Calculating Fiber Loss and Distance Estimates

There are a number of ways to tackle the problem of determining the power requirements for a particular fiber optic link. The easiest and most accurate way is to perform an Optical Time Domain Reflectometer (OTDR) trace of the actual link. This will give you the actual loss values for all events (connectors, splices and fiber loss) in the link. In the absence of an actual OTDR trace, there are two alternatives that can be used to estimate the power requirements of the link:

1. Estimate the total link loss across an existing fiber optic link if the fiber length and loss variables are known.

2. Estimate the maximum fiber distance if optical budget and loss variable are known.

Loss variables are connectors, splices and attenuation per kilometer of the fiber. If actual values for all of the loss variables are not known, an estimation for each is needed to complete the calculations. In this case, one would want to take a worst case approach to assure that there is adequate power available for the link. The following table includes commonly accepted loss values used in these calculations:

Fiber Type	Wavelength	Fiber attenuation / km *	Fiber attenuation / km #	Connector Loss	Splice Loss
Multimode 50/125µm	850nm	3.5 dB	2.5 dB	0.75 dB	0.1 dB
	1300nm	1.5 dB	0.8 dB	0.75 dB	0.1 dB
Multimode 62.5/125µm	850nm	3.5 dB	3.0 dB	0.75 dB	0.1 dB
	1300nm	1.5 dB	0.7 dB	0.75 dB	0.1 dB
Single Mode 9µm	1310nm	0.4 dB	0.35 dB	0.75 dB	0.1 dB
Single Mode 9µm	1550nm	0.3 dB	0.22 dB	0.75 dB	0.1 dB

**These values are per TIA/EIA and other industry specifications and are the values used by Transition Networks in all link loss calculations.*

#These values are one example of the performance that can be obtained with a new fiber installation.

The IEEE also recommends maximum cable distances as defined in the table below:

Standard	Data Rate (Mbps)	Cable Type	IEEE Standard Distance
10BASE-FL	10	850nm Multimode 50/125µm or 62.5/125µm	2 km
100BASE-FX	100	1300nm Multimode 50/125µm or 62.5/125µm	2 km
100BASE-SX	100	850nm Multimode 50/125µm or 62.5/125µm	300 m
1000BASE-SX	1000	850nm Multimode 50/125µm	550 m
		850nm Multimode 62.5/125µm	220 m
1000BASE-LX	1000	1300nm Multimode 50/125µm or 62.5/125µm	550 m
		1310nm Single mode 9/125µm	5 km
1000BASE-LH	1000	1550nm Single mode 9/125µm	70 km

Estimate Total Link Loss

This calculation will estimate the total link loss through a particular fiber optic link where the fiber length, as well as the number of splices and connectors, are known. This calculation is simply the sum of all worst-case loss variables in the link:

Link Loss = [fiber length (km) x fiber attenuation per km] + [splice loss x # of splices] + [connector loss x # of connectors] + [safety margin]

For example: Assume a 40 km single mode link at 1310nm with 2 connector pairs and 5 splices.

Link Loss = [40km x 0.4dB/km] + [0.1dB x 5] + [0.75dB x 2] + [3.0dB] = 21.0dB

In this example, an estimated 21.0 dB of power would be required to transmit across this link. Of course, it is very important to measure and verify the actual link loss values once the link is established to identify any potential performance issues.

Estimate Fiber Distance

This calculation will estimate the maximum distance of a particular fiber optic link given the optical budget and the number of connectors and splices contained in the link:

$$\text{Fiber Length} = \frac{[\text{Optical budget}] - [\text{link loss}]}{[\text{fiber loss/km}]}$$

Fiber Length = {[(min. TX PWR) - (RX sensitivity)]
- [splice loss x # of splices]
- [connector loss x # of connectors]
- [safety margin]}
÷ [fiber lost/km]

For example: Assume a Fast Ethernet Single mode link at 1310nm with 2 connector pairs and 5 splices.

$$\text{Fiber Length} = \frac{[(-8.0\text{dB}) - (-34.0\text{dB})] - [0.1\text{dB} \times 5] - [0.75\text{dB} \times 2] - [3.0\text{dB}]}{[0.4\text{dB/km}]}$$

$$\text{Fiber Length} = \frac{[26.0\text{dB}] - [0.5\text{dB}] - [1.5\text{dB}] - [3.0\text{dB}]}{[0.4\text{dB/km}]} = 52.5\text{ km}$$

In this example, an estimated 52.5 km distance is possible before dissipating the optical power to a value below the Rx sensitivity. As always, it is very important to measure and verify the actual link loss values once the link is established to identify any potential performance issues. Actual maximum distances will very depending on:

- Actual optical fiber attenuation per km
- Optical fiber design and age
- Quality of connectors and actual loss per pair
- Quality of splices and actual loss per splice
- Quantity of splices and connectors in the link

Calculating Fiber Optic Loss Budget

Criteria & Calculation Factors

Design of a fiber optic system is a balancing act. As with any system, you need to set criteria for performance and then determine how to meet those criteria. It's important to remember that we are talking about a system that is the sum of its parts.

