Fibre Formulas made simple

POWER BUDGET, LOSS BUDGET and NET OPTICAL POWER BUDGET

TXmin - represents the worst case transmit power for a device.
RXmin - represents the minimum amount of light required by the receiver.

The Power Budget

TX_{min} - RX_{min} = Power Budget *(i.e. +3dBm - -27dBm = 30dB)*

Loss values in dB are determined by subtraction of two dBm levels.

The Loss Budget

(Cable attenuation) *for example; 0.3 dB x 40 km* - ▸

+ (Splice attenuation x # of splices)

+ (Connector attenuation x # of connectors)

+ (Safety Margin)

= Total Loss dB

Without the cable attenuation!

$$\text{Distance} = \frac{\text{Power Budget - Loss budget}}{\text{Cable Attenuation dB/km}}$$

(for example; 0.3 dB/km)

Net Optical Power Budget

Net Optical Power Budget = (Power Budget dB) - (Loss Budget dB). Should the result be a negative number, the system will not operate. The ideal method in determining losses is of to measure your losses once the fibre has been installed…but of course, not practical for initial fibre design. This estimated Loss Budget will eventually be compared against the test source and power meter results obtained to gauge the quality of the installation.

SM commonly accepted loss values	
Mated Connector loss	0.5 dB
Typical cable attenuation at 1310nm	0.35 dB/km
Typical cable attenuation at 1550nm	0.22 dB/km
Typical splice attenuation	0.1 dB
Typical distance between splices	6 km
*Typical safety margin	3 dB

MM (50/125) commonly accepted loss values	
Mated Connector loss	0.5 dB
Typical cable attenuation at 850nm	3.5 dB/km
Typical cable attenuation at 1300nm	1.5 dB/km
Typical splice attenuation	0.1 dB
*Typical safety margin	3 dB

FTTH commonly accepted loss values	
WDM Head-end and CPE	0.8 dB
Splitter 1x4	7.3 dB
Splitter 1x8	10.5 dB
Splitter 1x16	14.0 dB
Splitter 1x32	17.5 dB
Splitter 1x64	20.6 dB
Splices	0.1 dB
Mated Connector loss	0.5 dB
Cable attenuation 1310nm	0.35 dB/km
Cable attenuation 1490nm	0.22 dB/km
Cable attenuation 1550nm	0.19 dB/km
*Safety margin	3 dB

Most system designers will add a safety margin of 3 to 10 dB

CALCULATING TOTAL CHROMATIC DISPERSION

When a pulse of light is made up of multiple wavelengths or colors, the pulse spreads because wavelengths arrive at differing intervals i.e. short wavelengths (1310nm) travel faster than long ones (1550nm) in +CD and longer wavelengths travel faster than short ones in -CD. Using fibre with a negative dispersion value, creating a reverse behavior of the velocity per wavelength… the effect of positive CD can be cancelled out.

Total CD = D_c **x** $\sigma\lambda$ **x L**

= 17 ps/nm.km x 0.1 nm x 50 km

= 85 ps total dispersion

D_c = *the dispersion coefficient (ps/nm.km)*

$\sigma\lambda$ = *transmitter source spectral width (nm)*

L = *the total fibre span (km)*

Transmitter Spectral Width (nm): The amount of the electromagnetic spectrum that a laser beam covers. Thus far, it has been impossible to produce light pulses with zero spectral width. For example, a 1540 nm pulse might cover 1539.9 to 1540.1 nm, but never dead on.
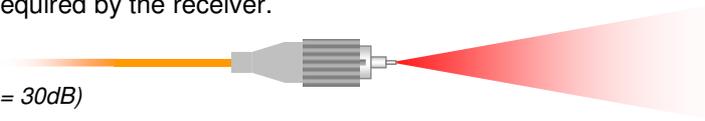
LED = 30 to 100 nm

Fabry-Perot = 3 to 20 nm

DFB = < 1 nm

0.1nm

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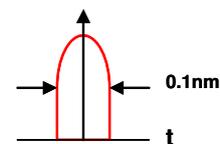
Bit rate	Max dispersion (ps/nm)
2.5 Gb/s	12,800
10 Gb/s	800 *16 x more sensitive than 2.5 Gb/s*
40 Gb/s	50 *16 x more sensitive than 10 Gb/s*

