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Optical
Fiber

SBS degradation of 10 Gb/s digital signal in EPON: Experiment and Model

S. Ten

Corning Incorporated
Science and Technology Division

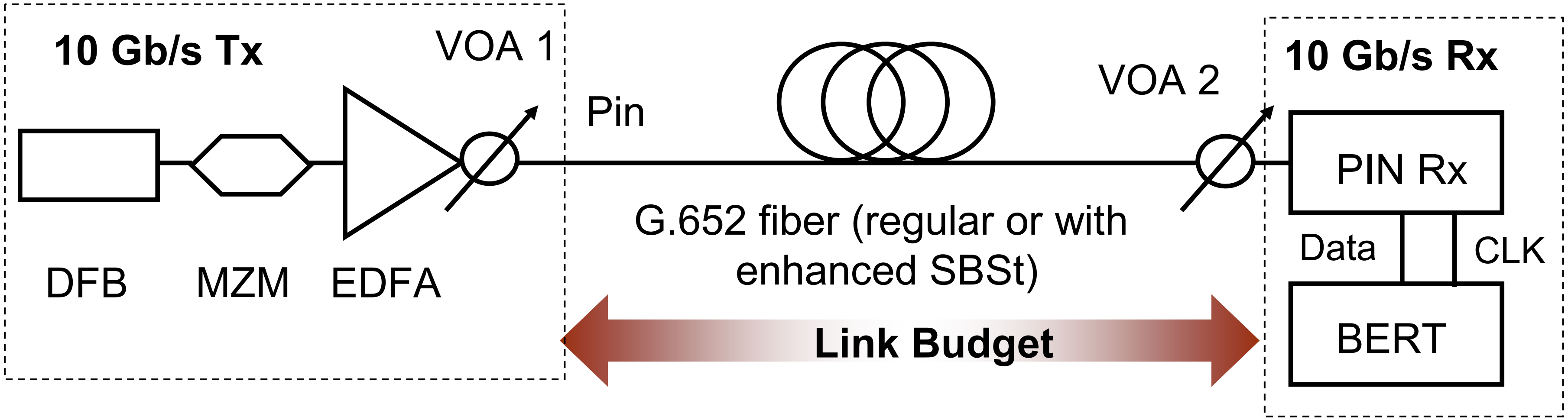
Background and Objectives

- Background:
  - At the present stage GEPON (1.25 Gb/s EPON) link budget is limited to 20 km and 24 dB maximum loss
  - 10 Gb/s EPON Task Force explores increasing the link loss budget up to 28+ dB *if possible*
  - Extrapolated Rx sensitivity of digital PIN receiver at 10 Gb/s (assuming the same number of photons per bit) is -15 dBm
  - Input powers in excess of 10 dBm will cause SBS

- Objectives
  - Evaluate how SBS degrades the digital signal and limits the link loss budget
  - Investigate the mechanism of SBS impairment and propose a simple model ("Excel Ready") to be implemented in the channel link model

