



**INSTITUTO  
DE INGENIERÍA  
UNAM**

Using SOAs as  
Booster and/or Pre-Amplifier for  
4x25-Gb/s 40-km 1310-nm PMD

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**(collaboration with Marcus Duelk, Bell Labs / Alcatel-Lucent)**



## Outline

- Feasibility with SOA pre-amplifier only
- Feasibility with SOA booster only
- Feasibility with SOA booster & pre-amplifier
- Conclusions



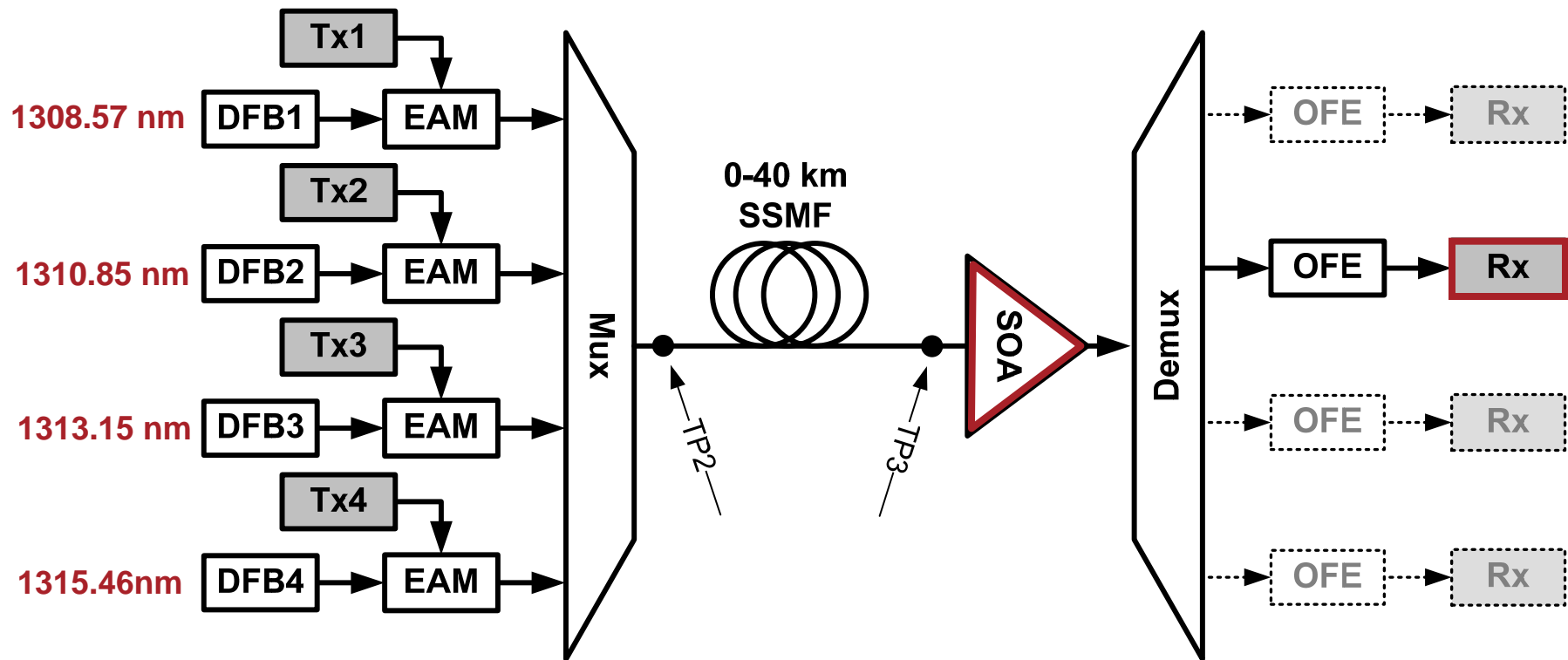
# Feasibility with SOA pre-amplifier only (SOA after the fiber link)



# SOA as Pre-Amplifier

400 GHz Channel Spacing

BER analysis in channel #2 (worst FWM scenario)





## Minimum $-\log(\text{BER})$ for Long Fiber Links (10-40 km)

	0 dBm EML output power		+2 dBm EML output power		+4 dBm EML output power	
	6 dB NF	9 dB NF	6 dB NF	9 dB NF	6 dB NF	9 dB NF
4 dB ER	4.6	2.9	6.5	4.1	8.8	5.5
6 dB ER	8.1	5.0	11.7	7.1	15.8	9.8
8 dB ER	11.9	7.3	17.4	10.5	24.1	14.6
10 dB ER	15.3	9.3	22.7	13.6	32.0	19.2

