

# TAP APPLICATION NOTE LINK LOSS BUDGET ANALYSIS

WHITE PAPER

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**CUBRO**  
NETWORK VISIBILITY

## Table of Contents

Basic Information .....	3
Link Loss Budget Analysis .....	3
Singlemode vs. Multimode .....	3
Dispersion vs. Attenuation.....	4
The Link Budget Analysis (LBA) .....	5
LBA Elements and their Influence.....	5
Fiber Losses.....	6
Splice Losses.....	6
Complete Passive System Loss .....	6
Active System Margin.....	6
The final LBA .....	7
Verification of the LBA.....	7
Integration of a TAP into an optical Link .....	8

## Basic Information

### Link Loss Budget Analysis

Loss budget analysis (LBA) is the basic calculation and verification method of a fiber optic link or system. It takes into account not only the physical properties of the used fiber but also the physical influences of connectors, routing and other fiber losses. Fiber attenuation and bandwidth are key parameters for the analysis. LBA is the appropriate way to ensure link safety for any optical link.

### Singlemode vs. Multimode

The basics of single- and multimode fibers are assumed to be known. What will be presented in this paper is the influence of the fiber type on the LBA and the necessary precautions that have to be taken into account.

Multimode and Singlemode fibers are the two common types of fiber. Both fibers have 125 microns outside diameter. Multimode fibers have a core diameter of 62.5 microns, allowing the light to travel in many rays, called modes. They are used at wavelengths of 850 and 1300 nm.

Singlemode fibers have a much smaller core of only 9 microns diameter. Light can travel in only one ray. It is used at wavelengths of 1300 and 1550 nm. Multimode fibers exist in two designs: Step index multimode or graded index multimode. Step index multimode was the first fiber design with two different refraction indices. It was too slow for most uses, due to the high dispersion caused by the different path lengths of the various modes. Step index fiber is not common any more.

Graded index multimode fiber uses continuous variation of the refraction index inside the core to compensate for the different path lengths of the modes. It offers hundreds of times more bandwidth than step index fiber. It is the common multimode fiber today. The different fiber types are shown in figure 1-1.

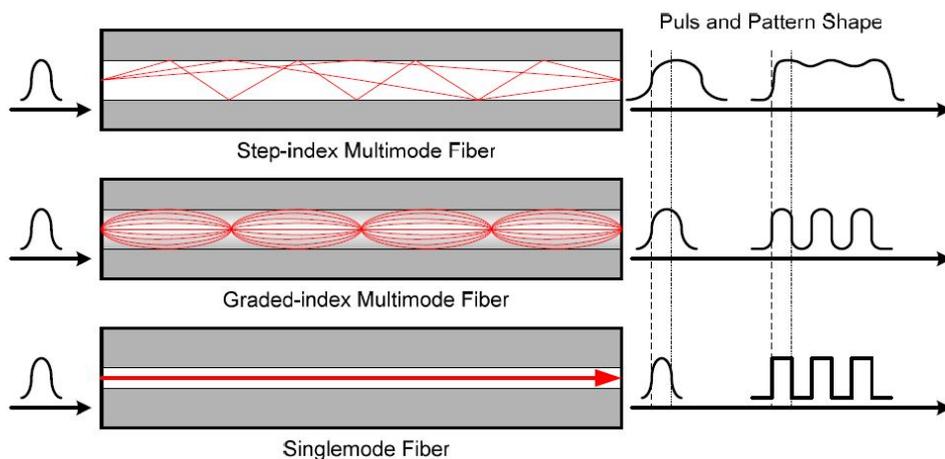


Figure 1-1: Different Fiber Types and their Dispersion

## Dispersion vs. Attenuation

Figure 1-1 shows the multiple modes (directions) the light can take in different fiber types. Since the length of different modes is very different in step index fibers, each pulse sent through a step index fiber gets heavily distorted. Some components (modes) are transmitted fast, some slow. This limits the maximum speed of continuous bits patterns, or in other words: Dispersion is a bandwidth limit. For a certain length of the fiber (mode delay) only a certain maximum frequency can be transmitted.

