White paper

Which Cut-off wavelength to be considered – Optical Fiber or Fiber Optic Cable?

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Abstract
Cutoff wavelength is one of the important optical characteristics of single mode optical fiber. This paper describes relationship between cutoff wavelength of cabled and un-cabled fibers.

Keywords
Optical fiber, cut-off wavelength

What is Cut-off Wavelength?

The CUTOFF WAVELENGTH of a single mode fiber is the wavelength above which the fiber propagates only the fundamental mode. Below cut-off, the fiber will transmit more than one mode. An optical fiber that is single-moded at a particular wavelength may have two or more modes at wavelengths lower than the cutoff wavelength.

The effective cutoff wavelength of a fiber is dependent on the length of fiber and its deployment and the longer the fiber, the lower the effective cutoff wavelength. Or the smaller the bend radius of a loop of the fiber is, the lower the effective cutoff wavelength will be. If a fiber is bent in a loop, the cutoff is lowered. The cutoff wavelength of a fiber is reduced when it is cabled.

What is Modal Interference?

Modal interference can occur in single-mode fiber systems causing signal degradation and potentially lower signal or carrier to noise figures. Modal interference results from the recombination of higher order modes exhibiting varying phase shifts with the fundamental mode. The phase shifts predominantly originate from the random wavelength changes of the optical source. Normally, when operated above a certain wavelength, a single-mode fiber propagates one fundamental mode, supporting the information carrying light signal. Under certain conditions, a second, higher order mode may be excited, which has significantly higher loss, but more importantly, may exhibit a difference in optical path length. In this state, the single-mode fiber supports multimode operation. If this secondary mode is not sufficiently attenuated or stripped out of the fiber, it may recombine with the fundamental mode at subsequent fiber connections or splices causing destructive or constructive interference.

Several conditions may cause the excitation of this higher order mode.

1. Transmitters that launch light into the fiber with overfilled conditions can initiate this mode,
2. The higher order mode can be generated at splice or connector junctions where significant fiber core misalignment exists. It becomes apparent that fiber geometry as well as splicing and connectorization practices are important.
3. Additionally, if a single-mode fiber is operated below a certain wavelength - the cutoff wavelength - the fiber may support the second order mode.

How do we avoid the second order mode?

Current industry standards address cabled cut-off wavelength requirements for indoor and outdoor cables. These cut-off requirements specify test methods[1,2] which are representative of actual field deployment conditions for optical fiber cable products. Since both bending and length may affect the cut-off wavelength of a fiber, the cabled cut-off measurement techniques provide consistent controls for determining the cutoff wavelength of deployed cables.

Operation of the optical fiber system at a wavelength above the specified cabled cut-off wavelength would ensure that the second order mode is not propagated on long lengths of fiber. The higher order mode will be attenuated before it can recombine with the fundamental mode. International standard specifies cabled cut-off wavelength < 1260 nm for dispersion-unshifted single-mode fiber, which is well below the typical operational wavelength of 1310 nm (refer Table 1). Even the specified value of cut-off wavelength is also satisfied network requirements of Cross Wavelength Division Multiplexing (CWDM), where minimum operation

wavelength is 1290nm (O-band). However this doesn't prevent excitation of the second order mode due to a source with an overfilled launch, or from miss-aligned fiber junctions where there is insufficient attenuation of the destructive mode before the next splice or connection.
The elimination of the second order mode initiated by a laser source is achieved with the optical fiber jumper or pigtail connected to the source. The bends introduced into the jumper at the end equipment, on the order of a 3" radius, will be sufficient to effectively remove the second order mode.

Table 1 Specification of Cut-off Wavelength of dispersion un-shifted single mode optical fiber[3,4,5,6]

Standard	Cable Cut-off Wavelength (λ_{cc})	Fiber Cut-off Wavelength (λ_{cf})
ITU-T G.652.A, B (03-03)	Maximum 1260 nm	Not Specified
ITU-T G.652.C,D (03-03)	Maximum 1260 nm Maximum 1250 nm (if operating at 1260 nm)	Not Specified
IEC-60793-2-50 (2nd Ed, 2004-01) for B1.1 & B1.3 category fibers	Maximum 1260 nm	Not Specified
ITU-T G.655.C, D, E (03-06)	Maximum 1450 nm	Not Specified

Which Cut-off wavelength to be considered- Fiber or Cable?