At 40 Gb/s (STM-256), the CD tolerances would be such that compensation will be required after only 4 km when deploying G.652 SM fibre… certainly is not a viable option

The maximum length of a link before being affected by CD is commonly established using the following calculation: Using 1550 nm externally modulated DFB lasers with a NRZ signal format, the "dispersion-limited distance" occurs approximately when: **B² x Dc x L = 104 000**

$$L = \frac{104,000}{D_c \times B^2}$$

104,000 = Max allowable CD in ps/nm with NRZ signals generated via an externally modulated laser source
L = Link distance in km.
Dc = Dispersion coefficient in ps/nm x km
B² = Bit rate in Gb/s

G.652 with a Dc of 17 ps/nm.km at 1550 =		
2.5 Gb/s	16,640 ps/nm	980 km
10 Gb/s	10,040 ps/nm	60 km
40 Gb/s	65 ps/nm	4 km

For G.652 fibre, the dispersion coefficient may vary from 16.9 to 18.2 ps/nm.km at 1550 nm. It is worth noting that for G.655 fibre, it may vary from only 2.6 to 6.0 ps/nm.km at 1550 nm.

CALCULATING POLARIZATION-MODE DISPERSION

At 2.5 Gb/s, PMD is not an issue. But at 10 Gb/s, it is a big issue and the issue gets even bigger at 40 Gb/s.

Let's examine how network planners can go about calculating the maximum allowable system PMD:

The difference between the arrival times of the two polarization modes is called differential group delay (DGD). DGD is measured in picoseconds (1 ps = 10^{-12} s). Modern fibre typically has a PMD value of around 0.2 ps / √km, whereas older fibre typically has a PMD of 1 - 2 ps / √km.

The Statistical Nature of PMD…as explained by clever people in white coats (I borrowed a white coat)
Oddly enough, we cannot refer to DGD per kilometer! Experiments show that the length of the fibre must be quadrupled for the average DGD to double and increased by a factor of 9 to triple it. OK, so if a 400km length of fibre is shortened to only 100km, DGD decreases to only 50% of its original value. Here's why; this somewhat odd behavior is a characteristic of random processes and can be summarized by saying that "your average DGD scales as the square root of the length of the fibre." Thus the PMD coefficient has units of ps / √km, or "ps per root km".

To keep PMD from causing errors, the DGD must be at most a small fraction of the time needed to transmit a single bit. **Formula: PMD x √km**

For a 2.5 Gb/s bit rate, the time to transmit a single bit is 1/2.5Gb/s = 0.4 ns/bit = 400 ps/bit. As a rule of thumb, the DGD must be kept to about 1/10 (10%) of this value i.e. 40 ps.

For a 10 Gb/s transmission rate, the DGD must thus be kept below 10 ps:	
PMD of 0.5 ps / √km and a 50 km length of fibre, the average DGD is **0.5 × √50 = 3.5 ps**	☺
PMD of 0.5 ps / √km and a 500 km length of fibre, the average DGD is **0.5 × √500 = 11.2 ps**	☹

Below…tolerable PMD coefficients and limits translated into fibre lengths:

Bit rate per channel	SDH	Bit time	* Max PMD limit	Max. Link Length		
				0.08 ps/√ km	0.2 ps/√ km	1 ps/√ km
2.5 Gb/s	STM-16	400 ps	40 ps	250,000 km	40,000 km	1,600 km
10 Gb/s	STM-64	100 ps	10 ps	15,000 km	2,500 km	100 km
40 Gb/s	STM-256	25 ps	2.5 ps	1,000 km	160 km	6 km

* Typically limited to 10% of the bit time

If the maximum PMD delay is known, the maximum admissible fibre length can be calculated:

The following formula can be applied:
L = Distance in km
B = Bit rate in Gb/s
PMD = Value in ps/√km

$$L = \frac{10^4}{(B \times PMD)^2}$$

Bit rate: 40 Gb/s
PMD: 0.2 ps / √km

$$\frac{10^4}{(40 \times .2)^2} = 156.25 \text{ km}$$