Single Mode Fibre Loss

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Motivation

Many solutions for 100 Gbit/s Ethernet have proposed to use CWDM to carry the multiple lanes over separate wavelengths on a single fibre.

The presentation from Monterey anslow_01_0107.pdf included a graph of assumed loss vs. wavelength to justify the choice of CWDM channels to be analysed. It was noted during the meeting that this loss vs. wavelength information was very different from the loss vs. wavelength curve built in to the 10G link model spreadsheet v 3.1.16a.

This document looks at the equation used in the link model spreadsheet and compares it to the loss assumptions used by the ITU-T in the development of the CWDM applications Rec. G.695.

Equation in link model spreadsheet

The equation that governs the loss coefficient vs wavelength in the link model spreadsheet is:

$$\text{Loss coeficient} = \frac{R_\lambda}{C_\lambda}\left[\left(\frac{1}{9.4\cdot10^{-4}\lambda_c}\right)^4 + 1.05\right]$$

Where: R_λ is the actual cable attenuation in dB/km at a specific wavelength λ_c (e.g. 850 nm or 1300 nm). For 850 nm C_λ = 3.5dB/km, at 1310 nm C_λ = 1.4846 dB/km.

The multiplier R_λ / C_λ allows the curve to be scaled to pass through the value R_λ at either 850 or 1310 nm

Equation derivation

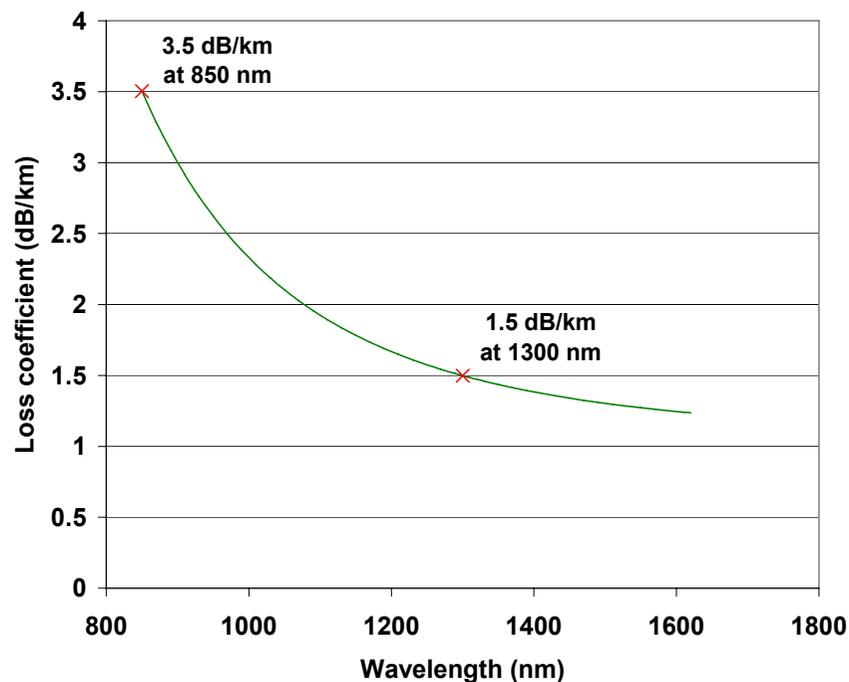Evaluating the term:

$$\left[\left(\frac{1}{9.4\cdot10^{-4}\lambda_c}\right)^4+1.05\right]$$

Gives the curve on the right and is the equation:

$$\alpha\,(\text{dB/km})=\frac{A}{\lambda^4}+B\quad[1]$$

Fitted to 3.5 dB/km at 850 nm and 1.5 dB/km at 1300 nm

[1] J.J. REFI, Fiber Optic Cable - A Lightguide, (ABC TeleTraining Inc., 1991)

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Comparison with G.695 Appendix I

The loss coefficient vs wavelength assumed by ITU-T in the development of the CWDM applications Recommendation G.695 is captured in Appendix I/G.695

This data is plotted on the next two slides (red curve for the assumed maximum and blue curve for the assumed minimum) together with a green curve which is the equation from the link model spreadsheet normalised to 0.4 dB/km at 1300 nm which is a reasonable figure and is the value assumed by some tabs of the link model spreadsheet.

