OAK RIDGE National Laboratory

Kapton Flex Hybrid R&D Update

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ORNL is managed by UT-Battelle LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Barrel TOF Flex PCB

- Connect 64 ASICs (+X) along stave to RDO at end of stave
  - Low voltage, bias (HV), ground
  - Differential e-links, **clocks**, slowcontrol/I^2C?
  - Individual ASIC output data rate is only ~Mbit/s (based on Tonko's initial estimates)
- Low mass: 1% X/X_0 total barrel material budget
- Needs to fit barrel TOF geometry
  - ~1.2m length
- Kapton flex PCB:
  - Custom geometry "sandwich" of thin kapton and conductor layers
  - Used in other tracking detectors already

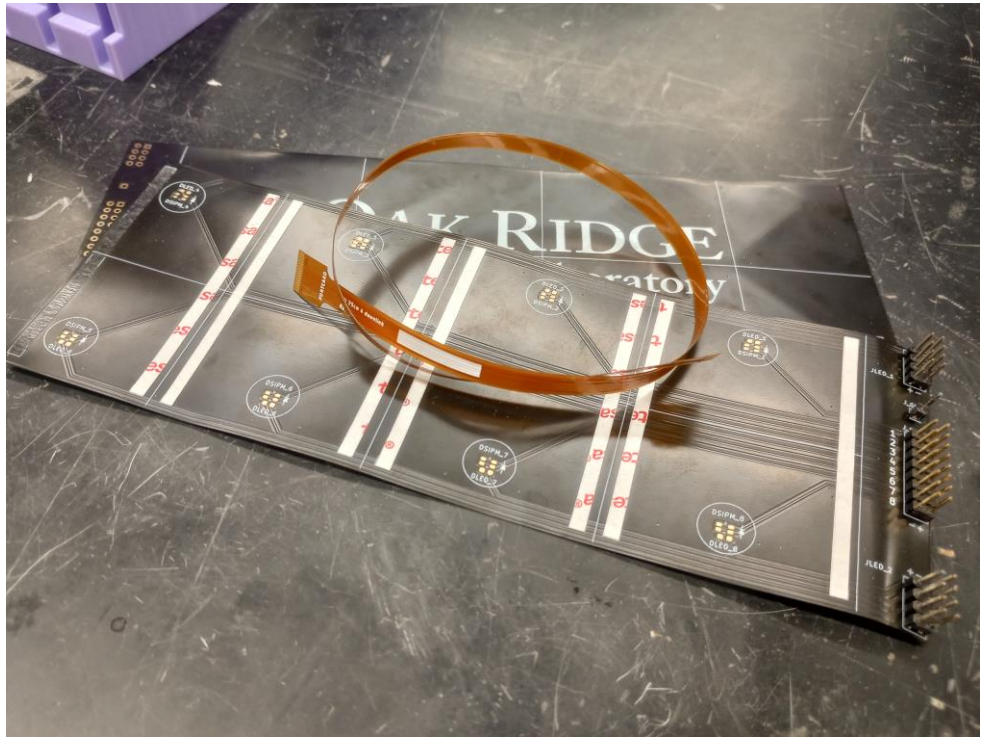
PID-TOF	3M-50M	240-500	6Gb/sec	12	EICROC / AC-LGAD	Channel / Fiber counts depend on sensor geometry. Considering pitches of: .5mm x 1cm, .5mm x .3cm, .5mm x .5mm

