Performance of optically amplified 10G sources

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IEEE P802.3av 10GEPON Task Force

January 2007, Monterey CA

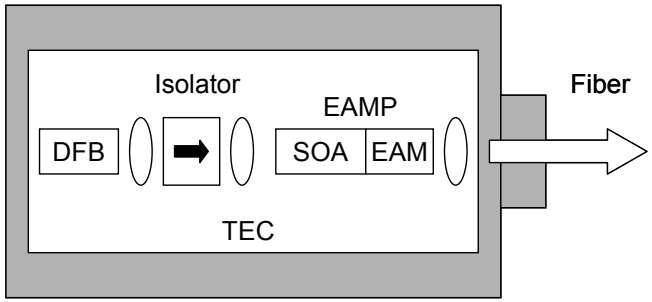
Apogee PHOTONICS

High power downstream transmitters

- **SOA or EDFA can increase transmitted power for C-band externally modulated EML sources**
  - Output power of standard EMLs is surveyed to be < +4dBm
- **SOA can be used either before or after the EA modulator**
  - SOA after EA mod. [EML+SOA] needs high saturation power (Psat) to minimize patterning effects
  - SOA before EA mod. [DFB+SOA+EA] does not require high Psat, but output power is limited by ability of EA mod. to switch large photocurrents
- **SOA before EA configuration, not discussed earlier can achieve a power range of +4 to +8.5dBm viz. between EMLs and external SOA based Tx**
- **Experimental results over 20km for three Tx configurations with powers from +4dBm to +17dBm is presented. Dispersion and non-linear transmission penalties are evaluated**
  1. SOA before EA → DFB + SOA + EA
  2. SOA after EA →EML + SOA
  3. EML + EDFA
- **Transmission data of SOA based Tx in two configurations obtained and possibility of integration into a single package offers a technically feasible and cost-effective path for standard links**

