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Introduction to Optical Fibers, dB, Attenuation and Measurements

Introduction

This document is a quick reference to some of the formulas and important information that are useful in understanding optical technologies. It focuses on decibels (dB), decibels per milliwatt (dBm), attenuation and measurements, and provides an introduction to optical fibers.

Prerequisites

This document has no specific prerequisites.

Hardware and Software Versions

The information in this document is not based on specific software or hardware versions.

The information presented in this document was created from devices in a specific lab environment. All of the devices used in this document started with a cleared (default) configuration. If you are working in a live network, ensure that you understand the potential impact of any command before using it.

What is a Decibel?

A decibel (dB) is a unit used to express relative differences in signal strength. A decibel is expressed as the base 10 logarithm of the ratio of the power of two signals:

$$dB = 10 \times Log_{10} (P1/P2)$$

where Log_{10} is the base 10 logarithm, and P1 and P2 are the powers to be compared.

Note: Log_{10} is different from the Neparian Logarithm (Ln or LN) base e logarithm.

Signal amplitude can also be expressed in dB. Since power is proportional to the square of a signal's amplitude, dB is expressed as follows:

$$dB = 20 \times Log_{10} (V1/V2)$$

where V1 and V2 are the amplitudes to be compared.

1 Bell (not currently used) = Log_{10} (P1/P2)

1 decibel (dB) = 1 Bell / 10 = 10 * Log_{10} (P1/P2)

dBr = dB (relative) = dB = 10 * Log_{10} (P1/P2)

Base 10 Logarithm Rules
Log_{10} (AxB) = Log_{10} (A) + Log_{10} (B)
Log_{10} (A/B) = Log_{10} (A) − Log_{10} (B)
Log_{10} (1/A) = − Log_{10} (A)
Log_{10} (0,01) = − Log_{10} (100) = −2
Log_{10} (0,1) = − Log_{10}(10) = − 1
Log_{10} (1) = 0
Log_{10} (2) = 0,3
Log_{10} (4) = 0,6
Log_{10} (10) = 1
Log_{10} (20) = 1,3 *Log_{10} (2 x 10) = Log_{10} (2) + Log_{10} (10) = 1 + 0,3*
Log_{10} (100) = 2
Log_{10} (1 000) = 3
Log_{10} (10 000) = 4

dB

Logarithm and dB (decibel)	
Power Ratio	**dB = 10 x Log_{10} (Power Ratio)**
AxB	x dB = 10 x Log_{10}(A) + 10 x Log_{10}(B)
A/B	x dB = 10 x Log_{10}(A) − 10 x Log_{10}(B)
1/A	x dB = + 10 x Log_{10} (1/A) = − 10 x Log_{10} (A)
0,01	− 20 dB = − 10 x Log_{10}(100)
0,1	− 10 dB = 10 x Log_{10} (1)
1	0 dB = 10 x Log_{10} (1)
2	3 dB = 10 x Log_{10} (2)
4	6 dB = 10 x Log_{10} (4)
10	10 dB = 10 x Log_{10} (10)

20	13 dB = 10 x (Log_{10} (10) + Log_{10} (2))
100	20 dB = 10 x Log_{10} (100)
1 000	30 dB = 10 x Log_{10} (1 000)
10 000	40 dB = 10 x Log_{10} (10 000)

Decibels in Milliwatts (dBm)

dBm = dB milliwatt = 10 x Log_{10} (Power in mW / 1 mW)		
Power	**Ratio**	**dBm = 10 x Log_{10} (Power in mW / 1 mW)**
1 mW	1 mW / 1 mW = 1	0 dBm = 10 x Log_{10} (1)
2 mW	2 mW / 1 mW = 2	3 dBm = 10 x Log_{10} (2)
4 mW	4 mW/1mW=4	6 dBm = 10 x Log_{10} (4)
10 mW	10 mW/1mW=10	10 dBm = 10 x Log_{10} (10)
0,1 W	100 mW/1mW=100	20 dBm = 10 x Log_{10} (100)
1 W	1000 mW/1mW=1000	30 dBm = 10 x Log_{10} (1 000)
10 W	10 000mW/1mW=10 000	40 dBm = 10 x Log_{10} (10 000)

Decibels Referencing One Watt (dBW)

dBW = dB Watt = 10 x Log_{10} (Power in W / 1 W)		
Power	**Ratio**	**dBW = 10 x Log_{10} (Power in W / 1 W)**
1 W	1 W / 1 W = 1	0 dBW = 10 x Log_{10} (1)
2 W	2 W / 1 W = 2	3 dBW = 10 x Log_{10} (2)
4 W	4 W / 1 W = 4	6 dBW = 10 x Log_{10} (4)
10 W	10 W / 1 W = 10	10 dBW = 10 x Log_{10} (10)
100 mW	0,1 W / 1 W = 0,1	−10 dBW = −10 x Log_{10} (10)
10 mW	0,01 W / 1 W = 1/100	−20 dBW = −10 x Log_{10} (100)
1 mW	0,001W/1W=1/1000	−30 dBW = −10 x Log_{10} (1000)

