groups/alice-its3-wp3/mosaix-testing/-/wikis/Getting-Started

```
HsChannelId,Ready,Locked,TestDuration_s,ErrorCount,TotalBits,BER,BER_Threshold,Status
HSCH_HSCHA[0],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[1],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[2],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[3],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[4],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[5],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[6],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
HSCH_HSCHA[7],YES,YES,5.000000,0,51200000000,0.000000,0.000000,PASS
```

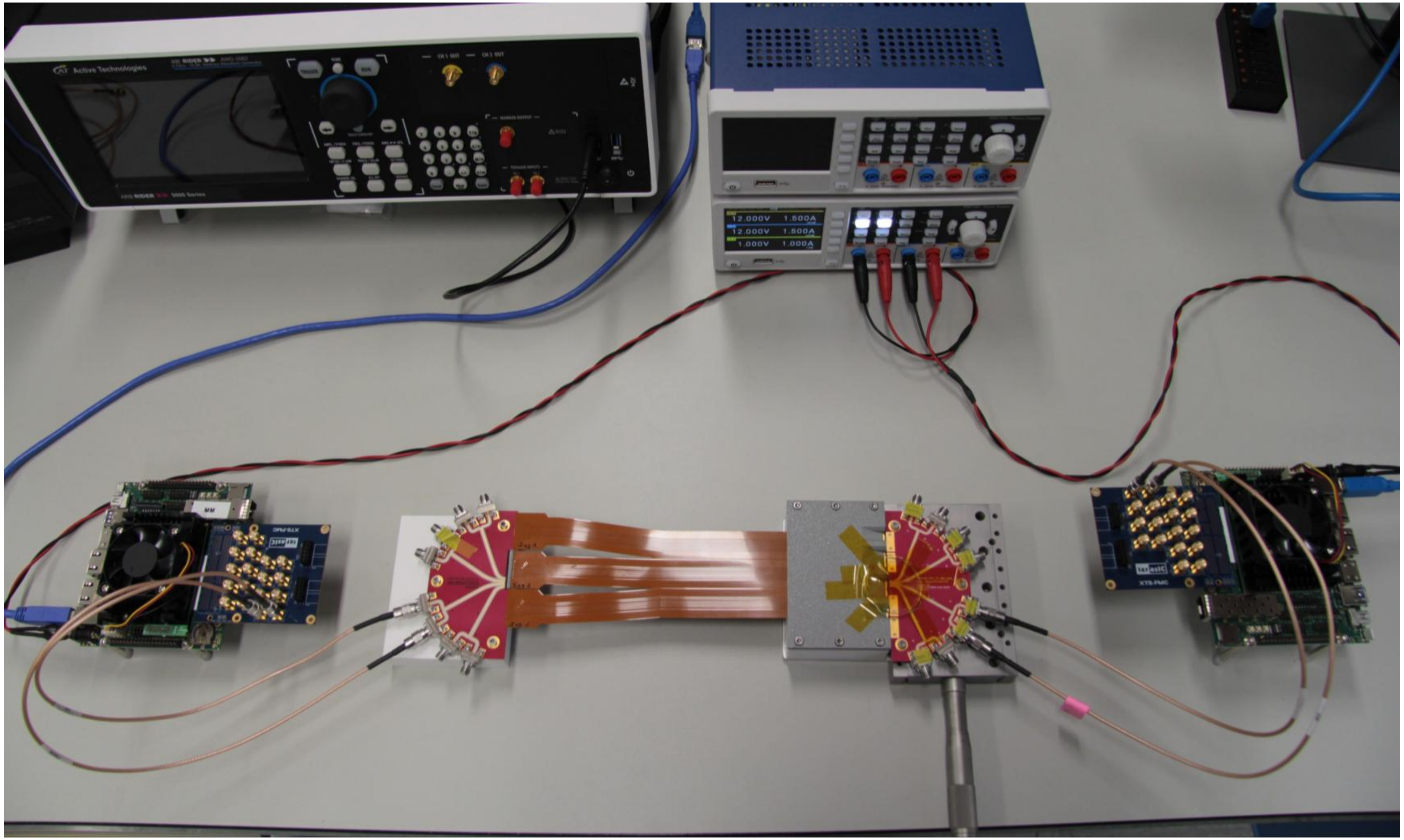
TRANSMITTER (MOSAIX EMULATOR) + CHANNEL (ITS3 FPC)



Seeing real eye-diagrams will only be possible in Q4-2026 with a new oscilloscope

(to-be-ordered)