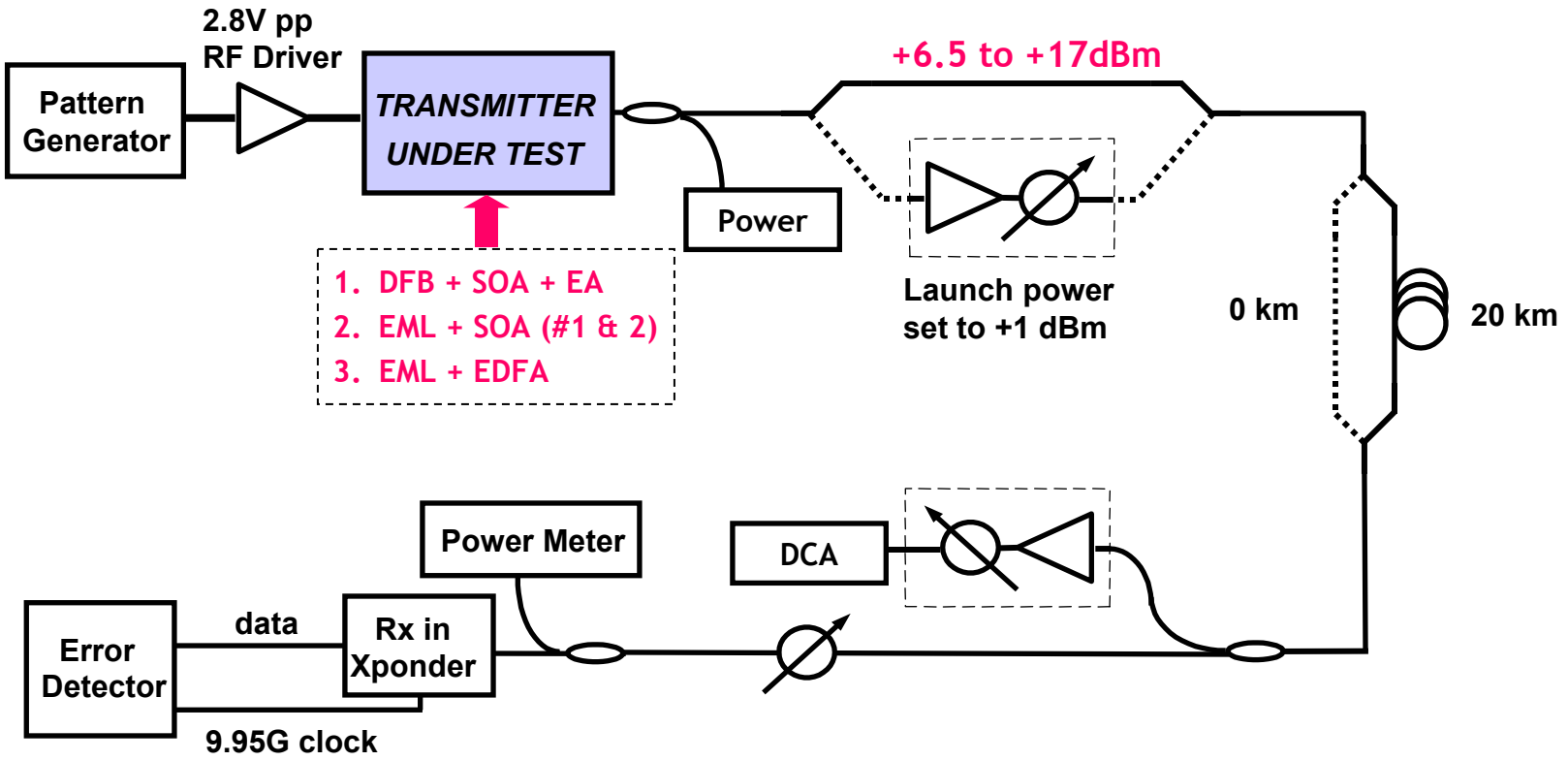
SOA before EA → DFB + SOA + EA

- Electroabsorption modulator (EAM) is monolithically integrated with a semiconductor optical amplifier (SOA) to form the EAMP chip, which is co-packaged with a pre-selected DFB laser
- Such a device is currently used in high power (+5dBm) Tx for 80km links
