FD2 PDS State of PoF, SoF, and CE for ProtoDUNE2-VD

23 September 2022 DUNE PDS Consortium Ryan Rivera - FD2 PDS L2

Introduction

- Goal is to provide an overall picture of...
 - Power-over-Fiber (PoF)
 - Signal-over-Fiber (SoF)
 - Cold Electronics (CE)
- ...with regard to Module-0 at ProtoDUNE2-VD including the following:
 - Design status
 - R&D towards Module-0
 - \circ Schedule

- Production
- Installation

FD2 PDS Weekly Schedule

Month	Sep '22				Oct '22				Nov '22			nar 122	74			Jan '23				Feb '23			Mar '23				Apr '23			May '23			CC1 an1	27 UNC		Jul '23					Aug '23			Sep '23			Oct '23	
Week#	37	38	39	40	41	43	4	45	46	47	48	49 50	51	52	53	-	3 10	4	5	9 1	7 8	5 6	10	#	2 6	13	15	16	17	18	20	21		24	25 26	27	28	29	30		33	34	35	36	38	39	40	41
Date	05-Sep	12-Sep	19-Sep	26-Sep	03-Oct 10-Oct	17-Oct	24-Oct	31-Oct	07-Nov	14-Nov	VON-12	28-Nov	12-Dec	19-Dec	26-Dec	02-Jan	09-Jan 16-Jan	23-Jan	30-Jan	06-Feb	13-Feb 20-Feb	27-Feb	06-Mar	13-Mar	20-Mar	IRINI-17	03-Apr 10-Apr	17-Apr	24-Apr	01-May	15-May	22-May 29-May	OF hun	12-Jun	19-Jun 26-Jun	03-Jul	10-Jul	17-Jul	24-Jul 31-Iul	IDP-10	07-Aug 14-Aug	21-Aug	28-Aug	04-Sep 11-Sen	18-Sep	25-Sep	02-Oct	09-Oct
Cold Box		Cold Box B++ Run	Cold Box CRP3 Install	(v4)	Cold Box CBP3 Run		Cold Box CKP2b Install (v5)	Cold Box CRP2h Run		Cold Box CRP4 Install	(v6)		Cold Box CRP4 Run																					Cold Box D Install (v7) "Module-1"		Cold Box D Run	"Module-1"											
Module-0						Module-0 Orders				Module-0 Production	Module-0 Flange &	Feedthrough Install	4x Module-0 non-TCO	Membrane Install (v6)				8x Module-0	Cathode Install		and the second se	4x Module-0 TCO-side Membrane Install			Module-0 Install milectone	Module-U Install milestone																	Module-0 Ops					
Reviews and Deliveries				FBK 250 SiPM Deliverey	Spain Hamamatsu 702 SiPM Deliverey	INFN Hamamatsu 1700 SiPM Deliverev						Final Design Review					FBK 750 SiPM Deliverey							CD2/3 Director's Review	Internal PD	Design Workshop				CD2/3 DOE	Review																1	Production Readmess Reviews Start

We are here

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PoF Design State

- Si (971 nm) and GaAs (808 nm) PoF systems have been demonstrated at the Cold Box
 - PoF system components: Transmitter, Fiber, and Receiver
 - Receiver a.k.a. LPC (Laser Power Converter) and PPC (Photovoltaic Power Converter)
 - Favor GaAs for Low Voltage and Si for SiPM Bias Voltage:

Power	Type	# of PPC	Current	Voltage	Power	Efficiency
Capability*			mA	V**	W	%
1W	GaAs warm	1	80	5.5	0.45	65
1W	GaAs cold	1	30	6.5	0.20	50
	Si warm	1	80	5.5	0.45	50
3W	Si cold	1	15	11.5	0.18	22