TRANSMITTER + CHANNEL + RECEIVER



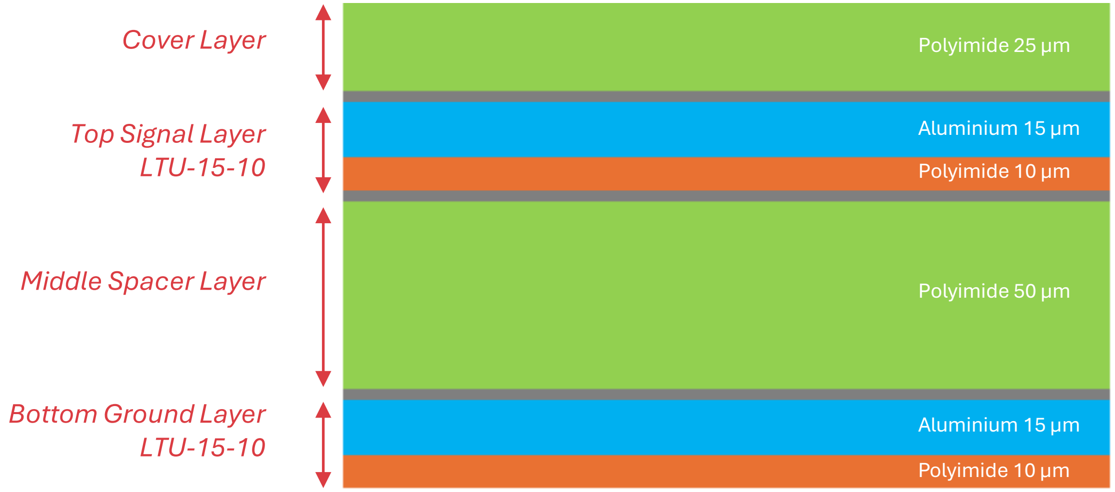
BER measurements ongoing

Activity #2
Preparing 1st LTU Prototypes

Prototypes For Signal Integrity Tests

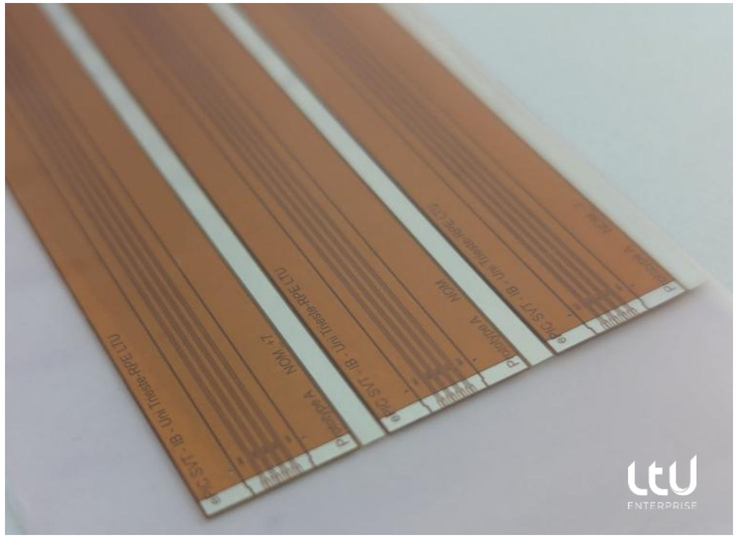
Prototype A-1

Prototype A-2



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

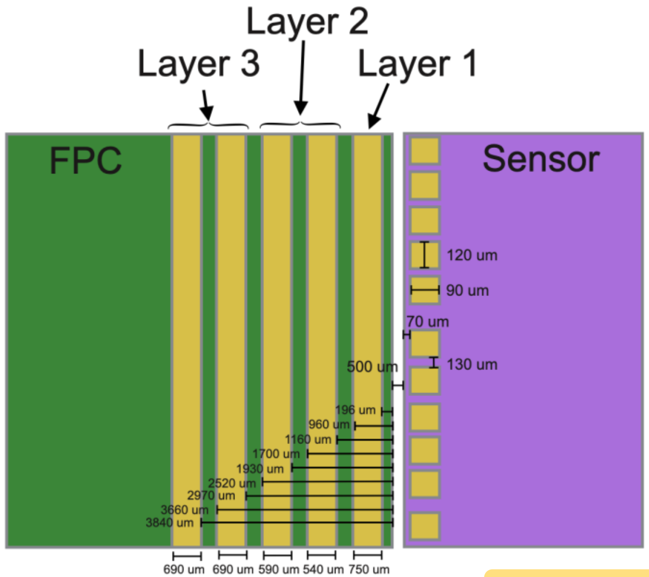
- A-1: Without cover layer, 25 µm middle spacer layer
- A-2: With cover layer, 50 µm middle spacer layer
- Diff. impedance = 100 Ω
- Space b/w traces = 80 µm
- Trace width = 70 µm
- Trace pitch = 150 µm
- Trace thickness = 15 µm
- Further sub-variants with ±10% trace width
- 5 test samples of each variant (18 cm trace length)



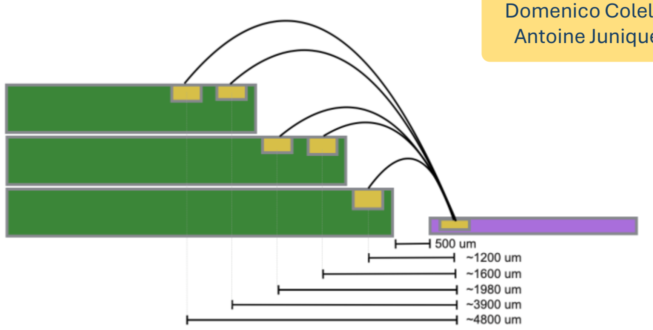
Delivered!

Prototypes For Bonding Tests

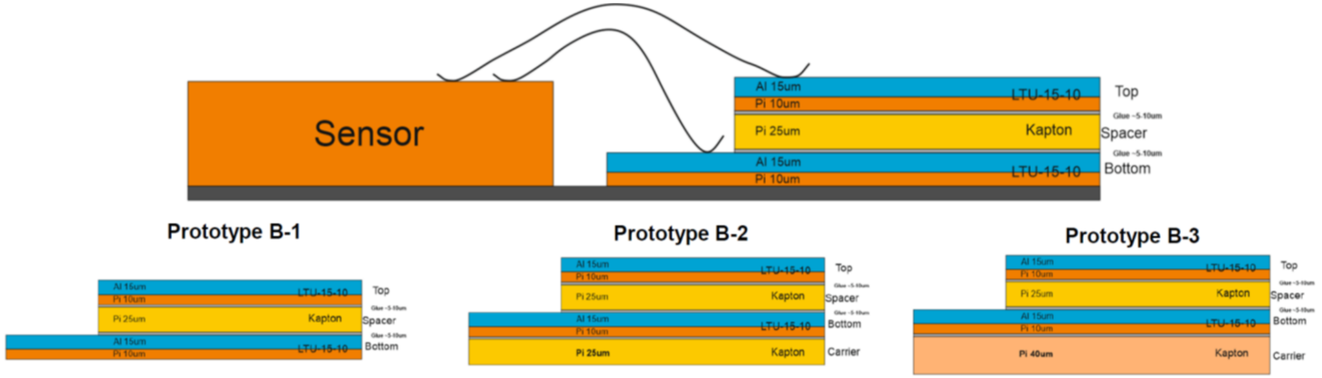
IB Wirebonding Geometric Parameters



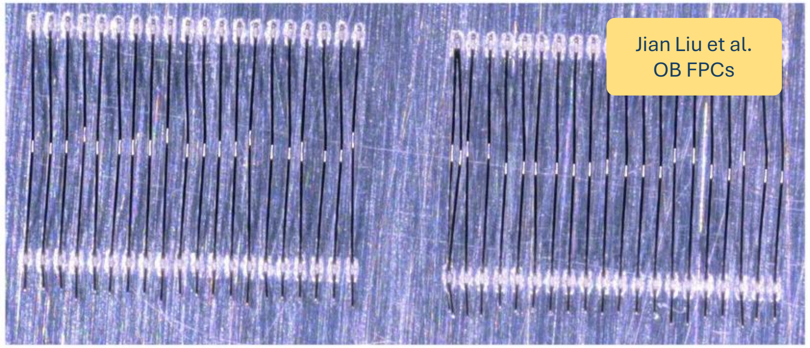
Domenico Colella
Antoine Junique



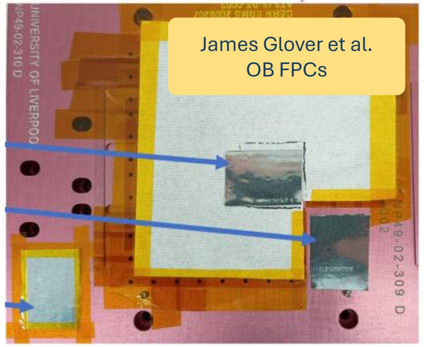
Tests with IB Wirebonding Geometric Parameters Next Week