A graded index fiber lacks also the disadvantages of mode dispersion, but due to the continuous variation of the refraction index from the core center to the core outside the performance gets a lot better. The 'longer' modes on the outside are traveling in a faster medium and the whole mode distribution is a lot better controlled inside the graded index fiber.

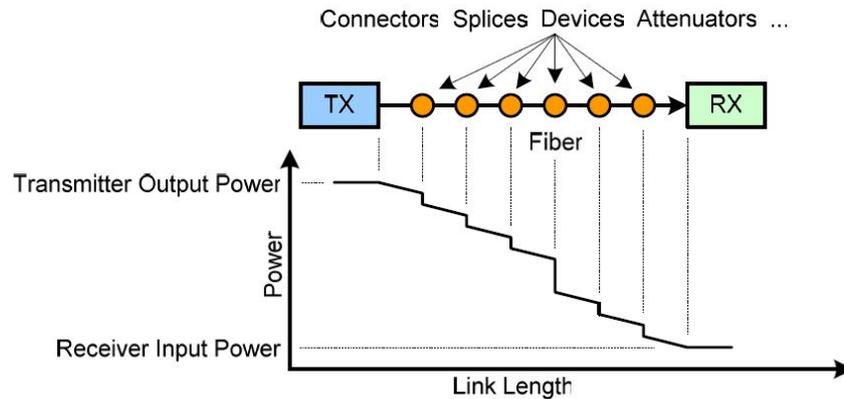
Inside the singlemode fiber is only one mode active and therefore the singlemode fiber bandwidth is far greater than any other fiber type. The big disadvantage of the singlemode fiber is the small core diameter. To ensure single mode behavior it is necessary to reduce the core diameter down to 9 microns. This is a problem for any kind of connector, connector reliability and for influences of dirt or dust.

Singlemode fiber connectors need a lot of attention during handling. Basically, they have a better connection ratio (less attenuation) than multimode connectors (due to the singlemode optical field). But even small amounts of dirt can bring excessive attenuation in singlemode systems.

Whereas in multimode systems is the influence of dirt and connector quality less important. The optical contact area of a multimode fiber (62.5 micron core) is nearly 50 times larger than a core area of a singlemode fiber. The general rule says that for short connections and for often reconfigured connections a multimode system is easier to handle. On the other hand, a singlemode system might be the only choice for wide range links.

## The Link Budget Analysis (LBA)

For a link budget analysis (LBA), both the passive and active components of the link have to be included in the calculation. Passive loss components are: Fiber loss, connector or splice loss, coupler loss or splitters inside the link. Active components are: System gain, transmitter power, receiver sensitivity (dynamic range).



**Figure 2-1: Link Budget Analysis**

Figure 2-1 shows a typical LBA diagram. The link consists of the optical transmitter. This transmitter emits a certain optical power (launch power). This optical power is attenuated with each length of fiber (slopes) and with each element within the link (vertical steps).

For every LBA there are two limiting factors which have to be taken into account, the attenuation of the whole link and the dispersion (bandwidth) of the whole link. Both parameters have to be within the specifications for the used transmitter and receiver.

### LBA Elements and their Influence

In the following chapters are the values collected which are stated by the EIA/TIA for different fibers or link elements. Especially for fibers another effect should not be forgotten. The fiber behaves different for different light sources. If the fiber is used with an LED then there are a lot of modes stimulated (wide optical bandwidth) and the angle of the entering light is also wide. This situation is called 'overfilled launch' (OFL). The OFL specifications of a fiber are good indicators on the performance of a fiber with LED illumination.

For high data rate systems (1Gbps) is the use of laser diodes instead of an LED necessary. This laser diode (VCSEL, Vertical Cavity Surface Emitting Laser) has a very narrow spectrum and a very small aperture (distinct direction). With such a light source only a narrow spot in the center of the fiber is illuminated (23.5 micron diameter states the standard definition). With this narrow spot illumination only a subset of modes are stimulated inside the fiber. This reduces the effects of dispersion and improves the performance of the multimode fiber. Since the use of a laser diode is obvious for high data rates a second standard for the launch condition is derived. It is called 'Restricted Mode Launch' (RML). All specifications based on the RML are a good indicator on the performance of a fiber with a laser diode.

