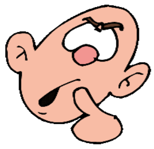
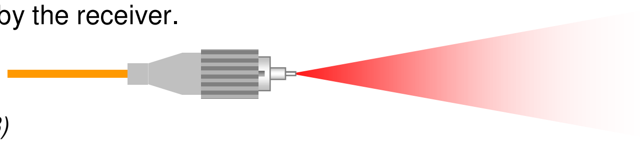
Fibre Formulas



Power Budget, Loss Budget and Net Optical Power Budget

TX min - represents the worst case transmit power for a device.
RX min - represents the minimum amount of light required by the receiver.



The Power Budget

TX min – **RX** min = Power Budget *(i.e. +3 dBm - -27 dBm = 30 dB)*

The Loss Budget

(Cable attenuation coefficient dB/km x distance)
\+ (Splice attenuation x # of splices)
\+ (Connector attenuation x # of connectors)
\+ (Safety Margin)
= Total Loss dB

(Minus total cable attenuation)

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

This distance is what is attainable with the Power Budget at one's disposal and our calculated Loss Budget.

Net Optical Power Budget

Net Optical Power Budget = (Power Budget) - (Loss Budget). If this result is a negative number, the system will not operate. The ideal method in determining losses is to measure your losses once the fiber has been installed, which of course, will not be practical for initial fiber 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.

MM (50/125) budgetary loss values	
Mated Connector loss	0.5 dB
Typical cable attenuation at 850nm	2.4 dB/km
Typical cable attenuation at 1300nm	1 dB/km
Typical splice attenuation	0.1 dB
Typical safety margin	3 dB

FTTH budgetary 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	0.3 dB/km
Cable attenuation 1490nm	0.22 dB/km
Cable attenuation 1550nm	0.2 dB/km
Safety margin	3 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)*

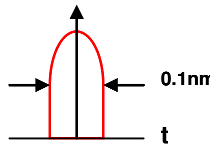
L *= the total fibre span (km)*

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



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

At 40 Gbps (STM-256), the CD tolerances would be such that compensation will be required after only 4 km when deploying G.652D 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: **B^2 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
B^2 = Bit rate in Gb/s

Note: Due to the emergence of next-generation modulation techniques, manufacturers are now able to overcome some previous distance limitations - therefore accept that the above formulas are based on the general acceptable industry norms i.e. an indication. If the exact CD limit (equipment and cable limit) is known the calculation would be as simple as:

$$L = \frac{\text{CD (equipment manufacturer's spec)}}{D_c \text{ (cable manufacturer's specs)}}$$

G.652D with a Dc of 17 ps/nm.km at 1550 =		
2.5 Gbps	16,640 ps/nm	980 km
10 Gbps	10,040 ps/nm	60 km
40 Gbps	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 as low as 2.6 to 6.0 ps/nm.km at 1550 nm.

Calculating Polarization-Mode Dispersion

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

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

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 coefficient value of around 0.2 ps / √km, whereas older fibre typically has a PMD coefficient of 1 - 2 ps / √km.

The Statistical Nature of PMD… as explained by clever people in white coats
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 (coefficient) **x √km**

For a 2.5 Gbps bit rate, the time to transmit a single bit is 1/2.5Gbps = 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 Gbps transmission rate, the DGD must thus be kept below 10 ps:	
PMD coefficient of 0.5 ps / √km and a 50 km length of fibre, the average DGD is **0.5 × √50 = 3.5 ps**	☺
PMD coefficient 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:

* Typically limited to 10% of the bit time				**Max. Link Length**		
Bit rate per channel	**SDH**	**Bit time**	*** Max DGD limit**	**0.08 ps/√ km**	**0.2 ps/√ km**	**1 ps/√ km**
2.5 Gbps	STM-16	400 ps	40 ps	250,000 km	40,000 km	1,600 km
10 Gbps	STM-64	100 ps	10 ps	15,000 km	2,500 km	100 km
40 Gbps	STM-256	25 ps	2.5 ps	1,000 km	160 km	6 km

If the maximum DGD 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 Gbps
PMD = Value in ps/√km

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

Bit rate: 40 Gbps
PMD: 0.2 ps / √km

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