Instructions for splicing Liekki fibers

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Contents:

1 Introduction

This document describes the techniques for splicing highly doped fibers: LF1200, LF2400 to undoped fibers: SMF-28, PureMode1060 (or similar) using Ericsson FSU975 or FSU995, Sumitomo T-36 and Fitel S176.

Due to the inherent variation in the equipment properties, the information in this document should be considered as “guidelines”. Especially the splicing program parameters may vary from equipment to equipment and from location to location. However, this document tries to explain how to fine-tune the splicer for best results.

v 2.0, August 1st, 2003

2 General recommendations for splicing

- **Understand your splicer**
  Read carefully the fusion splicer manual. Make sure you understand which parameters are active, how to change them, and what are their current values. Learn how to maintain the equipment: cleaning and checking the electrodes, fiber holders and imaging system. This is crucial to make repeatable good splices.
- **Maintain your splicer**
  Make sure you keep the splicer clean. Coating material can easily deposit on fiber holders, on electrodes or on optics. Perform “Clean electrodes” (Ericsson) or Arc Check (Sumitomo and Fitel) procedure every 20 splices. Replace the electrodes when (according to the manual) they reach the end of their lifetime.
- **Use the best fiber cutter**
  The quality of the fiber end is crucial for obtaining good quality splices. Make sure you use good quality fiber cutter and you maintain it in good condition. We recommend checking the cutter from time to time by inspecting the fiber end with a microscope.
  If you have reduced the maximum acceptable angle parameter to 1 degree, this will give you an indication of the cutter quality. If the rejection rate increases (more then 20% of gap angles are over 1 degree) this is an indication that the cutting blade is damaged and should be changed (or simply rotated for mechanical cutters).

3 Splice loss measurement

It is strongly recommended to perform splice loss test the first time you are splicing LF1200 and LF2400 to undoped fibers. This will allow you to fine tune the splicing parameters for the local climate and the specific equipment.

As well, it is recommended to check the splice loss from time to time to make sure that the splicing conditions have not been changed (especially by the climate and electrodes quality).

Because splicing fibers with large MFD variations (at 1550nm LFxx00 has MFD about 6.5um, SMF-28 has about 10um, and PureMode1060 has about 8um) produces losses that are dependent on the light propagation direction, different measurement set-ups have to be used for each propagation direction.

When measuring splice loss on highly doped fibers, the following facts have to be considered:

- Highly erbium doped fibers yield high absorption around 1550nm (LF1200 has 20dB/m at 1530nm, LF2400 has 40dB/m at 1530nm).
- The absorption in 1550 band is power dependent (also known as “bleaching effect”). The values presented above are valid only if the power at 1550nm in the doped fiber is bellow –30dBm (1uW). At higher powers the absorption decreases due to the significant excitation of the erbium ions.

- When the excitation of erbium ions is significant, extra light is created in the fiber due to the spontaneous emission (fluorescence).

Because of these facts, measuring splice loss at 1550nm is very difficult. Still, various techniques can be used, but the measurement is complicated and very time consuming.

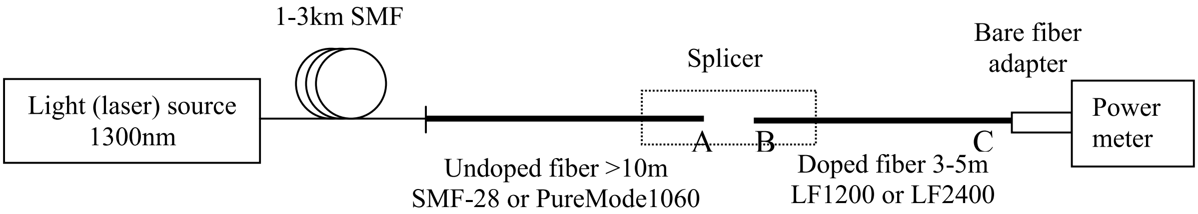
However, it can be easily demonstrated that there is only a small difference between splice loss at 1550nm and splice loss at 1300nm. As a consequence, the measurement can be performed at 1300nm where practically there is no erbium absorption. This is described below.

3.1 General recommendations for splice loss measurement at 1300nm

- The background loss of EDF at 1300nm has to be accurately measured in advance. The classical cutback technique can be used.
- If there is no isolator available, a long span of SMF (several km) should be used to reduce the effect of back-reflections on light source.
- Because the measurement accuracy should be below 0.01dB, the light source and the detector should be stabilized.
- When measuring optical power in the fiber, 0.01dB variation can be easily observed by simply modifying the fiber layout on the table. We recommend that after the set-up calibration, the fiber should be kept fixed. The only moving parts will be (obviously) the fiber ends to be spliced, but even those should be placed on the table, as much as possible, in a predefined position, before the power is recorded.
- The fiber under test should be arranged on a 15cm diameter loop to remove the cladding modes. Do not bend the fiber below 5cm radius because bending loss might affect the results.
- Switch on the light (laser) source and the power meter well in advance to allow them to warm up. Depending of the equipment, this might take 15 minutes to 1 hour.
- Some power meters have a “setting time”, that is the time necessary to stabilize after the light reaches to detector (the moment when the splice is done). It is recommended to determine this time and then to record each power value only after this time elapsed. Try to keep constant the delay between the moment of splicing and the moment or reading the power.
- Since the measurement requires a bare fiber adaptor, it is recommended to test the repeatability of the measured power. Before the measurement, connect the fiber using the adaptor several times and record the power variations. Because the fiber end might be damaged in the process of inserting the fiber in the bare fiber adaptor, a good technique is to cut the fiber AFTER the fiber is inserted in the adaptor. To do this, the coating of the fiber should be stripped from about 10cm of the fiber end. Then the fiber end is cleaned with alcohol and it is inserted in the adaptor. Then the fiber end is cut and adjusted to the tip of the adaptor before connecting the adaptor to the detector.