- Output power can be increased to +8.5 dBm for transmission to 20km and higher for 10 km links
- Total current consumption is < 100mA for +8.5dBm output power
- DFB+SOA+EA can be monolithically integrated in the future and can produce > +4dBm monolithic EA-based sources



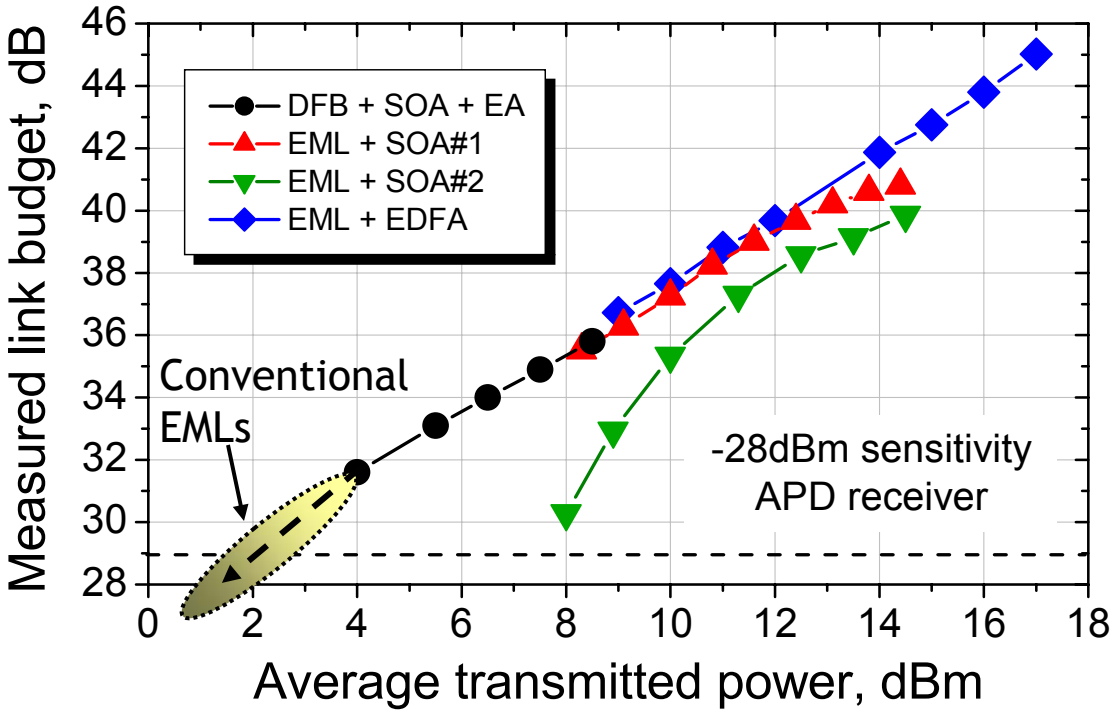
Schematic of DFB + SOA + EA module tested