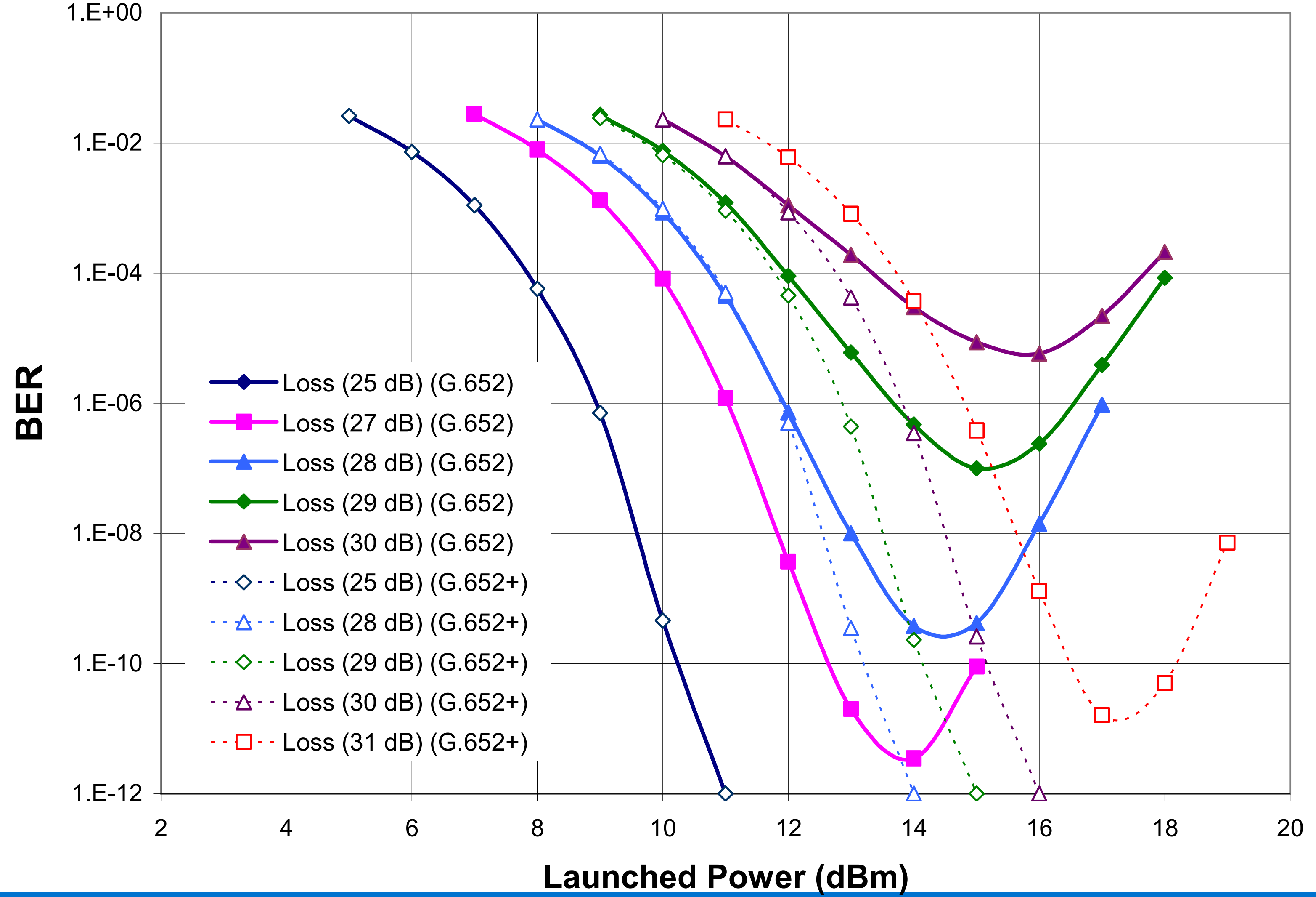
Experiment

Representative of worst case scenario 10 GEPON



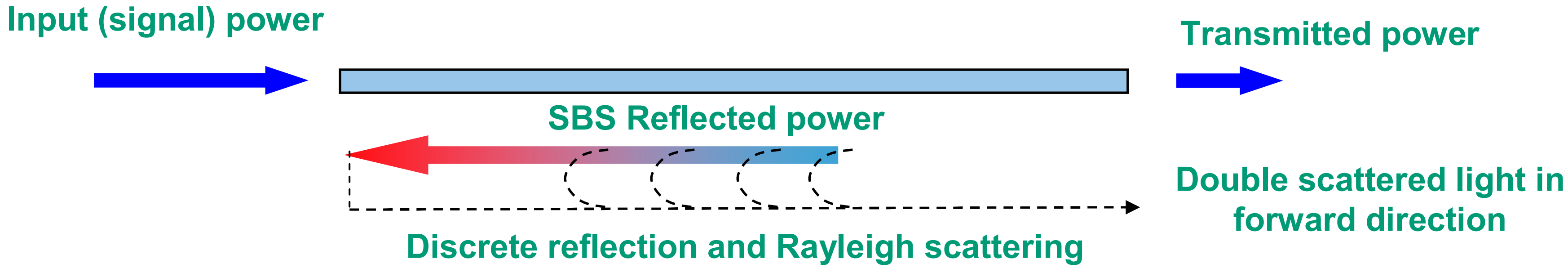
- Test system specifications:
  - Tx could launch variable power Pin (up to 22 dBm)
    - DFB with Mach-Zehnder modulator
  - Fiber: 20 km of regular G.652 fiber or G.652+ fiber (>3 dB enhanced SBS threshold (SBSt))
  - PIN Receiver had sensitivity of -15 dBm (at 10^{-9} BER)
  - Link loss varied with VOA 2