3.2 Testing splices between undoped fiber - EDF

3.2.1 Measurement set-up



Set-up calibration:
1. Connect the undoped fiber (point A) to the power meter using the bare fiber adaptor and record the power as Reference power (Pref in dBm)
2. Remove the undoped fiber from the adaptor and connect the end C of doped fiber to the power meter using the adaptor.
3. Measure accurately the length of the doped fiber.
4. Fix the fibers on the table leaving only fiber ends A and B free to move.
5. Adjust the splicing parameters as desired.
6. If necessary (usually after every 20 splices) perform "Clean electrodes" (Ericsson) or Arc Check (Sumitomo, Fitel).

Measurement:
1. Prepare the fiber ends A and B and perform the splice.
2. Record the power indicated by the power meter (Pm in dBm).
3. Record the splice loss estimation provided by the splicer (Es in dB).
4. Measure and record the doped fiber length (L in m). Because the length measurement requires the movement of the fiber, estimation can be made instead by assuming that a constant fiber length is cut every time the fiber end B is prepared before splicing. Depending on the cutting device, this may vary between 1 and 2cm.
5. Repeat points 1-4 at least 20 times.

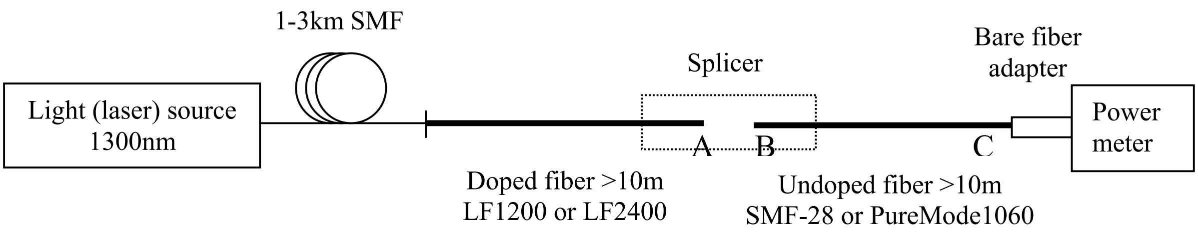
Processing the measurement data:
The splice loss (Loss in dB) for each performed splice can be calculated as:

$$Loss=Pref-Pm-L*Bg$$

Where Bg (in dB/m) is the doped fiber background loss at 1300nm (measured in advance).
Put all data in a table and calculate the average and the standard deviation. Compare the measured losses with estimations provided by the splicer.

3.3 *Testing splices between EDF - undoped fiber*

3.3.1 Measurement set-up



Set-up calibration:

7. Connect the doped fiber (point A) to the power meter using the bare fiber adaptor and record the power as Reference power (Pref in dBm)
8. Remove the doped fiber from the adaptor and connect the end C of the undoped fiber to the power meter using the adaptor.
9. Fix the fibers on the table leaving only fiber ends A and B free to move.
10. Adjust the splicing parameters as desired.
11. If necessary (usually after every 20 splices) perform "Clean electrodes" (Ericsson) or Arc Check (Sumitomo, Fitel).

Measurement:

6. Prepare the fiber ends A and B and perform the splice.
7. Record the power indicated by the power meter (Pm in dBm).
8. Record the splice loss estimation provided by the splicer (Es in dB).
9. Repeat points 1-3 at least 20 times.

Processing the measurement data:
The splice loss (Loss in dB) for each performed splice can be calculated as:

Loss=Pref-Pm

This formula assumes that the reference power is not changed when the doped fiber end is cut for a new splice. This is valid for 5 to 10 splices. If the test contains more then 10 splices then the reference power should be adjusted by considering the amount of cut fiber.

Put all the data in a table and calculate average and standard deviation. Compare the measured losses with estimations provided by the splicer.

4 Splicing with Ericsson FSU975 and FSU995

Ericsson splicers are advanced equipment allowing the user to perform various splices. To do this, the splicer accepts a long list of parameters to be set by the user.

After extensive testing, we have concluded that when the right process type is selected, it is enough to control only three parameters in order to obtain good splices: Fusion Current 2, Fusion Time 2, and Overlap. (Please refer to the splicer manual for description of the parameters). As a consequence, there are only small differences between the parameter lists presented below.

The only parameter that is different in the following tables is **Fusion curr. 2**. However, information on the effect of changing **Fusion time 2** and **Overlap** is also provided.