Extinction ratio of EML transmitter

Noise figure of SOA pre-amplifier

- Minimum  $-\log(\text{BER})$  value = worst-case BER  
→ obtained for longest fiber link (40 km = 22 dB span loss)
- Gray-shaded areas do not meet BER 1E-12 requirement !

see gutierrez\_01\_1107 for more information



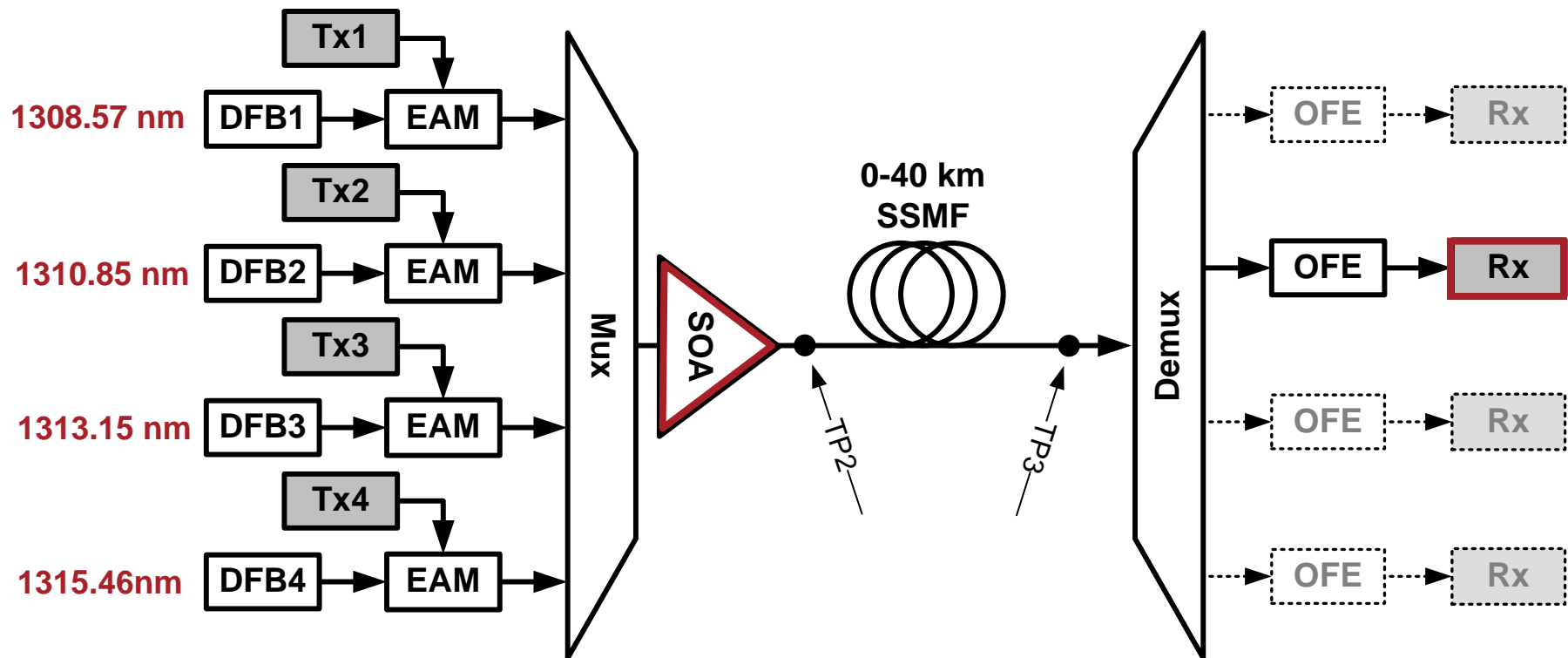
**Feasibility with  
SOA booster only  
(SOA before the fiber link)**



# SOA as Booster Amplifier

400 GHz Channel Spacing

BER analysis in channel #2 (worst FWM scenario)





