Practical Demonstration of live-traffic Optical DMT Link using DMT Test Chip

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Summary

- Presenting live optical DMT transmission results showing 100Gb/s on a single wavelength using a 28nm CMOS DMT Test-chip

- This demonstrates the feasibility of using a DMT modulation format for 400GE transmission using 4 wavelengths each carrying 100Gb/s

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DMT Transmission Protocol Details

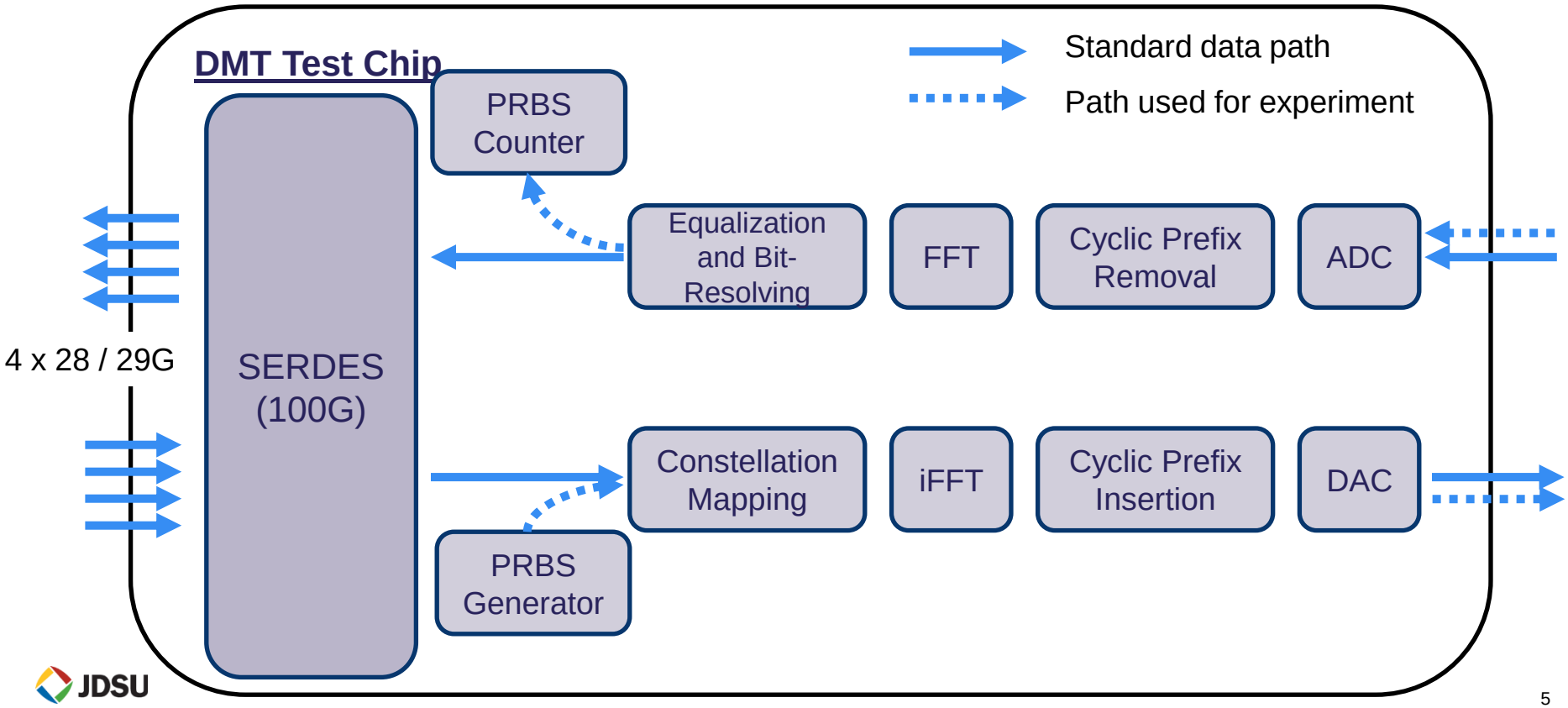
- A DMT test-chip incorporating the following features was used:
  - D/A and A/D sampling rates tied to bit-rate: simplifies DSP clocking architecture
  - SerDes of 4 x 25G lanes at 28 or 29 Gbit/s
  - DMT Engine mapping bits to QAM constellations on 256 subcarriers
  - DMT-Symbol frame-synchronization using 2 dedicated adjacent subcarrier tones
  - Implementation of CP of length 16, 32, 48 or 64 samples

