Update on Advanced Modulation for a Low Cost 100G Single Mode Fiber PMD

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Overview

- Recap on Objectives
- Recap on leading solutions under consideration
- Advanced Modulation
  - Background and Drivers
  - Summary of contributions to date
  - PAM MPI update
  - Cisco PAM16 Test Chip update
- Summary

Objectives - Background

- The primary driver for a new 100G SMF PMD is cost
- nowell_01_1111:

  A "step function reduction" in system cost is needed to justify a new SMF PMD"

- A straw ballot held in Atlanta provided some insight into the Study Group's definition of 'step function reduction':

Strawpoll 3 (Chicago rules)
A: I would be interested in a PMD supporting a 500m reach at 75% the cost of 100GBASE-LR4
B: I would be interested in a PMD supporting a 500m reach at 50% the cost of 100GBASE-LR4
C: I would be interested in a PMD supporting a 500m reach at 25% the cost of 100GBASE-LR4
A:1 B:10 C:40

Approved Objective & 5 Criteria Response

- The following 100G SMF objective was approved by the Study Group[1]:

  "Define a 100 Gb/s PHY for operation up to at least 500 m of SMF"

- Associated with this objective the following 'Distinct Identity' comment was included in the 5 Criteria Response presentation[2]:

  "The amendment will enable new PHY types over SMF which consist of the existing 100GBASELR4 and 100GBASE-ER4 optical PMDs with four electrical interconnect lanes in each direction. The amendment will define a new 100 Gb/s SMF PMD in addition to these if it can be shown that a SMF PMD with a shorter reach than 100GBASE-LR4 has sufficient cost, density, or power difference to justify an additional SMF PMD type."

1. http://www.ieee802.org/3/100GNGOPTX/objectives_01_0512_optx.pdf
2. http://www.ieee802.org/3/100GNGOPTX/dove_02a_0512_optx.pdf

Objectives – The Bottom Line

- With regard to a new 100G SMF PMD the SG has essentially agreed to:
  - Define one, and only one, new 100G SMF PMD
  - Only define a new PMD if it provides a sufficient improvement in Cost, Density and Power over the existing 100GBASE-LR4 PMD
  - An acceptable outcome is “Do Nothing”

Recap on Leading Solutions

1. Do Nothing.

   The default solution. Let 100GE LR4 remain as the sole option and volume/time/technology maturity will cost reduce the solution

2. 4x25G CWDM

   Minor modification to LR4, wider wavelength spacing reduces need for cooler. This option is seen as not really adding a lot of value towards the goal of significant cost reduction, it just splits the LR4 market.

3. PSM4

   Adoption of SMF ribbon. 4x25G. ~500m. Highly leveraging MMF transceiver (array) technology to achieve cost reductions. Some concern over adoption of new cable type in data center.

4. Advanced Modulation.

   Reach 1-2km. Uses standard SMF duplex cabling. Move complexity into electronics to ideally reduce optics down to single laser and receiver (optics being the dominant cost driver). Most analysis has been done on a PAM-N approach so far, but alternative modulation approaches have been raised and proposed.

Advanced Mod – Background and Drivers

- Underlying assumption is that optics, and specifically optical component count and associated packaging, is the dominant cost driver.

  "Reduction of number of components is key to achieve the lowest cost solution for data center application"   (Source: anderson_01_1111)