Experimental setup



- BER measurement setup for 9.95Gbps through 20km of SMF-28 fiber
- Three transmitter configurations tested:
  - [DFB + SOA + EA] , [EML + SOA #1/2] and [EML + EDFA]
  - Psat of both SOA ~ +16dBm, SOA #2 had larger gain and NF versus SOA #1
- -28 dBm APD receiver in 300 pin transponder used as receiver
- Fiber launch is direct or at constant +1dBm using EDFA+VOA

Measured link budget for various Tx

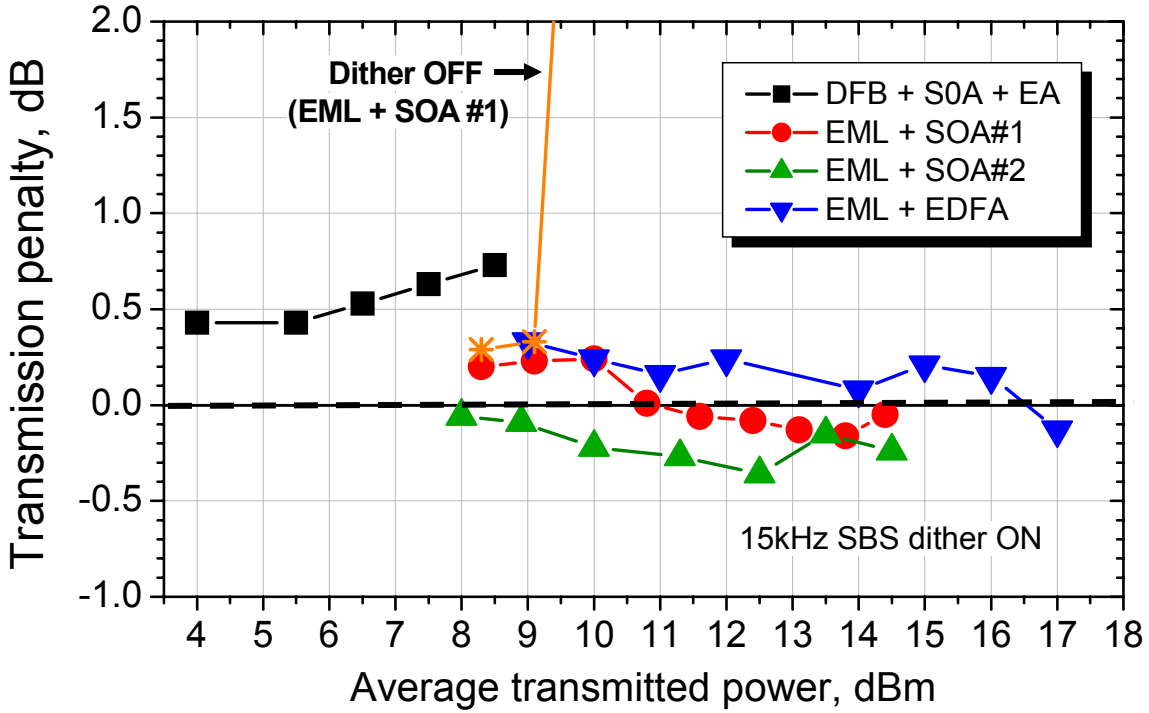


9.95Gbps, 20km

Transmitter	Power range	Max. link budget
EML	0 to 4dBm	31 / 21 dB (APD/PIN)
DFB + SOA + EA	0 to 8.5dBm	36 / 26 dB (APD/PIN)
EML + SOA	max. 10 to 12dBm	38 / 28 dB (APD/PIN)
EML + EDFA	up to 17dBm	45 / 35 dB (APD/PIN)

Assuming -18dBm PIN receiver

Transmission penalty for 20km



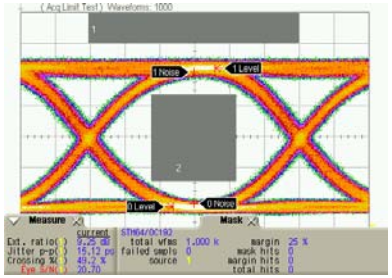
- Back to back and 20km sensitivity measured at BER = 10^{-12}
- 15kHz SBS suppression dither used for EML+SOA/EDFA transmitters
- Transmission penalty measurement including dispersion and non-linear effects yields < 1dB
  - Transmission penalty is low for EA + SOA beyond +10dBm