Results: BER vs Input Power for G.652 Fibers

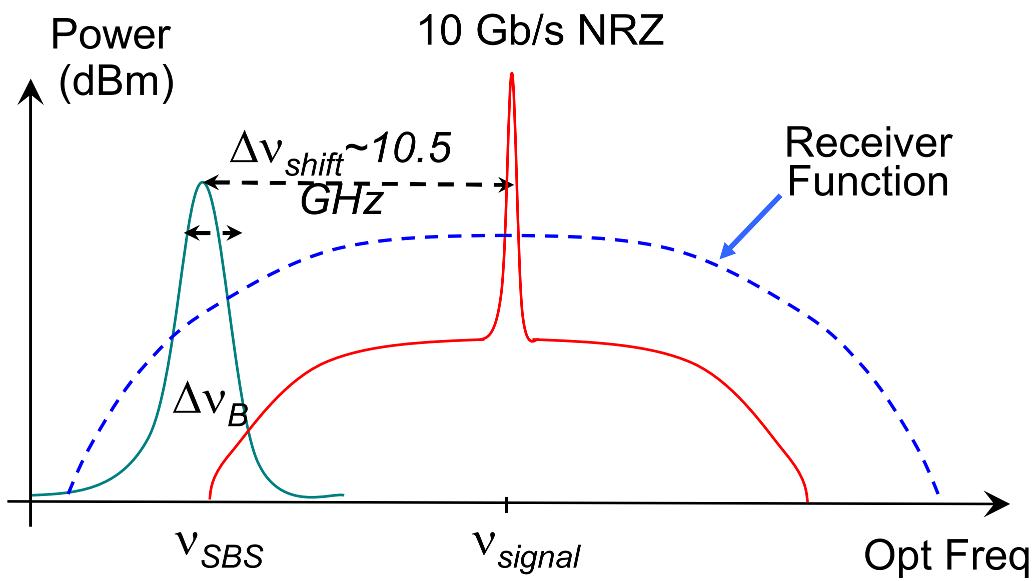


Two mechanisms of SBS impairment

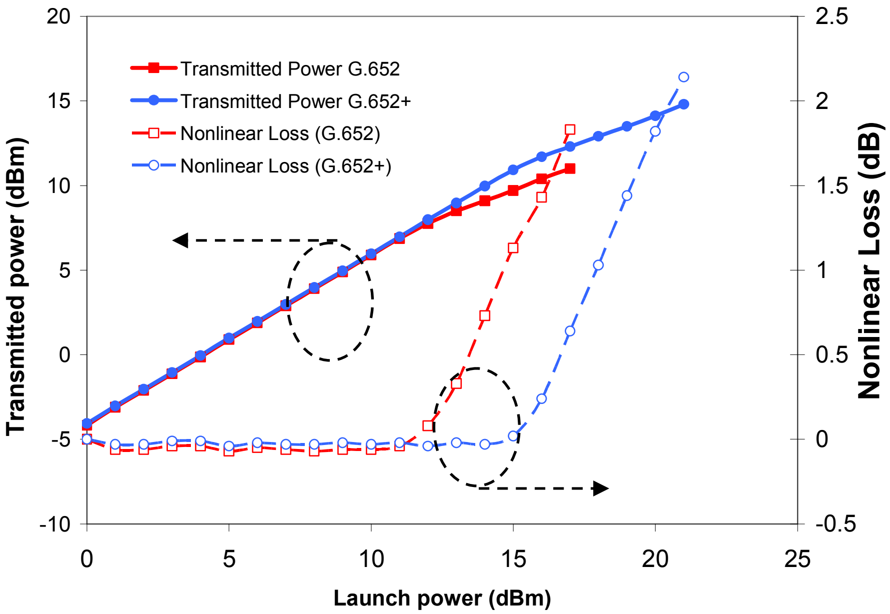
Which one is stronger and should be considered?