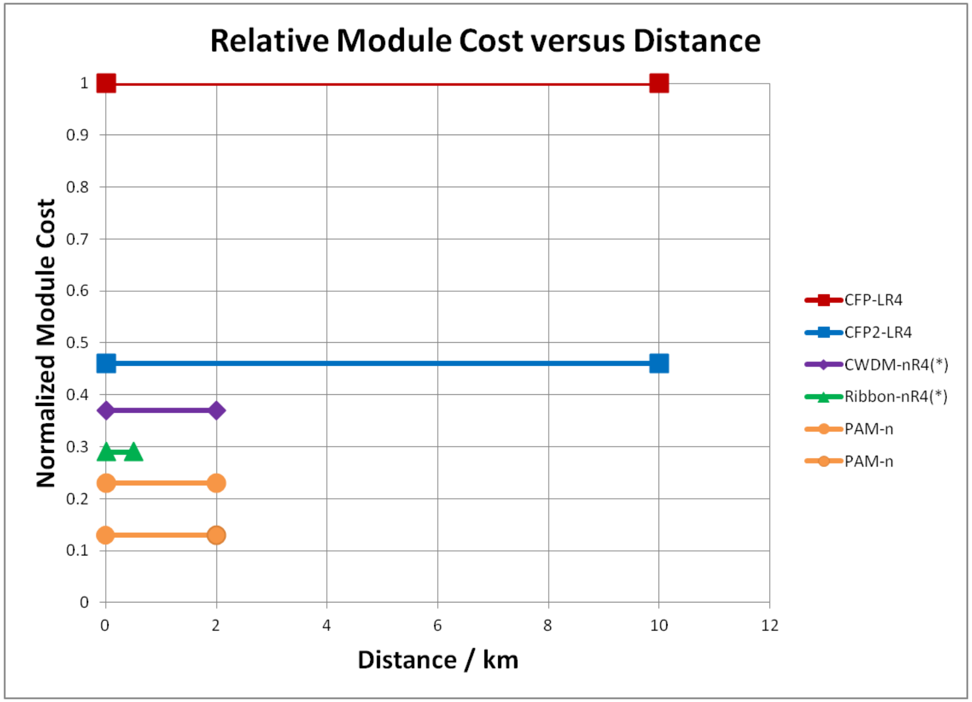
- The goal of advanced modulation is to move complexity into the electronics in a attempt to simplify the optics, resulting in a reduction in optical component count and associated packaging complexity (ideally to a single laser and receiver).

- First proposal on advanced modulation was made in Newport Beach, Jan 12. Initial proposal was based on PAM-N modulation, but since then alternative modulation approaches have been raised and proposed.

  bhoja_01_0112 : "Study of PAM modulation for 100GE over a single laser"

  nicholl_01_0112: "Economic Feasibility for NG 100G SMF Objective"

Advanced Mod – Cost Driver



- Presented in nicholl_01_0112
- Analysis has been reviewed several times since, with essentially the same conclusion
- PAM cost savings primarily driven by reduction in optics component count, and associated optical packaging complexity

Advanced Mod – Contributions to date

Newport Beach, January 2012 (4):

bhoja_01_0112 : "Study of PAM modulation for 100GE over a single laser"
nicholl_01_0112: "Economic Feasibility for NG 100G SMF Objective"
szczepanek_01_0112: "Feasibility of Transimpedance Amplifiers and CDRs for PAM Modulation"
cole_03_0112: "PAM-N Eye Diagrams"

Big Island, Hawaii, March 2012 (10)

cole_01b_0312: "100G PAM PMD Observations"
king_02_0312: "PAM-N, coherent interference and return loss specs"
heaton_01a_0312: "Bandwidth Requirements for PAM"
dama_01_0312: "High Speed NRZ and PAM optical modulation using CMOS Photonics"
palkert_05_0312: "PAM Simulation"
ghiasi_03_0312: "Multipath Interference Penalty"
kogure_01_0312: "Analysis of Phase-to-Intensity Noise by multiple reflections in 100G-PAM SMF links"
nicholl_01b_0312: " Update on technical feasibility for PAM modulation"
szczepanek_02_0312: "PAM8 Gearbox issues"
tremblay_01_0312: "PAM-8 and PAM-16 Optical Receivers for 2km 100G Links with a 4dB loss budget"

Minneapolis, May 2012 (8)

bhatt_01_0512: "PAM MPI – Overview & Recommendations "
ingham_01_0512: "Performance Studies of 100 Gigabit Ethernet Enabled by Advanced Modulation Formats"
lewis_01a_0512: "Update on Bandwidth Requirements for PAM"
ghiasi_01_0512: "PAM-8 Optical Simulations"
nicholl_01_0512: "PAM-16 Implementation Update"
kogure_01_0512: "Multiple reflected MPI analysis for 100G-PAM8 Transmission"
shang_01a_0512: "Optical Modulation Format and Direct Detection Schemes for the Single-Carrier PMD"
tremblay_01a_0512: "PAMx specs and penalties"

All SMF PMD Contributions to date

And just for fun …..