Transmitter eye quality at maximum power

DFB + SOA + EA

Pmax: +8.5 dBm

ER = 9.25dB, 26% margin

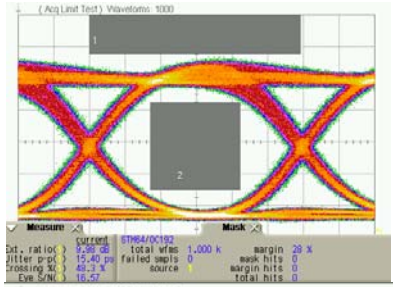


Same eye up to **+8.5dBm**
>25% SONET mask margin

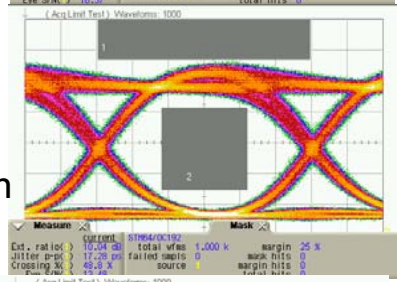
EML + SOA #1

Pmax: +10 dBm

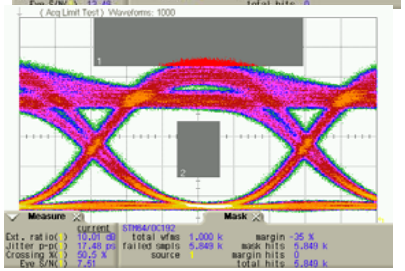
ER = 10dB, 28% margin



+12.5 dBm



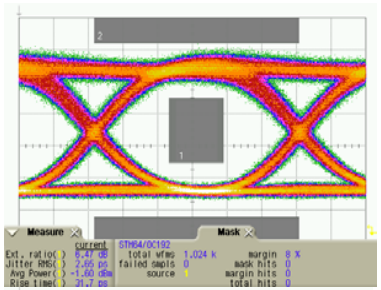
+14.5 dBm



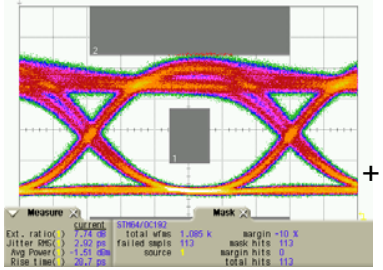
EML + SOA #2

Pmax: +10 dBm

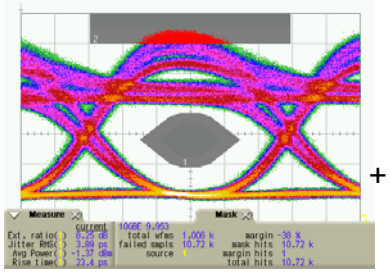
ER = 6.5dB, 8% margin



+12.5 dBm



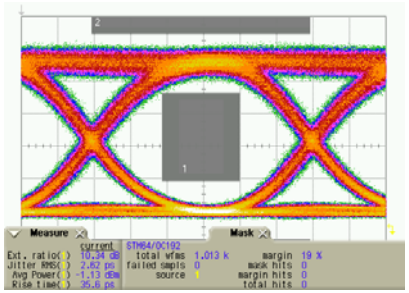
+14.5 dBm



EML + EDFA

Pmax: +17.0dBm

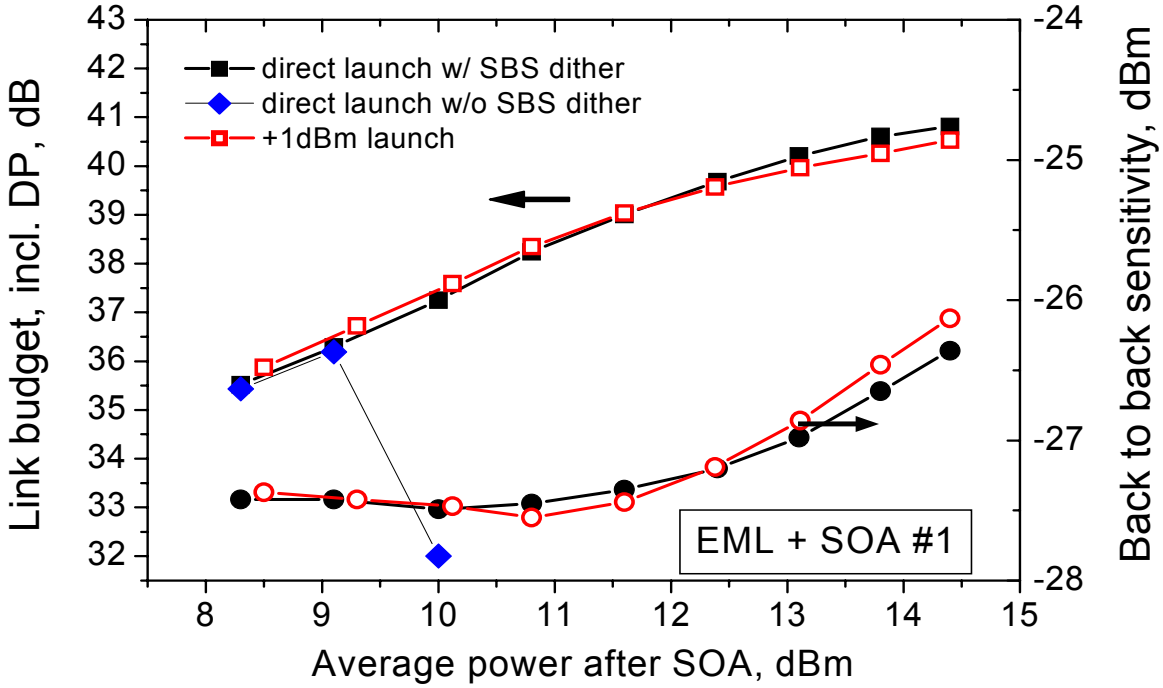
ER = 10.3dB, 19% margin



Same eye up to **+17.0 dBm**
>18% SONET mask margin

Margin for OC-192 SONET mask

Non-linear effects for EML + external SOA



- To measure non-linear effects, link performance was measured by launching constant +1 dBm power independent of transmitter power
- Both back to back and 20km sensitivity measured at BER of 10^{-12} show negligible non-linear effect up to +14.5dBm
- Link budget variation < 0.5dB; roll-off at higher powers due to increase in back to back sensitivity
- 15kHz SBS suppression dither essential to transmit > +9dBm