OB Wirebonding Machine Parameters with LTU Prototypes



Jian Liu et al.
OB FPCs



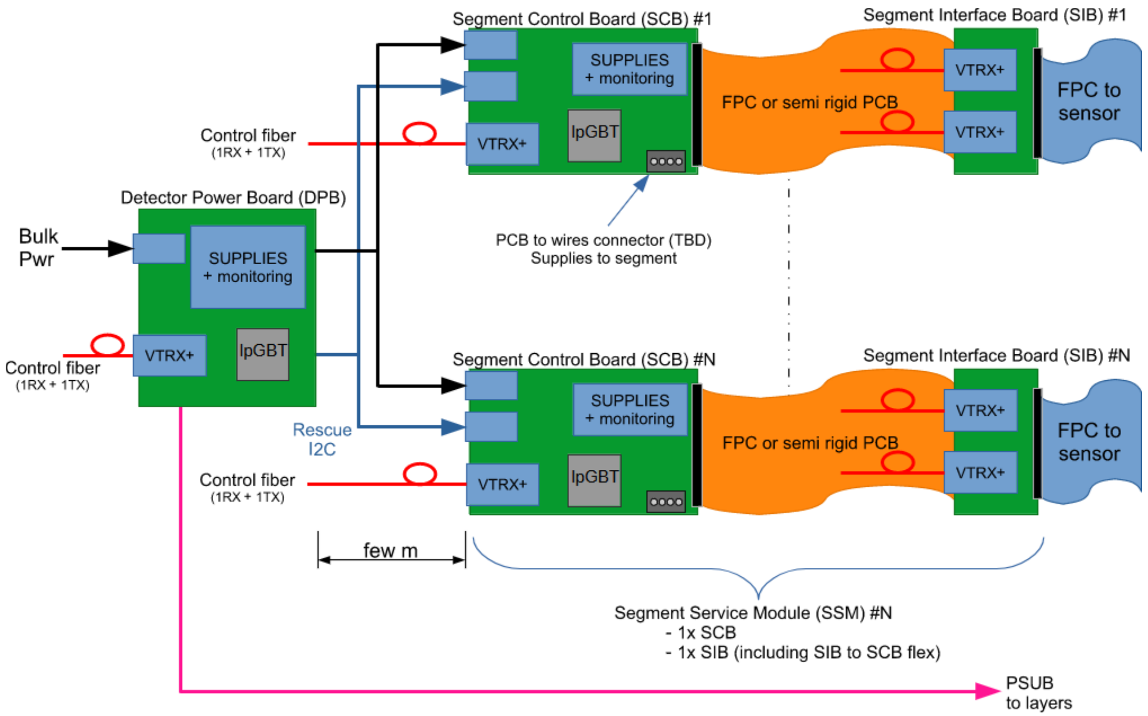
James Glover et al.
OB FPCs

Activity #3
Extrapolating To (Almost) Final Design

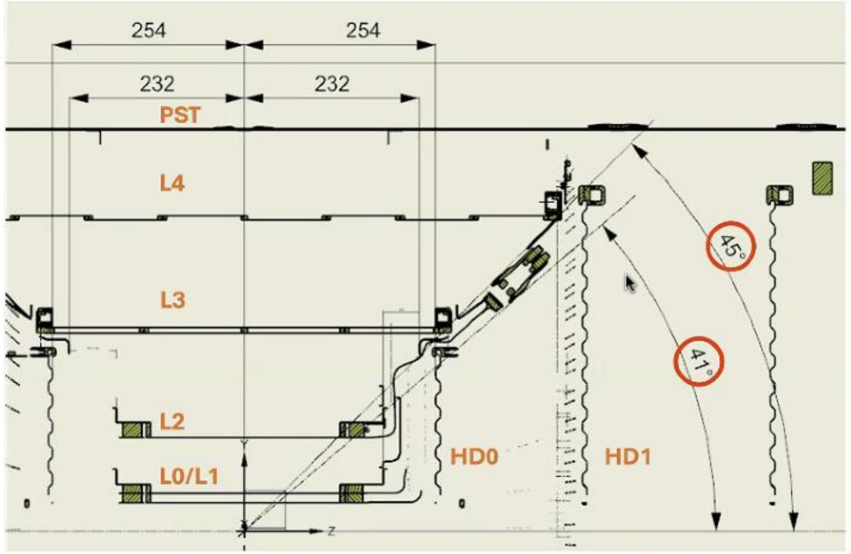
FPC: Sensor To Segment Interface Board (SIB)

Finding fundamental signal FPC properties to inform next LTU prototypes

- Many “auxiliary” boards and connections in current test setups which won’t be in the final readout scheme
- FPC lengths (and maybe cross-sections) are subject to change
- Next set of LTU FPC prototypes are foreseen to be ordered later this year



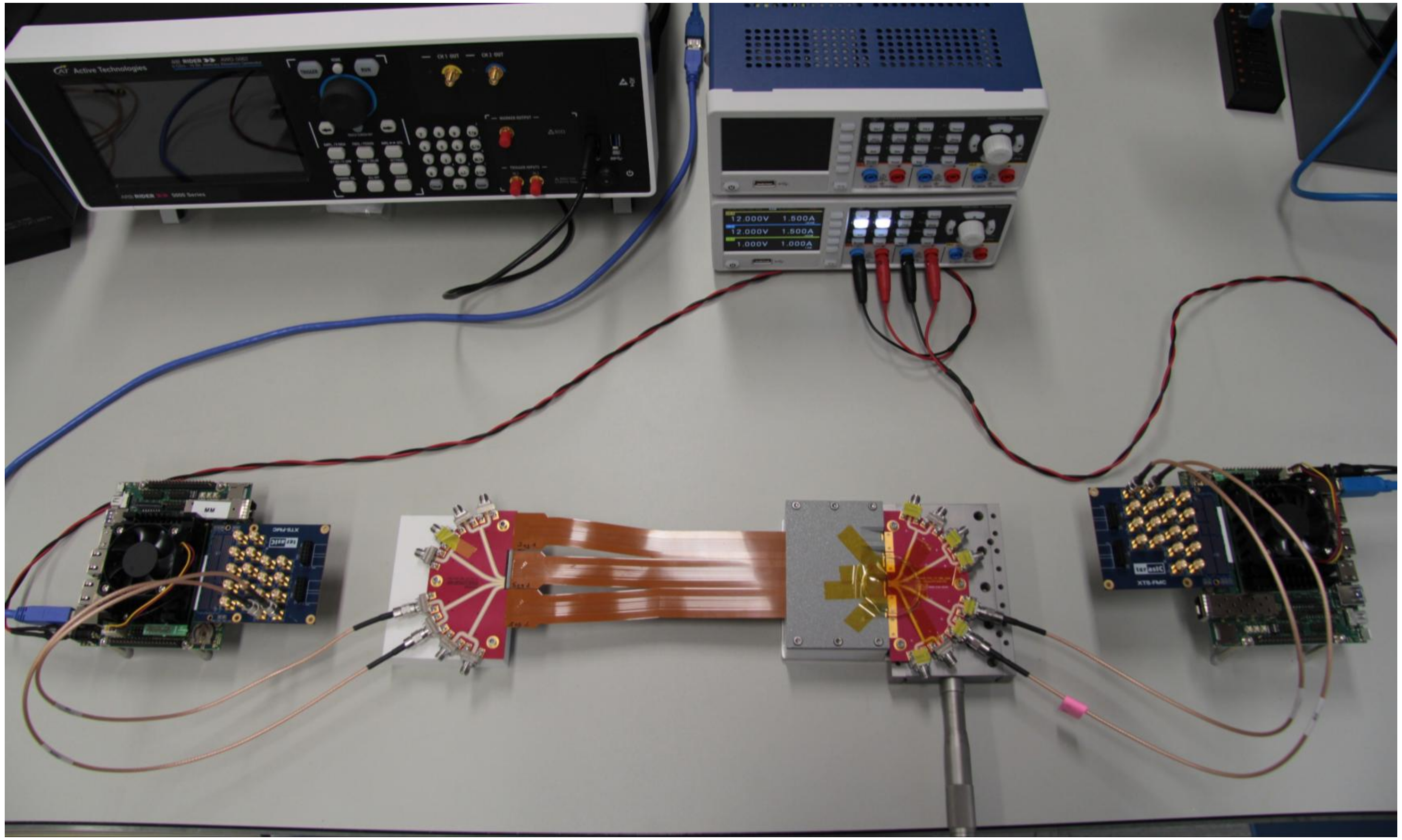
Cross sections – check the shadow!