DMT Transmission Protocol Details

Test-Chip Process	CMOS	28nm
Line-Rate	B_R	116 Gbit/s
Sample Rate	$F_S = B_R / 2$	58 GS/s
Expected FEC Rate		12.5%
Intended Payload Rate	$B_R / (1 + 12.5\%)$	~103.1 Gbit/s
Supported QAM Constellation Range	2-QAM (BPSK)	256-QAM (8-bit)
Number of Subcarriers	$N_{FFT}/2$	256
Subcarrier spacing	ΔF	~113.3 MHz
Highest subcarrier	Nyquist – $\Delta F = F_S / 2 - \Delta F$	~29 - 0.1133 = 28.891 GHz
Cyclic Prefix Length	CP	16
#samps / DMT-symbol	N_{FFT} + CP	528
Symbol (Frame) Rate	$F_F = F_S / (N_{FFT} + CP)$	109.8 MHz
# Bits/DMT-Symbol	$b_F = B_R / F_F$	1056

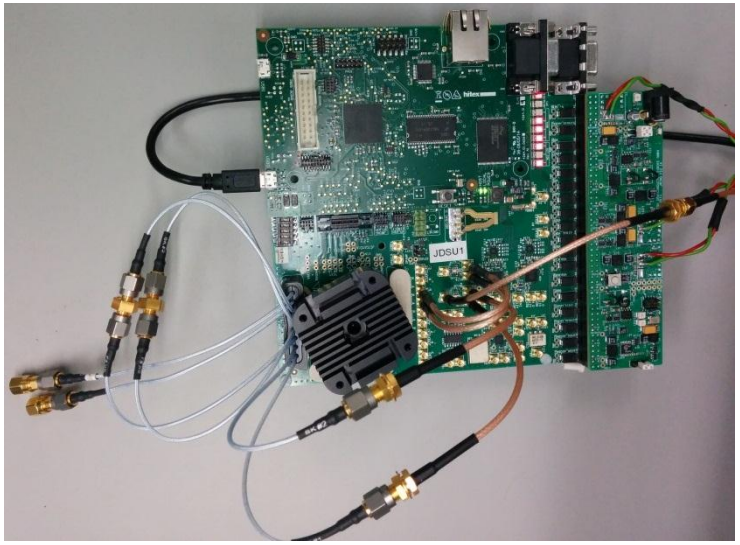
DMT Test Chip Architecture

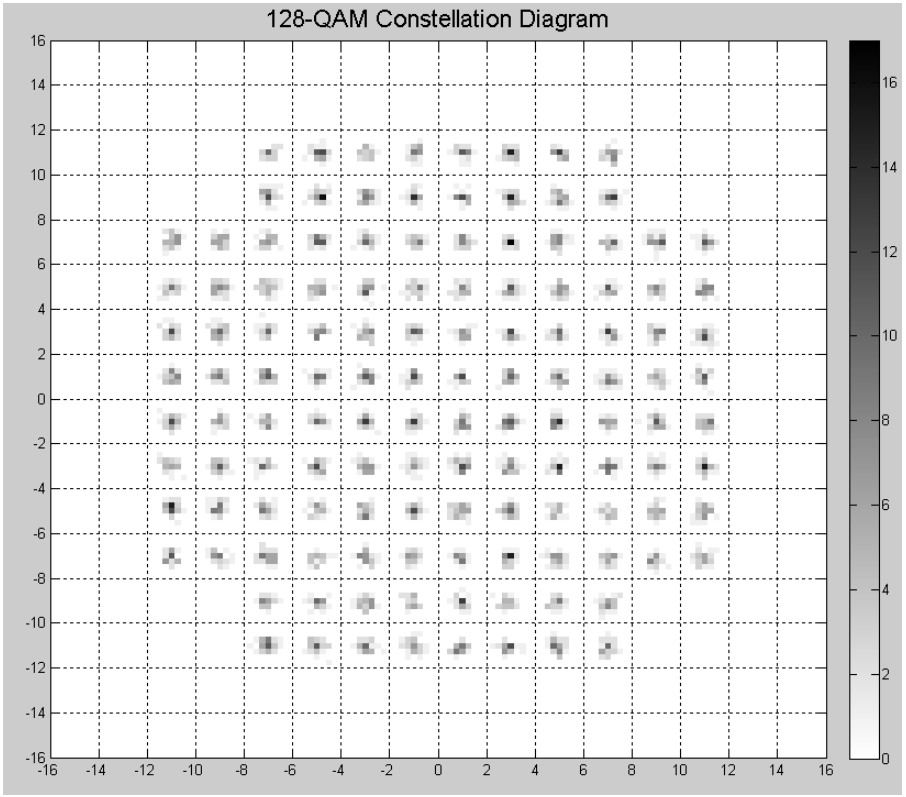
- For these experiments, a single test-chip was configured in loopback operation, using the internal PRBS Generator / Counter.
- Frame-synchronization successfully achieved, using 2 dedicated adjacent subcarriers at 7.36 and 7.47GHz for this purpose.
- Link-negotiation was performed with external software control, for bit and power allocation and subcarrier equalization.
  - This functionality to be moved to on-chip firmware in future.