- * The power delivered is not all converted to usable power; e.g. for Si cold, the efficiency is about 22% in LAr. ** Each PPC module voltage can vary about 3%.
- 30-year qualification?
 - Literature: Most satellites use GaAs or some version of GaAs, in both near and far orbit, due to their long lifetime. A typical system operates for 15 + years. Lifetime and performance measurements of GaAs photovoltaic match theoretical data predictions. A typical thin cell unit will decrease efficiency by 8% under moderate radiation levels (1 MeV electron exposure tests).
 - The units being deployed for DUNE VD have nearly 40% overhead to compensate for a decrease in power production or photon conversion. We do not expect the radiation damage modeled in space-based systems and therefore expect very little degradation.
 - GaAs is not new and has been heavily studied since the 1990s for PV use. Their popularity has
 increased as manufacturing costs have come down. Presently, they are rated nearly the same as Si for
 power versus weight and therefore are now the default choice for space applications.



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PoF Transmitter State

- Commercial transmitters
- Custom packaging into rackmount unit is design from FNAL and SDSMT
 - Prototypes demonstrated at Cold Box
- Safety surrounding Class-4 lasers is paramount!
 - Wikipedia: "Class 4 is the highest and most dangerous class of laser... By definition, a class 4 laser can burn the skin, or cause devastating and permanent eye damage as a result of direct, diffuse or indirect beam viewing. These lasers may ignite combustible materials, and thus may represent a fire risk... Class 4 lasers must be equipped with a key switch and a safety interlock..."



PoF Transmitter R&D towards Module-0

- Transmitter regulation using a feedback loop
 - Could prove critical to walk-up supply voltage over 30-years to compensate for any degradation in the detector or cold-electronics.
 - e.g. to increase the SiPM bias or SoF laser drive bias
 - This could remove the need for cold LDOs and their risk of failure
- Packaging of 8 lasers in 3U rackmount box



PoF Transmitter Schedule (Production/Installation)

- January '23 Cathode Warm Testing
 - Minimum 1 Tx XA unit needed for Warm Testing during installation
 - Already in-hand at Cold Box
- July '23 ProtoDUNE2-VD Operations
 - Full optimized 8 Tx XA units needed for Ops
 - Joint SDSMT/FNAL effort in the spring
- Critical Path Severity: Low

				Module-0	Date	Week #	Month
	05-Jun	23	Jun '23		07-Nov	46	Nov '22
	12-Jun	24			14-Nov	47	
	19-Jun	25		Module-0 Production	21-Nov	48	
	26-Jun	26					
	03-Jul	27	Jul '23		10N-07	5 4	
	10-Jul	28			05-Dec	50	Dec '22
	17-Jul	29		4x Module-0 non-TCO	12-Dec	51	
	24-Jul	30		Membrane Install (v6)	19-Dec	52	
	31-Jul	31			26-Dec	53	
	07-Aug	32	Aug '23		02-Jan	-	Jan '23
	14-Aug	33			09-Jan	2	
	21-Aug	34			16-Jan	ę	
Module-0 Ops	28-Aug	35			ac 60	-	
	04-Sep	36	Sep '23	8x Module-0	20-04II	t	
	11-Sen	37			30-Jan	5	

PoF Fiber State

- 2 fiber types ordered: MH GoPower (62.5um) and Polymicro/Molex (105um)
 - Both are black, 1.5mm OD, 40m length FC-FC
 - We have received partial delivery from MH GoPower, none received from Polymicro
 - Expect full delivery by end-of-October (20-week lead times!)



FIA105125250 BLACK

Estimated Shipping Cost - FedEx Ground

Fused Silica Optical Fiber

<u>Low-OH Core</u>: 105 ± 2µm <u>Doped Silica Clad</u>: 125 +1/-3µm <u>Black Acrylate Buffer</u>: 250 ± 15µm <u>NA</u>: 0.22 ± 0.02

Cable Structure



2. Fiber Characteristic

Fiber type	ltem	Description
	Numerical Aperture (NA)	0.27
	Index Profile	GI
	Core Diameter	62.5 ± 3 μm
MM	Cladding Diameter	200 ± 4 μm
	Coating Diameter	23 0 ± 10 μm
	Diameter of Buffer	500 ± 50 μm
	Fiber Attenuation	< 3.5 dB/km (@980nm)