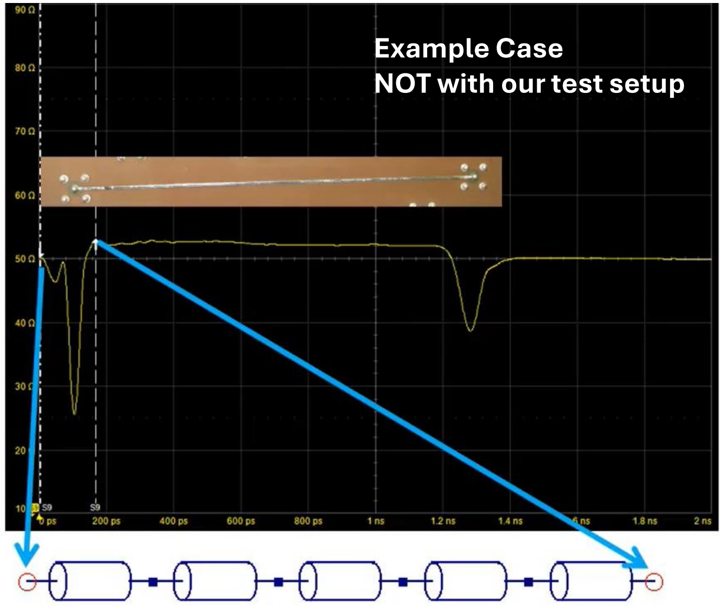


FPCs lengths:
L0 415 mm
L1 387 mm
L2 310 mm
typical values, few mm variations happen within the same layer

De-Embedding Auxiliary Connections

LeCroy WavePulser High-Speed Interconnect Analyzer for De-Embedding (will arrive in July)

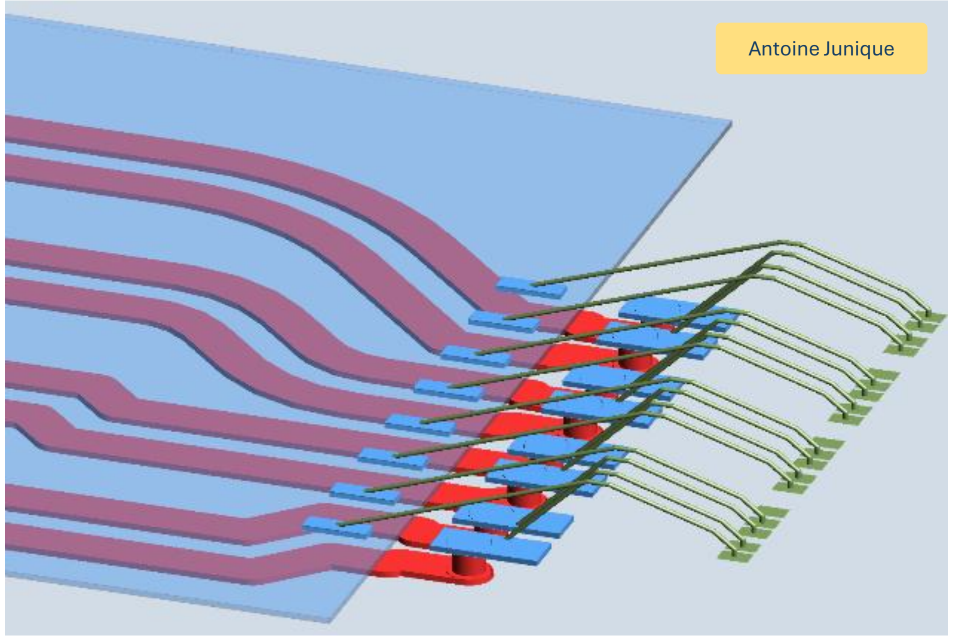




https://www.teledynelecroy.com/wavepulser/

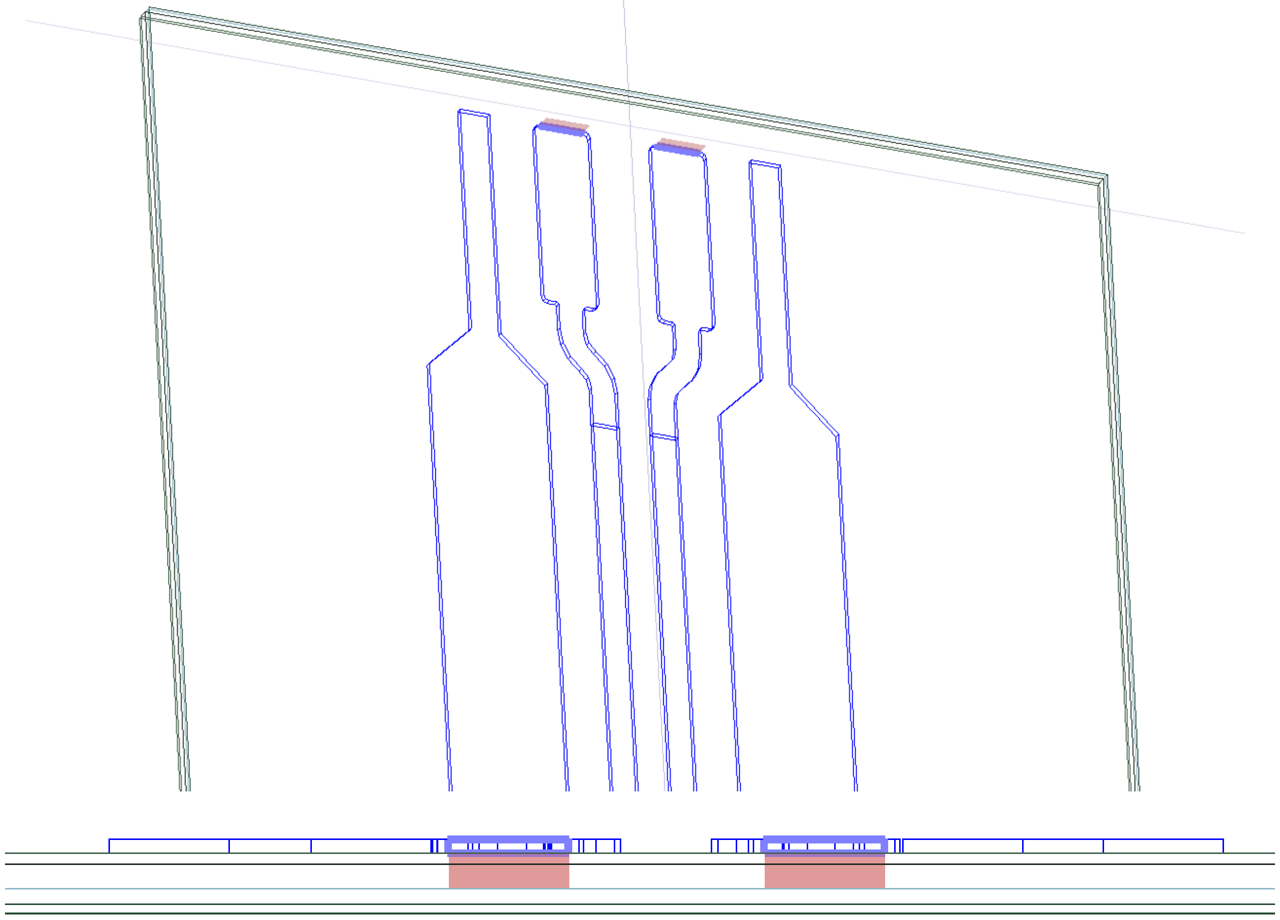
ANSYS SIMULATIONS OF FPC

Example Case:
ITS3 FPC 3D Simulations (with wire bonds)