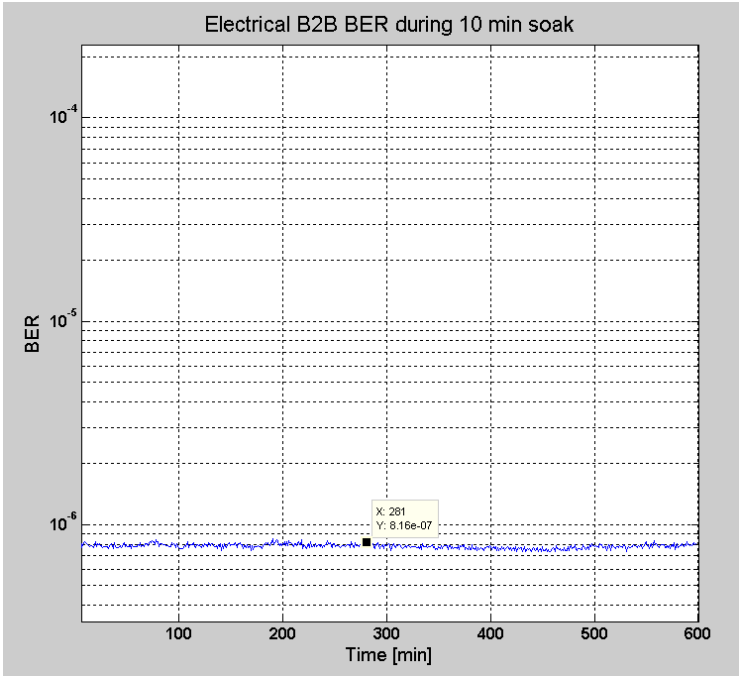


Electrical Back-to-Back Results

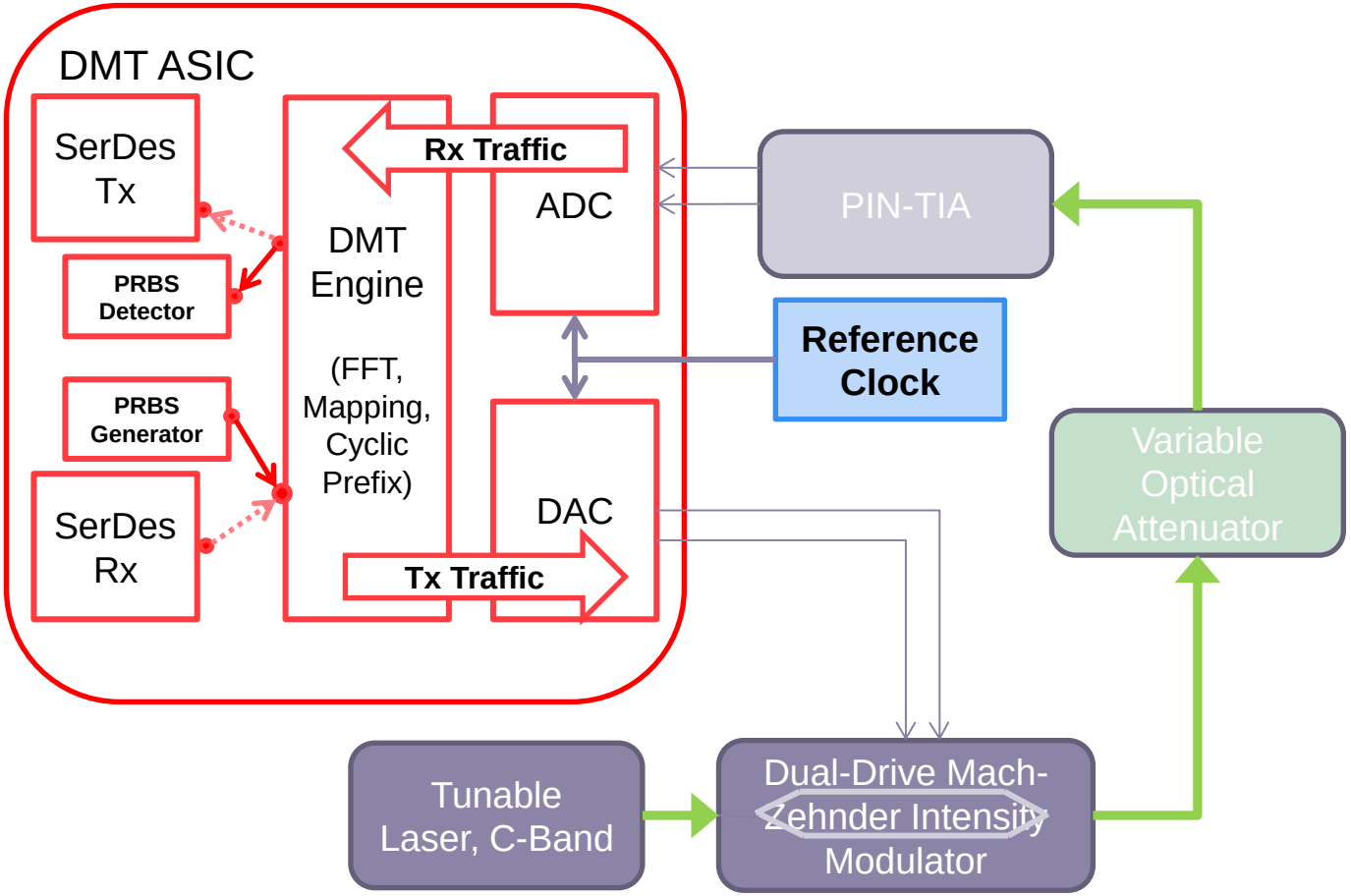
- DMT transmission was tested in an electrical Back-to-Back configuration, DAC-to-ADC.
  - a stable BER of ~8e-7 was demonstrated.
- Constellations ranged from 128-QAM (7 Bit) to BPSK (1 Bit) across subcarriers.
  - Note that the maximum constellation enabled by the chip is 256-QAM (8-bit).