## Power Budget Analysis for a 10-dB ER Signal

	Saturated SOA		Unsaturated SOA	
	Power**	Loss	Power**	Loss
EAM output	+2.2 dBm		-21.8 dBm	
Aging & accuracy	+1.2 dBm	-1.0 dB	-22.8 dBm	-1.0 dB
MUX & splice loss	-1.5 dBm	-2.7 dB	-25.5 dBm	-2.7 dB
SOA booster output	+8.1 dBm	+9.6 dB	-3.2 dBm	+22.3 dB
<b>Total power @ TP2</b>	<b>+14.1 dBm</b>		<b>+2.8 dBm</b>	
Fiber loss (40 km)	-13.9 dBm	-22.0 dB	-25.2 dBm	-22.0 dB
<b>Total power @ TP3</b>	<b>-7.9 dBm</b>		<b>-19.2 dBm</b>	
Aging & accuracy	-15.4 dBm	-1.5 dB	-26.7 dBm	-1.5 dB
DEMUX & splice loss	-19.1 dBm	-3.7 dB	-30.4 dBm	-3.7 dB
OFE input	-19.1 dBm		-30.4 dBm	

- Despite high output power (+14.1 dBm @ TP2) the per-channel power at the OFE is well below the required power sensitivity !
- SOA with 23 dB small-signal gain and +8 dBm  $P_{\text{sat}}$  is assumed

\*\* per-lane average power, except total power values @ TP2 / TP3





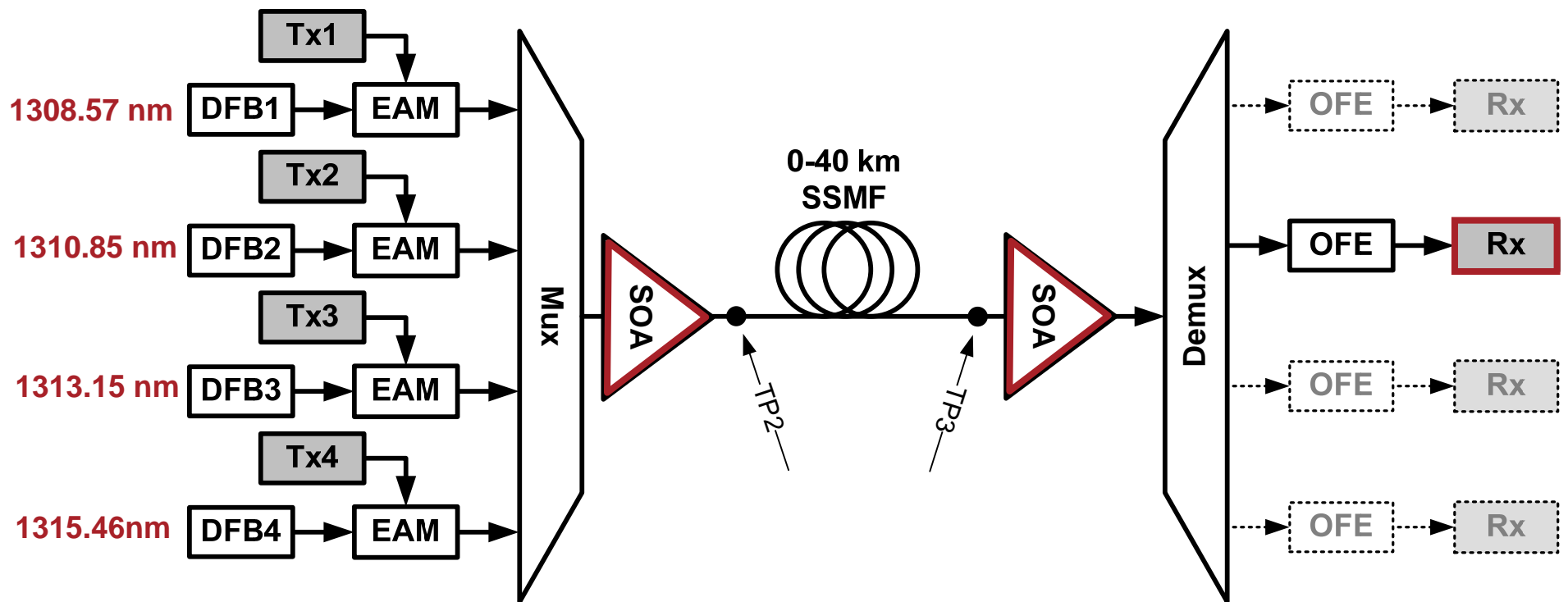
# Feasibility with SOA booster and pre-amplifier (SOA before & after the fiber link)