PoF Routing State

- PTFE ³/₈" ID ¹/₂" OD black tubing ordered
 - Enforces min bending of 10cm
 - Procedure is slit and install 8 fibers







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Fiber Routing State

- 8 fibers per XA (2 PoF + 2 SoF + 4 spare)
- 8 fibers per ³/₄" feedthrough
- 8 fibers per PTFE tube

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• Fiber spliced on floor <u>or</u> pulled all the way to feedthrough







Fiber Routing State cont.

Slot 12,7 mm height (x40 mm) to « store » the 8 fibers => the ½ inch OD tube fits a bit tight

Opening 24x54 to insert the

8 connectors

Opening 24x54 to insert the 8 connectors (8 ones by 8 ones !!

Slot 12,7 mm height (x40 mm) to « store » 24 fibers to let space for the 4th bundle

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Fiber R&D towards Module-0

- Resolution needed on <u>SoF fiber</u> selection (MMF is what is ordered!)
- Resolution needed for <u>light leakage</u> at bends and connectors of PoF and SoF.
- Automated jig for <u>slicing tubing</u> needed.
- Gain confidence in <u>relative CTE</u> of all materials and connectors.
- <u>Splicing</u> R&D at SDSMT.
- <u>Feedthrough</u> R&D to avoid in-situ termination.
- Fiber and tube <u>labeling scheme</u> needed.
 - E.g. Binary code using 3x wide/thin tie wraps. 8x colored fiber tip covers.









Fiber Schedule (Production/Installation)

- 10x 100' Tubing order to be placed 29-Sept + 4 weeks⇒ 28-Oct
- 10-Oct: Finalize Flange Design
- 07-Nov: Complete Flange Fabrication
- 28-Nov: Flange & Feedthrough Installation
- 05-Dec: **Dress** fibers/tubing on membrane
- 30-Jan: <u>Splice</u> fibers
- Need to plan personnel travel!
- Critical Path Severity: Medium

<u>Module-0</u>	<u>Date</u>	Week #	Month
	07-Nov	46	Nov '22
Module-0 Production	14-Nov	47	
	21-Nov	48	
Module-0 Flange & Feedthrough Install	28-Nov	49	
	05-Dec	50	Dec '22
4x Module-0 non-TCO	12-Dec	51	
Membrane Install (v6)	19-Dec	52	
	26-Dec	53	
	02-Jan	-	Jan '23
	09-Jan	2	
	16-Jan	e	
8x Module-0	23-Jan	4	
Cathode Install	30-Jan	5	
	06-Feb	9	Feb '23
	13-Feb	7	
4x Module-0 TCO-side	20-Feb	80	
Membrane Install	27-Feb	6	



PoF Receiver State

- 20 GaAs (200mW/LPC) LPCs in-hand.
- Opportunity for InGaAs (UIUC) or large area GaAs LPC (Broadcom) for higher power (~400mW/LPC).
- Parallel redundant scheme final.





PoF Receiver R&D towards Module-0

- 3 potential receiver optimizations on the horizon (but may be too late):
 - UIUC packaging of InGaAs lower-series-resistance LPC solution
 - Broadcom wide area LPC for increased efficiency and power delivery
 - Broadcom InGaAs LPCs
- Light leakage mitigation is critical
 - E.g. Copper-clad G10 box
 - E.g. Silicon/potting







PoF Receiver Schedule (Production/Installation)

- If cathode CE power remains <200mW, we have sufficient GaAs LPCs in-hand
- If power requirements increase, PoF receiver lead-times becomes critical path!
 - Broadcom hopes to deliver high power (400mW) units in December
- 21-Nov: install and test on CE motherboards
 - 8 motherboard kits