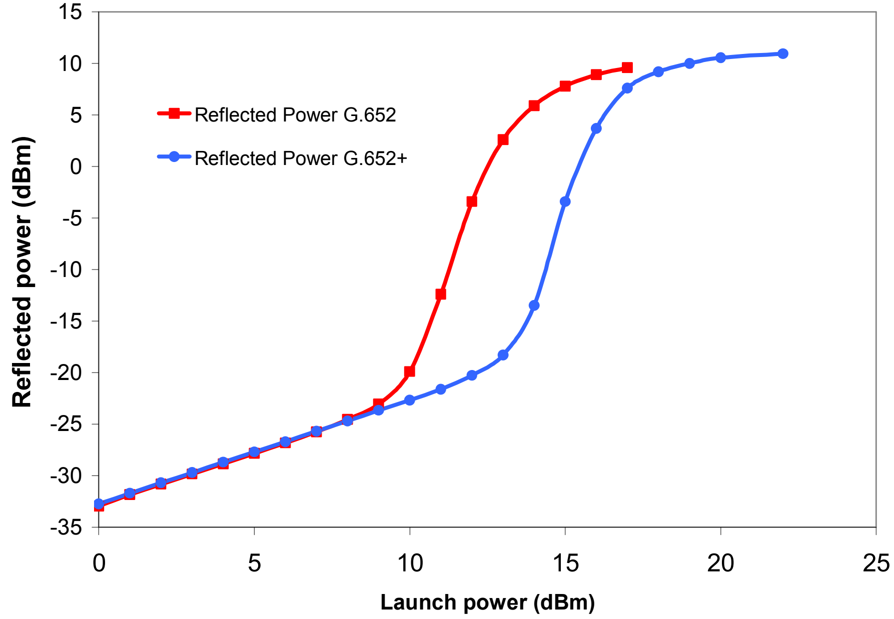


- SBS limits transmitted power i.e. effectively increases link loss
- SBS generates noise through double (Brillouin, Rayleigh and discrete) scattering/reflection
  - Scattered light falls in the electrical bandwidth of the receiver



SBS Reflected Power and Induced Nonlinear Loss





- SBS limits growth of the transmitted fiber but does not “flatten it” i.e. the induced nonlinear loss growth < 1 dB per 1 dB increase of launch power
- Thus BER behavior can only be explained by additional SBS induced noise caused by “explosive” growth of reflected and double reflected powers

Model Development

Calculation of Double-reflected Power

- Double-reflected power due to combined processes of SBS and Rayleigh backscattering (RBS) is calculated as*

$$P_{SBS-RBS} = \frac{\sqrt{\pi}}{4}\rho\frac{\alpha_{RBS}}{\alpha}\frac{kT\nu_0\Delta\nu_B}{\nu_{shift}}\frac{\left(1-e^{-\alpha L}\right)e^{A}}{A^{3/2}}\left(2e^{-\alpha L}+\frac{1}{A}\right)$$