Power/Voltage Gains

We can compare the power and voltage gains in the following table:

Power/Voltage Gain					
dB	**Power Ratio**	**Voltage Ratio**	**dB**	**Power Ratio**	**Voltage Ratio**
0	1,00	1,00	10	10,00	3,16
1	1,26	1,12	11	12,59	3,55
2	1,58	1,26	12	15,85	3,98
3	2,00	1,41	13	19,95	4,47
4	2,51	1,58	14	25,12	5,01
5	3,16	1,78	15	31,62	5,62
6	3,98	2,00	16	39,81	6,31
7	5,01	2,24	17	50,12	7,08
8	6,31	2,51	18	63,10	7,94

9	7,94	2,82	19	79,43	8,91
10	10,00	3,16	20	100,00	10,00

With this information, we can define the following formula:

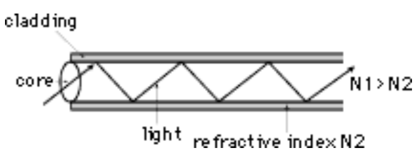
Attenuation (dB) = 10 x Log_{10}(P in/P out) = 20xLog_{10}(V in/V out)

Gain (dB) = 10 x Log_{10}(P out/P in) = 20 x Log_{10}(V out/V in)

dB & dBm Calculator

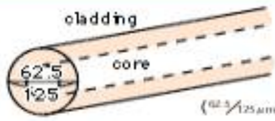
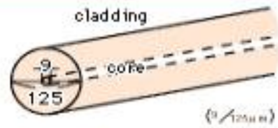
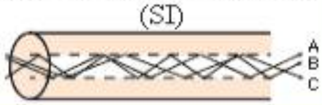
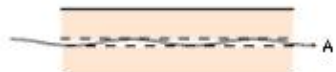
Optical Fiber Structure

Optical fiber is an information−carrying medium made of silica−based glass. It consists of a core surrounded by cladding. The central part of the fiber, the core, has a refractive index of N1, and the cladding which surrounds the core has a lower refractive index of N2. When light is launched into the fiber, the cladding confines the light to the fiber core and the light travels down the fiber by internal reflection between the boundaries between the core and the cladding.



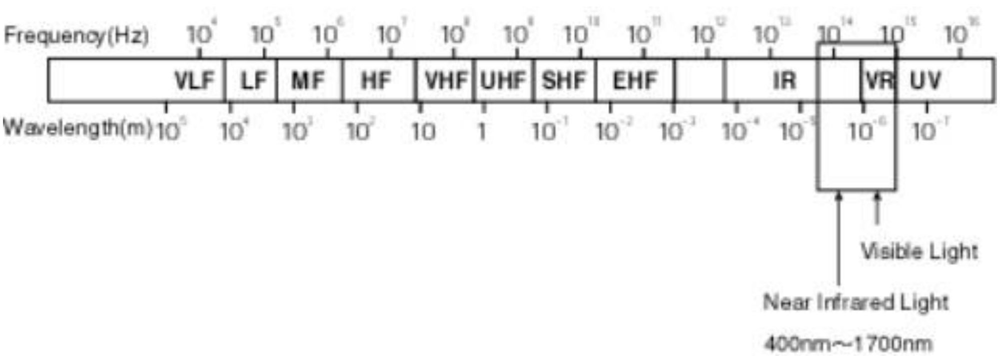
Fiber Type

The mainstream fibers manufactured and marketed today are singlemode (SM) and multimode (MM). The diagram below provides more information on both of these fiber types.

fiber type	MM	SM
		
fiber size	50/125 µ m 62.5/125 µ m 100/140 µ m	9/125 µ m 10/125 µ m
type	Multimode Step-index fiber (SI)  Multimode Graded-index fiber (GI) 	
Application	Short Distance LAN	Long Distance Telecoms,CATV, Brioadcast, Data communication

Wavelength

A small amount of light is injected into the fiber. This falls into visible wavelength (from 400nm to 700nm) and near infrared wavelength (from 700nm to 1700nm) in the electromagnetic spectrum shown here.

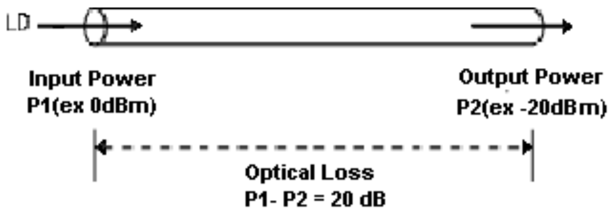


There are four special wavelengths that can be used for fiber optic transmission with low optical loss levels.

Windows	Wavelength	Loss
1st wavelength	850nm	3dB/km
2nd wavelength	1310nm	0.4dB/km
3rd wavelength	1550nm (C band)	0.2dB/km
4th wavelength	1625nm (L band)	0.2dB/km

Optical Power

To measure optical loss, we use two units such as dBm and dB. dBm is the actual power level referred to in milliwatts and dB (decibel) is the difference between the powers.



