

# Investigation of Bend Loss Performance of Standard G.652D Fibres Relative to the ITU-T Bend Loss Requirements in Optical Access Networks

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## Abstract

In this paper, we have investigated the detailed macro bend loss performance of 60 samples of G.652D fibres with MAC numbers in the upper range of MAC values that could typically be found in current G.652D fibres. The samples thus contain an elevated number of fibres with expected poor bending properties, and have been tested relative to the test limits in ITU-T Recommendation G.657, class A fibres. For the 30 mm-10 turn test, we have found that 2 % of the investigated fibres were outside the test limits at 1550 nm and 1621 nm. For the 20 mm-1 turn test, 12 % and 15 % of the investigated fibres at 1550 nm and 1621 nm, respectively, were outside the test limits. Evidence is found for a linear relationship between bend losses and MAC number. By choosing 7.40 as an upper limit for the MAC number, the percentage of investigated fibres outside the test limits has been reduced to zero percent in the 30 mm-10 turn test, and to 6 % and 11 % at 1550 nm and 1621 nm, respectively, in the 20 mm-1 turn test. In addition, we have removed the fibres with the highest bend losses.

**Keywords:** Fibre; cable; macro-bend, loss, G652D, MAC-number

## 1. Introduction

The purpose of ITU-T Recommendation G.657 [1] is to support fibres with improved bending performance compared with the existing G.652 single mode fibre and cables. This is accomplished by introducing two classes of single mode fibres, one of which, class A, is fully compliant with the G.652 single mode fibres and can be used in all parts of the access network, while the other class, class B, is not necessarily compliant with G.652 but is capable of very low values of macro bending losses at very low bend radii, and is pre-dominantly intended for in-building use.

In particular, for G.657 class A fibres, four bending tests consisting of two different combinations of bending radii and number of turns (15 mm/10 turns and 10 mm/1 turn) as well as two different wavelengths (1550 nm and 1625 nm) with corresponding values of maximum recommended macro bend losses, are given.

In comparison, we find in ITU-T recommendation G.652: "Characteristics of a single-mode optical fibre and cable", that only one single bending test at radius 30 mm and 100 turns with 0.5 dB of maximum recommended macro bend loss at 1625 nm, is given.

Clearly, it is impossible to compare directly the G.657 class A and G.652 tests and the question arise to what extent standard G.652

fibres are qualified according to the improved bending performance given in G.657.

In order to have a better understanding of this problem, we have performed the macro bend tests given in G.657, class A, on a significant number of G.652D fibres and investigated their detailed macro bend loss performance. For each bending condition, macro bend loss dependence on individual fibre parameters such as MAC number and test wavelength has been investigated.

## 2. Fibres and measurements

### 2.1 Fibres

Theoretically, the macro bend losses in G.652D fibres are proportional to the MAC number of the individual fibres. The MAC number (MAC) is defined as mode field diameter (MFD) divided by fibre cut-off wavelength value, shown in equation (1).

$$1) \quad \text{MAC} = \text{MFD}/\text{fibre cut-off wavelength}$$

60 fibres in a number of cables of a few hundred meters lengths containing G.652D fibres with known MAC numbers have been tested. The MAC numbers in the test fibres have been in the range 6.9-7.7, covering the upper range of MAC values that could typically be found in current G.652D fibres. The reason for this is to increase the number of fibres with expected poor bending properties in our sample selection. In Figure 1 is shown a typical distribution of MAC-numbers that could be found in G.652D fibres as well as the distribution of the investigated fibres.

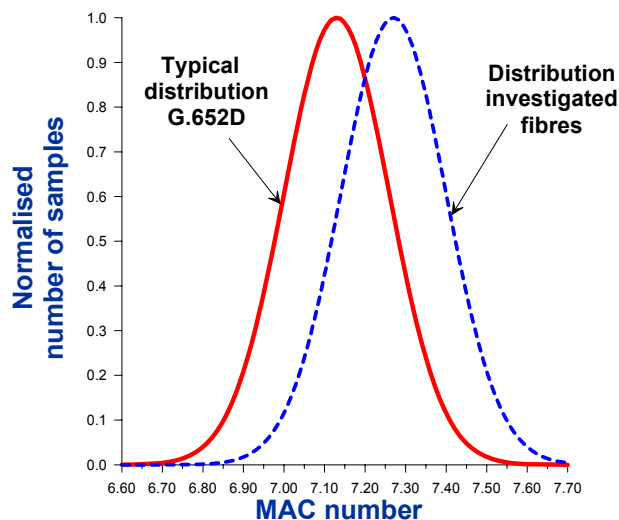


Figure 1: MAC number distributions.

## 2.2 Macro bend test and ITU-T requirements

The fibres were spliced together to form suitable measurement loops, and each fibre was wound 10 turns and 1 turn around mandrels with diameter 30 mm and 20 mm, respectively. For each mandrel diameter combination, the macro bend losses were measured at 1300 nm, 1550 nm, 1621 nm and 1642 nm, respectively. We have used OTDR's with the above wavelengths to measure the added macro bend loop losses.