- 23-Jan: install CE kits w/XA on cathode
- Critical Path Severity: Low

Date Week# Mont	07-Nov 46 Nov 1 14-Nov 47	21-Nov 48	28-Nov 49	05-Dec 50 Dec '	12-Dec 51	19-Dec 52	26-Dec 53	02-Jan 1 Jan	09-Jan 2	16-Jan 3	23-Jan 4	30-Jan 5	06-Feb 6 Feb '	13-Feb 7	20-Feb 8	27-Feb 9
<u>Module-0</u>	Module-0 Production		Module-0 Flange & Feedthrough Install		4x Module-0 non-TCO	Membrane Install (v6)					8x Module-0	Cathode Install			4x Module-0 TCO-side	Membrane Install

SoF Design State

- 3 signal conditioning flavors: 'ARGON2x2' 'Simp3x' and 'digital'
- Critical issue is lasers flooding





SoF Laser Flooding R&D

- Signal-over-Fiber fiber coupling
 - Compensate for LAr refractive index
- Attempts which have flooded:
 - FNAL potting
 - APC potting
 - IOC vendor 'hermetic seal'
 - Lasermate vendor 'hermetic seal'
- Attempts that remain:
 - Allow flooding and overdrive (20mA > 3mA)
 - Lasermate seal + potting
 - Lasermate defocus fiber stub
 - Broadcom defocus fiber stub

Repercussions!

- Power requirement impact on PoF (+85mW)
- Constrains fiber coupling options and ability to mitigate modal noise



General SoF R&D

- LDO selection (vs regulated PoF) needed
- Full BOM Component selection (including vendor) needed
 - Trust issues with manual component installation and change tracking
- Digital SoF implemented anywhere?
 - Due to power needs of 500mW, and risk of HV discharge distributing signals across XAs, may only make sense at the membrane (where HD has already shown >6 S/N)
 - Worth it for redundancy? Built in noise isolation?
 - DAPHNE only supports 250mW per cable! (not enough power for digital readout!)

SoF Schedule (Production/Installation)

- 8-week lead times on lasers implies last order is 29-Sep.
 - Working on Lasermate defocus order
- 20-week lead times on fibers implies must use PoF black MMF.
- 6-week turnaround for Laser Adapter daughtercard design to turnkey delivery implies last design change is 10-Oct.
- Critical Path Severity: High

Date Week# Mo	19-Sep 39	nstall 26-Sep 40	03-Oct 41 Oct	Run 10-Oct 42	Install 17-Oct 43	24-Oct 44	31-Oct 45	07-Nov 46 Nov	14-Nov 47	Install 21-Nov 48	28-Nov 49	05-Dec 50 Dec	12-Dec 51	19-Dec 52	26-Dec 53	02-Jan 1 Jan	09-Jan 2	16-Jan 3	23-Jan 4	30-Jan 5	06-Feb 6 Feb	13-Feb 7	20-Feb 8	27-Feb 9
Cold Box		Cold Box CRP3 (v4)		Cold Box CRP3	Cold Box CRP2b	(v5)				Cold Box CRP4 (v6)		7000 mea FI-0												
<u>Module-0</u>					Module-0 Orders				Module-0 Production		Module-0 Flange & Feedthrough Install		4x Module-0 non-TCO	Membrane Install (v6)					8x Module-0	Cathode Install			4x Module-0 TCO-side	Membrane Install

Cold Electronics (CE) State

- SiPM Flex circuits are in production
- 3 flavors of cathode motherboards
 - 'ARGON2x2', 'Simp3x', and 'HD+Simp3x'
- 2 flavors of membrane motherboards
 - 'w/SiPM bias gen' and 'w/out bias gen'
- 4 flavors of DC-DC SiPM bias gen

 PICO, LBL-DCDC, LBL-Opto, and INFN









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CE R&D towards Module-0

- Downselect motherboard
 - Cathode: Based on SoF pairing, S/N, and power optimization.
 - Membrane: Based on S/N, power optimization (<250mW), and adjustability.
- Downselect SiPM bias gen
 - Based on S/N, cost, adjustability, and 30-year qualification.
- Downselect LDO
 - Based on voltage stability, 30-year qualification, and PoF warm-side regulation.
- Need selection of BOM components (including vendor) for turnkey order
 - Avoid manual population variation and change tracking.