Attention:

- **Reduce the acceptable MAX GAP ANGLE**
  The default acceptable maximum gap angle (the cleaving angle of the fiber) is 2 degree. This value is too large for splicing small core fibers like erbium doped fibers (EDF) and should be changed to 1 degree. The MAX GAP ANGLE parameter is located in program 00 under “Edit basic param.?” and it is valid for any splice you make. Use the manual instructions to change it.
  OBSERVATION: In Ericsson FSU975 manual there is a warning saying that the parameters in program 00 are intended for authorized service personnel only. However, Ericsson confirmed that the user could also change MAX GAP ANGLE. For FSU975 use 975 as a key code. For FSU995 use 995 as a key code. Be sure you change only MAX GAP ANGLE, and leave all the other parameters unchanged!
- **Adjust the ALTITUDE**
  The splicing parameters are sensitive to climate: pressure, temperature, and humidity. Ericsson FSU975 and FSU995 can automatically adjust the arc currents according to altitude (pressure).
  The splicing parameters presented in this document are tested at 0km altitude (Finland). If you are using the splicer at a different altitude, change accordingly the parameter ALTITUDE in program 00, under “Edit basic param.?”. See OBSERVATION above.
  Unfortunately there is no possibility to adjust the arc current for different temperature and humidity. **If you are using the splicer in different climate than in Finland, we strongly recommend testing the splice loss and adjusting the splicing parameters as described bellow in “4. Splice loss measurement”**.

4.1 Splicing LF1200

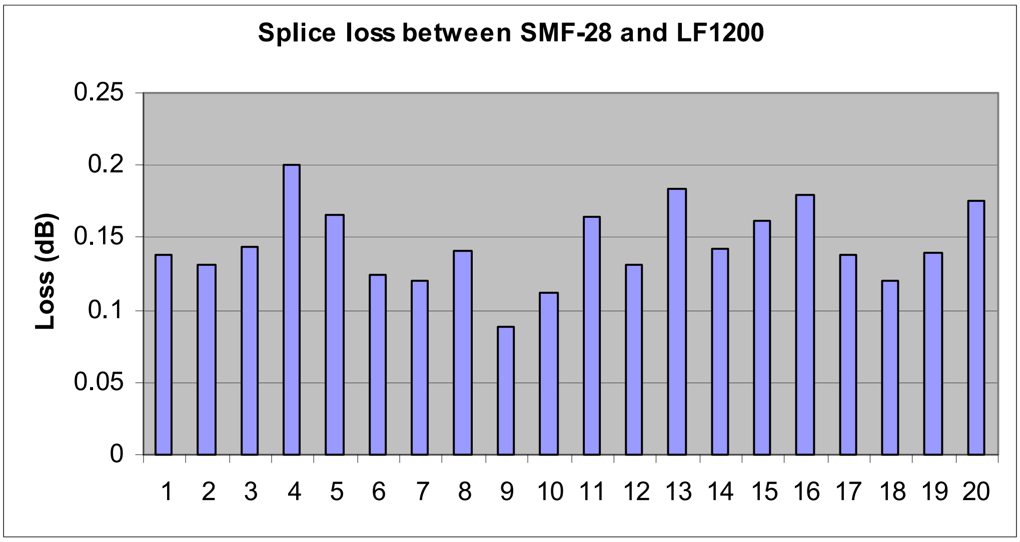
4.1.1 LF1200 to SMF-28

Parameter	Value
Fiber type	Erbium fiber
Process type	Normal splicing
Prefuse time, (s)	0.2
Prefuse current, (mA)	10
Gap, (µm)	50
Overlap, (µm)	15
Fusion time 1, (s)	0.3
Fusion curr. 1, (mA)	10.5
Fusion time 2, (s)	**2**
Fusion curr. 2, (mA)	**14.5**
Fusion time 3, (s)	0.5
Fusion curr. 3, (mA)	11
Left MFD, (µm)	8
Right MFD, (µm)	8
Set center position	255
AOA current, (mA)	0.0
Early prefusion	NO
Align accuracy, (µm)	0.1

Expected splice loss (measured at 1300nm):

-When light propagates from SMF-28 to LF1200: 0.15dB with standard deviation: 0.03dB

- When light propagates from LF1200 to SMF-28: 0.07dB with standard deviation: 0.02dB



Observation:

-There is no correlation between actual splice loss and the estimation provided by the splicer. To verify the splice quality, a loss test has to be performed (as described in this document).