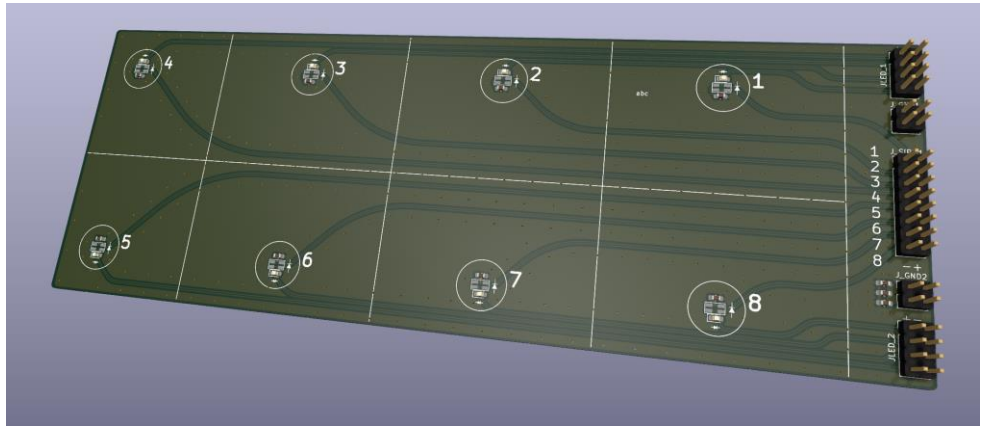
Update

- ORNL engineers with the right expertise seem busy at the moment…
- Instead looking into outside engineering support now
  - Have interested and capable candidates, figuring out payment…
- In the meantime: produced flex PCBs with different vendor
- Alice Bean (Kansas U.) on sabbatical in ORNL RNP group
  - Experience with long flex lines for ATLAS pixel upgrades
  - (n.b.: they seem to move away from long flex and do long twisted pair data lines for mechanical reasons)

LFHCAL Flex PCB

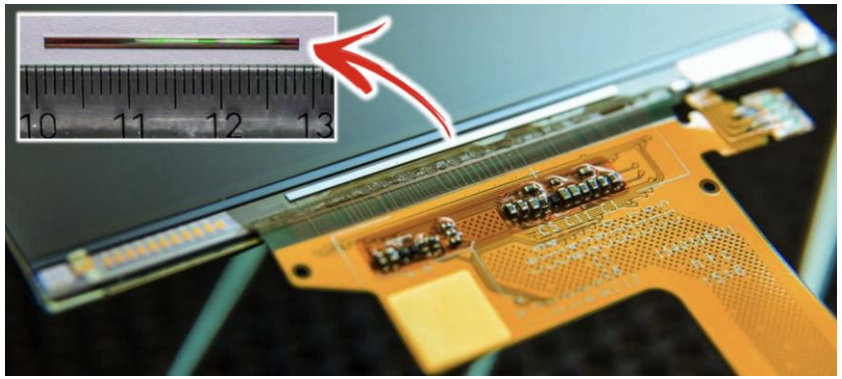
- ePIC LFHCAL uses Kapton flex to gather SiPM signals per layer
  - Different geometry then TOF flex, but same technology and similar conductor layout
- V1 designed ourselves, works well in testbeam
  - V2 just submitted for production with minor improvements, next testbeam in 2 weeks will show whether improvements are tangible…
- Different vendor than previous prototypes
  - Fast production, good quality, more detailed layup options etc.