# SOA as Booster & Pre-Amplifier

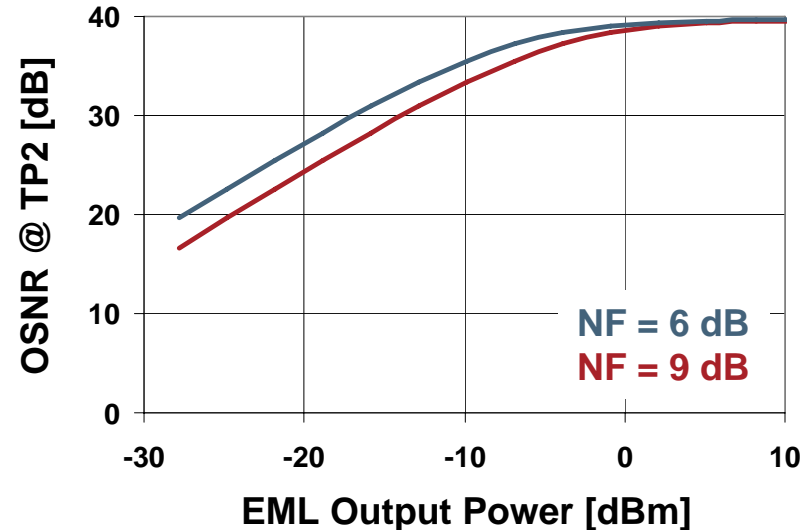
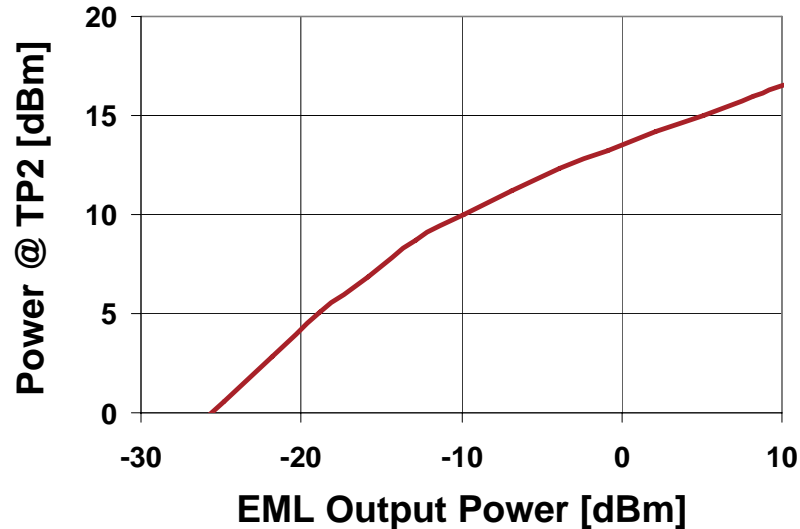
400 GHz Channel Spacing

BER analysis in channel #2  
(worst FWM scenario)





