



Optical Fibre Splice Loss

APPLICATION NOTE

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ABSTRACT

To build a network with optical fibres, one may eventually join two fibre ends with a connector or fusion splicer. The amount of optical power lost at these connections is a concern for many system designers. This application note discusses the splice loss measurement technique and investigates the extrinsic and intrinsic factors affecting the splice loss measurements when joining two bare fibre strands.

Definition

Splice loss refers to the part of the optical power that is not transmitted through the splice and is radiated out of the fibre [1]. The total loss in decibels at the fusion splice is given by the following equation,

$$\alpha_{\text{splice}} = 10 \text{Log}_{10} \frac{P_{\text{in}}}{P_{\text{trans}}} \quad (1)$$

where P_{in} is the total power incident on the fusion splice and P_{trans} is the desirable portion of the optical power transmitted across the fusion splice. Since $P_{\text{in}} > P_{\text{trans}}$, the splice loss is always a positive number. The important advantage of fusion splice over other competing fibre interconnection technologies is the relatively small amount of optical power reflected by fusion splices. Therefore in the subsequent sections of the application note, we neglect the optical power reflected from fusion splice.

The parameters that control and contribute to the fusion splice loss can be categorized as,

1. Intrinsic - Differences in the optical characteristics of the fibres, in particular, core diameter, and numerical aperture.
2. Extrinsic - Defective splicing due to core to core offset, tilt (misalignment) or deformation at the splice.

Intrinsic Parameters

In real scenario considering the fibres to be spliced are single-mode, the principal difference between them comes from the modal field radius which can be calculated using the following equation [2],

$$\omega \approx a_{\text{core}} \left(0.65 + \frac{1.6}{3} \frac{1}{V^2} \right) \quad (2)$$

where a_{core} is the fibre core radius and V is the generalised wave number defined as $V = \frac{2\pi}{\lambda} a_{\text{core}} \text{NA}$. From the above equations, two fibres with different core diameter or numerical aperture (NA) will have different mode field radius, at a given wavelength. Therefore the difference in modal field radius results in loss, if the two fibres are spliced. The loss due the modal field diameter (MFD) mismatch is calculated by using the following formula

$$\alpha_{\text{MFD}} = -20 \text{Log}_{10} \left[\frac{2 \omega_1 \omega_2}{\omega_1^2 + \omega_2^2} \right] \quad (3)$$

The solid lines in Fig. 1 shows the variation in splice loss when the MFD of the one fibre is varied keeping the other fixed. We maintain from theoretical calculations that with increase in the MFD mismatch results in increase in the loss which can reach as high as 0.05dB for a MFD difference of $1\mu\text{m}$. Thus in order to have a realistic splice loss reduction, the MFD mismatch should be minimised and is evident in Fig. 1.

Fig. 2 shows an illustration of worst case experimentally measured splice loss for G.652.D fibres where one test fibre with a fixed MFD value is spliced to fibres having a range of MFD values. As can be seen, splice loss is minimum when MFD values of the two fibres match, and splice loss increases fairly symmetrically with MFD mismatch between two fibres, with a worst case loss of about 0.05dB for $0.5 \mu\text{m}$ MFD mismatch. Please note that these are worst case results with the available data at the factory. Typical splice losses due to MFD mismatch are expected to be lower.