Comparison with G.652.A&B data
Standard Single Mode Fibre (SSMF)
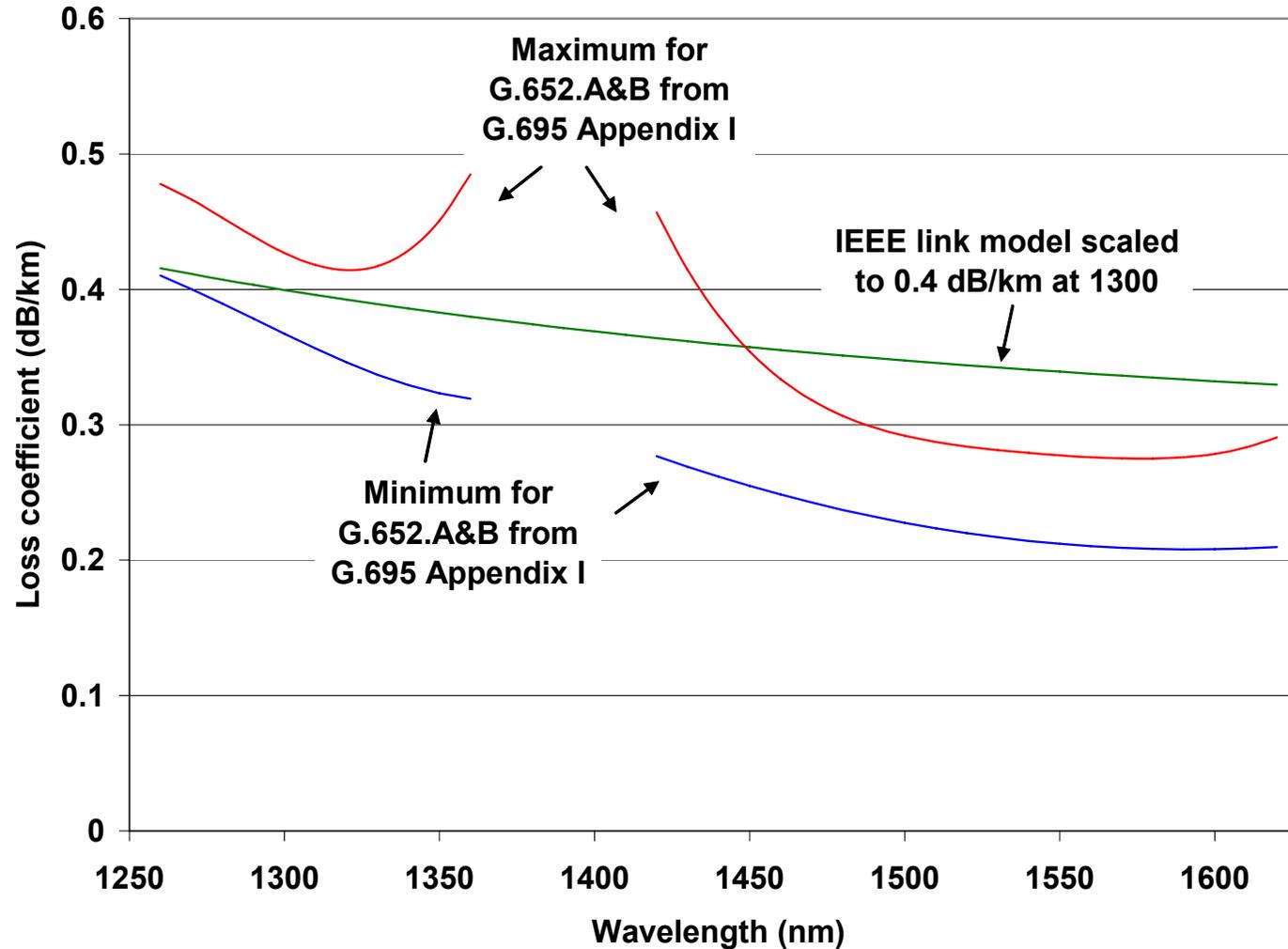
Comparison with G.652.C&D data low water peak fibre
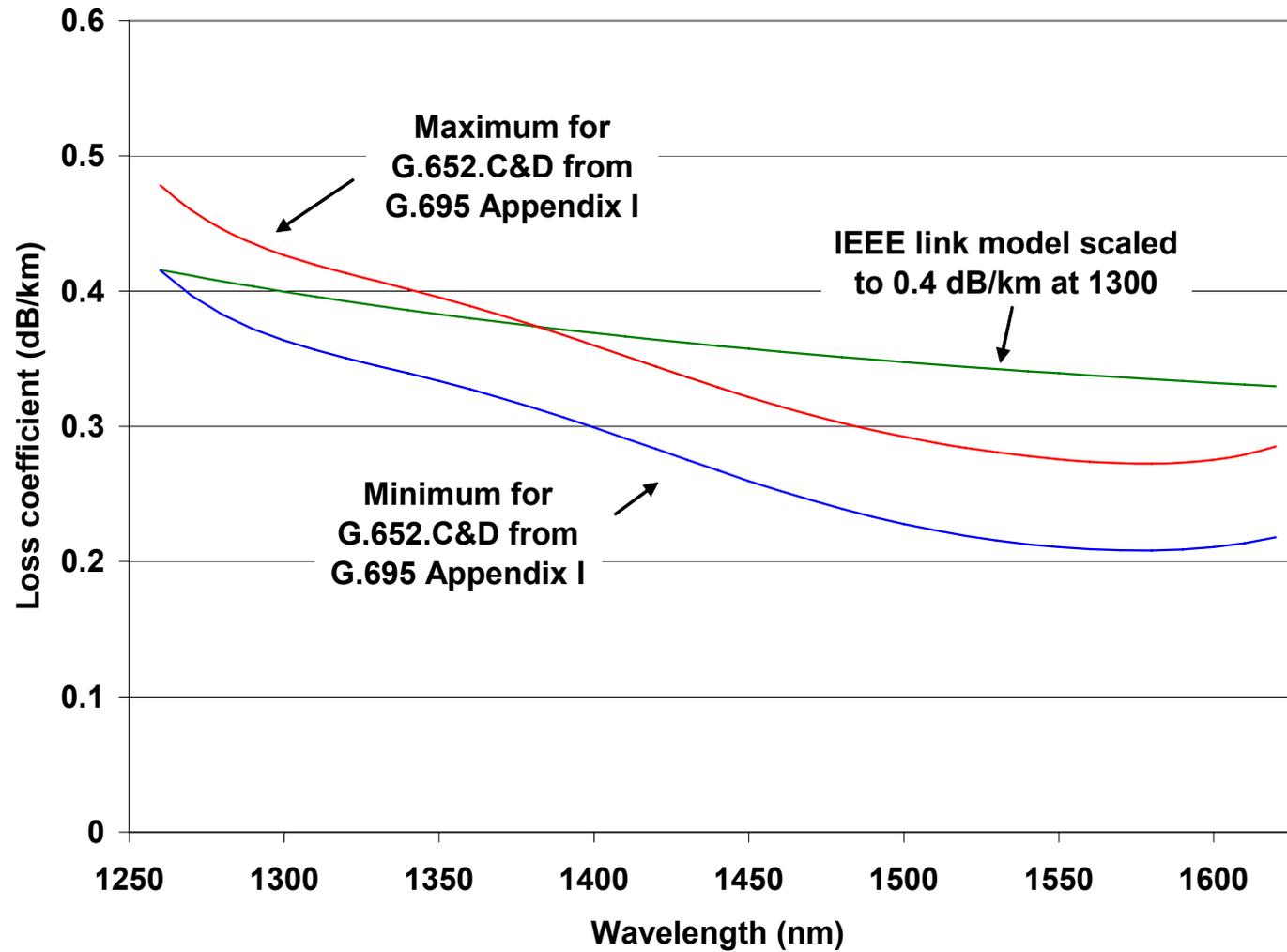
G.695 Appendix I data