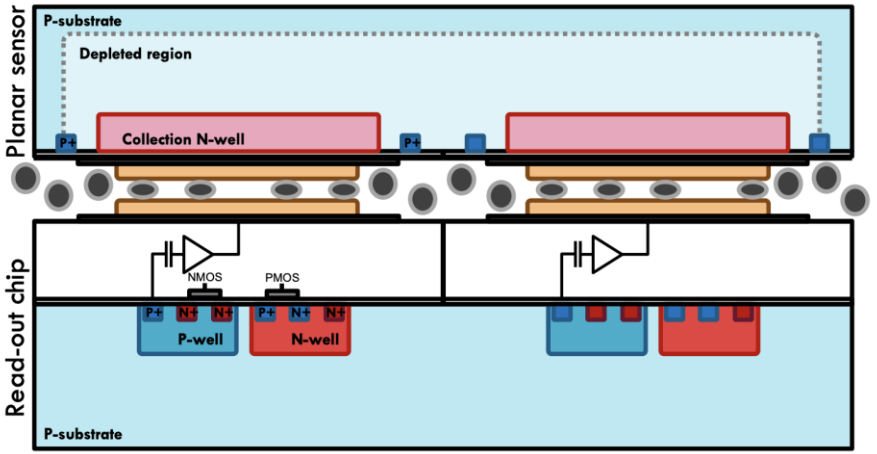


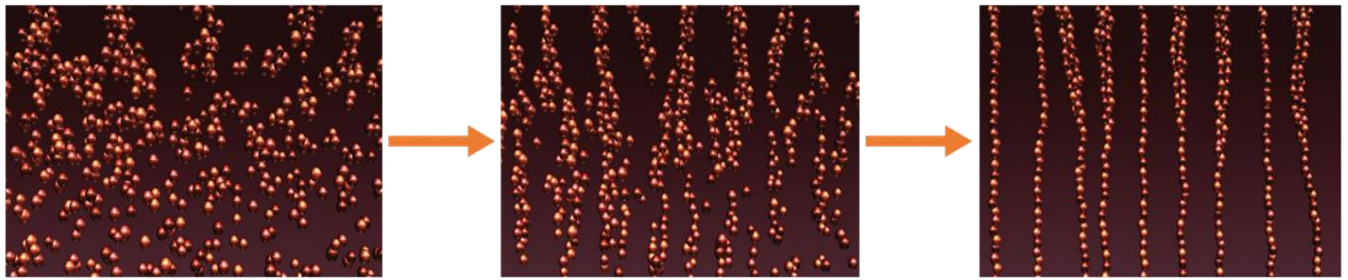


ASIC-to-Flex Interconnect (M. Benoit)

- FY'24 continuation: produce flex prototype with connected readout ASIC
- Anisotropic Conductive Films (ACF)
  - Technology developed for the LCD Display industry
  - Low cost, no lithography involved
  - New method allow arrangement of micro-particles (i.e. with Magnetic Field) to reach finer pitch with better yield
  - ORNL in contact with multiple industry partner to investigate these bonding methods





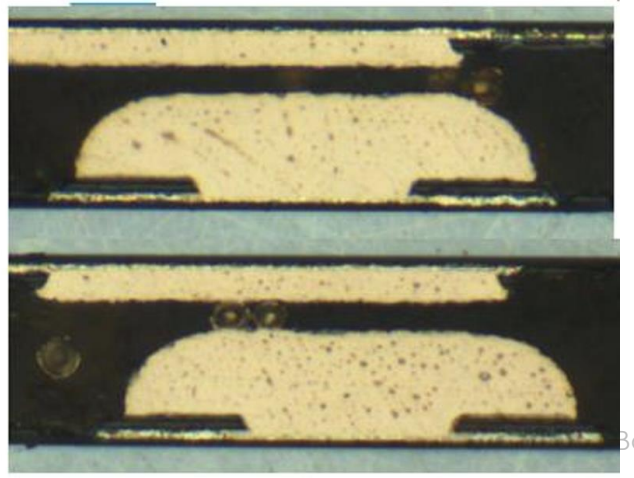


BEFORE CURE
Randomly dispersed particles

WITHIN 4 SECONDS
Particles start aligning due to magnetic field exposure

WITHIN 10 SECONDS
Conductive columns fully form and are locked in place by the curing of the polymer matrix