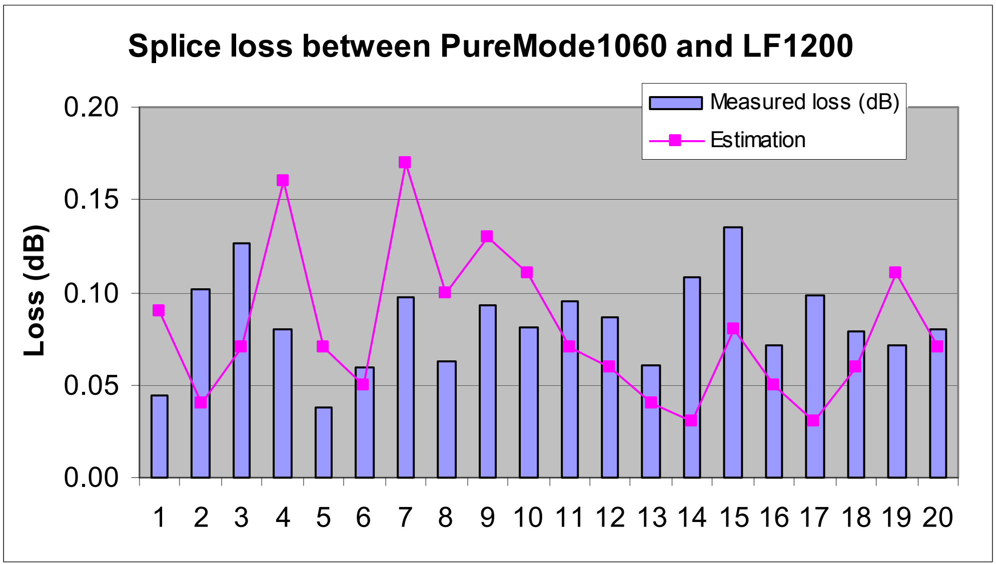
4.1.2 LF1200 to PureMode1060

Parameter	Value
Fiber type	Erbium fiber
Process type	Normal splicing
Prefuse time, (s)	0.2
Prefuse current, (mA)	10
Gap, (µm)	50
Overlap, (µm)	15
Fusion time 1, (s)	0.3
Fusion curr. 1, (mA)	10.5
Fusion time 2, (s)	**2**
Fusion curr. 2, (mA)	**13.5**
Fusion time 3, (s)	0.5
Fusion curr. 3, (mA)	11
Left MFD, (µm)	8
Right MFD, (µm)	8
Set center position	255
AOA current, (mA)	0.0
Early prefusion	NO
Align accuracy, (µm)	0.1

Expected splice loss (measured at 1300nm):

-When light propagates from FlexCore1060 to LF1200: 0.08dB with standard deviation: 0.025dB

- When light propagates from LF1200 to FlexCore1060: 0.06dB with standard deviation: 0.02dB



Observations:

-Reducing the **Fusion time 2** to 1.5s and/or **Fusion curr. 2** to 13mA might reduce the minimum achievable splice loss, but the standard deviation will increase.

-There is a good correlation between the actual splice loss and the estimation provided by the splicer. The average error is bellow 0.01dB (measured from 20 splices)

4.2 Splicing LF2400

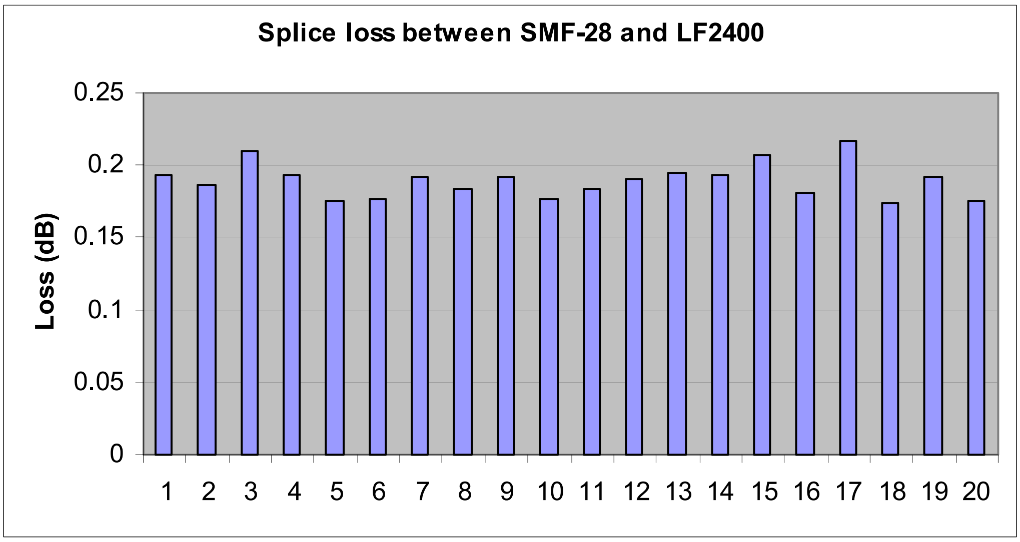
4.2.1 LF2400 to SMF-28

Parameter	Value
Fiber type	Erbium fiber
Process type	Normal splicing
Prefuse time, (s)	0.2
Prefuse current, (mA)	10
Gap, (μm)	50
Overlap, (μm)	15
Fusion time 1, (s)	0.3
Fusion curr. 1, (mA)	10.5
Fusion time 2, (s)	**2**
Fusion curr. 2, (mA)	**14.5**
Fusion time 3, (s)	0.5
Fusion curr. 3, (mA)	11
Left MFD, (μm)	8
Right MFD, (μm)	8
Set center position	255
AOA current, (mA)	0.0
Early prefusion	NO
Align accuracy, (μm)	0.1

Expected splice loss (measured at 1300nm):

-When light propagates from SMF-28 to LF2400: 0.19dB with standard deviation: 0.01dB

- When light propagates from LF2400 to SMF-28: 0.07dB with standard deviation: 0.02dB



Observations:

-There is no correlation between actual splice loss and the estimation provided by the splicer. To verify the splice quality, a loss test has to be performed (as described in this document).