## Output Characteristics of Booster SOA

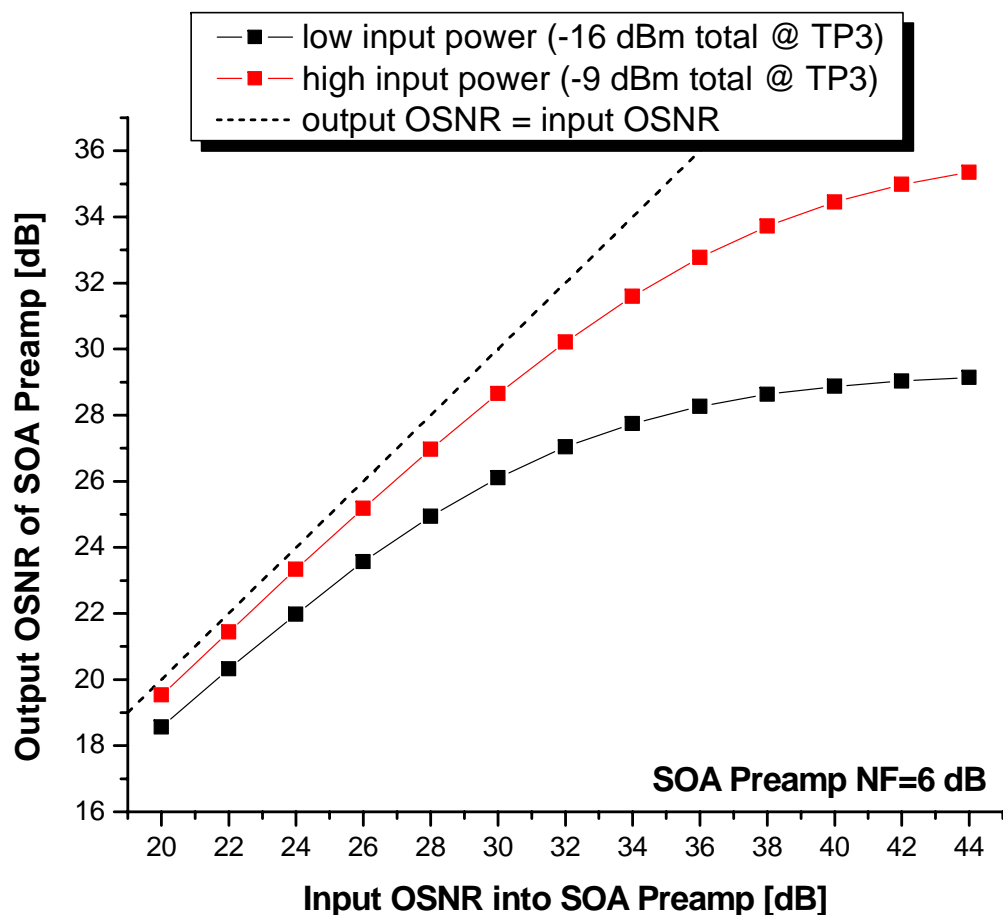


- **Impact of Booster SOA:**

- Higher output power @ TP2
  - higher input power into SOA pre-amplifier (TP3)
  - lower OSNR degradation in SOA pre-amplifier
- OSNR degradation in SOA booster
  - lower input OSNR into SOA pre-amplifier
- Nonlinear eye distortions in SOA booster (e.g., FWM)
- More nonlinear effects in optical fiber (tbd)



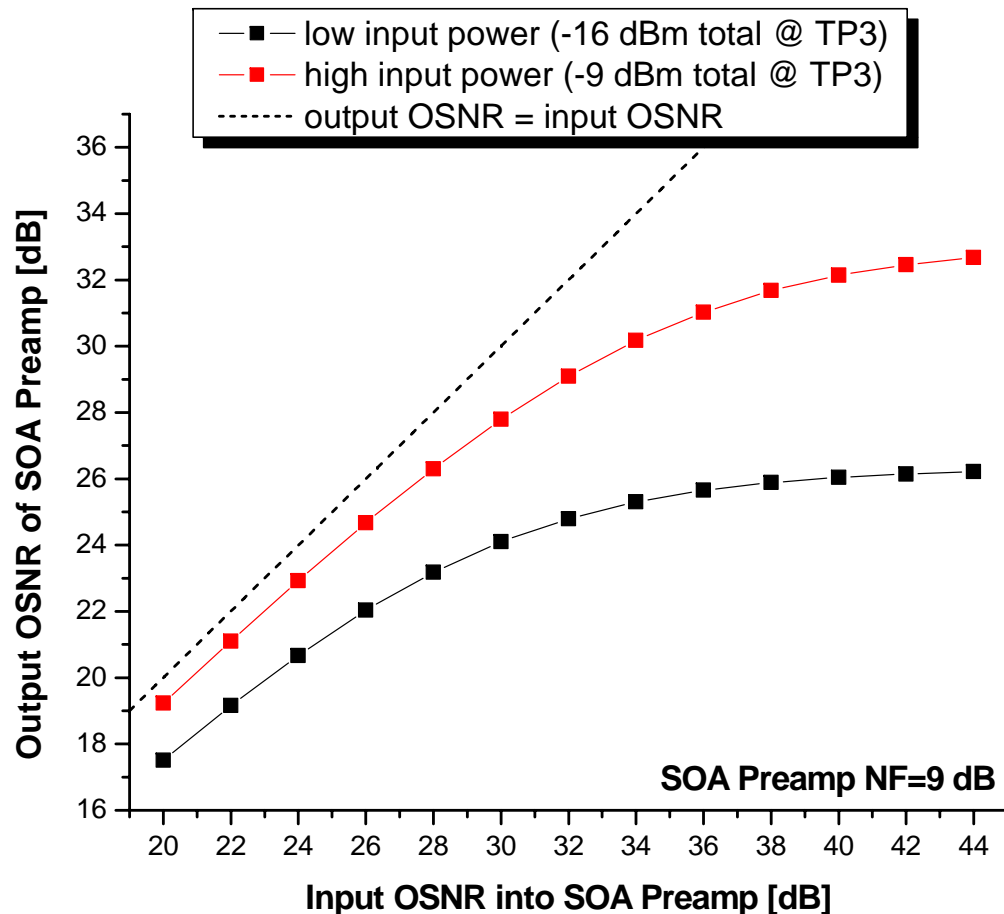
## Output OSNR of SOA Pre-Amplifier vs Input OSNR