Meeting	General Contribution	CWDM	PSM4	Advanced Mod
Chicago Sept/11	4	-	-	-
Atlanta Nov/11	5	-	1	-
Newport Beach Jan/12	2	1	3	4
Big Island, Hawaii Mar/12	4	1	4	10
Minneapolis, MN May/12	-	-	2	8
TOTAL	15	2	10	22

PAM-N MPI - Background

- In a link with multiple connectors, MPI (Multipath Interference) Noise can limit the performance of a link.
- For lower speeds and NRZ, the MPI Noise penalty was modest.
- For higher speeds and PAM, the increased MPI Noise penalty motivated some members to take a second look at MPI link model.
- Work in progress currently includes refining the analysis and link model to take into account the statistical nature of laser phase noise and data pattern.

PAM-N MPI – Key Variables Affecting Penalty

- Key variables that affect performance and choice of link configuration are:
  - Laser linewidth / phase noise
  - Number of connectors
  - Return loss (of connectors and of MDI interface)
  - Number of PAM levels

PAM-N MPI – Key Variables Affecting Penalty

- MPI analysis was viewed and approached from three perspectives. (For details, please refer to bhatt_01_0512_optx.pdf, May 2012)
  1. Frequency-domain analysis, modeling MPI as Link RIN.
  2. Time-domain mixing, looking at MPI statistics.
  3. Upper-bound approach, looking only at bounds of MPI process.
- These approaches yielded a spectrum of results.

MPI Penalty in dB, as a function of connector return loss:

Frequency Domain Method

R (dB)	PAM-8	PAM-16
-30	< 0.3	
-35	< 0.2	

Matched polarization, all phases at worst case, for 10^-5 error rate.

Time Domain Method

R (dB)	PAM-8	PAM-16
-30	1.0	2.7
-35	0.3	0.7

Matched polarization, random data amplitudes, for 10^-5 error rate.

Upper Bound Method

R (dB)	PAM-8	PAM-16
-30	3.57	High
-35	0.85	2.07

Matched polarization, pathological data pattern of m^(-cN) probability, for zero errors.

PAM-N MPI – Next Steps

- The analysis done so far points to a return loss value in the range of 30 dB for PAM-8, and 35 dB for PAM-16.
- For PMD reflectance, this value is achievable cost-effectively.
- For connector return loss, this value is in line with IEC/ISO 11801.
- Next steps: Refine the assumptions, improve the analysis.

Connector to Connector

ORL	AS/NZS 3080 ISO/IEC 11801	TIA 568.C-3
MMF	-20 dB	-20 dB
SMF	-35 dB	-26 dB
SMF + Video	Not Specified	-55 dB