Source configurations for 1:16 and 1:32 links

Distance	Split ratio	IL, dB	Penalty, dB	PIN sens, dBm	Tx power w/ PIN, dBm	Tx with PIN+FEC, dBm	APD sens, dBm	Tx power w/ APD, dBm	Tx with APD+FEC, dBm
10km	1:64	29.6	2	-18	13.6	9.6	-24	7.6	3.6
	1:32	26.6	2	-18	10.6	6.6	-24	4.6	0.6
	1:16	23.6	2	-18	7.6	3.6	-24	1.6	-2.4
20km	1:64	34.6	2	-18	18.6	14.6	-24	12.6	8.6
	1:32	31.6	2	-18	15.6	11.6	-24	9.6	5.6
	1:16	28.6	2	-18	12.6	8.6	-24	6.6	2.6

- Insertion loss for 16 & 32 split ratio was estimated from worst case scenario for 64 split studied by ad-hoc group (*3av_0611_hajduczenia_2.pdf*)
- 2db penalty includes dispersion and non-linear effects
- Link budget calculated for PIN/APD receiver with/without FEC gain

EML + EDFA	≤ 17 dBm
EML + SOA	≤ 11 dBm
SOA + EA	≤ 8.5 dBm
EML	≤ 4 dBm

1:16 split, 10 km link requires +7.6dBm Tx power (SOA based Tx) without FEC or +3.6 dBm EML with 4dB FEC gain

For PIN + FEC receiver, 3 out of 6 links need Tx power from +6.6 and +9.6dBm, which can be obtained using SOAs (before or after EA)

Cost estimation for amplified Tx sources

Assumptions (based on *3av_0611_lee_1.pdf*)

- PIN cost = X, APD = 3X
- EML = 10X
- DFB+SOA+EA = 15X (new!)
- EML + SOA = 30X; Integrated version = 20X (new!)
- EDFA = 50X

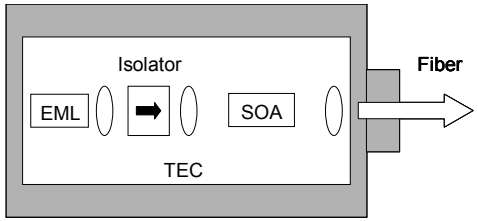
Lowest cost configurations

Span	Split ratio	PIN	Tx+Rx cost (no FEC)	PIN + FEC	Tx+Rx Cost (w/FEC)	% savings due to FEC	Comment
10km	64	EML+EDFA	1.78	EML+SOA	1.47 or 1.31	17% or 26%	red ⇒ integrated EML+SOA
	32	EML+SOA	1.94 or 1.63	SOA+EA	1.47	24% or 10%	red ⇒ integrated EML+SOA
	16	SOA+EA	1.94	EML	1.63	16%	
20km	64	EML+EDFA	1.78	EML+EDFA	1.78	0%	
	32	EML+EDFA	2.56	EML+EDFA	2.56 or 1.63	0% or 36%	red ⇒ EML+SOA used (P=11.6dBm)
	16	EML+EDFA	4.13	EML+SOA	2.88 or 2.25/1.94	30%, 45%, 53%	red ⇒ integrated; blue ⇒ SOA+EA

No scenario where APD is more cost effective!

Conclusions

- **Transmission through 20km fiber studied for three amplified (SOA and EDFA) transmitter configurations**
- **Output power ranges per configuration are:**
  1. DFB + SOA + EA : 0 to +8.5 dBm
  2. EML + SOA: +6 to +10 (12.5) dBm
  3. EML + EDFA: 0 to +17 dBm
- **Use of SBS suppression dither results in negligible transmission penalty due to non-linear effects**
  - Dispersion penalty + transmission penalty typically < 0.5dB
- **PMDs for 10GEPON should include SOA based links**
  - Output power in +4 to +12.5 dBm range achieved using SOA based Tx
  - With FEC, 3 out 6 standard links work with SOA Tx
  - SOAs can be used either before or after EA depending on application
  - Potential cost savings possible by integration (EML +SOA) into single package



EML + SOA integrated module