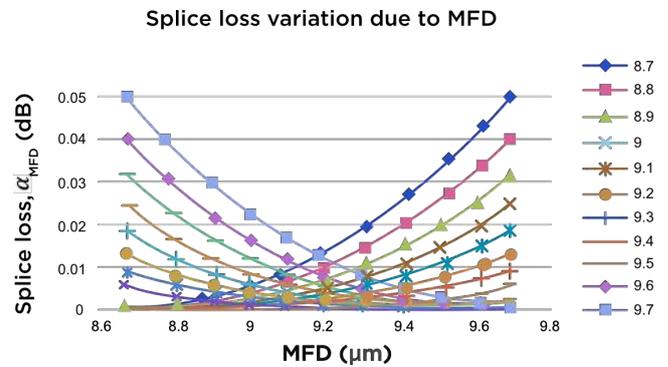


Fig. 1 Splice loss as a function of mode field diameter

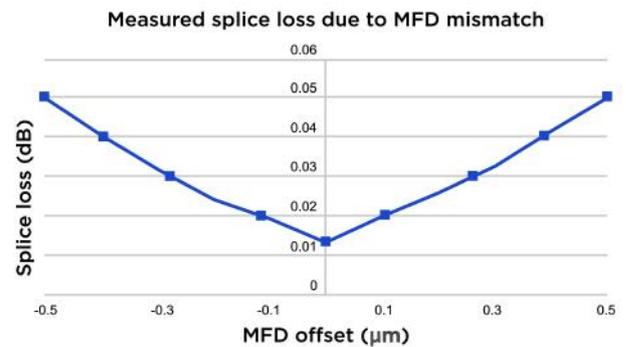


Fig. 2 Measured splice loss as a function of MFD mismatch

Extrinsic Parameters

Extrinsic parameters are those induced by splicing methods and procedures. These parameters include lateral and angular alignment, contamination of fibre ends and core deformation due to un-optimised heating & pressing. These external parameters can be controlled/minimised by utilising the services of a skilled operator and by automated fibre alignment and fusion cycles. It has been observed that splice loss between two identical fibres with same MFD and geometry parameters can be as high as 0.04 dB due to misalignment and other splice process parameters. Fig. 3 is an illustration of some un-optimised splicing parameters.

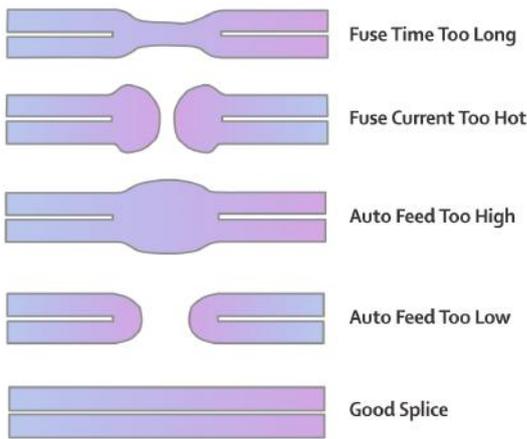


Fig. 3 Fibre end conditions

Other important extrinsic parameter is fibre end angle. Proper fibre end preparation is the most fundamental step to get acceptable splice loss. Generally, end angle of less than two degrees gives acceptable field splice loss. End angle is dependent on condition of cleaver and cleaver blade. Typical end angle of well - maintained cleaver is around one-half degree. Fig. 4 shows examples of bad and good cleaving. Acceptable field splice loss can be achieved if extrinsic parameters are well controlled.

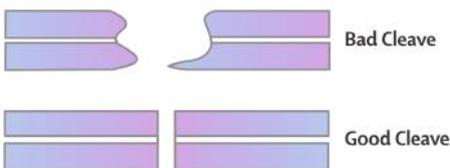


Fig. 4. Bad v/s Good Cleave

How is splice loss measured?

An Optical Time Domain Reflectometer (OTDR) is commonly used for measurement of fusion splice loss. The basic backscattering principle makes the OTDR very sensitive to fibre MFD dependent light coupling properties. Different fibres with different geometric properties will intrinsically capture more or less backscattered light resulting in varying signal levels back to the OTDR. When two fibres with different MFD values are joined and measured with an OTDR, either an apparent gain or loss artefact appears at the interface as shown in the Fig. 5 and Fig. 6, respectively. This error component of the measured loss is governed by the following equation,

$$\alpha_{OTDR} = 10 \text{ Log} \left[\frac{\omega_1}{\omega_2} \right] \quad (4)$$

Considering the core to core offset, tilt, and other loss mechanisms (α_{others}), the total unidirectional OTDR measured splice loss is governed by the following equation,

$$\alpha_{measured} = [\alpha_{others} + \alpha_{MFD}]_{splice\ loss} + \alpha_{OTDR} \quad (5)$$