-Reducing the **Fusion time 2** to 1.5s and/or **Fusion curr. 2** to 14mA might reduce the minimum achievable splice loss, but the standard deviation will increase.

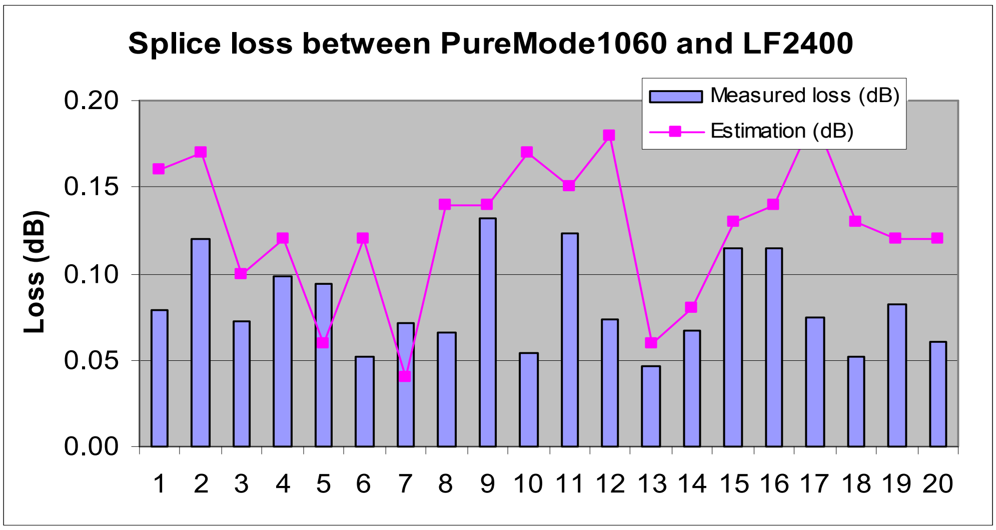
4.2.2 LF2400 to PureMode1060

Parameter	Value
Fiber type	Erbium fiber
Process type	Normal splicing
Prefuse time, (s)	0.2
Prefuse current, (mA)	10
Gap, (µm)	50
Overlap, (µm)	15
Fusion time 1, (s)	0.3
Fusion curr. 1, (mA)	10.5
Fusion time 2, (s)	**2**
Fusion curr. 2, (mA)	**13**
Fusion time 3, (s)	0.5
Fusion curr. 3, (mA)	11
Left MFD, (µm)	8
Right MFD, (µm)	8
Set center position	255
AOA current, (mA)	0.0
Early prefusion	NO
Align accuracy, (µm)	0.1

Expected splice loss (measured at 1300nm):

-When light propagates from FlexCore1060 to LF2400: 0.08dB with standard deviation: 0.03dB

- When light propagates from LF2400 to FlexCore1060: 0.03dB with standard deviation: 0.02dB



Observations:

-There is a good correlation between the actual splice loss and the estimation provided by the splicer. The average error is bellow 0.04dB (measured from 20 splices).

4.3 Recommendations for splicing parameters adjustment

As mentioned before, due to climate conditions, electrodes status and equipment characteristics, the parameters to be used for splicing may vary from case to case. As a consequence, to ensure the best splice quality, for each location, each equipment and whenever the electrodes are changed we recommend to perform splice tests.

If the result of a splice test is not acceptable (average splice loss and/or standard deviation are too high) the following parameters should be changed:

- **Fusion Curr. 2**
- **Fusion Time 2**
- **Overlap**

The solution of this three-dimensional optimisation problem is not straightforward, but understanding the splicing process will help you to reduce the number of steps.

Due to the high dopant concentration in the core of EDF, during splicing the MFD in doped fiber expands faster than the MFD in undoped fiber. This is a good effect since the MFD in doped fiber is smaller then MFD in undoped fiber. The challenge is to find the right values for splicing parameters that minimize the MFD mismatch.

Within reasonable limits, both fusion current and fusion time have a direct effect on the MFD expansion: the higher the time and/or the current, the higher the MFD expansion. Monitoring the optical power during the splicing will give an indication of the necessary change of these parameters (for this, set the power meter integration time to 100 or 200ms). The following rules may be used:

- If during the splice you observe a constant increase of the optical power, then the fusion time and/or fusion current are either to low or they are at optimum.
- If during the splice you observe first an increase in optical power followed by a decrease, then the fusion current and/or time are too high.

Draw a conclusion based on at least 5 splices.

When adjusting the fusion current and time, remember that:

- Too low current and time decrease the strength of the splice. It is not recommended to decrease the current bellow 13mA and the time bellow 1s.
- While the solution of the problem is not unique, it is recommended to choose longer time and lower current. This will make the splicing process smoother allowing better repeatability.

The third parameter mentioned above, the overlap, expresses the distance the fibers are push against each other during splicing, after they touch. A lower value might decrease a little bit the average loss but will increase the standard deviation. For volume splicing we recommend a large value (15um) to ensure better splice repeatability at a reasonable splice loss.