Telecommunication Industry Association (TIA) had released cut-off measurement procedures for both fiber and cable. For fiber cut-off measurement 2 m bare fiber sample is used (FOTP-80), where for cable cut-off measurement 22 m bare (uncabled) fiber is used (FOTP-170). In latter case, 22 m uncabled fiber is put in a loop with a minimum radius of 140 mm to conservatively simulate cabling effects. Application point of view cable cut-off is more important than fiber cut-off wavelength. Thus, none of the international standard specifies fiber cut-off.
The fiber cut-off wavelength, (λ_{Cf}), measured under the standard length and bend conditions of FOTP-80, will generally exhibit a value larger than λ_{CC}. For short cables, e.g. pigtail and jumper cables, λ_{CC} may be larger than λ_{Cf}. So for application in long-haul telecommunication; optical fiber should be selected on the basis of cable cutoff wavelength rather than fiber cutoff wavelength.
Optical fiber manufacturers are generally measured fiber cut-off wavelength as this is easy and less time consuming compared to cable cut-off wavelength measurement. However, regression equation can be established to predict λ_{CC} from λ_{Cf}.

Figure 1 is showing fitted linear plot of λ_{CC} vs λ_{Cf}. of G.652 category fiber (i.e. Sterlite's OHLITE™, PMD-LITE® and BOW-LITE™) Correlation factor is 83% , which is high enough to conclude good correlation exists between these two parameters. Regression equation is given below

λ_{CC} = 101 + 0.84 x λ_{Cf} ---------------------Eq.(1)

Figure 2 is showing fitted linear plot of λ_{CC} vs λ_{Cf}. of G.655 category fibers with reduced dispersion slope i.e. Sterlite's DOF-LITE™ (RS). Correlation factor is 77%, which is high enough to conclude good correlation exists between these two parameters. Regression equation is given below

λ_{CC} = 143.52 + 0..764 x λ_{Cf} ---------------------Eq.(2)

Figure 3 is showing fitted linear plot of λ_{CC} vs λ_{Cf}. of G.655 category fibers with large effective area i.e. Sterlite's DOF-LITE™ (LEA). Correlation factor is 94% , which is high enough to conclude good correlation exists between these two parameters. Regression equation is given below

λ_{CC} = 85.89 + 0.764 x λ_{Cf} ---------------------Eq.(3)

From the upper 95% predictor band, below relation between λ_{CC} & λ_{Cf} can be derived for G.652 category fibers.

Cable Cut-off (λ_{CC})	Fiber Cut-off (λ_{Cf})
≤1260 nm	≤1350 nm
≤1250 nm	≤1340 nm

From the upper 95% predictor band, below relation between λ_{CC} & λ_{Cf} can be derived for G.655 category fibers.

Fiber Type	Cable Cut-off (λ_{CC})	Fiber Cut-off (λ_{Cf})
DOF-LITE™ (RS)	≤1450 nm	≤1660nm
DOF-LITE™ (LEA).	≤1450 nm	≤1716 nm

The fiber cut-off value is calculated from the extrapolated line of upper 95% predictor band of Figure 2 & 3. As commercially available cut-off wavelength measurement instrument measures values upto 1600 nm accurately, below table shows correlation between cable and fiber wavelength of realistic band of G.655 category fibers.