As recommended by ref [2], the most effective way of overcoming the measurement error is by taking bidirectional OTDR measurements. The evaluation of splice loss is carried out by obtaining the backscattering trace from the opposite sides of the spliced fibres and measuring the step/gain, A_1 and A_2 , at the splice point. As shown in Fig. 5 and Fig. 6, A_1 and A_2 , are composed of an error component - backscattered loss ($\Delta\omega = \alpha_{OTDR}$) depending on the MFD variation of the two fibres, and a term which is actual splice loss term ($\delta (= [\alpha_{Others} + \alpha_{MFD}]_{splice\ loss}$).

To extract the significant value, δ compute

$$Splice\ loss = \frac{A_1 + A_2}{2} = \frac{(\Delta\omega + \delta) + (-\Delta\omega + \delta)}{2} = \delta \quad (6)$$

Therefore splice losses must be evaluated through the bi-directional average of the OTDR traces. This approach is however not always feasible in the field due to location and access restraints. If unidirectional OTDR measurements are to be used for splice loss evaluation, the corrections based on the MFDs of each fibre must be used to offset the effect of α_{OTDR} .

The illustration of a gainer and exaggerated loss in splice loss measurements using OTDR is shown in the Fig. 5 and Fig. 6. where dB(\pm R) represents 'true' or 'actual' loss, L(\pm R) represents the loss as seen by the OTDR, B(\pm R) represents backscattered loss due to MFD mismatch as seen by the OTDR, and ω_1 and ω_2 represent the respective fibre mode-field radius of the first and second fibre.

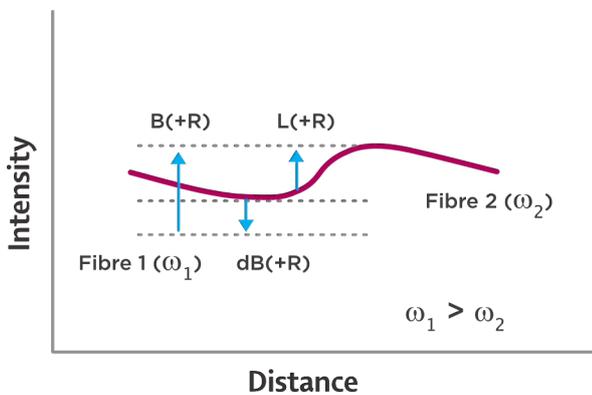


Fig. 5 Illustration of a Gainer

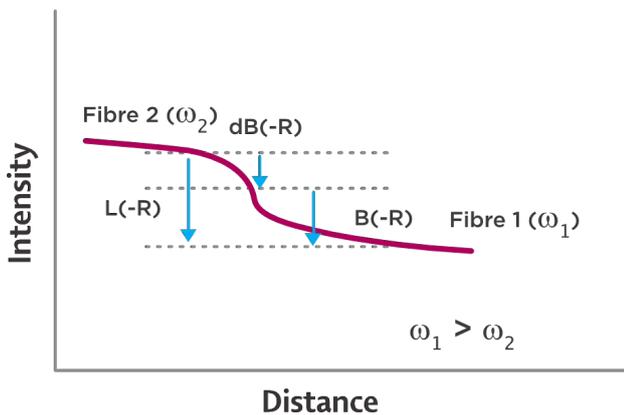


Fig. 6 Illustration of an Exaggerated Loss

Splicing of G.657 fibres

The principles explained above for splice loss measurements, including impact of MFD variation and the intrinsic and extrinsic factors are all applicable to splicing of G.657 fibres, whether they are spliced to G.652.D fibres or splicing

amongst different variants of G.657 fibres. Sterlite Technologies Limited rigorously tests splice loss compatibility of fibres as part of its Quality Assurance and Reliability process, prior to releasing fibres for general availability in the market. The minimum and maximum values of MFD referenced to 1310nm for the G.652.D, G.657.A1, G.657.A2/B2, and G.657.B3 series of fibres in micrometers are (8.7, 9.5), (8.4, 9.2), (8.2, 9.0), (8.2, 9.0), respectively. Manufacturing distributions ensure that the mean is very close to the center of the range, keeping the probability of finding fibres at the opposite end of the MFD range very small.