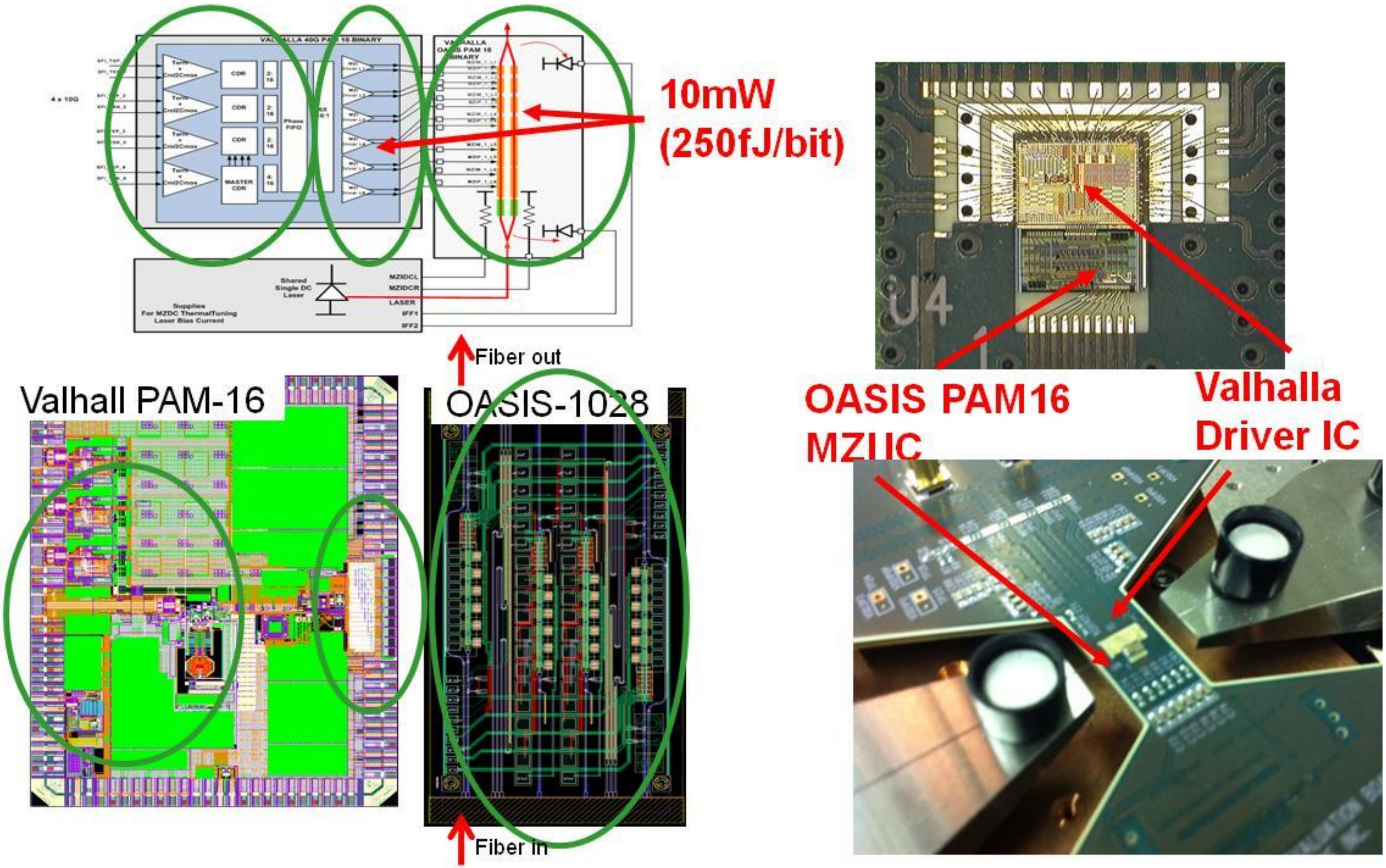
PAM-16 Test Chip Update

- As reported at the last meeting Cisco are in the process of evaluating and testing a PAM-16 test chip in the lab.

  (For more details, please refer to nicholl_01_0512_optx.pdf, May 2012)