The data in Appendix I/G.695 was generated from two data sets.

The first set includes the measurements of the loss difference for G.652 fibre (older samples with a water peak for G.652.A&B and newer low water peak fibre G.652.C&D) at various wavelengths compared to 1550 nm parameters.

The second set includes the measurements of end-to-end installed link loss at 1550 nm, carried out between 2003 and 2005 for 309 links from 9 different owners. All of the links in the data set were selected to be > 20 km in length to avoid connector losses at the ends from dominating the loss / unit length results.

The second data set is shown on the next slide together with red lines showing the 0.21 and 0.275 dB/km maximum and minimum values assumed by ITU-T which are at approximately the 10% and 90% points.

End-to-end link loss data at 1550 nm
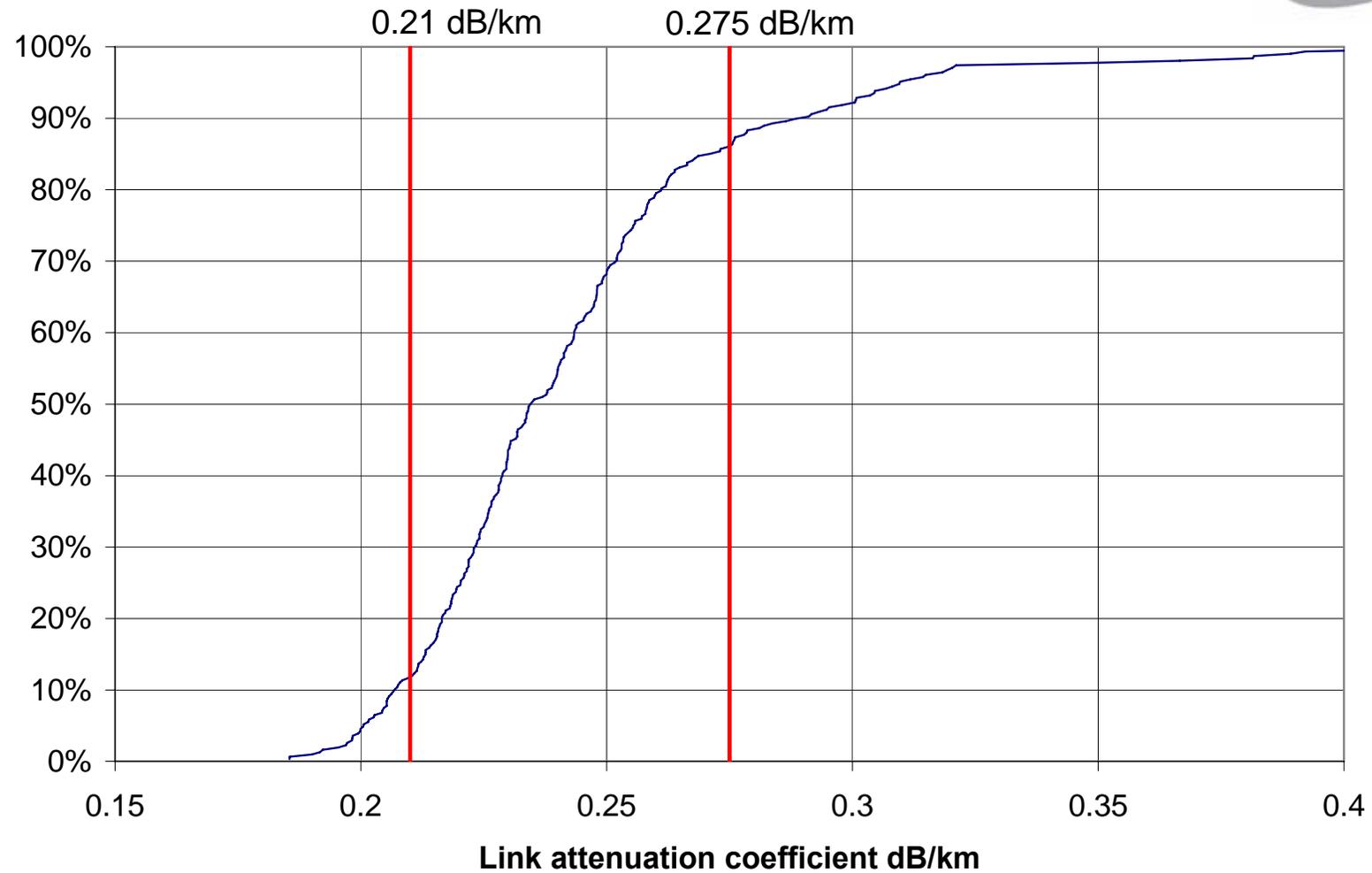
G. Supplement 39 data