The following section presents the experimentally measured splice loss between G.652.D and G.657.A1, G.652.D and G.657.A2/B2, G.657.A1 and G.657.A2 fibres along with their measured MFD values. In case of splice loss between G.652.D with G.657.A1 fibre, the observed average splice loss after fitting a Gaussian curve is 0.04 dB with standard deviation (SD) of 0.017 dB at 1310nm as shown in Fig. 7. While at 1550 nm, the average splice loss and SD is observed to be 0.037 dB and 0.013 dB, respectively as shown in Fig. 8. The sample set included fibres with worst case MFD mismatch of 0.7 μ m. Extrapolating from the Gaussian curve the worse case (average + 3 x SD) splice loss would be less than 0.09 dB and 0.076 dB at 1310 nm and 1550 nm respectively.

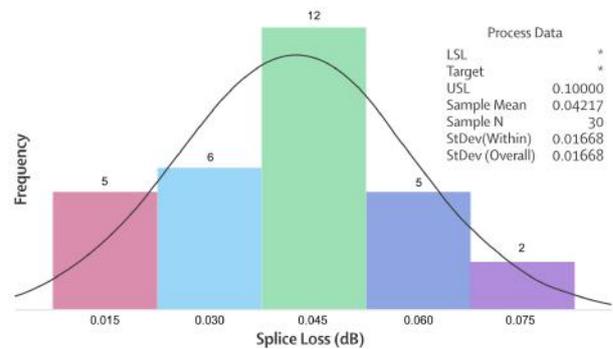


Fig. 7 Splice loss of G.652.D - G.657A1 fibre at 1310 nm

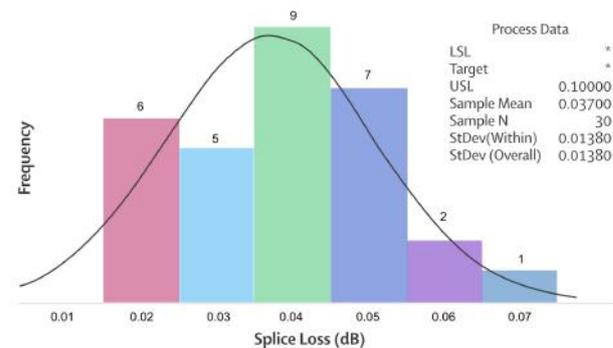


Fig.8 Splice loss of G.652.D - G.657A1 fibre at 1550 nm

Similarly splice loss between G.652.D with G.657.A2 fibre at 1310 nm and 1550 nm are depicted in Fig. 9 and Fig. 10, respectively. The observed average splice loss at 1310 nm is 0.054 dB with SD of 0.015 dB, while at 1550 nm the average splice loss and SD is 0.045 dB and 0.014 dB, respectively. The sample set included fibres with worst case MFD mismatch of 0.8 μm . Extrapolating from the Gaussian curve the worse case (average + 3 x SD) splice loss would be less than 0.096 dB and 0.086 dB at 1310 and 1550 nm respectively.