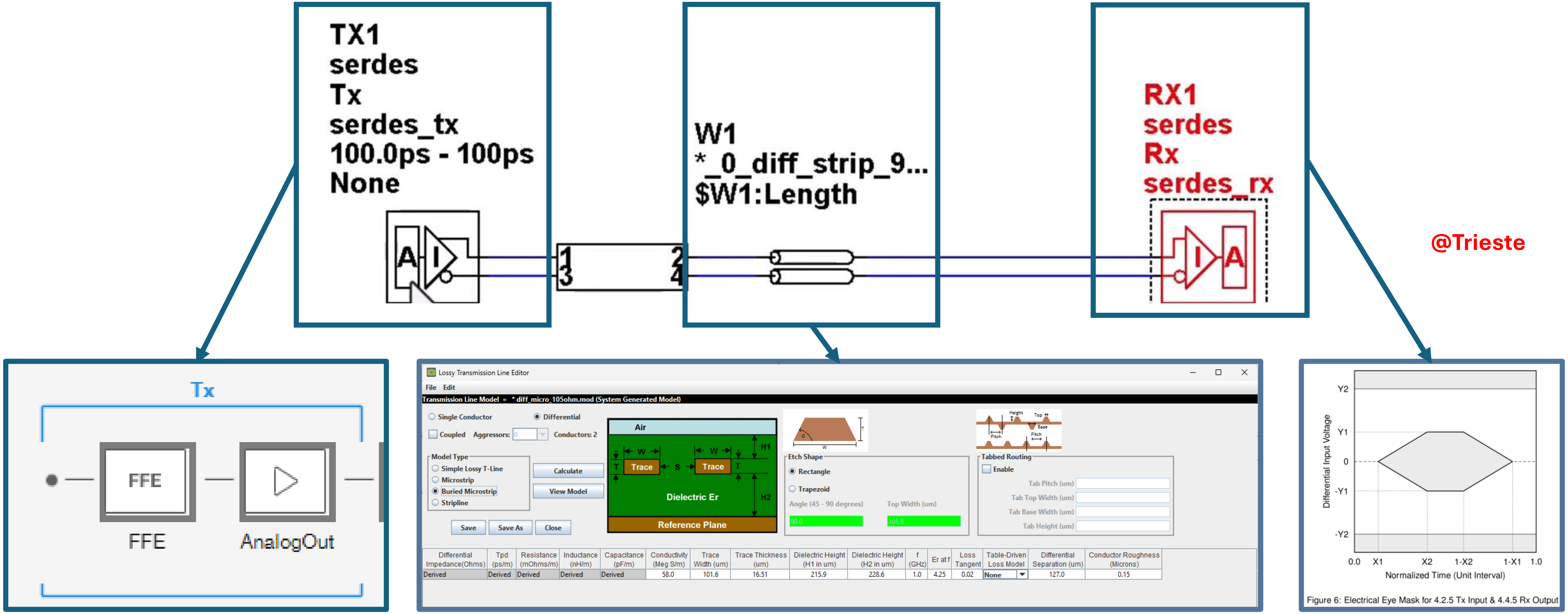
https://indico.cern.ch/event/1603472/contributions/6756797/attachments/3162243/5618933/A_JUNIQUE_TWEPP_2025_.pdf

Initiated 3D simulations mimicking LTU A1 prototypes



MATLAB Calculation And Simulation Framework

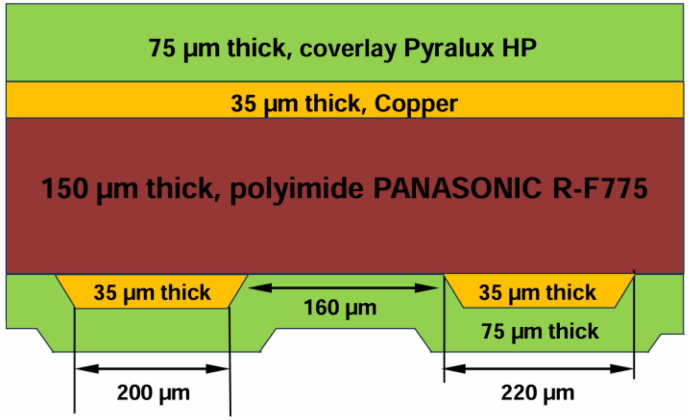
Preliminary statement / estimate on the max. LTU FPC length usable with GWT_PSI Tx and VTRx+

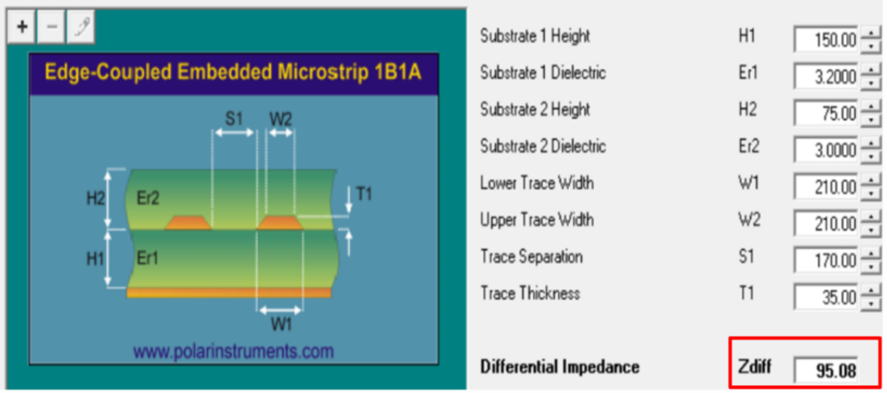


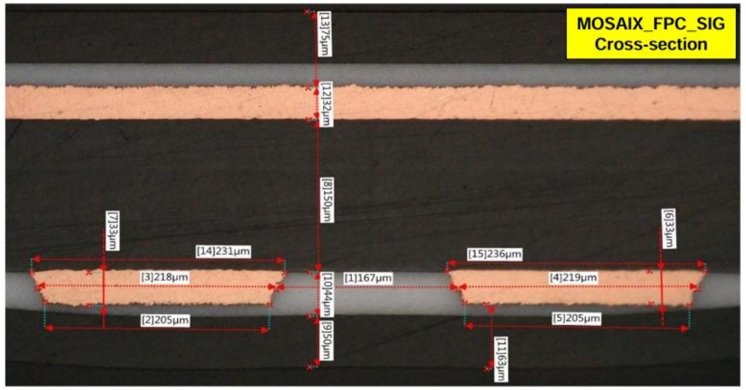
IMPLEMENTING ITS3 SIGNAL FPC

A. Junique's Calculations and Observations

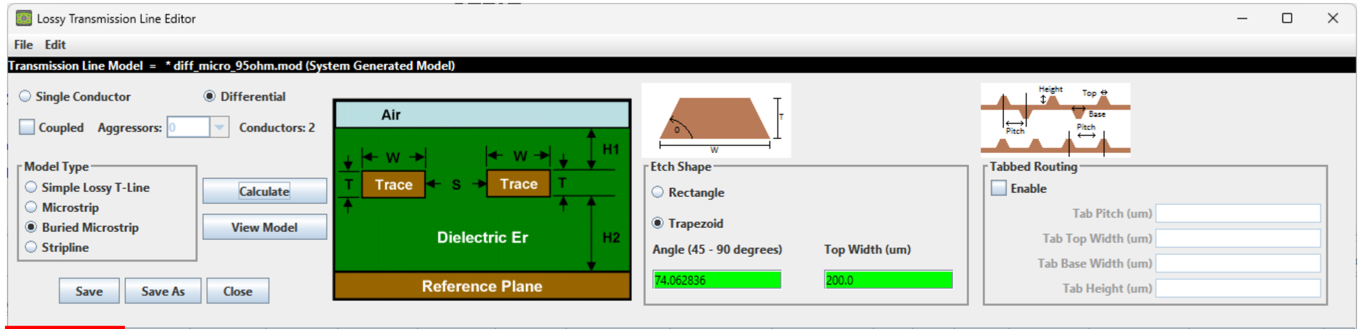
A. Junique, TWEPP 2025 | Link







MATLAB Simulations



Differential Impedance(Ohms)	Tpd (ps/m)	Resistance (mOhms/m)	Inductance (nH/m)	Capacitance (pF/m)	Conductivity (Meg S/m)	Trace Width (um)	Trace Thickness (um)	Dielectric Height (H1 in um)	Dielectric Height (H2 in um)	f (GHz)	Er at f	Loss Tangent	Table-Driven Loss Model	Differential Separation (um)	Conductor Roughness (Microns)
95.417	5419.1733	2345.748	324.92126	96.65354	58.0	220.0	35.0	40.01	150.0	1.0	3.13	0.003	None	160.0	0.0