- **SOA noise figure = 6 dB**
- Curves valid for all extinction ratio (ER) values
- Power values @ TP2:
  - High:  
per-channel power = +7 dBm  
total power = +13 dBm
  - Low:  
per-channel power = 0 dBm  
total power = +6 dBm
- Power values @ TP3 for 40-km fiber link:
  - High:  
per-channel power = -15 dBm  
total power = -9 dBm
  - Low:  
per-channel power = -22 dBm  
total power = -16 dBm



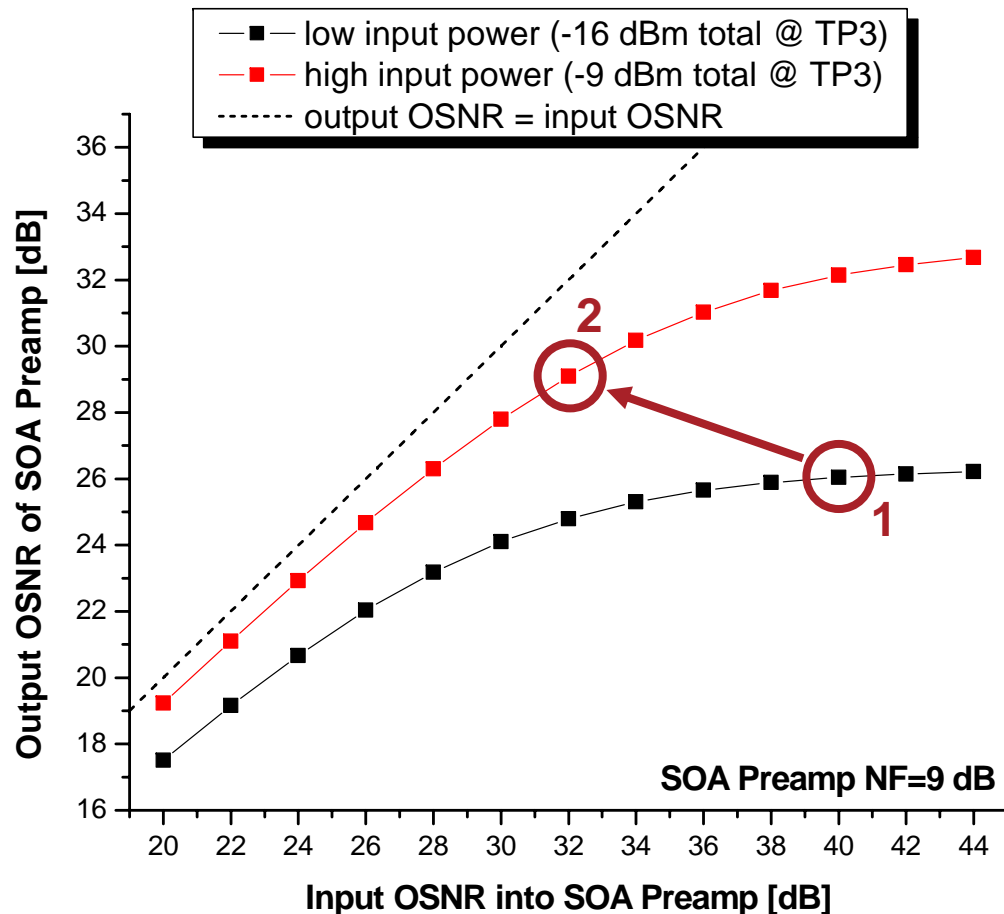
## Output OSNR of SOA Pre-Amplifier vs Input OSNR



- **SOA noise figure = 9 dB**
- Curves valid for all extinction ratio (ER) values
- Power values @ TP2:
  - High:  
per-channel power = +7 dBm  
total power = +13 dBm
  - Low:  
per-channel power = 0 dBm  
total power = +6 dBm
- Power values @ TP3 for 40-km fiber link:
  - High:  
per-channel power = -15 dBm  
total power = -9 dBm
  - Low:  
per-channel power = -22 dBm  
total power = -16 dBm