4.4 Acknowledgements

Special thanks to Dr. Wei-Ping Huang from Ericsson Network Technologies AB for very fruitful discussions.

5 Splicing with Sumitomo T-36

Sumitomo T-36 is an "easy to use" splicer because it has an easy way to clamp the fibers and a small number of splicing parameters to adjust. However, this comes with the drawback of having less flexibility in optimising the splice.

Because this splicer does not have any environmental adjusting parameter, ARC CHECK should be performed every time there is a significant change of temperature, and humidity in the atmosphere. See also the recommendations for adjusting the splicing parameters.

Make sure that the parameter 211 "FIBER END ANGLE" is set to 1 degree or lower and that the "SPLICE CONDITION / ALIGN METHOD" is set to "CORE" (see the splicer's manual for information about setting these parameters)

5.1 Splicing LF1200

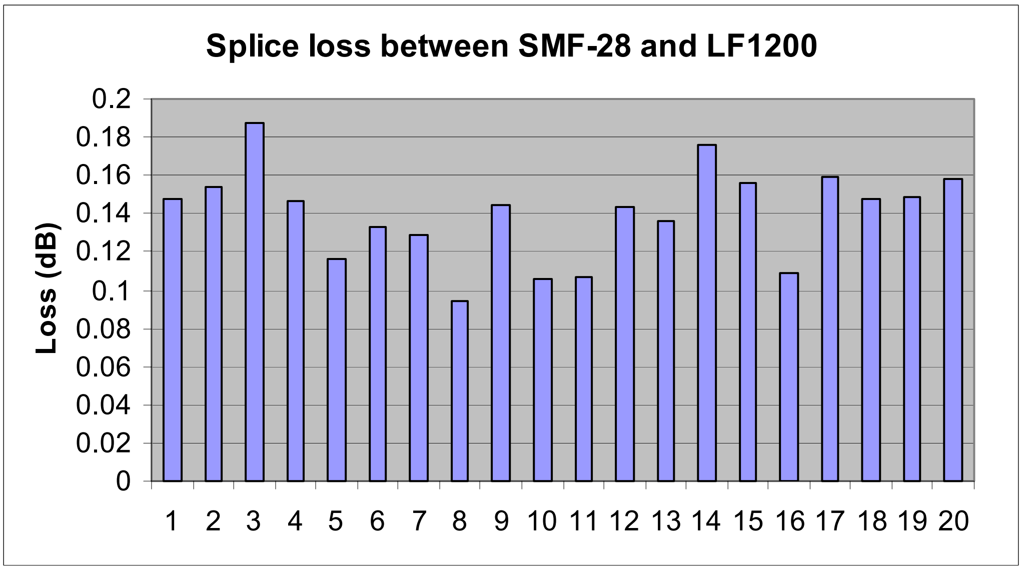
5.1.1 LF1200 to SMF-28

Parameter	Value
ARC DURATION	**2**
PREFUSION	0.2
ARC GAP	8
OVERLAP	15
ARC POWER	**18**

Expected splice loss (measured at 1300nm):

-When light propagates from SMF-28 to LF1200: 0.14dB with standard deviation: 0.025dB

- When light propagates from LF1200 to SMF-28: 0.09dB with standard deviation: 0.03dB



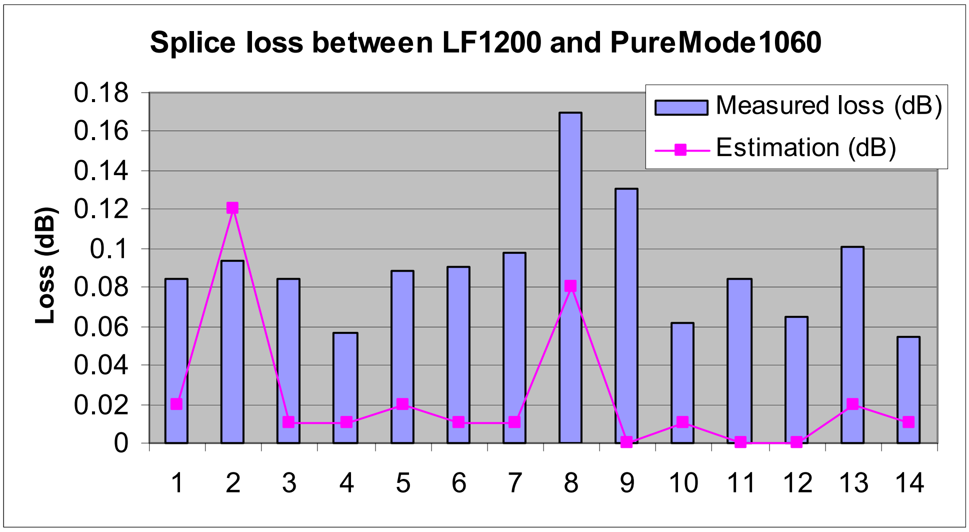
Observation: There is no correlation between measured and estimated splice loss.