- MATLAB uses a relatively simple FPC simulator, which requires calculating effective dielectric constant ($\varepsilon_{r\,\mathrm{eff}}$) of the FPC cross-section

$$\varepsilon_{r\,\mathrm{eff}} = \frac{\varepsilon_{r_1} \cdot h_1 + \varepsilon_{r_2} \cdot h_2}{h_1 + h_2} = 3.13$$

For ITS3, $\varepsilon_{r_1} = 3.2, h_1 = 150\,\mu m$; $\varepsilon_{r_2} = 3.0, h_2 = 75\,\mu m$

Comparable differential impedance (≈ 95Ω)

SETTING UP RECEIVER (VTRX+) EYE MASK

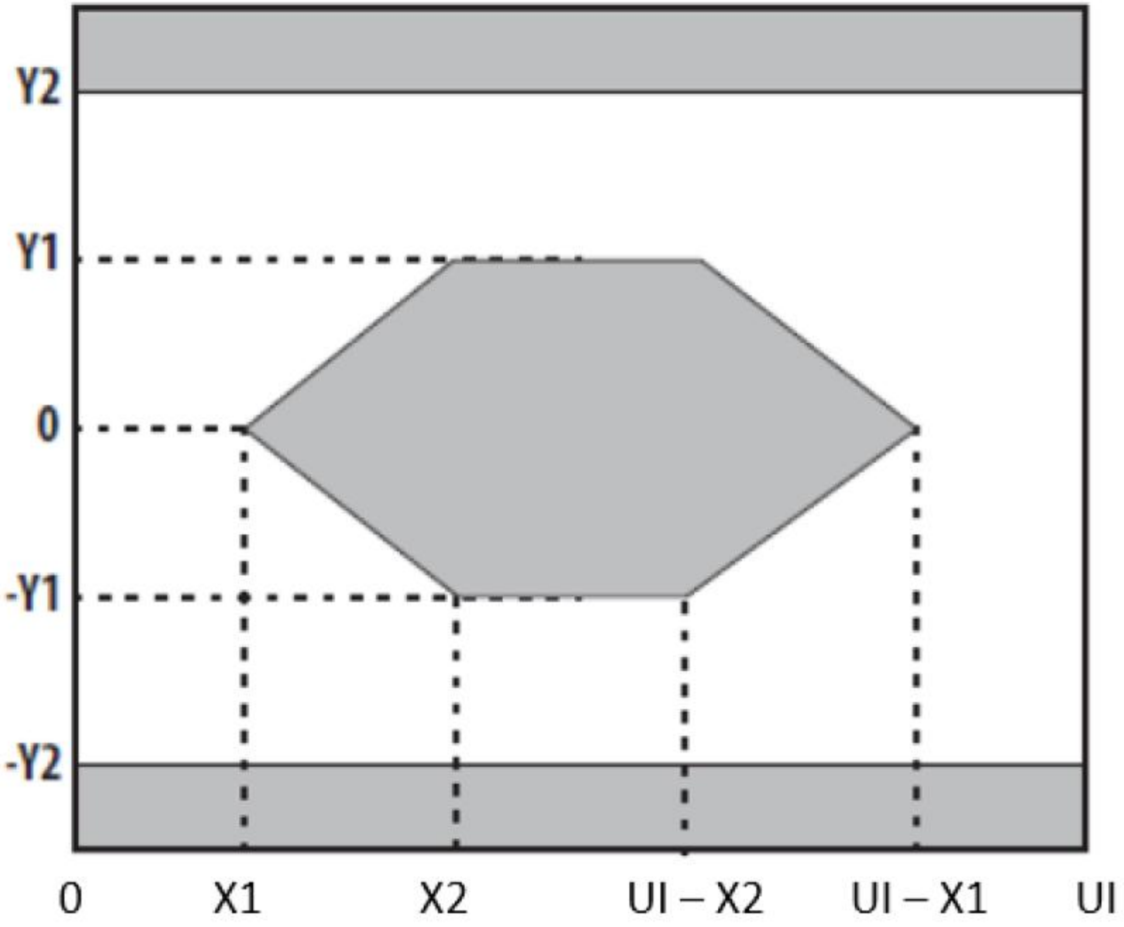


Figure 7.1 Mask 1

- Mask specs based on Optical Internetworking Forum's guidelines (OIF-CEI-05.3 Clause 8) for NRZ baud rates of 9.95 … 11.2 Gsym/s

Implementation Agreement OIF-CEI-03.0, Common Electrical I/O (CEI) (2011) | Link

Table 7.2. Uplink Electrical and optical eye mask for VTRx+ and TRx (UI = 97.66 ps)

7.2.1	VTx+ Elec. Input @TP1; (Mask 1, Fig. 7.1)	X1	X2	X3	Y1	Y2	Y3
	Value	10.7	30.3		95	350	
	Unit	ps	ps		mV	mV	
7.2.2	VTx+ Optical Output @TP2 (Mask 3, Fig. 7.3)						
	Value	22.5	33.2	42	0.27	0.35	0.40
	Unit	ps	ps	ps	Norm. Amp.*	Norm. Amp.*	Norm. Amp.*
7.2.3	COTS Rx Elec. Output @TP4 (Mask 2, Fig. 7.2)						
	Value	28.3	48.8		150	425	
	Unit	ps	ps		mV	mV	

*Normalized Amplitude

Alan Prosser et al., Versatile Link Plus Technical Specification - Part 1, EDMS Document No.1719328 (2019)
J. Troska et al., The Versatile Link+ Application Note, EDMS Document No. 2149674 (2021)

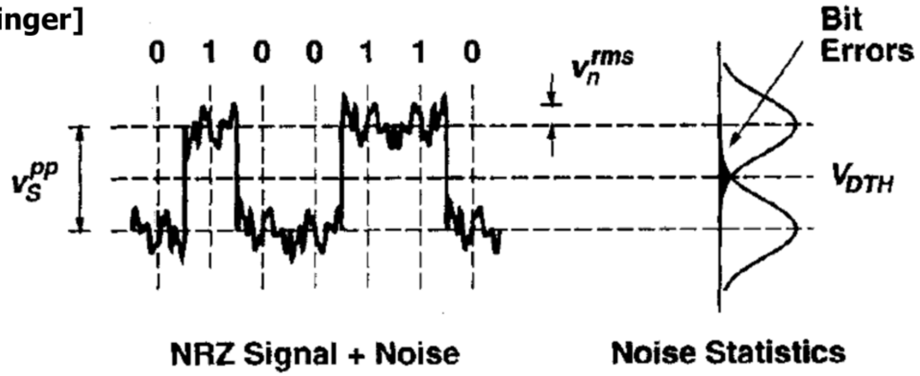
Setting Up Transmitter (GWT-PSI) – Jitter

Test Name	Configuration	Acceptance Criteria	Reference
Tx Output Jitter (Intrinsic)	**Rate:** 10.24 Gbps **Pattern:** PRBS-31 **Pre-emph:** OFF (`cfg=00`)	**Total Jitter (TJ):** < 0.30 UI (standard) **Random Jitter (RJ):** $< 0.04\ \mathrm{UI}_{RMS}$ (simulation) $< 0.01\ \mathrm{UI}_{RMS}$ (standard) **Duty Cycle Distortion:** < 0.05 UI	**[OIF-CEI]** 11G-MR Tx Spec, Table 9-3. $RJ = 0.15\ \mathrm{UI}_{pp}/16 = 0.0094\ \mathrm{UI}_{RMS}$ derived from Uncorrelated High Probability Jitter req. **Note the big discrepancies between the standard and the simulation expectations, thus TJ requirement is probably too strict.**