# Improving Output OSNR by Using Booster SOA



## Data point 1:

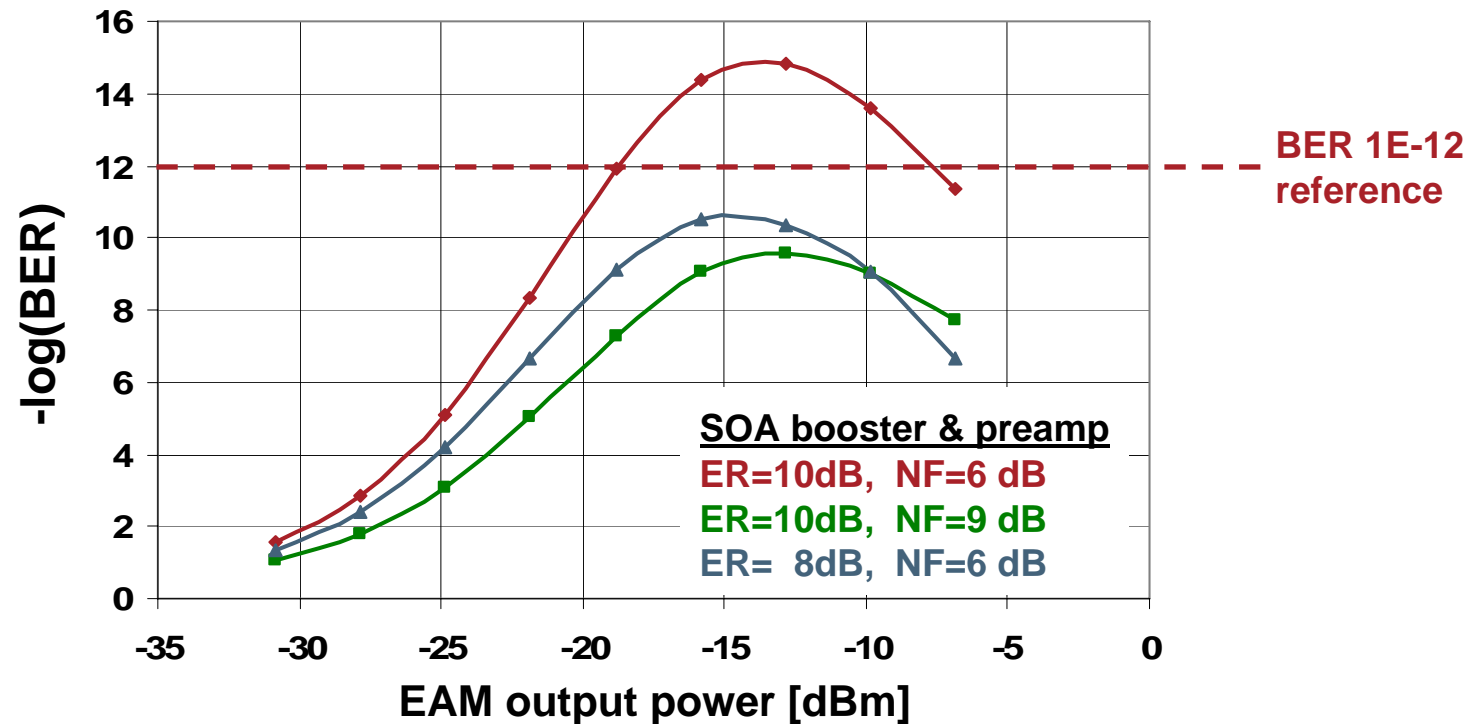
- Low input power  
+6 dBm total @ TP2  
-16 dBm total @ TP3
- Input OSNR = 40 dB
- Corresponds to high output power case (+4 dBm per EML) from gutierrez\_01\_1107
- **Output OSNR = 26 dB**

## Data point 2:

- High input power  
+13 dBm total @ TP2  
-9 dBm total @ TP3
- Input OSNR = 32 dB
- **Output OSNR = 29 dB**  
→ could improve OSNR by 3 dB by using booster amplifier