Source : https://sunrayscientific.com/solutions/



Barrel Flex

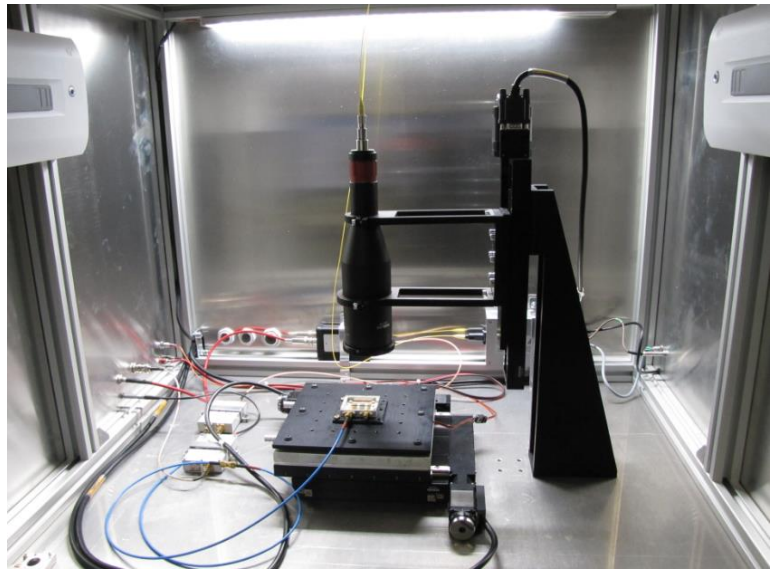
SET FC150 precision bonder

ORNL will purchase a FC150 flip-chip bonder in FY'24 from lab funds

- Up to 150mm substrate and chip handling
- +- 1µm post-bonding accuracy
- +- 1µRad parallelism with active levelling
- Pressure up to 200 kg
- Temperature up to 400C (~1C/s)
- Can be operated in fully automated mode
- Liquid dispenser integrated in the machine for glue, underfill distribution

Other ORNL News

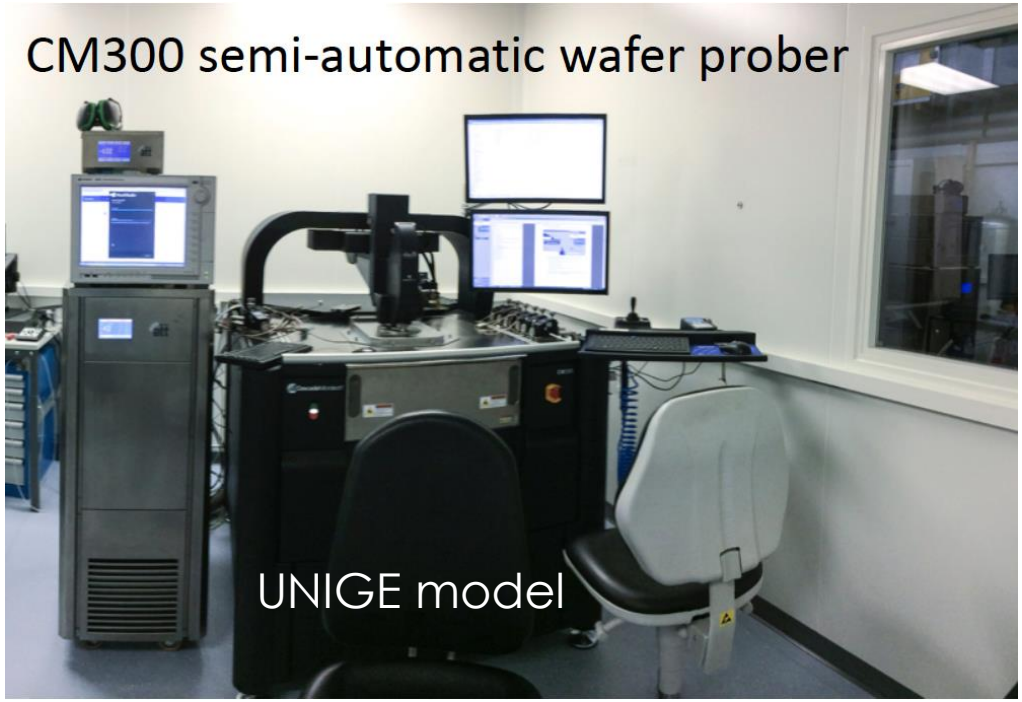
- TCT Setup finally arrived…
  - 1064nm, 550nm lasers
- New wire bonder available (*)

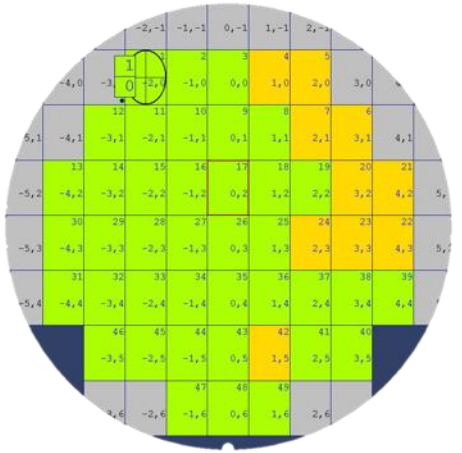


FormFactor CM300xi probe station

We **plan** to purchase a 300mm semi-automatic prober that will be installed at ORNL:

- Accommodate 5-300mm sample size
- Light tight and airtight thermal chamber
  - -60C to 125C testing range
- Probes :
  - 8 x DC probe for parametric measurement
  - 2 x RF probes
  - 1 x XYZ robotic probe with optical probing
  - Probe card holder for open, closed top probe cards
- 4 x Cameras :
  - Top view up to 1000x
  - Bottom-up view (probe alignment)
  - Side view (wafer surface alignment)
  - Auxiliary view (closed top probe card alignment)
- Fully automated alignment of wafers and dices
- Fully programmable for unattended testing





Same machine installed at University of Geneva, CERN building 14, Fermilab

Summary/Timeline

- Designed and produced more Cu-flex foils by ourselves
- Engineering support at ORNL difficult to find, looking outside ORNL now
  - Simulations, design, expertise…
- Continue prototype evaluations in our lab
  - Using DPTS CML driver as reference
- Investigating low-cost interconnect technologies for ASIC-to-Flex bonding
- Significant investments by ORNL into microelectronics equipment

Backup

Budget Request FY'24

Inst.	Resource	FTE (%)	Budget (k$)
	Barrel Low-Mass Service Hybrid R&D		
ORNL	Electrical Engineering + Technician	10	10
ORNL	Staff Scientist	10	0 (in-kind)
ORNL	Materials and Supplies	-	10
ORNL	Production and Bonding	-	10
ORNL	Low cost interconnect	-	15
Total			**45**

Table 15: eRD109 Budget request for the continuation of the ORNL flexible Kapton PCB R&D in FY24, starting from December 1st 2023. All entries in thousands of dollars.

Budget Request FY'23

Inst.	Personnel		Budget (k$)
	Readout and Timing Distribution R&D		
BNL	Electrical Engineer		38
BNL	Staff Scientist	2x0.2 FTE	0 (in-kind)
BNL	Xilinx Dev. Kit		4
BNL	Timing Chips + Boards		15
BNL	Travel Support		5
	Barrel Service Hybrid R&D		
ORNL	Electrical Engineer		32
ORNL	Staff Scientist	0.1 FTE	0 (in-kind)
ORNL	Materials and Supplies		8
ORNL	Xilinx Dev. Kit		4
	Endcap Service Hybrid R&D		
Rice	Electrical Engineer	0.15 FTE	18
Rice	Faculty	0.1 FTE	0 (in-kind)
Total			**116**

Table 22: Budget request for the TOF system readout electronics R&D in FY23. All entries in thousands of dollars.

Test Structure and Measurements

- Design test prototype: As long as possible
  - Differential link loops at various lengths, geometries (?)
  - LV/HV conductors
- RF testing:
  - Confirm simulations: bandwidths, insertion losses, crosstalk
  - Test link speed/BER with FPGA/established line driver, edge jitter
  - Eventually integration into timing distribution test bench at ORNL
- DC testing:
  - Acceptable voltages, currents, resistances
- Mechanical:
  - Thermal cycling
  - Handling, bending, folding