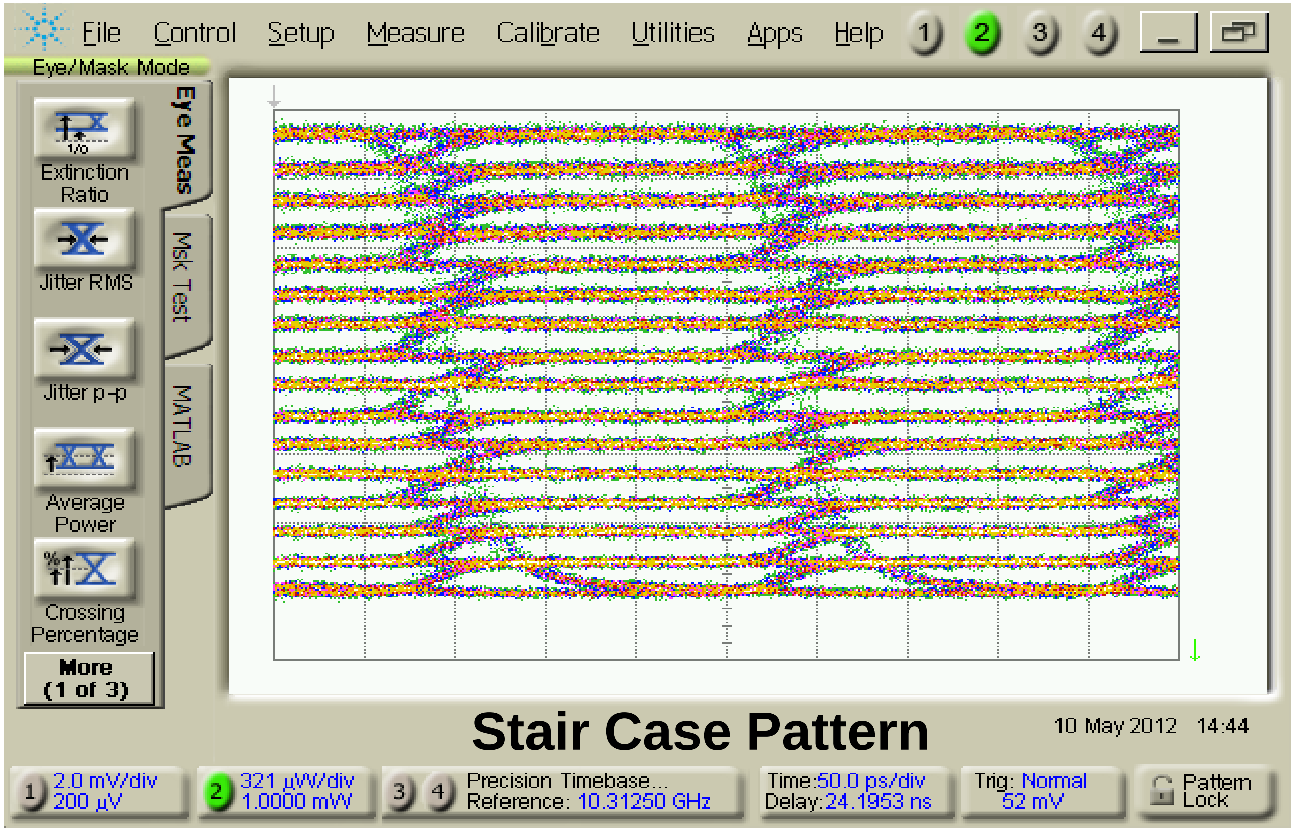
- The test chip was originally developed by Lightwire as part of a DARPA project
- The test chip implements PAM-16 @ 10Gbaud (40Gbps) based on a segmented Silicon Photonics MZI structure
- The following slides provide an update of the ongoing evaluation