An additional source of loss vs wavelength data can be found in [Supplement 39](#) to the G Series of ITU-T Recommendations Table 10-3.

This supplement provides measured loss vs wavelength data from one operator for the following cable batches:

- installed before 1990
- installed around 2000
- installed in 2003

The presented values **do not** include connector loss for cable ends.

The shape of the obtained curves (especially if shifted upwards to account for additional connector loss), however, agrees very well with the shape of the curves from G.695 Appendix I. See the following slide for the average loss curves (green lines).

One operator's data vs installation date
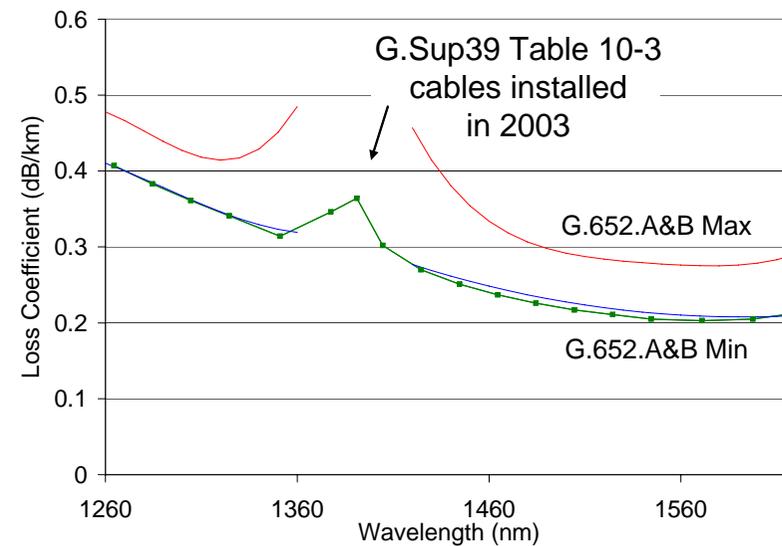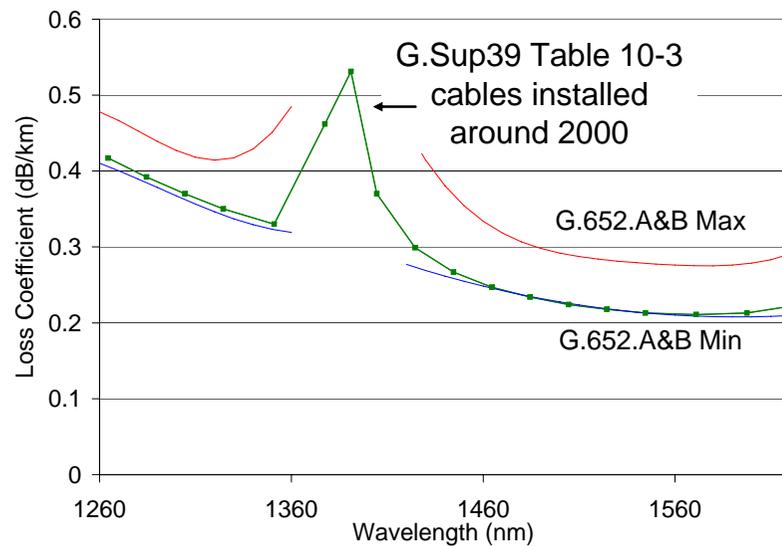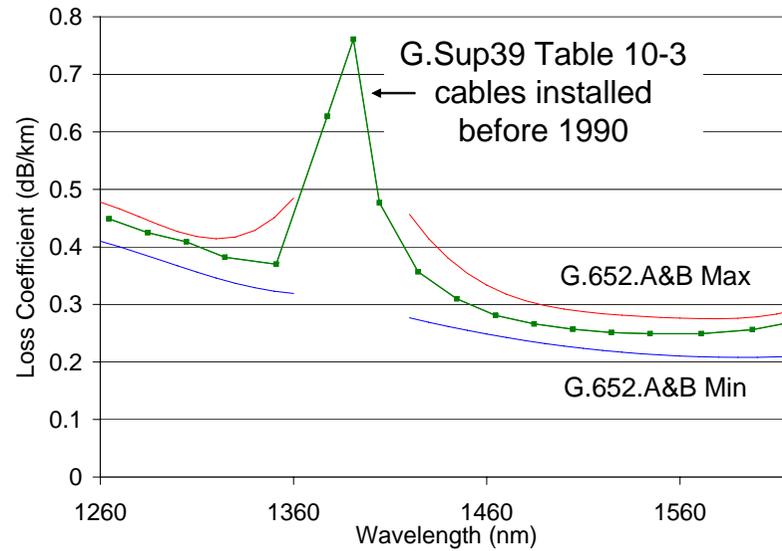
Non-linear effects in 10G EPON systems (1)