Simulation and Design

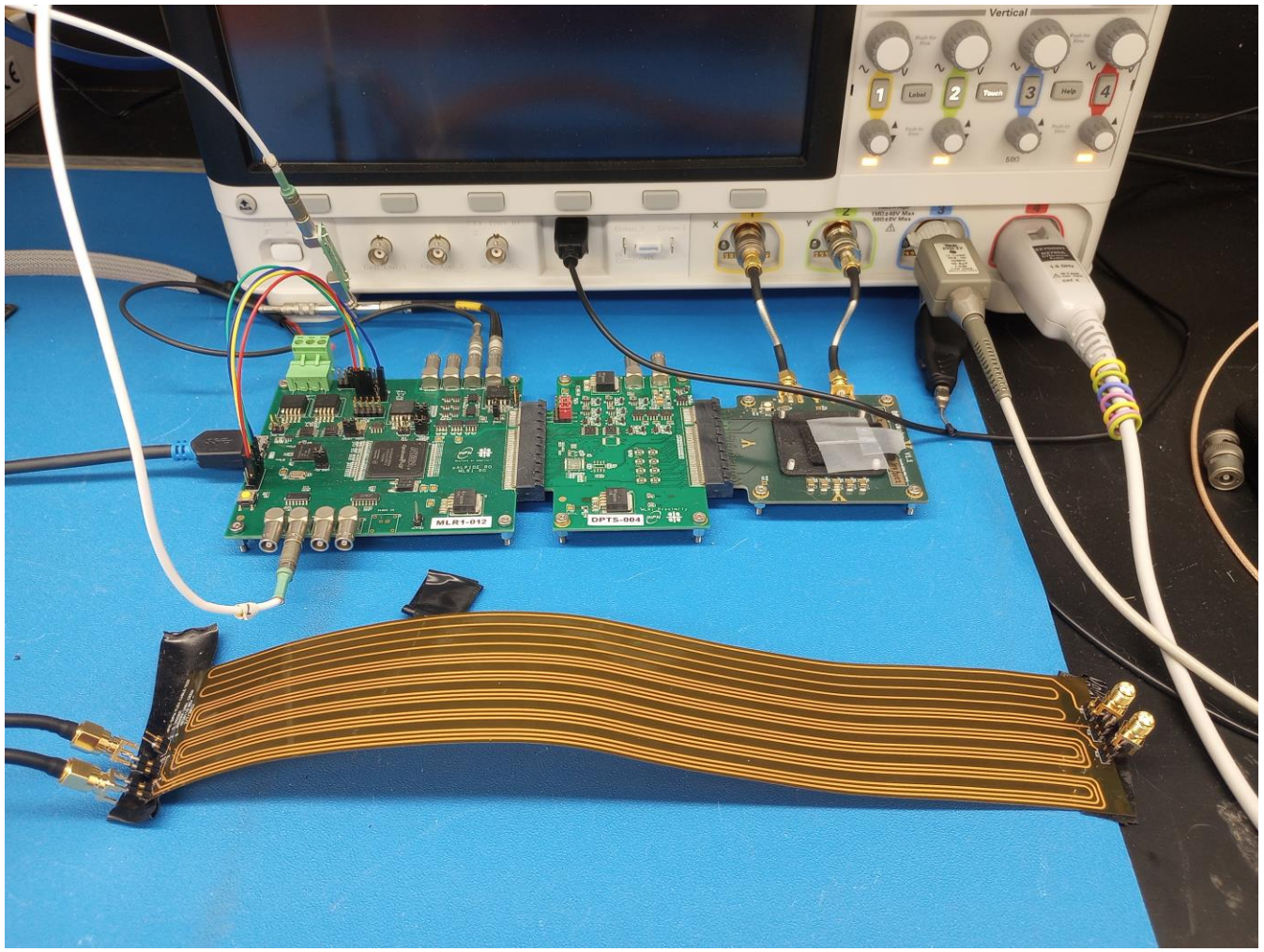
- LV/HV
  - Required material budget for current requirements
  - How much DC-DC converters for given ASIC?
  - Serial powering?
  - Design requirements for HV conductors
- Differential links:
  - Insertion losses, analog bandwidth for different lengths
  - **Crosstalk on clock line(s)!**
  - Ultimately informs output drive strength
- Common flex foil, or separate for LV/HV/RF?
- Supported by ORNL electrical engineering

Technological Survey

- Kapton-Cu flex foils are available from various vendors
  - Cheap (~$100/3pcs), quick (3-4 weeks)
  - Can produce many prototypes for a more experimental approach
- Low mass Kapton-Al is more specialized and expensive
  - Not worth it for prototypes at this point
- Max size: 1m?
  - Depends on vendor, but can fit very long traces on moderately sized foils in any case…