5.1.2 LF1200 to PureMode1060

Parameter	Value
ARC DURATION	**1.7**
PREFUSION	0.2
ARC GAP	8
OVERLAP	15
ARC POWER	**17**

Expected splice loss (measured at 1300nm):

- When light propagates from SMF-28 to LF1200: 0.09dB with standard deviation: 0.03dB
- When light propagates from LF1200 to SMF-28: 0.08dB with standard deviation: 0.04dB



Observations: Estimations can be used to detect some bad splices.

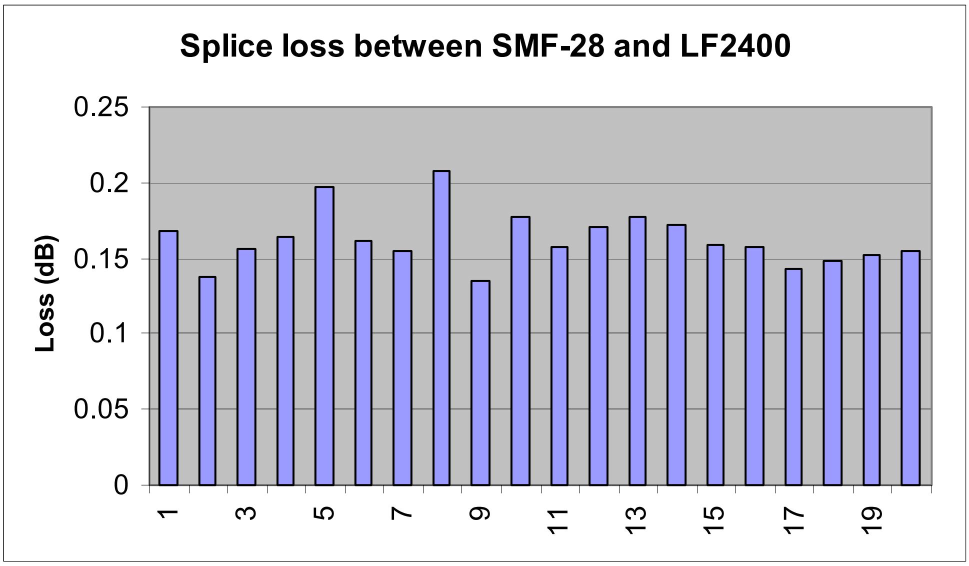
5.2 Splicing LF2400

5.2.1 LF2400 to SMF-28

Parameter	Value
ARC DURATION	**1.7**
PREFUSION	0.2
ARC GAP	8
OVERLAP	15
ARC POWER	**18**

Expected splice loss (measured at 1300nm):

- When light propagates from SMF-28 to LF1200: 0.16dB with standard deviation: 0.02dB
- When light propagates from LF1200 to SMF-28: 0.07dB with standard deviation: 0.025dB



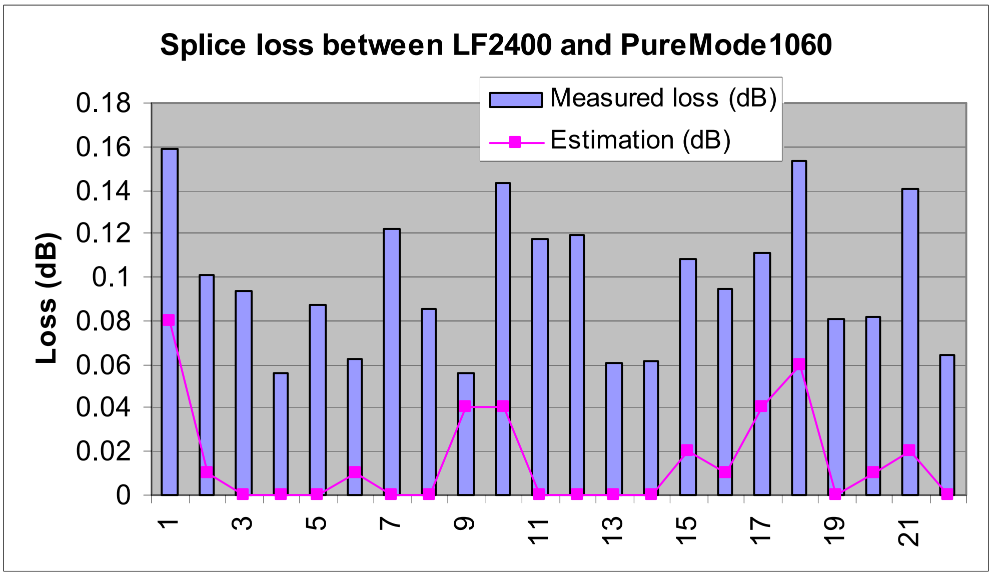
Observation: There is no correlation between measured and estimated splice loss.

5.2.2 LF2400 to PureMode1060

Parameter	Value
ARC DURATION	**1.5**
PREFUSION	0.2
ARC GAP	8
OVERLAP	15
ARC POWER	**17**

Expected splice loss (measured at 1300nm):

- When light propagates from SMF-28 to LF1200: 0.1dB with standard deviation: 0.03dB
- When light propagates from LF1200 to SMF-28: 0.08dB with standard deviation: 0.025dB



Observations: Estimations can be used to detect some bad splices.