SBS in 10 Gb/s PON is a leading nonlinear impairment for the digital signal and will limit the achievable link budget (3av_0701_ten_1.pdf)

In a 1G EPON (IEEE 802.3-2005) the downstream digital traffic is carried in the 1490 nm window, while the CATV analog signal is broadcast in the 1550 nm window.

These signals lie within the Stokes shift of silica and therefore experience Raman interaction. The latter causes depletion of the digital signal which acts as a pump for the analog signal (3av_0701_ten_2.pdf).

Non-linear effects in 10G EPON systems (2) – SRS recap (1)

Coupled equations describe pump-signal interaction due to Raman effect ([3av_0701_ten_2.pdf](3av_0701_ten_2.pdf))

signal, 1550 nm

$$\frac{dP_s}{dz} = C_R P_s P_p - \alpha_s P_s$$

undepleted signal approximation

'pump', 1490 nm

$$\frac{dP_p}{dz} = -\frac{\lambda_s}{\lambda_p} C_R P_s P_p - \alpha_p P_p$$

Solution for undepleted signal application

Extra loss due to Raman effect

$$P_p(z) = P_{p0} \exp\left[-\frac{\lambda_s}{\lambda_p} C_R \frac{P_s(0)}{\alpha_s} \left(1 - e^{-\alpha_s z}\right) - \alpha_p z \right]$$

Non-linear effects in 10G EPON systems (2) – SRS recap (3)

Video channel: +20 dBm
Digital channel: -2 dB
Δ SRS penalty @ 20 km: 0.30885 dB
Δ fibre attenuation: 0.15 dB/km

Video channel: +10 dBm
Digital channel: -2 dBm
Δ SRS penalty @ 20 km: 0.03089 dB
Δ fibre attenuation: 0.15 dB/km

Non-linear effects in
10G EPON systems (2) – SRS recap (3)