### Fiber Losses

The EIA/TIA 568 standard states the following values: typical and [maximum]

Fiber Type	Multimode		Singlemode	
	850	1300	1300	1550
Wavelength (nm)	850	1300	1300	1550
Fiber Atten.(dB/km)	3 [3.5]	1 [1.5]	0.4 [1]	0.3 [1]
Bandwidth (MHz·km)	220[160]	550[500]	NA	NA

### Connector Losses

The standard states the following values: typical and [maximum]

	Multimode		Singlemode	
	850	1300	1300	1550
Wavelength (nm)	850	1300	1300	1550
Attenuation (dB)	0.3 [0.75]	0.3 [0.75]	0.2 [0.75]	0.2 [0.75]

### Splice Losses

The standard states values in the following range: typical and [maximum]

	Multimode		Singlemode	
	850	1300	1300	1550
Wavelength (nm)	850	1300	1300	1550
Attenuation (dB)	0.2 [0.3]	0.2 [0.3]	0.1 [0.3]	0.1 [0.3]

### Complete Passive System Loss

When all connectors and the complete fiber system is taken into account then the total passive attenuation and bandwidth can be calculated.

For example, for a multimode gigabit link of 100 meters and 4 connectors, 0 splices for 850nm the estimation shows 0.3dB [0.35dB] fiber attenuation and 4 times 0.3dB [0.75dB] connector attenuation. This gives a total of 1.5dB [3.35dB] attenuation.

For the dispersion calculation, the maximum length for gigabit would be 220m [160m] as stated in the standards (e.g. TIA-568-C.3).

### Active System Margin

The next step for a complete LBA is the calculation of the active system margin. The transmitter has a certain optical launch power stated in the datasheet. The launch power for a 850nm multimode transmitter is typical > -10dBm (typical -8dBm). On the other end of the link there is the receiver sensitivity. This value indicates the minimal necessary optical power for correct reception of the optical signal. A typical value for an 850nm transceiver would be -19dBm. This gives a dynamic range of around 10dB for the link (minimum -9dB). Since it is not recommended to use the whole dynamic range a certain safety margin should be considered for an optical link. Transmitter aging, connector degrading and other influences might cost another 1-3dB of optical power in the future.

## The final LBA

For the complete LBA the active system margin gives room for optical link attenuation. The link budget analysis compares the optical attenuation by the passive components with the dynamic margin of the transmitter and receiver components.

For the given example, the passive attenuation would be 0.9-1.8dB and the active dynamic range would be >9dB. This gives more than 7dB link budget margin for the complete optical connection with 100 meters.

All values are treated as rough estimations. On one hand is the transmitter performance improving (e.g. RML allows longer connections due to better dispersion performance). On the other hand, a conservative point of view is always better when a safety margin is evaluated. Any device located inside an optical link has to be taken into account. In the following example a Cubro Test Access Port (TAP) is included into a multimode link. Details on the influence and the performance of a TAP can be found in the following chapter.

LBA for an 850nm optical link:  
100m multimode (62.5 micron), 4 connectors, 0 splices, TAP

Active launch condition:	
Optical launch power (dBm)	-10.0dBm
Passive attenuation components:	
Fiber Attenuation 100m	-0.3dB
Connector Attenuation (4 Connections per Fiber)	-1.2dB
TAP insertion loss	-3.0dB
Additional Connectors (2 per TAP)	-0.6dB
Optical power at receiver input:	-15.1dBm
Sensitivity of optical receiver:	-19.0dBm
Link budget margin:	3.9dB

## Verification of the LBA

During design time it is necessary to estimate all influencing factors for the LBA. When the link is realized the optical budget can be measured on the receiver side. For a reliable operation of an optical link the minimum optical input power of the receiver should never be reached under all operating conditions.