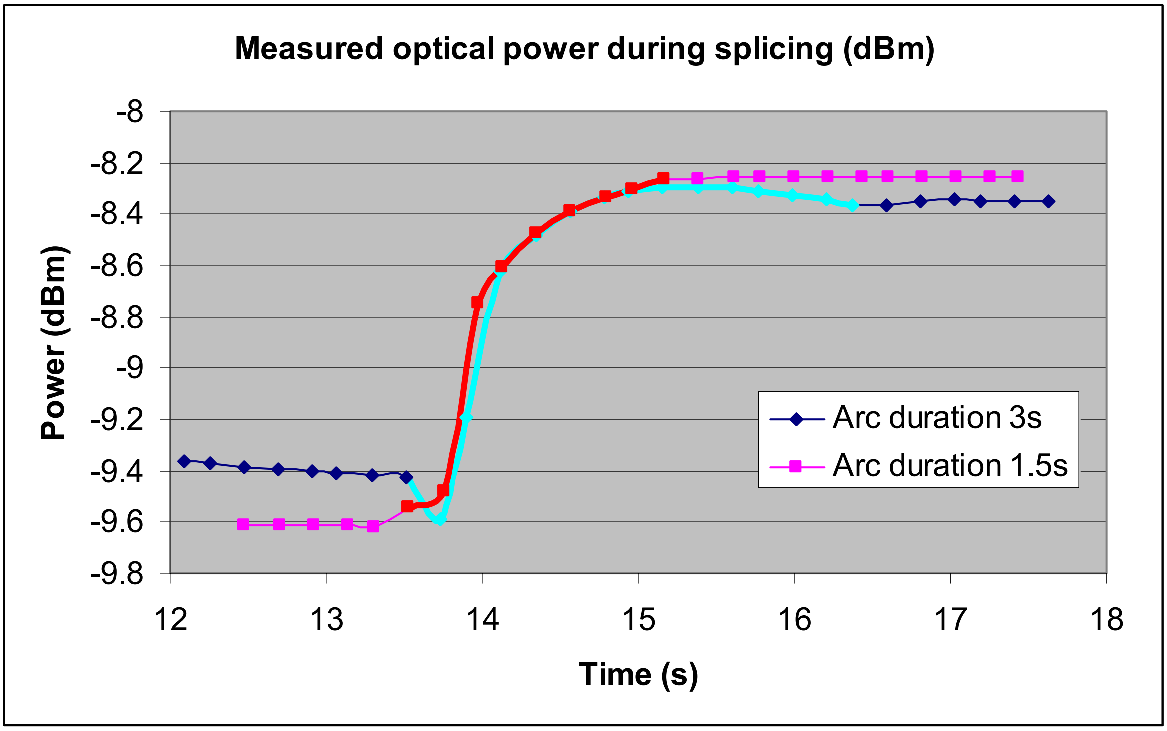
5.3 Recommendations for splicing parameters adjustment

Within reasonable limits, both ARC POWER and ARC DURATION have a direct effect on the MFD expansion: the higher the time and/or the current, the higher the MFD expansion. Monitoring the optical power during the splicing will give an indication of the necessary change of these parameters (for this, set the power meter integration time to 100 or 200ms). The following rules may be used:

- If during the splice you observe a constant increase of the optical power, then the arc duration and/or arc power are either to low or they are at optimum.
- If during the splice you observe first an increase in optical power followed by a decrease, then the arc duration and/or arc power are too high.

Draw a conclusion based on at least 5 splices.

The figure below indicates both situations. The thick lines (read and light blue) indicate the period when the arc is on.



Climate change (temperature, humidity and pressure) may induce important parameter changes. The values indicated in previous paragraphs are valid for 22C, 760mmHg and 60%OH. For example, when splicing LF1200 to 1060 type of fibers the arc power had to be changed between 16 in a hot and humid summer day and 20 in a cold and dry winter day, even though the tests have been performed indoor, with regular acclimatisation switched on.

6 Splicing with Fitel S-176 (preliminary data)

August 1st, 2003
The results presented below are only preliminary. Tests are currently running and this section will be updated as soon as new results will be ready.

Fitel S176 splicer

	Erbium-doped ↔ SMF	Erbium-doped ↔ Flexcore1060
Arc Power	80	90
Arc Duration	1500	1000
Average splice loss	0.19 dB	0.03 dB

The other necessary Fitel S176 splicing parameters correspond to splicing program no. 26 (EDSM):

Arc power compensation=0
Cleaning A-power offset=20
Cleaning time=200
Pre-fuse time=160
Z Pull start time=0
Z Push Distance=15
Z Pull distance=0
Repeat arc times=0
Repeat arc duration=1000
Repeat arc interval=1000
Repeat arc power offset =0
Attenuation=0
Aligning type=CORE
Auto additional arc=0 *
Offset=0
Cleave angle=1
Loss limit=15
Wavelength=1550
Mode field radius L=2.45
Mode field radius R=5.37

* Because the estimation of the splice loss given by the splicing machine is not reliable we recommend that the "Auto additional arc" feature of the fusion splicer should not be used.