- For typical parameters of 20 km long G.652 fiber this expression simplifies to

$$P_{SBS-RBS}[\mathrm{dBm}] \approx -98 + 4.34A - 15\lg A$$

$$A = \frac{g_B}{A_{ao}} P_{in} L_{eff}$$

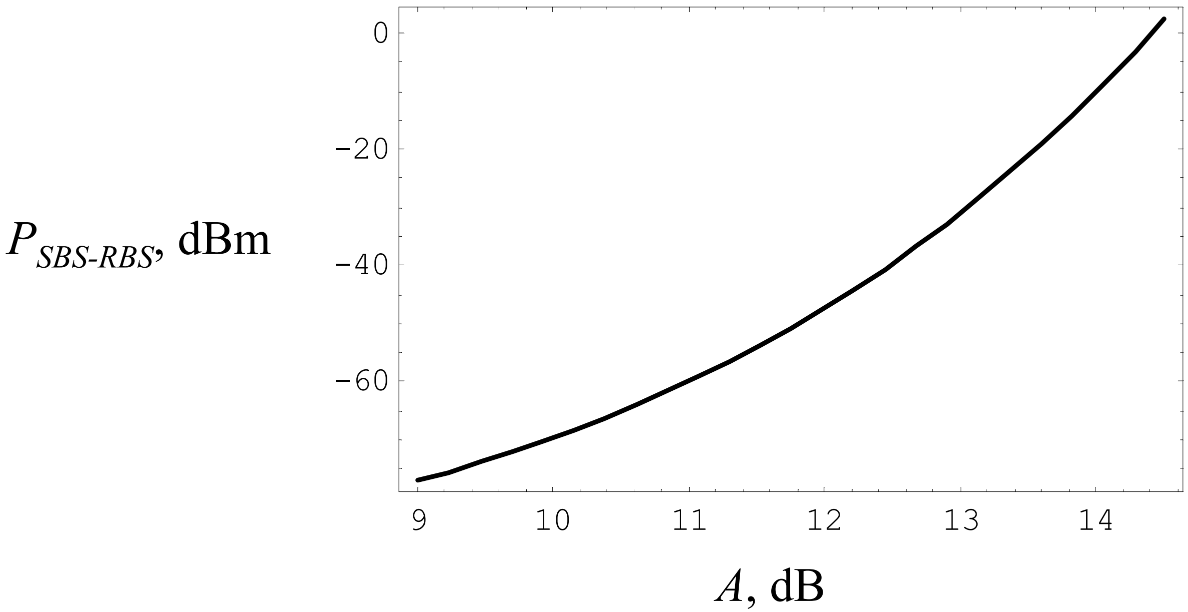
- g_B is the Brillouin gain coefficient, A_{ao} is the acousto-optic effective area**, L_{eff} is the effective length, P_{in} - input signal power

* detailed calculation of SBS power can be found in A. Kobyakov et al., Opt. Commun. vol. 260 pp. 46-49 (2006)

** rigorously defined in A. Kobyakov et al., Opt. Express, vol.13 pp. 5338-5346 (2005)

Model Development

Total SBS-RBS Power at the Receiver



- for 20 km long G.652 fiber and 10 Gb/s NRZ data parameter A at corresponding to SBSt is about 11.5 dB
- a 3dB increase in the input power over the threshold value causes > 50 dB cross-talk increase
- noise impairment quickly grows with increased input power

Model Development

SBS Impairment in the Link Model - Discussion

- SBS induced impairment at the receiver can be calculated as a crosstalk
  - At 10 Gb/s (see slide 5) this cross talk could be classified as “in-band” even though the noise spectrum is falling at the edge of the receiver transfer function

$$\sigma_X^2 = aX\left|H(\nu_{shift})\right|^2 + bX\int_{-\infty}^{+\infty} d\nu \left|H(\nu)\right|^2 \left\{ \left(\frac{\sin(\pi(\nu+\nu_{shift})/B)}{\pi(\nu+\nu_{shift})/B} \right)^2 + \left(\frac{\sin(\pi(\nu-\nu_{shift})/B)}{\pi(\nu-\nu_{shift})/B} \right)^2 \right\}$$

where σ^2 is noise variance and $X=P_{SBS\text{-}RBS}/P_{rec}$ is cross talk at the receiver

- The presented statistical description is not fit for direct implementation in the Excel spreadsheet model
- Implementation of the SBS impairment model is pending

Summary

- SBS in 10 Gb/s PON is a leading nonlinear impairment for the digital signal and will limit the achievable link budget
  - For G.652 fiber in the assumptions of our experiment the max budget is 27 dB
- SBS must be mitigated by one of the following techniques or their combination
  - Use fiber with higher SBS threshold (e.g. G.652+ fiber gives >3 dB)
  - Dithering at the transmitter
  - FEC or receivers with better sensitivities
- The leading impairment mechanism of SBS is noise generation rather power limiting at the receiver
- A statistical model was proposed (Excel implementation is pending)

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