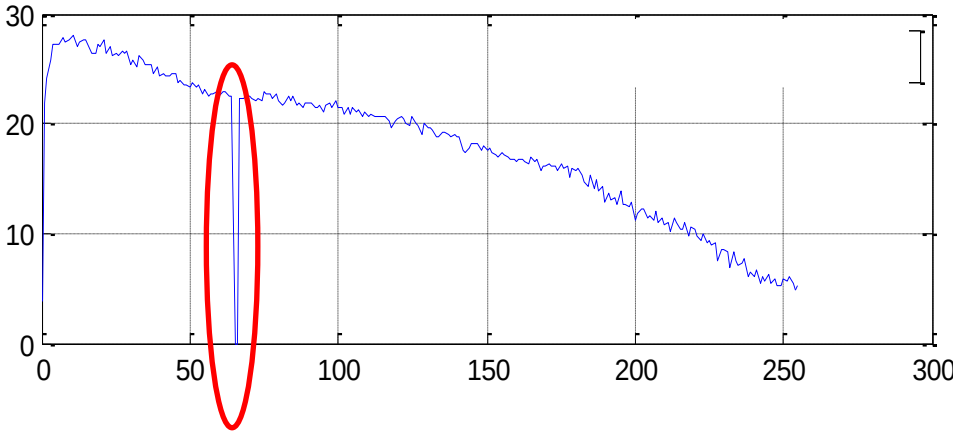
Live DMT Traffic Configuration with Reference Transmitter



Live DMT Traffic Performance with Reference Transmitter

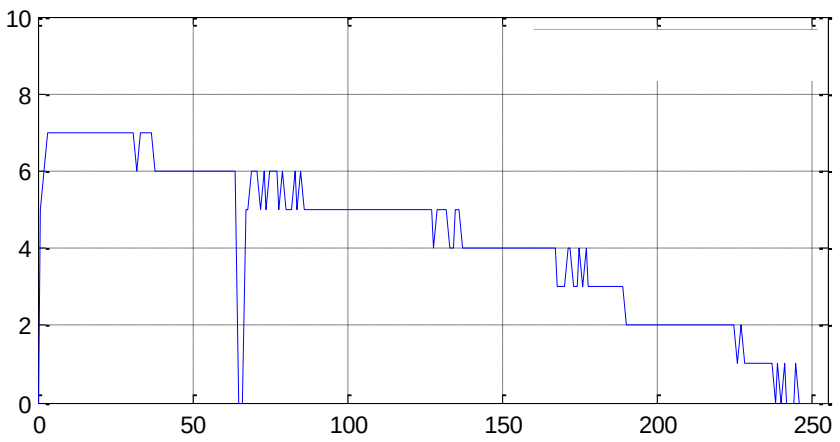
- A bit-error rate of 3e-4 was achieved, below low-latency FEC threshold of 1e-3.
- Bit-error rate was maintained steadily over 12 hours.