In order to be able to measure the macro bend losses in a well defined manner, the guidelines given in IEC standard 60793-1-47 [2], describing the measurement methods and test procedures for macro bend losses, have been closely followed.

Table 1 lists the limits for maximum macro bend losses at different wavelengths and bending conditions, as stated in ITU-T Recommendation G.657, class A fibres.

Diameter (mm)	30	20
Number of turns	10	1
Max. 1550 nm (dB)	0.25	0.75
Max. 1625 nm (dB)	1.00	1.50

Table 1: G.657- Class A macro bend loss requirements

## 3. Results

### 3.1 Analysis of OTDR curves

Since we have measured more than 60 different fibres at four wavelengths and at two different bending conditions, it was necessary to develop software for automated analysis. Here, the loop losses were calculated for all fibres at all wavelengths and bending conditions and the corresponding reference loop loss were subtracted to find the induced bending losses.

### 3.2 Wavelength dependence statistics

#### 3.2.1 30mm diameter-10 turns

The following Figures show the statistics from the bend tests performed at 30 mm diameter and 10 turns. In Figure 2, Figure 3 and Figure 4 are shown histograms including all fibres of the bending losses at 1550 nm, 1621 nm and 1642 nm, respectively. The bend losses at 1300 nm turned out to be zero for all the measured fibres

Some features should be noted from these figures. Firstly, we note that only 1 fibre of 60 is outside the G.657 limits, indicating that 98 % of the tested G.652D fibres have passed the 30mm/10 turn test.

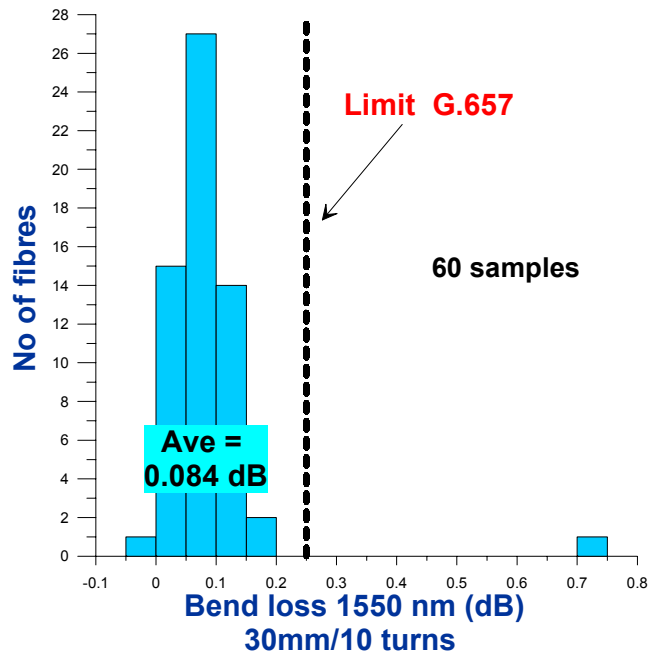


Figure 2: Bend loss statistics at 1550 nm.

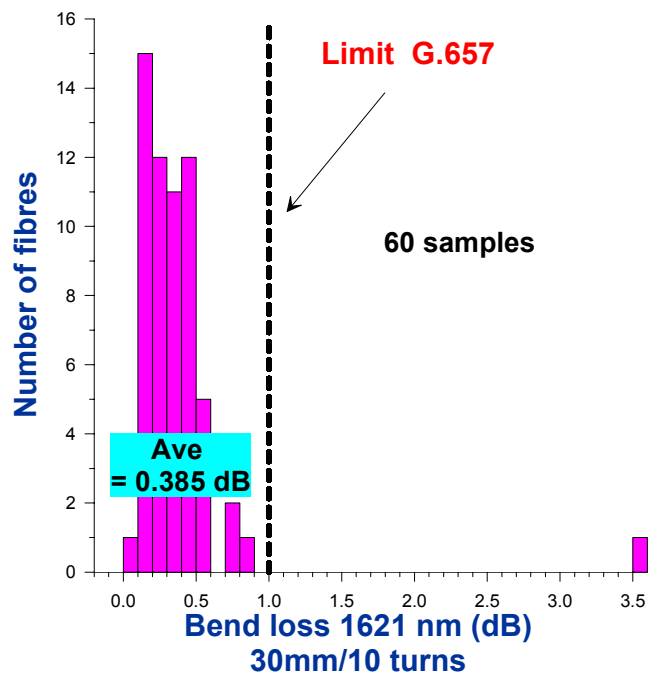


Figure 3: Bend loss statistics at 1621 nm.