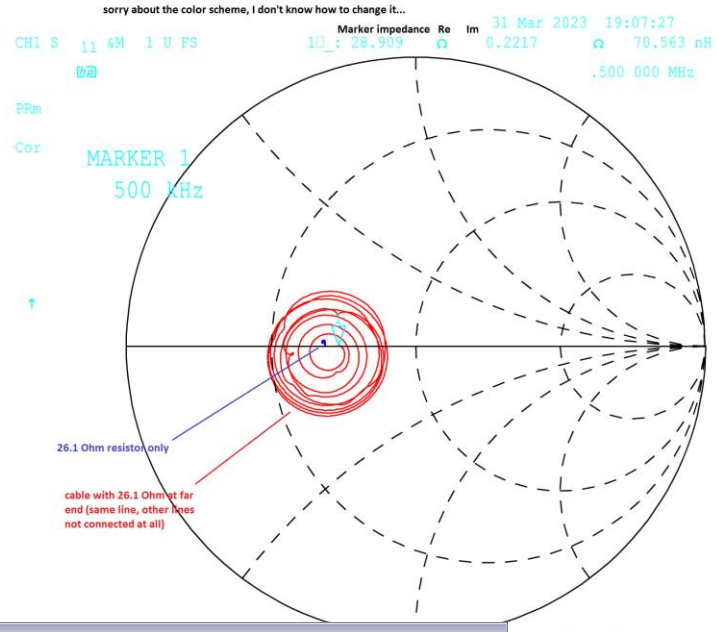
The “Experimentalist Approach”

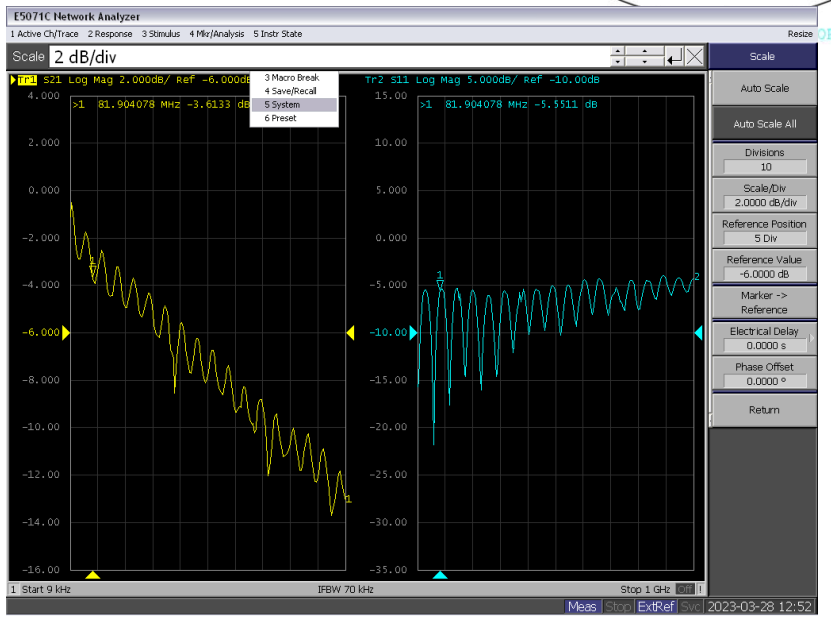
- Still identifying the right ORNL engineering resources…
- Producing cheap Cu-flex prototypes instead
  - 2x 1.5m differential pairs on 40cm flex
- Using DPTS (ITS3 test structure) CML driver as test bench driver
  - 65nm CMOS line driver
- First attempt does not yield useful data on the scope
  - Not sure if due to transmission line or connectors



Vector Network Analyzer Measurements

- Measurements by G. Visser (Indiana) and ORNL
- Our first attempt at transmission line is not 50Ohm…
  - "Easy" fix for next attempt…





Available Equipment

- 4ch Vector Network Analyzer – available
  - Insertion loss
  - Inter-line crosstalk
  - Need proper 50R transmission line to make sense of measurements
- Time domain reflectometer – still looking
  - Characterize impedance mismatches along length of transmission line

DC Resistance Measurements

- 0.595Ohm along strip
  - 1.49 m length, 1mm pitch, 35um thickness
  - 2.35E-8 Ohm*m (c.f. 1.8E-8 Ohm*m for Cu)
- Inter-strip resistance
  - Could not get reliable measurement so far (capacitive effects dominate)
  - Tested up to 500V without notable leakage