Fiber Type	Cable Cut-off (λ_{CC})	Fiber Cut-off (λ_{Cf})
DOF-LITE™ (RS)	≤1350 nm	≤1520 nm
DOF-LITE™ (LEA).	≤1350 nm	≤1584 nm

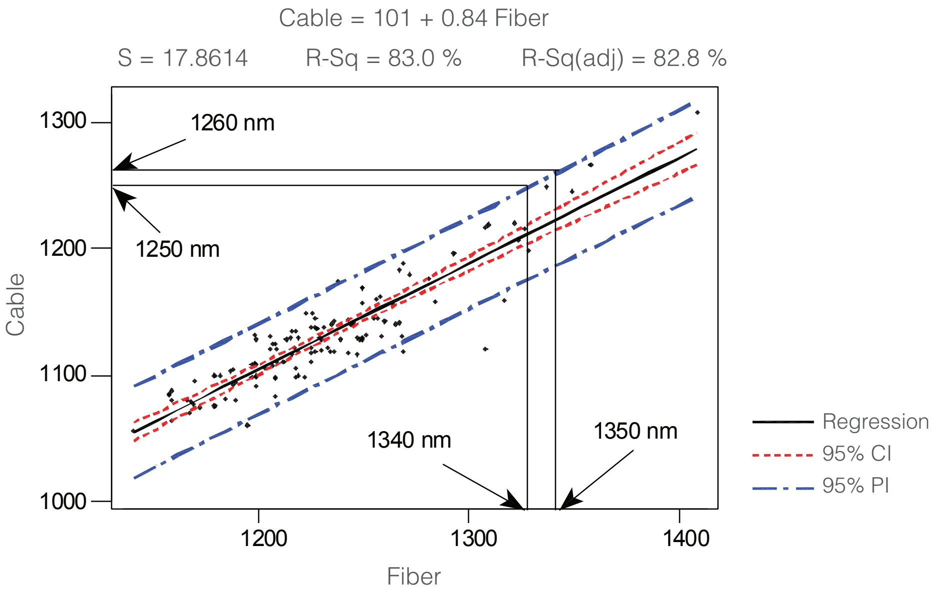

Figure 1 Regression plot between Fiber and Cable Cut-off Wavelength (SMF dispersion unshifted fiber, ITU-T G.652)

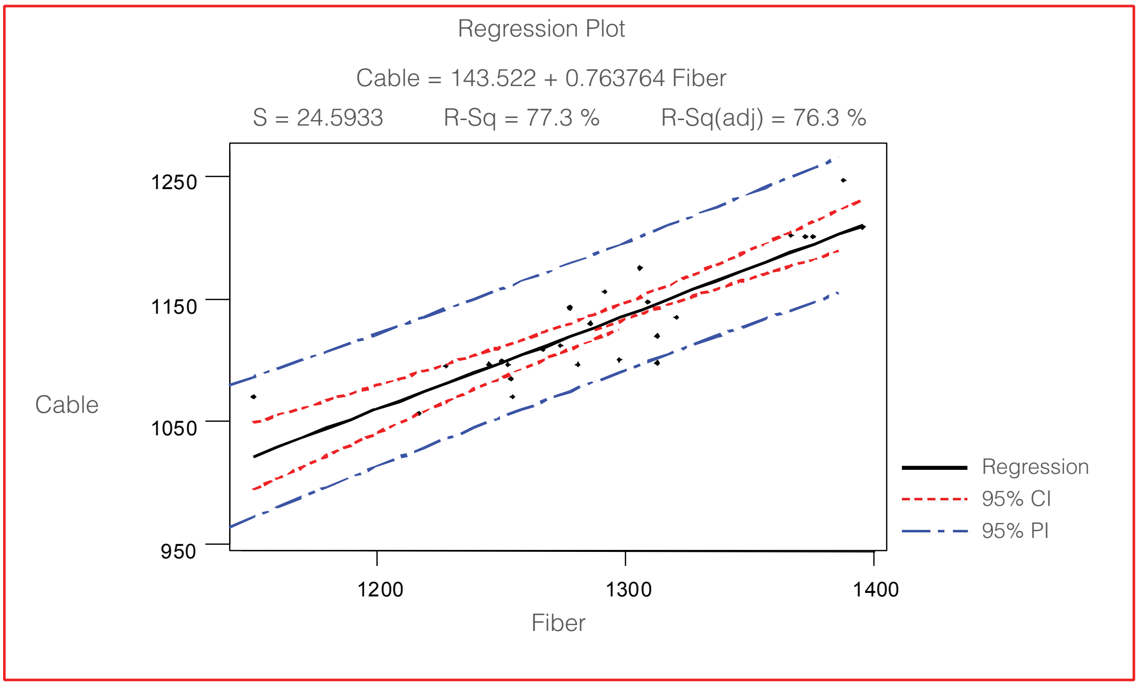

Figure 2 Regression plot between Fiber and Cable Cut-off Wavelength (ITU-T G.655, DOF-LITE™ RS)