Video channel: +20 dBm
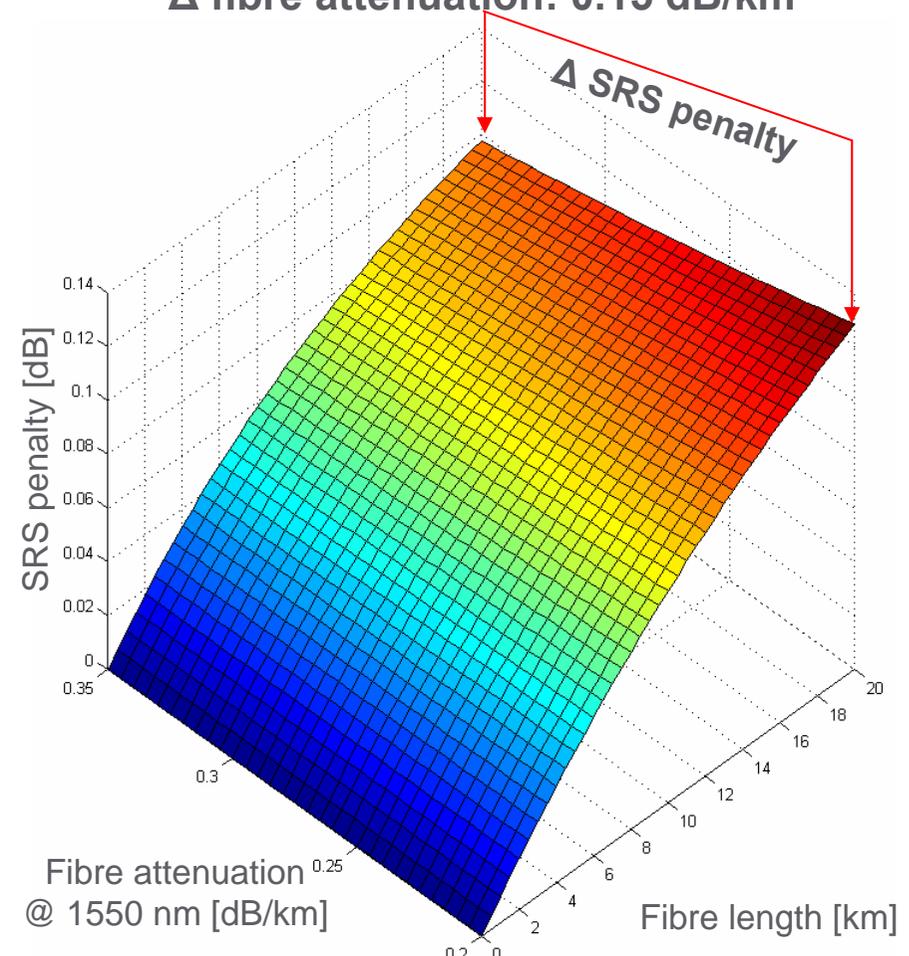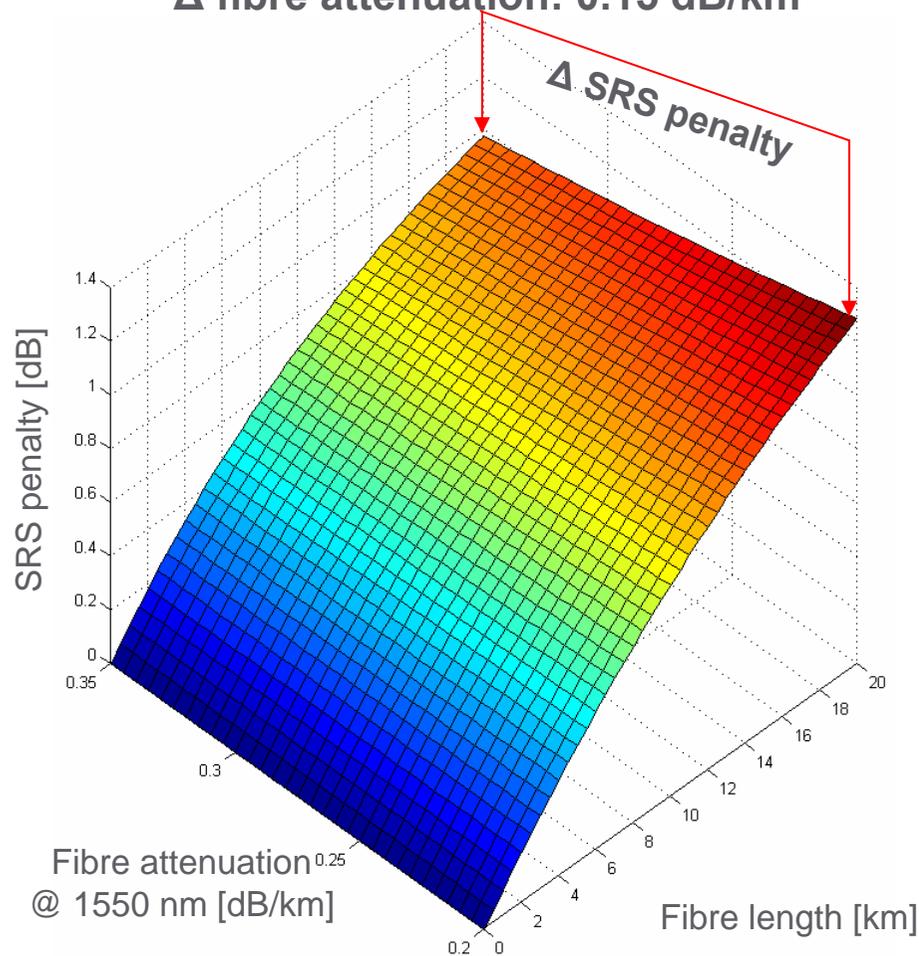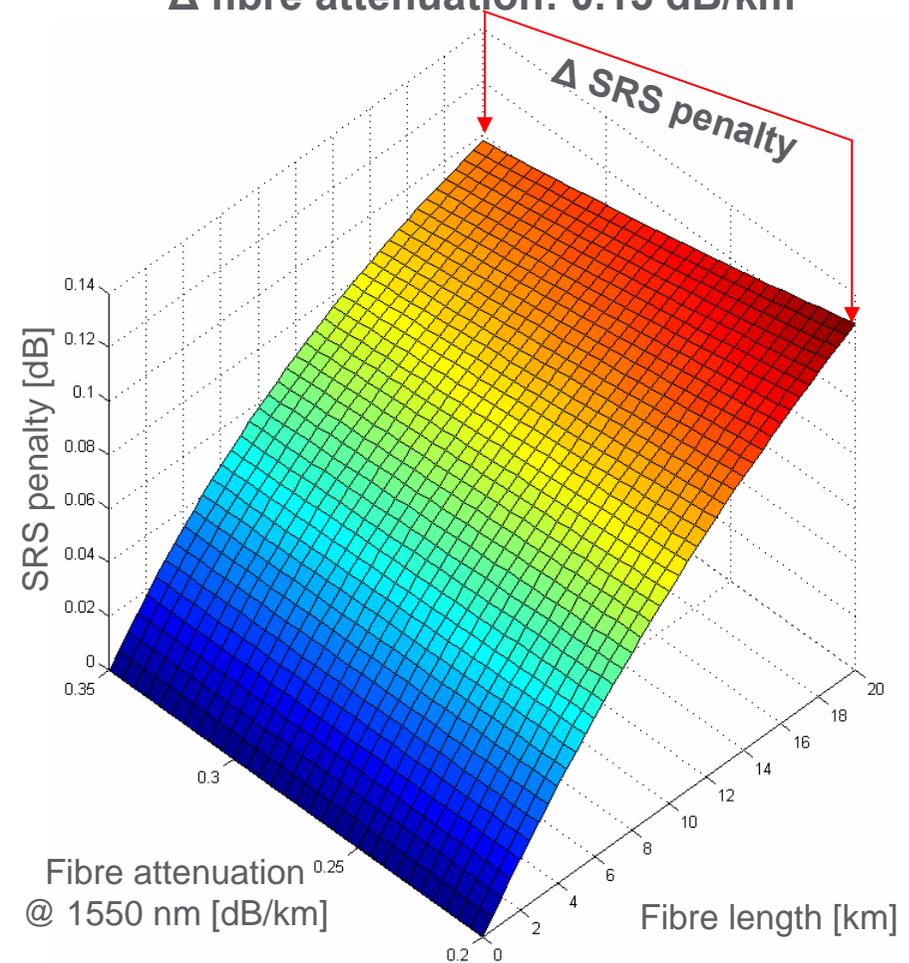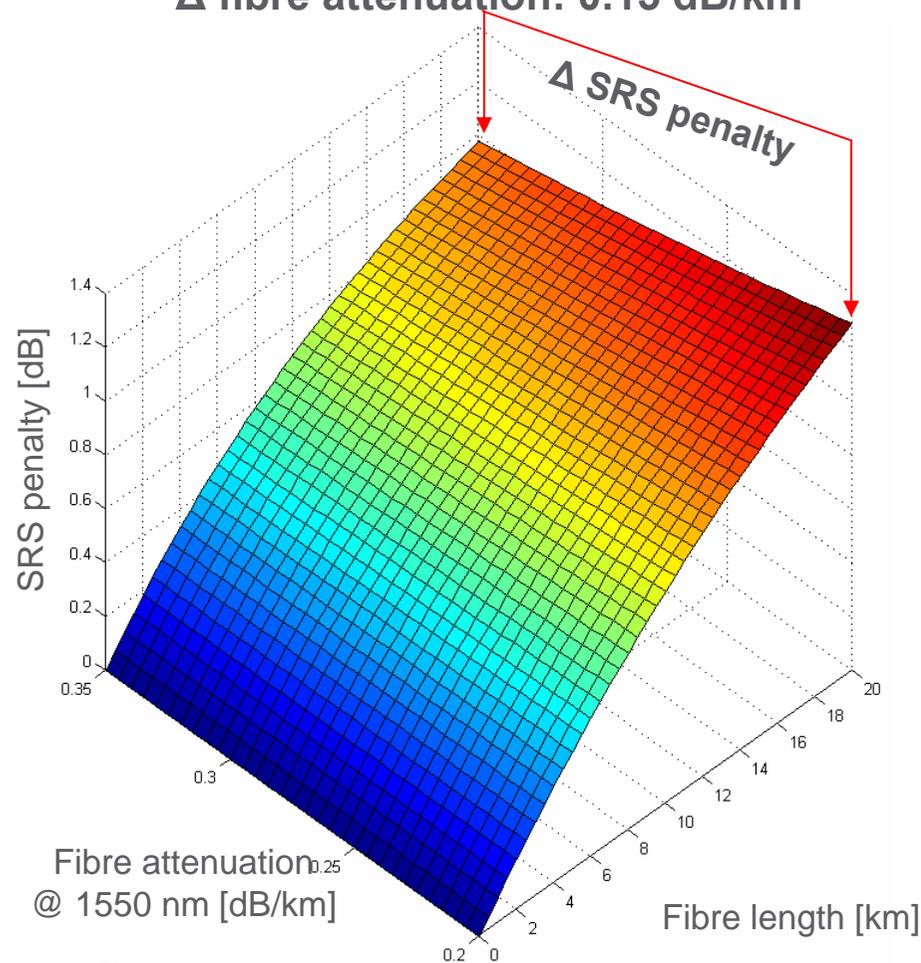**Digital channel: +5 dB**
Δ SRS penalty @ 20 km: 0.31059 dB
Δ fibre attenuation: 0.15 dB/km