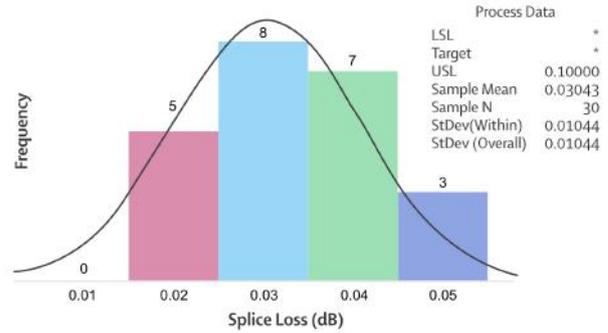


Fig.11 Splice loss of G.657A1 - G.657A2 fibre at 1310 nm

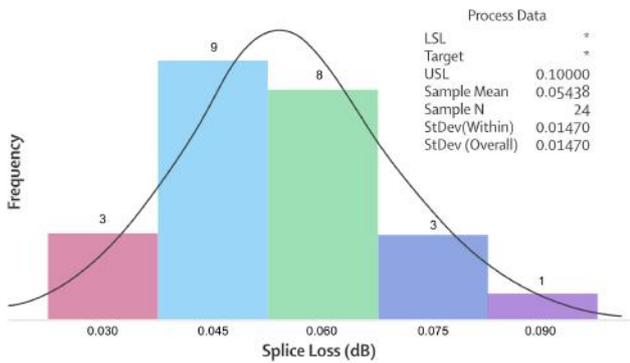


Fig. 9 Splice loss of G.652.D - G.657A2 fibre at 1310 nm

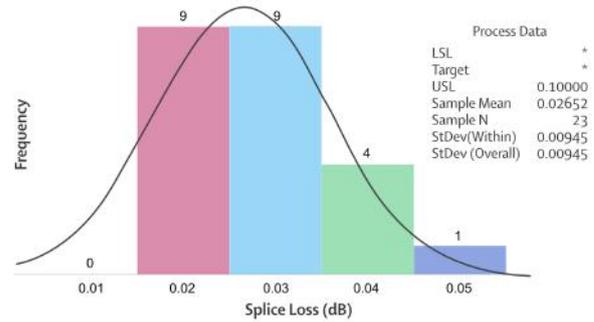


Fig.12 Splice loss of G.657A1 - G.657A2 fibre at 1550 nm

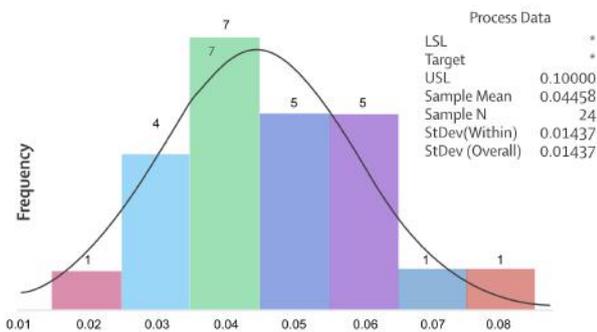


Fig. 10 Splice loss of G.652.D - G.657A2 fibre at 1550 nm

Splice loss of G.652.D - G.657.A1 fibre		
Test frequency	Splice Loss (avg.)	Splice Loss (max.)
1310 nm	0.042 dB	0.075 dB
1550 nm	0.037 dB	0.070 dB
Splice loss of G.652.D - G.657.A2 fibre		
Test frequency	Splice Loss (avg.)	Splice Loss (max.)
1310 nm	0.054 dB	0.090 dB
1550 nm	0.045 dB	0.080 dB
Splice loss of G.657.A1 - G.657.A2 fibre		
Test frequency	Splice Loss (avg.)	Splice Loss (max.)
1310 nm	0.030 dB	0.050 dB
1550 nm	0.027 dB	0.050 dB

Note: Max. splice loss 0.1 dB is allowed as per ITU-T standards

Another important splice combination that is encountered in FTTH network is G.657.A1 - G.657.A2. Fig. 11 and Fig. 12 capture the measured splice loss of G.657.A1 with G.657.A2 fibre at 1310 nm and 1550 nm, respectively. The observed average splice loss and SD at 1310 nm is 0.03 dB and 0.01 dB, respectively, while at 1550 nm they are 0.027 dB and 0.009 dB, respectively. The sample set included fibres with worst case MFD mismatch of 0.7 μm . Extrapolating from the Gaussian curve the worse case (average + 3 x SD) splice loss would be less than 0.06 dB and 0.054 dB at 1310 and 1550 nm respectively. In all the above measurements, the ITU-T G.982 recommendation is followed in estimating the worst case splice loss [3].

Acknowledgement:

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