SNR by subcarrier

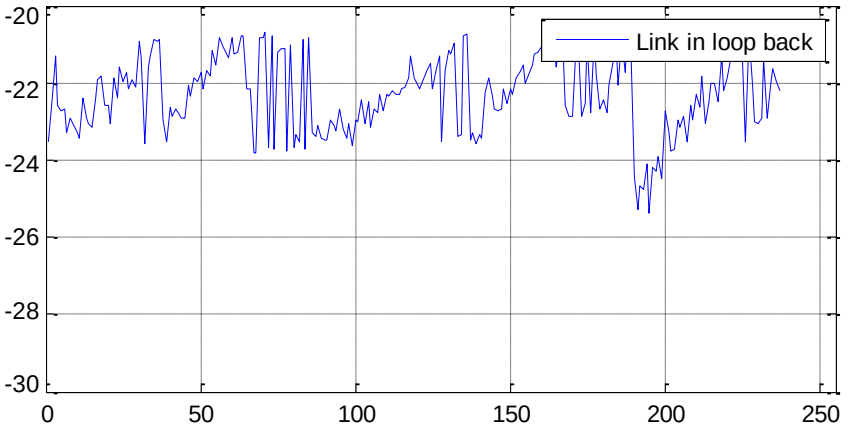


These 2 subcarriers dedicated to frame synchronization

Bit Allocation

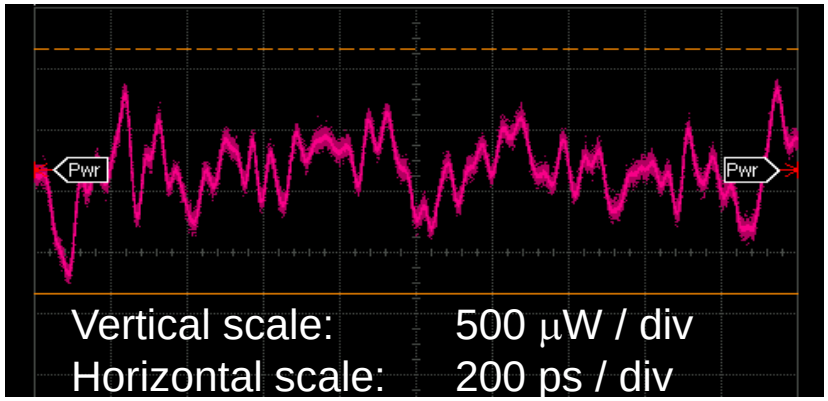


Power Allocation



DMT Traffic Test Details with Target DML

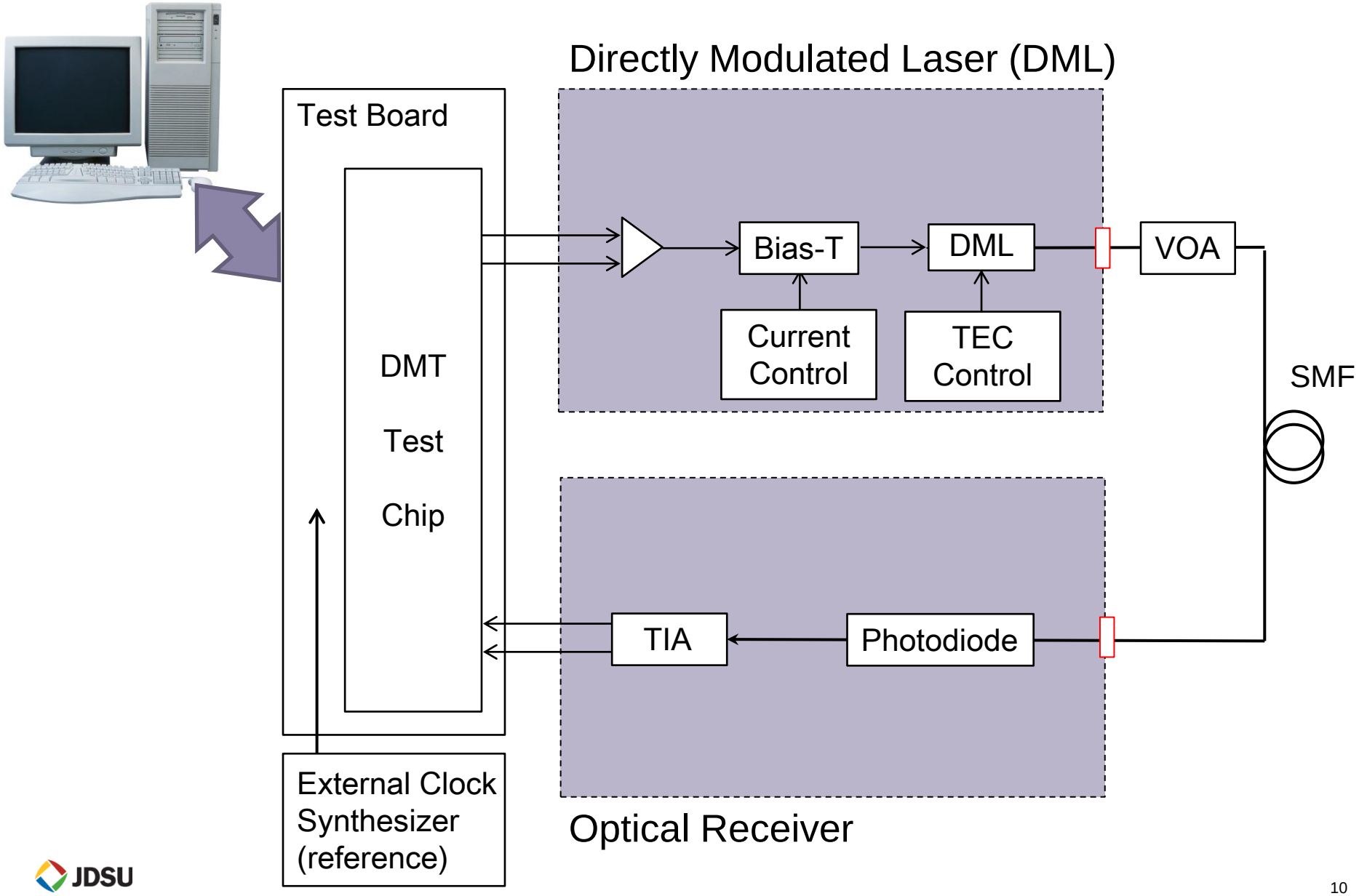
- Uncorrected BER continuously measured by PRBS-counter over a finite duration.
- Cooled DML was used as Tx.
- Driver configured for a Tx output peak-to-peak optical amplitude of 1.32mW (1.2dBm) at an average output-power of 1.26mW (1dBm).
  - Equivalent to peak-to-peak extinction-ratio of ~5dB
- PIN-TIA with fixed gain (550 Ohm) was used as Rx.
- Back-to-Back results were measured with optimum receiver input power of 1dBm.
  - Which uses the full dynamic range of the ADC
- Over-fiber results were measured with 0.4dBm receiver input power
  - Which introduces a penalty due to underfilling the ADC.