Video channel: +10 dBm
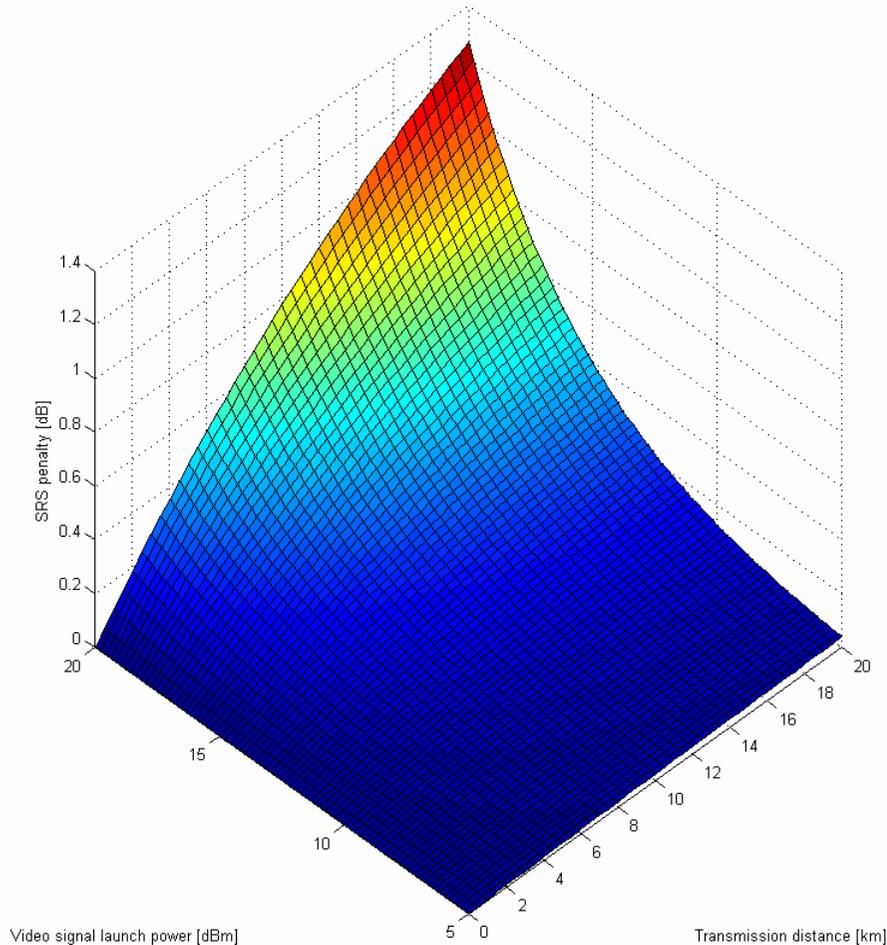**Digital channel: +5 dBm**
Δ SRS penalty @ 20 km: 0.03106 dB
Δ fibre attenuation: 0.15 dB/km