If the optical input power is P1 (dBm) and the optical output power is P2 (dBm), the power loss is P1 − P2 dB. You can see how much power is lost between input and output by referring to this dB value in the power conversion table.

For example, when direct line (LD) optical input into the fiber is 0dBm and output power is −15dBm, optical loss for the fiber is calculated as follows:

Input	Output	Optical Loss
0dBm −	(−15dBm)	=15dB

In the power conversion table, 15dB for optical loss equals 96.8 percent of lost optical power. Therefore, only 3.2 percent of optical power remains by traveling through the fiber.

dB	Power Out as a % of Power In	% of Power lost	Remarks
1	79%	21%	−
2	63%	37%	−
3	50%	50%	1/2 the power
4	40%	60%	−
5	32%	68%	−
6	25%	75%	1/4 the power
7	20%	80%	1/5 the power
8	16%	84%	1/6 the power
9	12%	88%	1/8 the power
10	10%	90%	1/10 the power
11	8.0%	92%	1/12 the power
12	6.3%	93.7%	1/16 the power
13	5.0%	95%	1/20 the power
14	4.0%	96.0%	1/25 the power
15	3.2%	96.8%	1/30 the power

Understanding Insertion Loss

In any fiber optic interconnection, some loss occurs. Insertion loss for a connector or splice is the difference in power that is seen by the insertion of the device into the system. For example, take a length of fiber and measure the optical power through it. Now cut the fiber in half, terminate the fibers and connect them, and re−measure the power. The difference between the first reading (P1) and the second (P2) is the insertion loss−the loss of optical power contributed by inserting the connector into the line. This is measured as follows:

$$IL (dB) = 10 \log_{10} (P2 / P1)$$

There are two important things to understand about insertion loss:

- **The specified insertion loss is for identical fibers.** If the core diameter or the NA of the transmitting side is larger than the diameter or NA of the receiving fiber, there is additional loss.

  $$Ldia = 10 \log_{10} (diar/diat)^2$$

  $$LNA = 10 \log_{10} (NAr/NAt)^2$$

  where:

  Ldia = Loss diameter

  diar = diameter receive

  diat = diameter transmit

  LNA = Loss on optical fiber

  Additional loss can occur from Fresnel reflections. These occur when two fibers are separated so that a discontinuity exists in the refractive index. For two glass fibers separated by an air gap, Fresnel reflections are 0.32 dB.

- Loss depends on the launch and receives conditions in the two fibers being joined. In a short launch, the fiber can be overfilled with optical energy carried in both the cladding and core. Over distance, this excess energy is lost until the fiber reaches a condition known as equilibrium mode distribution (EMD). In the long launch, the fiber has already reached EMD, so the excess energy is already stripped away and is not present at the connector.

  Light crossing the fiber−to−fiber junction of an interconnection may again overfill the fiber with excess cladding modes that will quickly be lost. This is the short−receive condition. If you measure the power output of a short−receive fiber, you will see extra energy that will not be propagated far. The reading is therefore misleading. Similarly, if the length of the receive fiber is long enough to reach EMD, the insertion loss reading may be higher, but will reflect actual application conditions.

  EMD (long launch and receive) can be easily simulated by wrapping the fiber around a mandrel five times. This strips the cladding modes.

Calculating a Power Budget

A rough estimate of a link power budget can be made by allowing 0.75 dB for each fiber−to−fiber connection and assuming that fiber loss is proportional with length in the fiber. If you want more accurate details click here.

For a 100 meter run with three patch panels and 62.5/125 fiber having a loss of 3.5 dB/km, the total loss is 2.6 dB:

Fiber: 3.5 dB/km = 0.35 dB for 100 meters

Patch Panel 1 = 0.75 dB

Patch Panel 2 = 0.75 dB

Patch Panel 3 = 0.75 dB

Total = 2.6 dB

Measured loss is normally less. For example, the average insertion loss for an AMP SC connector is 0.3 dB. This being so, the link loss is only 1.4 dB. It does not matter if you are running Ethernet at 10 Mbps or ATM at 155 Mbps. The loss is the same.

Optical time−domain reflectometry (OTDR) is a popular certification method for fiber systems. The OTDR injects light into the fiber and then graphically displays the results of detected back−reflected light. By measuring elapsed transit time of reflected light, the OTDR can calculate the distance to different events. The visual display allows determination of loss per unit length, evaluation of splices and connectors, and fault location. Capabilities, such as zooming in to certain locations, allow a close−up picture of portions of the link.

While power meters and signal injectors can be used for many link certifications and evaluations, OTDRs provide a powerful diagnostic tool unsurpassed at giving a comprehensive picture of the link. But OTDR requires more training and some skill at interpreting the display.

Related Information

- **Optical Product Support Pages**
- **Tools and Utilities − Cisco Systems**
- **Technical Support − Cisco Systems**