## BER Analysis Using Identical SOAs for a 40-km Link

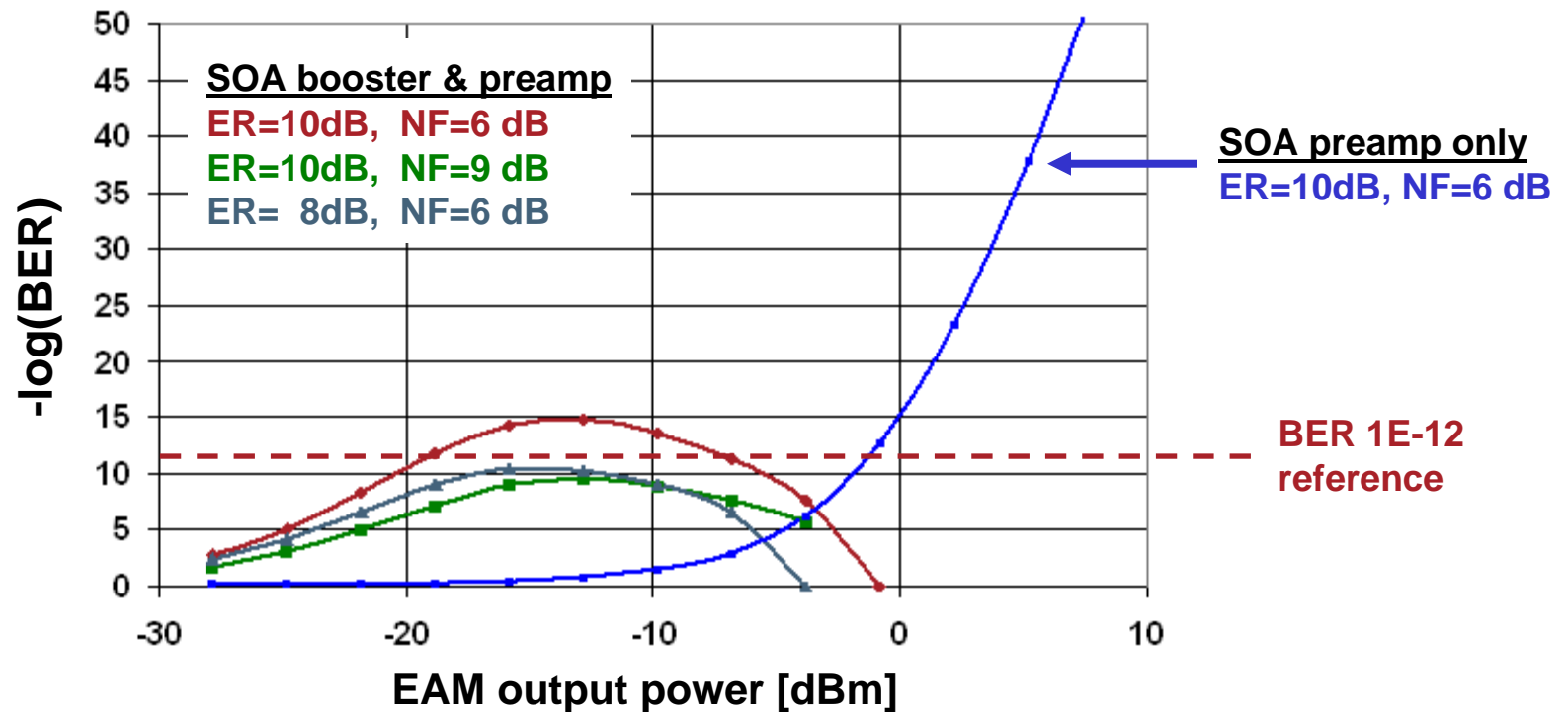


- Identical SOA (23 dB small-signal gain, +8 dBm  $P_{\text{sat}}$ ) for booster and pre-amplifier
- This configuration barely meets the BER requirements for the most favorable scenario (ER=10 dB, NF=6 dB)
- Other booster/pre-amplifier combinations tested as well, similar results

Improvement in received OSNR is traded off with an increase in nonlinear eye distortions in booster SOA !



## Comparison to “Pre-Amplifier Only” for a 40-km Link



- The configuration with only one SOA as pre-amplifier performs better in terms of BER but at higher EML output powers
  - EML output power >0 dBm yields better BER performance





## Conclusions

- Three 4x25-Gb/s PMDs at 1310-nm for 40-km reach have been numerically analyzed, namely:
  - **SOA as pre-amplifier only**
    - Best BER performance for long fiber links
    - EML output power of +2 to +4 dBm required
    - EML extinction ratio of 8 to 10 dB required
  - **SOA as booster only**
    - Not feasible
  - **SOAs as pre-amplifier and booster**
    - Booster amplifier may improve received OSNR
    - Nonlinear eye distortion under high output power critical
    - BER performance worse than “pre-amplifier only” configuration