Non-linear effects in 10G EPON systems (2) – SRS recap (4)

SRS penalty for minimum fibre attenuation @ 1550 nm [+5dBm]

Video channel: +5 ... 20 dBm
Digital channel: +5 dBm
Fibre attenuation: 0.21063 dB/km (min. @ 1550 nm for G.652.C&D type fibre)
No PSC accounted for

Max SRS penalty @ 20 km = 1.2596 dB

SRS penalty depicted as absolute value, under worst case scenario conditions:
• minimum attenuation of 0.21063 dB/km
• +5 dBm digital signal launch power +20 dBm video signal launch power

Conclusions:
• under unfavourable conditions, SRS penalty can easily exceed 1 dB
• worst case scenario – low (minimum) fibre attenuation

Non-linear effects in 10G EPON systems (3) – SBS recap

Double-reflected power due to combined processes of SBS and Rayleigh backscattering (RBS) is calculated as (3av_0701_ten_1.pdf)

$$P_{SBS-RBS} = \frac{\sqrt{\pi}}{4} \rho \frac{\alpha_{RBS}}{\alpha} \frac{kTv_0 \Delta v_B}{v_{shift}} \frac{\left(1 - e^{-\alpha l}\right)e^A}{A^{3/2}} \left(2e^{-\alpha l} + \frac{1}{A}\right)$$

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

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

Non-linear effects in 10G EPON systems (4)

Both SBS and SRS depend on the material properties of the optical channel the signal propagates through

> How can we evaluate the impact of non-linear effects if the basic parameters of optical fibre (i.e. attenuation) are ill defined and do not match the installed ODN?

> We have to consider the worst case scenario attenuation figures for 1550 nm transmission window

> Is higher attenuation necessarily worse in this case?

> Probably not because the SRS and SBS intensity diminishes with the increase in the fibre attenuation value

> Should we use minimum fibre attenuation for non-linear effect estimation and maximum value elsewhere?

Conclusions

Since the loss vs. wavelength curves in Appendix I/G.695 covers G.652 fibre installed from before 1990 and also installed in 2003 and later and since it has been adjusted so that the maximum loss curve covers the measured losses of ~ 90% of recently measured installed end-to-end links, it seems worth capturing these loss values in an updated version of the spreadsheet anslow_02_0107.xls that was presented in Monterey.

The fibre loss equation in the link model spreadsheet predicts 0.34 dB/km at 1550 nm and 0.4 dB/km at 1300 nm, thus any attempt to use this equation for CWDM applications seems to be problematic.

Exact evaluation of non-linear effects and their impact on the 10G EPON transmission in the downstream channel requires worst case scenario fibre loss – we therefore need to use minimum attenuation values for nonlinear calculations and maximum attenuation for receiver power levels.

Thanks!

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