Time Domain Capture of DMT signal

Test Parameters	
PRBS length	2^{31} - 1
Average Launch Power	1 dBm
Tx pk-pk Optical Amplitude	1.2 dBm
Extinction Ratio (pk-pk)	~5 dB
Configurations tested	
Fiber Type	**Length**	**Loss**
SMF-28	0 km	0.0 dB
SMF-28	2 km	0.6 dB

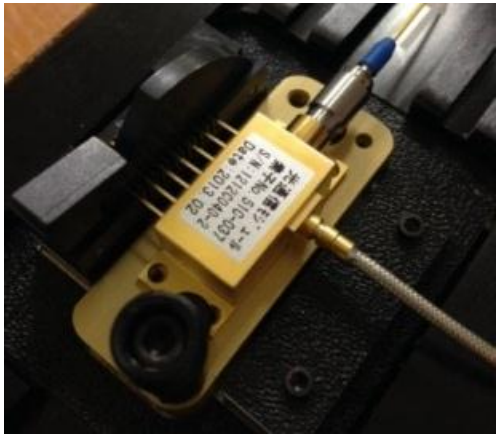
Experimental Setup



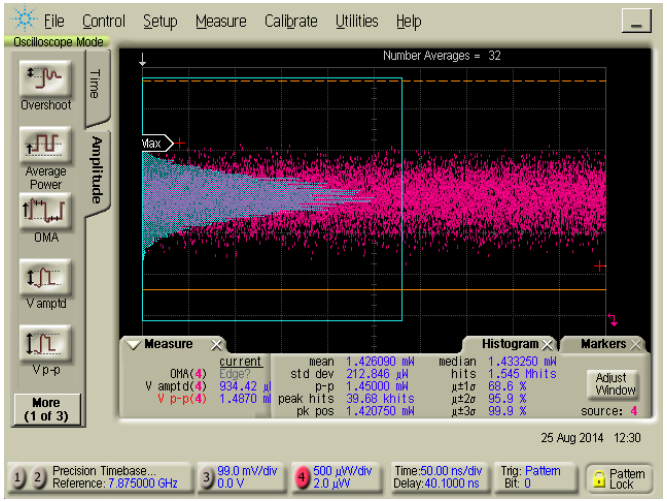
Optical Components: Tx

- Transmitter was an experimental prototype Directly Modulated Laser (DML), courtesy of Fujitsu Labs.
  - Testing occurred at 1295.5nm
- Differential input / output driver. One output terminated