PAM-16 Test Setup

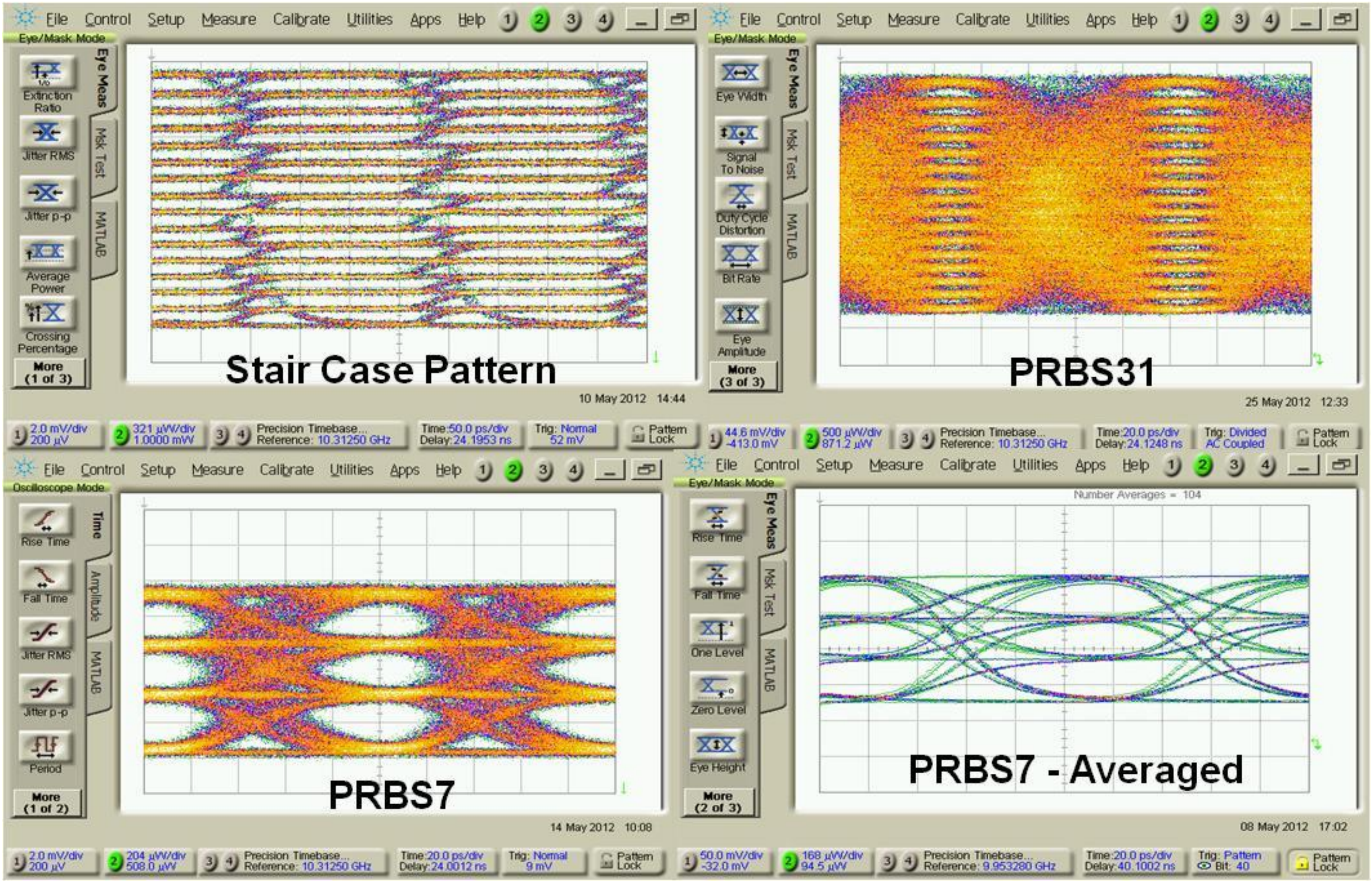


PAM-16 Optical Output

It is alive .. and there are 16 distinct levels !



PAM-16 Optical Outputs



PAM-16 Test Chip Summary

- Demonstrated PAM16 modulation using a segmented MZI, driven by an inverter based digital driver
  - Optical DAC!
- Power consumption for MZI Driver and MZI is 10mW (250 fJ/bit)
- Power consumption for whole transmit datapath including CDR, MZI, CW Laser (complete transmit solution) is 450mW
- PRBS-31 Eye Noisy – Currently under investigation
  - Excessive optical noise at the scope – 112uW each level with 17G optical filter
  - Rise time / fall time larger than design intent due to modeling error - 48-54ps instead of target 30-33ps – need to size inverter correctly
- Next steps
  - Continue evaluation and testing

Summary

- Objective is to develop a new SMF PMD that provides a ‘step function reduction’ in cost over 100GBASE-LR4
- Cost is dominated by optics, and specifically optical component count and associated packaging
- Advanced modulation is a promising approach to reduce optical complexity/cost.
- Interest and activity in this area is growing rapidly (based on both contributions and offline discussions)
- Initial focus was on PAM-N modulation, but since then alternative modulation approaches have been raised and proposed

Advanced Modulation is the (Right) Way Forward !