Side remark: Value higher than the VTRx+ eye compliance mask

GWT-PSI Chiplet Characterisation and Qualification Plan (2026) | Link

[Sackinger]



Sam Palermo, ECEN720: High-Speed Links Circuits and Systems, Spring 2023, Texas A&M University | Link
Jitter Analysis: The dual-Dirac Model, RJ/DJ, and Q-Scale, Agilent White Paper (2004) | Link

- Jitter specs based on Optical Internetworking Forum's guidelines (OIF-CEI-05.3 Clause 8) for NRZ baud rates of 9.95 … 11.2 Gsym/s

Implementation Agreement OIF-CEI-03.0, Common Electrical I/O (CEI) (2011) | Link

- System Jitter Budget to achieve minimum BER performance

  Total Jitter = Deterministic Jitter + Random Jitter

  $TJ_{pp}(BER) = \underbrace{DP_{pp}}_{\text{Dual-Dirac Fit}} + \underbrace{2 \cdot Q(BER) \cdot \sigma_{RJ}}_{\text{Gaussian Tail Fit}}$

- GWT-PSI serialiser has BER requirement of ideally 10^{-15} ($\leq 10^{-12}$)

  $Q = \sqrt{2} \cdot \mathrm{erfc}^{-1}(2 \cdot BER) = \sqrt{2} \cdot \mathrm{erfc}^{-1}(2 \cdot 10^{-15}) = 7.94$

- Total Jitter (TJ_{pp}) = 0.30 UI = 29.30 ps

  Random Jitter (RJ) = $2 \cdot 7.94 \cdot 0.01$ = 0.16 UI = 15.63 ps

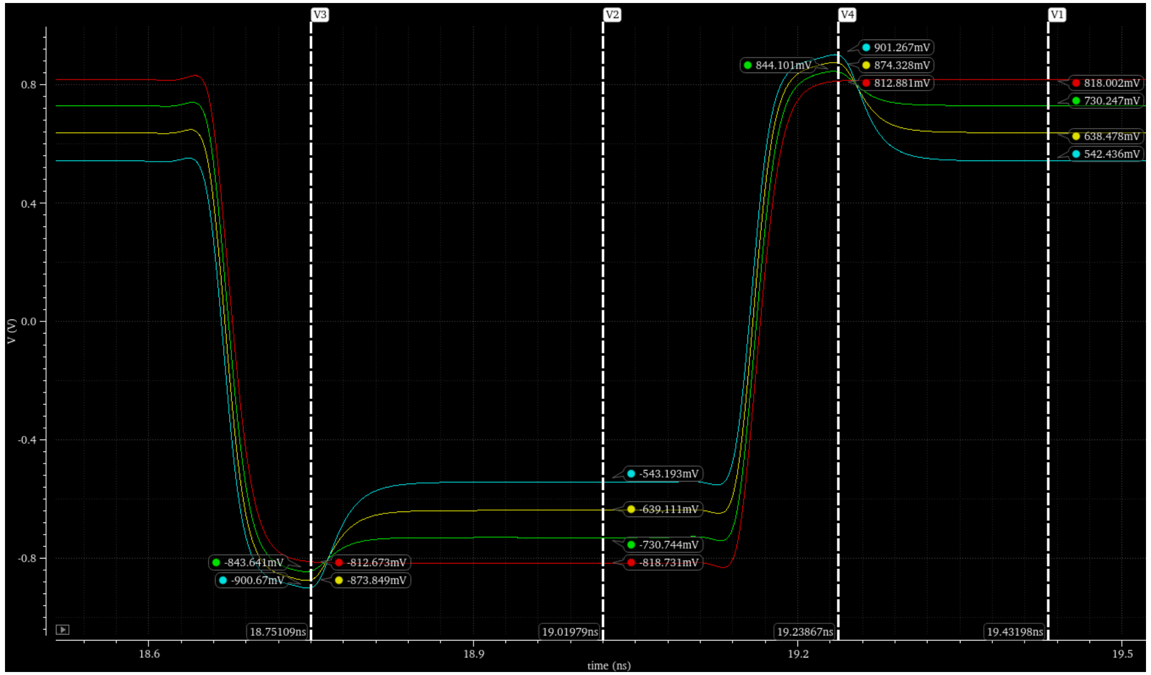
  Deterministic Jitter (DP_{pp}) = $TJ_{pp} - RJ$ = 0.14 UI = 13.67 ps

  DP_{pp} comprises duty cycle distortion of 0.05 UI

(Worst case) values of each jitter components applied in serialiser definition

SETTING UP TRANSMITTER (GWT-PSI) – PRE-EMPHASIS

Simulations by: Giacomo Ripamonti (CERN)
M. Rossewij (U. Utrecht), Private Communication, 08.06.2026
M. Rossewij, ALICE TIS3 WP3 Meeting, 09.06.2026 | Link



Pre-Emphasis Mode (`serializer_cfg_2`)		Cursor Tap (c_0)	Post-Cursor Tap (c_1)
Off	(2'b00)	+1.000	0.000
Mild	(2'b01)	+0.933	-0.067
Moderate	(2'b10)	+0.865	-0.135
Max	(2'b11)	+0.801	-0.199

- Feed Forward Equaliser (FEE) for transmitter pre-emphasis

$$H(f) = \sum_k c_k \cdot e^{-j2\pi f k T_{sym}}$$

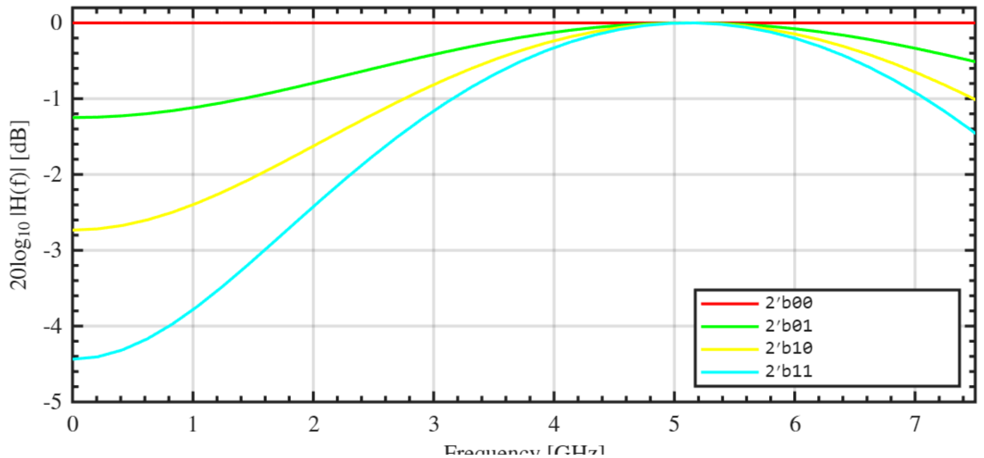
- For GWT-PSI transmitter with two taps, 1 cursor and 1 post-cursor

k : Tap indices [0, +1]