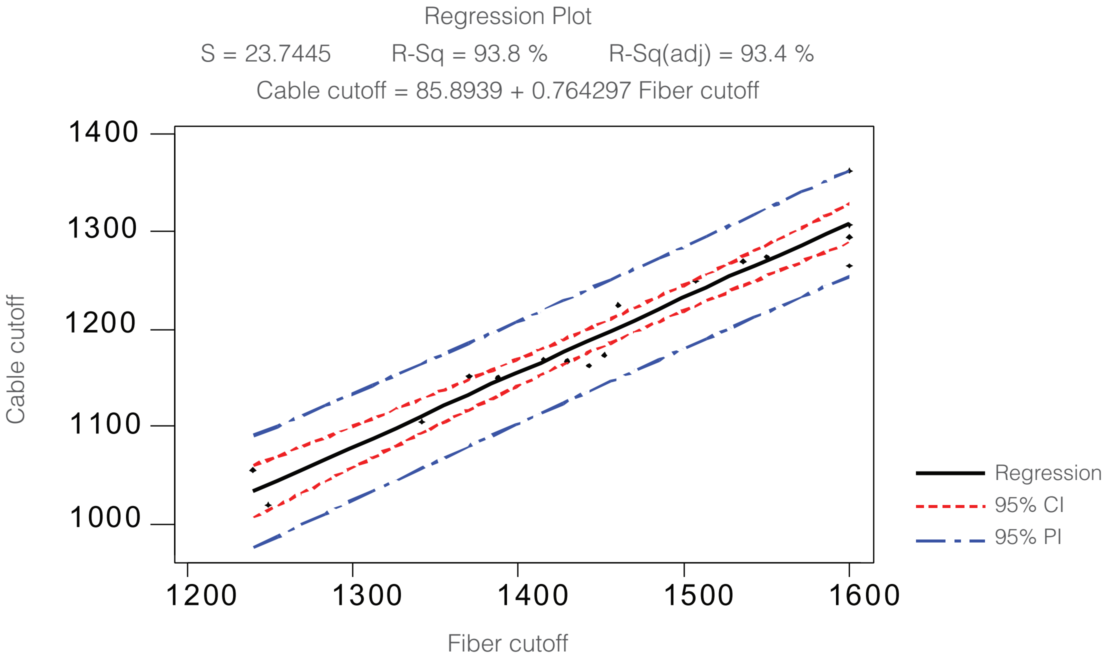

Figure 3 Regression plot between Fiber and Cable Cut-off Wavelength (ITU-T G.655, DOF-LITE™ LEA)

Conclusion

To eliminate modal inference and ensure single mode operation of dispersion un-shifted (ITU-T G.652) & dispersion shifted (ITU-T G.655) optical fiber, cut-off wavelength must be less than the operating wavelength. Cut-off wavelength can be measured in two stages: fiber and cable. Fiber cut-off wavelength (λ_{Cf}) is always found higher than that of in cable stage as measured cut-off wavelength is dependent on bend and length of the sample under measurement. As optical fiber is used only in cable form, cable cut-off (λ_{CC}) is more important and relevant for application point of view. Thus international standards are specified cut-off wavelength of cable, not fiber.

Optical fiber manufacturers are generally measured λ_{Cf} as this is easy and less time consuming compared to λ_{CC} measurement. Regression analysis between λ_{CC} and λ_{Cf} shows good correlation. Regression equation is established in between these parameters. From the 95% prediction band, λ_{Cf} values are determined to meet specified λ_{CC} for both G.652 and G.655 category fibers.

References

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