CE Schedule (Production/Installation)

- 60 FBK + 140 HPK <u>SiPM Flex boards</u> ordered by UCSB
 - Flex expected 14-Oct, then ship to INFN
 - INFN/Spain expect 2652 SiPMs by 24-Oct
 - Enough for 16 X-ARAPUCA
 - 250 FBK + 2402 HPK (+750 FBK Jan 23')
 - INFN is planning **<u>SiPM population</u>** order
 - Keep SiPMs for 8x Membrane XA
 - For CERN/Ciemat/INFN XA assembly?
 - Ship NIU SiPMs for 8x Cathode XA
 - Fallback plan is use SiPMs from 4x Cold Box XA for non-TCO Membrane XA install
- 17-Oct: Readout/DC-DC <u>PCB Designs and</u> <u>BOMs frozen</u>
 - 2-weeks to place order + 4-week lead times on turnkey orders
- Critical Path Severity: High

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0-ainbow	COID BOX	nate	Week #	MONT
		19-Sep	39	
	Cold Box CRP3 Install (v4)	26-Sep	40	
		03-Oct	41	Oct '22
	Cold Box CRP3 Run	10-Oct	42	
Module-0 Orders	Cold Box CRP2b Install	17-Oct	43	
	(v5)	24-Oct	44	
	Cold Boy CBB3h Bun	31-Oct	45	
		07-Nov	46	Nov '22
Module-0 Production		14-Nov	47	
	Cold Box CRP4 Install (v6)	21-Nov	48	
Module-0 Flange & Feedthrough Install		28-Nov	49	
		05-Dec	50	Dec '22
4x Module-0 non-TCO	COID BOX CKP4 KUN	12-Dec	51	
Membrane Install (v6)		19-Dec	52	
		26-Dec	53	
		02-Jan	۲	Jan '23
		09-Jan	2	
		16-Jan	e	
8x Module-0		23-Jan	4	
Cathode Install		30-Jan	5	
		06-Feb	9	Feb '23
		13-Feb	7	
4x Module-0 TCO-side		20-Feb	80	
Membrane Install		27-Feb	6	

Summary

• PoF/SoF (Response & Monitoring) Fiber Routing

- Design decision:
- Biggest challenge:
- Critical Path Severity:
- PoF
 - Design:
 - Biggest challenge:
 - Critical Path Severity:
- SoF
 - Design decision:
 - Biggest challenge:
 - Critical Path Severity:
- CE
 - Membrane Design decision:
 - Cathode Design decision:
 - DC-DC SiPM Bias decision:
 - Biggest challenge:
 - Critical Path Severity:

Fiber route path; dressing/conduit approach; other consortia interfaces Order lead-times

Medium

GaAs system Splicing; adapting to <u>laser flooding</u> Low

laser and fiber pairing <u>Laser flooding</u>; order lead-times High

Bias gen vs DAPHNE gen

ARGON2x2 vs Simp3x; LDO-a vs LDO-b vs regulated-PoF

PICO vs LBL-a vs LBL-b vs INFN

Adapting to laser flooding

High

Organizing FD2 PDS Travel

- For Cold Box, PD team entered unconfirmed/confirmed travel to help everyone plan, should we extend use for Module-0?
 - <u>https://docs.google.com/spreadsheets/d/1qT_wY5rvEtjS2t741bd8TGejxSAtKZIWIWu3m8Goz</u>
 <u>zA/edit?usp=sharing</u>
- Daily 'FD2 PDS Calendar' schedule maintained here:
 - <u>https://calendar.google.com/calendar/u/0?cid=bjVmaGNqZ2NhMzM1MmFrbmJtYjNIODRkMmt</u> <u>AZ3JvdXAuY2FsZW5kYXIuZ29vZ2xILmNvbQ</u>