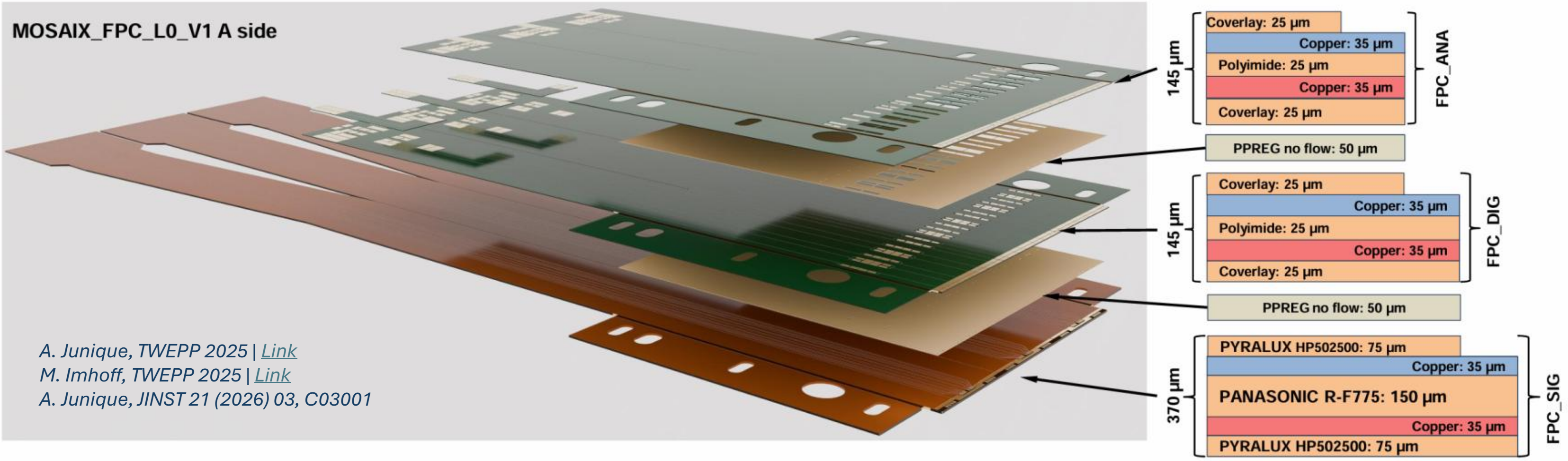
T_{sym} : Symbol period or 1 UI (1/10.24Gbps = 97.66 ps)

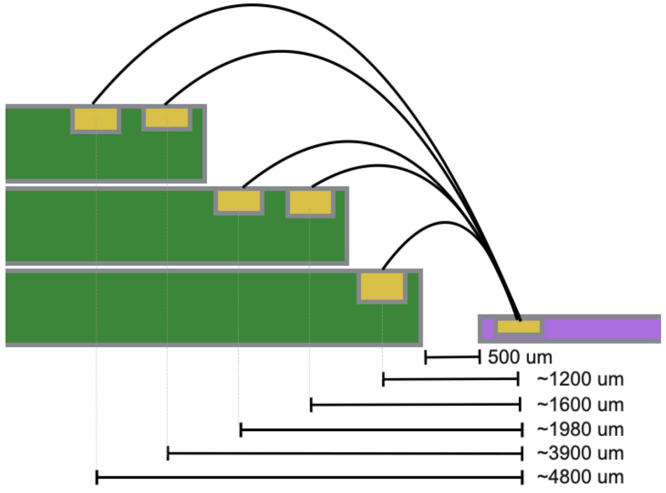
c_k : Tap coefficients ($\sum_k |c_k| = 1$)

$$c_0 = \frac{|V_{steady}| + |V_{peak}|}{2 \cdot |V_{peak}|} \qquad c_1 = \frac{|V_{steady}| - |V_{peak}|}{2 \cdot |V_{peak}|}$$



WIREBONDS B/W MOSAIX AND SIGNAL FPC





D. Colella (Uni. & INFN Bari), Private Communication, 09.06.2026

- Signal FPC is at the bottom of the FPC stackup, i.e., shortest bond wire $\lesssim$ 3 mm
- Inductance (L) for a straight bond wire
  - r : Bond wire radius (25 µm / 2 = 12.5 µm)
  - l : Bond wire length (3 mm)
  - μ_0 : Permeability of free space (1.2566 µH/m)

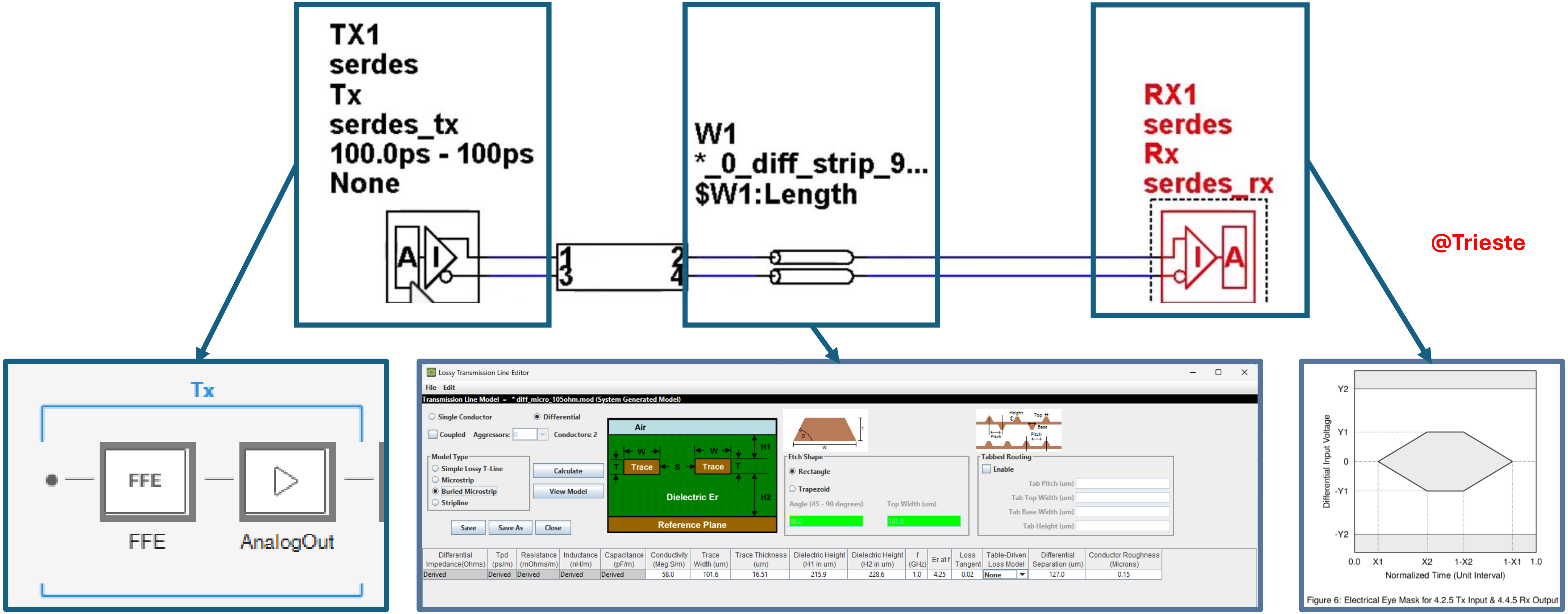
$$L = \frac{\mu_0}{2\pi} \times l \times \left[\ln\left(\frac{l}{r} + \sqrt{1 + \frac{l^2}{r^2}} \right) - \sqrt{1 + \frac{r^2}{l^2}} + \frac{r}{l} + \frac{1}{4} \right] \approx \frac{\mu_0}{2\pi} \times l \times \left[\ln\left(\frac{2l}{r} \right) - 0.75 \right]$$

For the signal FPC, the bond wire inductance is ≈ 3.25 nH

Xiaoning Qi, PhD Dissertation, Stanford University (2001) | Link
Joerg Berkner, Klaus-Willi Pieper, Bondwire Inductance, Infineon | Link
Straight-wire model overestimates the inductance by 10 to 50%

MATLAB Calculation And Simulation Framework

Preliminary statement / estimate on the max. LTU FPC length usable with GWT_PSI Tx and VTRx+



THANK YOU

EXTRA SLIDES