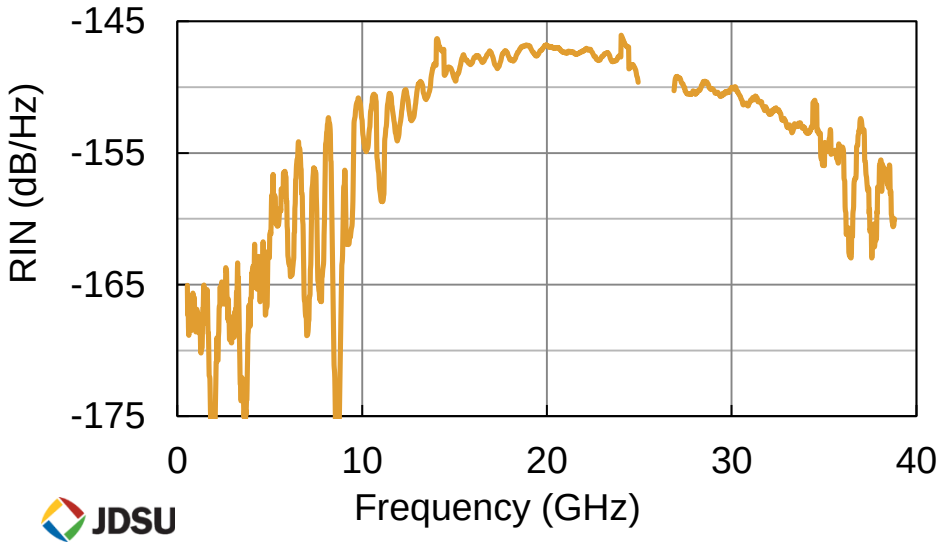
Parameter	Unit	Value
Available Wavelengths	nm	~1295.5 ~1300.0 ~1304.5 ~1309.0
3-dB bandwidth	GHz	28
Output power	mW	10