## Integration of a TAP into an optical Link

For high quality data links the use of test access ports is common. With a TAP it is possible to continuously monitor the performance of a link. Excessive bit errors or retransmits can be detected any time even in a 24/7 load condition. Furthermore, it is possible to diagnose the exact problem without any further disturbance to the system. Any expensive measurement devices can be flexibly connected to any link and the maintenance work during a maintenance time-slot can be optimized in advance.

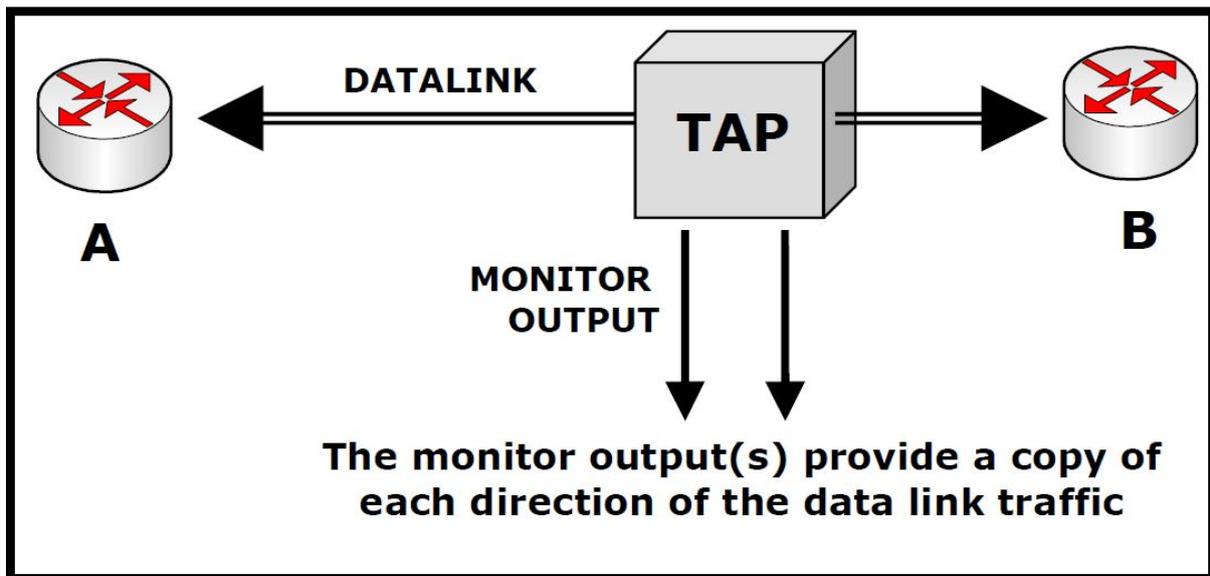


Figure 3-1: Typical Application of a TAP

Since a TAP presents a network element, it has to be included into the LBA. Generally, it is common to split the optical signal inside a TAP. To get maximum flexibility it is common to split the optical power at a 50% ratio. This means that the TAP introduces around 3dB attenuation into the system.

For 850nm multimode systems this is usually not a problem since the length of the link is mainly limited by the optical dispersion. For the described link (100m, 850nm, 4 connectors) the passive attenuation was 1.5 [3.3dB]. With an additional 3dB of the TAP the total passive attenuation at 4.5dB [6.3dB] is well beyond the 11dB [9dB] safety margin.

The TAP only introduces attenuation and no modal dispersion. This means that the modal dispersion influenced limits (220m [160m] bandwidth for gigabit) are not compromised by the use of a TAP.

Furthermore, it is possible to optimize a TAP for a certain link budget if this gets necessary in a special situation. Since the transceiver situated in the optical link have basically the same sensitivity than the receiver on the monitor side of a TAP it is useful to start with a 3dB TAP (50:50). If special equipment on the monitor side of a TAP allows better sensitivity than common receivers then it is possible to tune the TAP for this situation.