Calculation of a system's capability to perform is based upon a long list of elements. Following is a list of basic items used to determine general transmission system performance:

- Fiber Loss Factor – Fiber loss generally has the greatest impact on overall system performance. The fiber strand manufacturer provides a loss factor in terms of dB per kilometer. A total fiber loss calculation is made based on the distance x the loss factor. Distance in this case the total length of the fiber cable, not just the map distance.
- Type of fiber – Most single mode fibers have a loss factor of between 0.25 (@ 1550nm) and 0.35 (@ 1310nm) dB/km. Multimode fibers have a loss factor of about 2.5 (@ 850nm) and 0.8 (@ 1300nm) dB/km. The type of fiber used is very important. Multimode fibers are used with L.E.D. transmitters which generally don't have enough power to travel more than 1km. Single mode fibers are used with LASER transmitters that come in various power outputs for "long reach" or "short reach" criteria.
- Transmitter – There are two basic type of transmitters used in a fiber optic systems. LASER which come in three varieties: high, medium, and low (long reach, medium reach and short reach). Overall system design will determine which type is used. L.E.D. transmitters are used with multimode fibers, however, there is a "high power" L.E.D. which can be used with Single mode fiber. Transmitters are rated in terms of light output at the connector, such as -5dB. A transmitter is typically referred to as an "emitter".
- Receiver Sensitivity – The ability of a fiber optic receiver to see a light source. A receiving device needs a certain minimum amount of received light to function within specification. Receivers are rated in terms of required minimum level of received light such as -28dB. A receiver is also referred to as a "detector".
- Number and type of splices – There are two types of splices. Mechanical, which use a set of connectors on the ends of the fibers, and fusion, which is a physical direct mating of the fiber ends. Mechanical splice loss is generally calculated in a range of 0.7 to 1.5 dB per connector. Fusion splices are calculated at between 0.1 and 0.5 dB per splice. Because of their limited loss factor, fusion splices are preferred.
- Margin – This is an important factor. A system can't be designed based on simply reaching a receiver with the minimum amount of required light. The light power budget margin accounts for aging of the fiber, aging of the transmitter and receiver components, addition of devices along the cable path, incidental twisting and bending of the fiber cable, additional splices to repair cable breaks, etc. Most system designers will add a loss budget margin of 3 to 10 dB

Calculating a "Loss Budget"

Let's take a look at typical scenario where a fiber optic transmission system would be used.

Two operation centers are located about 8 miles apart based on map distance. Assume that the primary communication devices at each center is a wide area network capable router with fiber optic communication link modules, and that the centers are connected by a fiber optic cable. The actual measured distance based on walking the route , is a total measured length (including slack coils) of 9 miles. There are no additional devices installed along the cable path. Future planning provides for the inclusion of a freeway management system communication link within 5 years.

Note: All distance measurements must be converted to kilometers. Fiber cable is normally shipped with a maximum reel length of 15,000 feet (or 4.5km). 9 miles is about 46,000 feet or 14.5km. Assume that this system will have at least 4 mid-span fusion splices.

Table 11-2: Fiber Loss Budget Calculation

Fiber Loss	14.5 km × 35dB = -5.075
Fusion splice Loss	4 × .2dB = -.8
Terminating Connectors	2 × 1.0dB = -2.0
Margin	-5.0
Total Fiber Loss	-12.875

The manufacturer of the router offers three transmitter/receiver options for single mode fiber:

Reach	**Transmit Power**	**Receiver Sensitivity**
Short	-3dBm	-18dBm
Intermediate	0dBm	-18dBm
Long	+3dBm	-28dBm

To determine the correct power option add the transmit power to the fiber loss calculation.

Reach	**Transmit Power**	**Fiber Loss**	**Loss Budget**
Short	-3	-12.875	-15.875
Intermediate	0	-12.875	-12.875
Long	+3	-12.875	-9.875

Compare this to the receiver sensitivity specification

Reach	**Receiver Sensitivitiy**	**Loss Budget**	**Difference**
Short	-18	-15.875	+3.0
Intermediate	-18	-12.875	+6.0
Long	-28	-9.875	+19.0

Because a loss margin of 5.0dB was included in the fiber loss calculation, the short reach option will provide sufficient capability for this system. In fact, the total margin is 8.0db because the difference between the loss budget and receiver sensitivity is 3.0db.