DMT transmit signal



Measured RIN spectrum

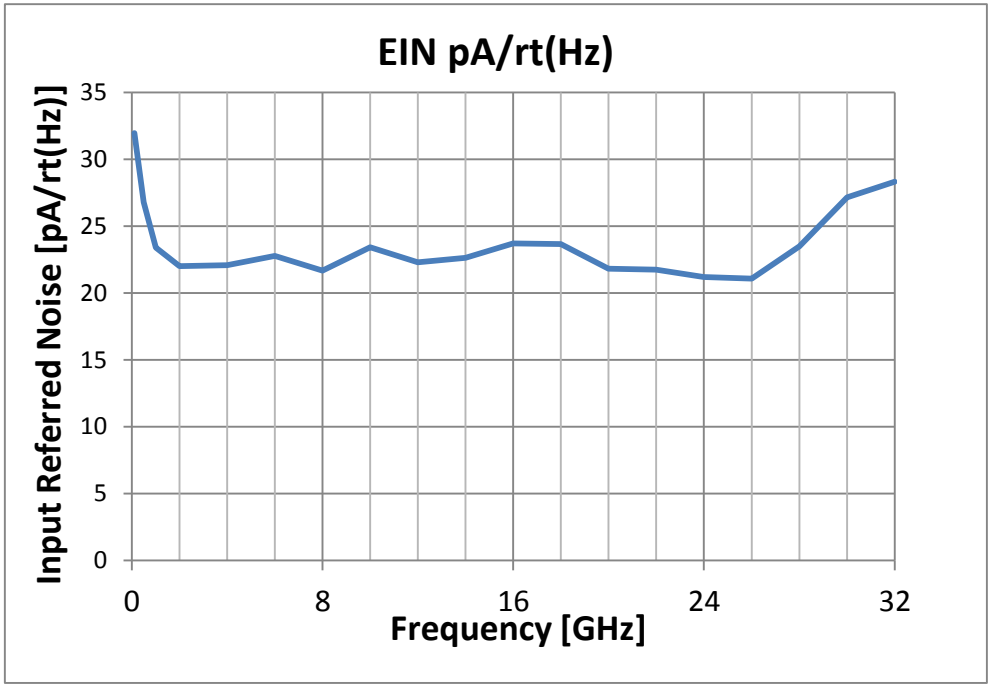


JDSU

Optical Components: Rx

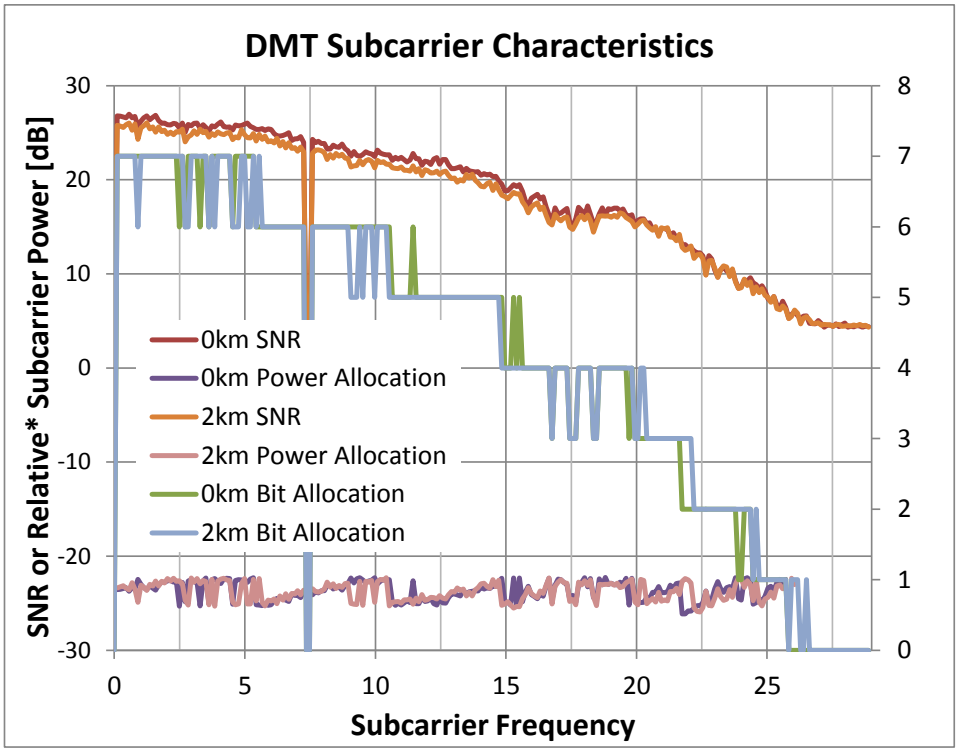
- Receiver was Discovery R409 Linear differential PIN-TIA, fixed gain.

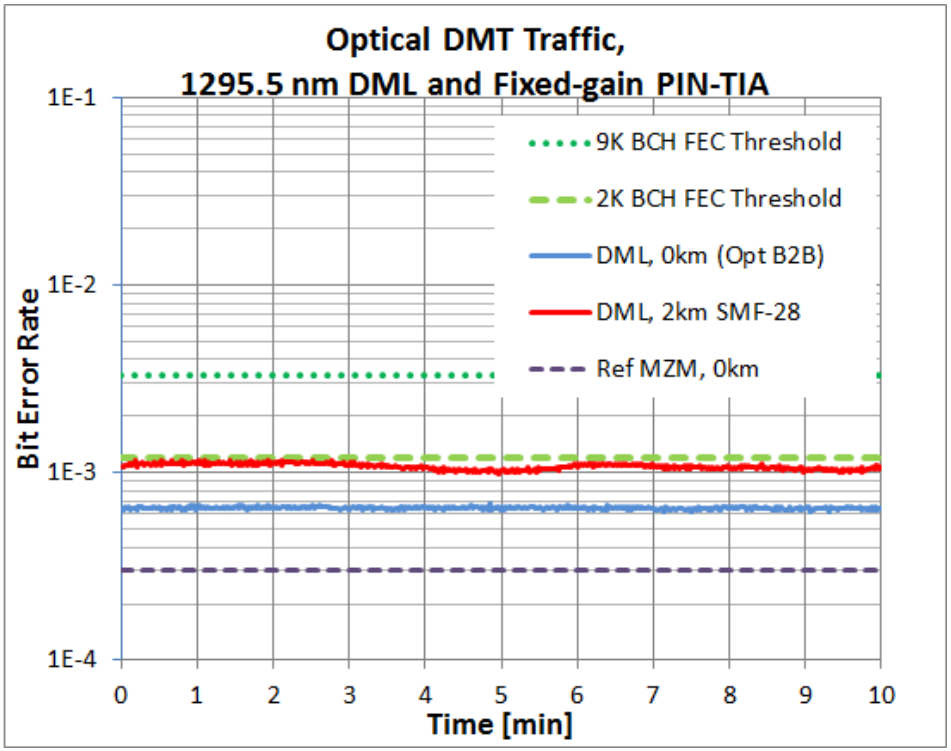
Parameter	Unit	Value
Wavelength range	nm	[1060, 1650] nm
3-dB bandwidth	GHz	30
Differential TIA Gain	Ω	550
Input Referred Noise	pA/√Hz	~23



Optical Back-to-back and Over-Fiber Results

- Optical traffic was run continuously over 0 and 2km of fiber.
  - Small penalty for 2km fiber transmission due to power drop (see slide 8).
- Proposed 12.5% overhead BCH FEC thresholds plotted.
  - Post-FEC results would be error-free.
- Traffic (PRBS-31) stable over 10 minutes.





* Subcarrier power is relative to maximum DAC amplitude.

Conclusion

- Demonstrated continuous live optical traffic at 116 Gb/s on a single wavelength, using the DMT protocol with 256 subcarriers.
  - Results demonstrated with both 1310 DML and externally modulated reference transmitter.
- Experiments were run with first functional DMT transceiver test chip implemented in 28nm CMOS
- Measured BER over 2km SMF-28 is stable and below the BCH FEC threshold
- Initial results limited by capability of available optical components.
- This demonstrates the feasibility of using a DMT modulation format for 400GE transmission using 4 wavelengths each carrying 100Gb/s.