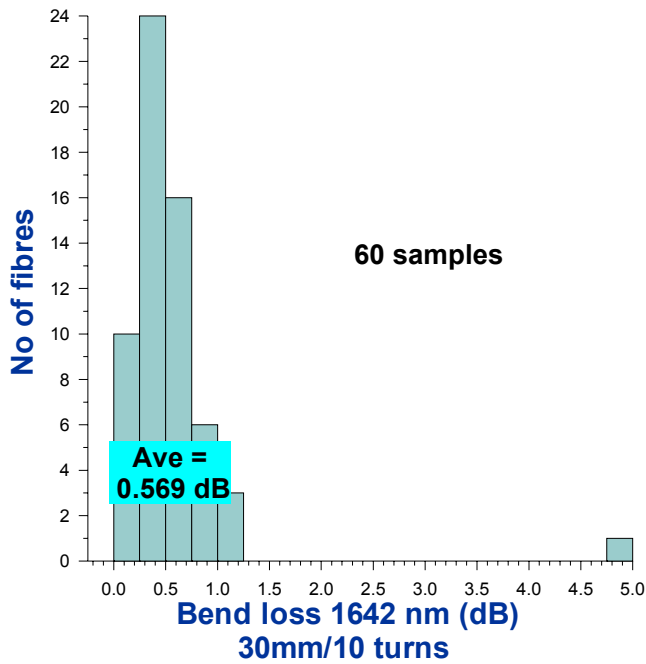


Figure 4. Bend loss statistics at 1642 nm.

Secondly, the average bend losses at 1621 nm are approximately 4.5 times larger than the average bend losses at 1550 nm. This is in good agreement with other reported investigations as well as in agreement with the ratio between the limits for the two wavelengths (4x) set in G.657A (Table 1).

Finally, the average ratio between the bend losses at 1642 nm and 1621 nm is found to be approximately 1.5.

### 3.2.2 20 mm diameter- 1 turn

The following Figures show some statistics from the bend tests performed at 20mm diameter and 1 turn.

In Figure 5, Figure 6 and Figure 7 are shown histograms including all fibres of the bending losses at 1550 nm, 1621 nm and 1642 nm, respectively. Again, the bend losses at 1300 nm turned out to be zero for all the measured fibres

Clearly, this test results in significantly higher losses at all three wavelengths, than the previous test. This has been reflected in the higher test limits set in G.657A (Table 1) for this test.

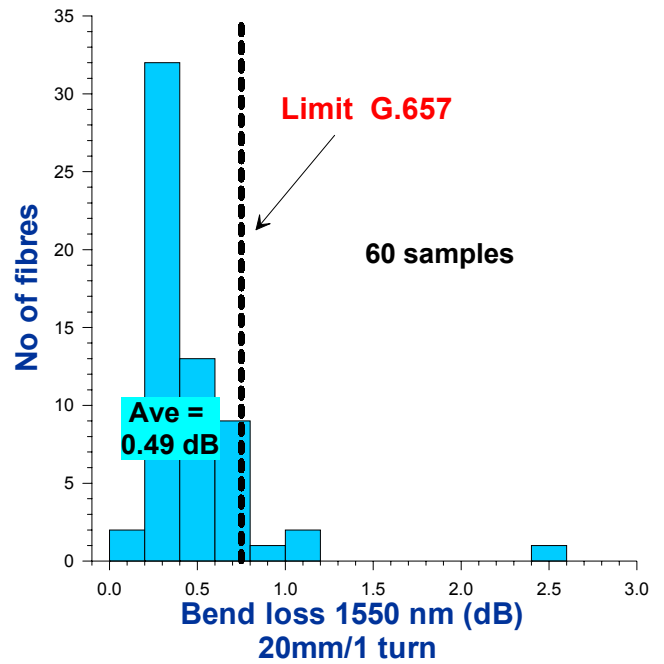


Figure 5: Bend loss statistics at 1550 nm.

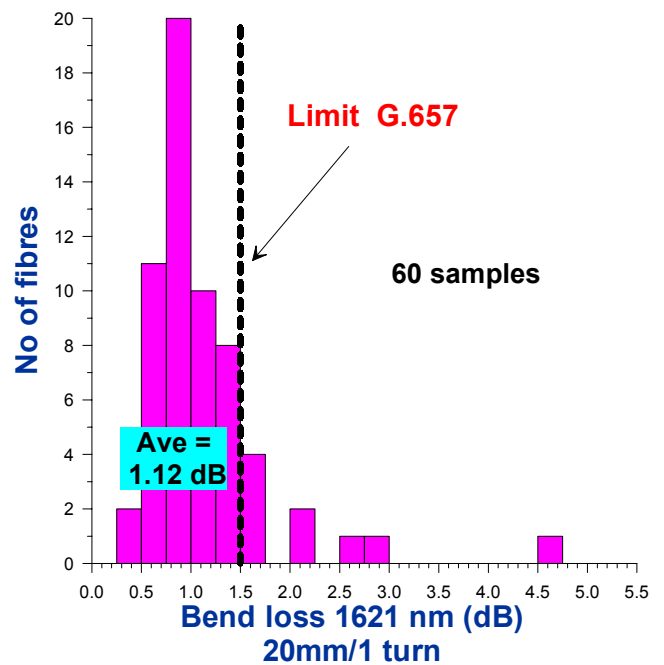


Figure 6: Bend loss statistics at 1621 nm.

It is evident that more fibres will fall outside the G.657 limits in this test than in the previous test. Considering the “worst case” at 1621 nm, 9 fibres of 60 will not pass the test, indicating that a percentage of 15 % of the investigated fibres will not pass the test.

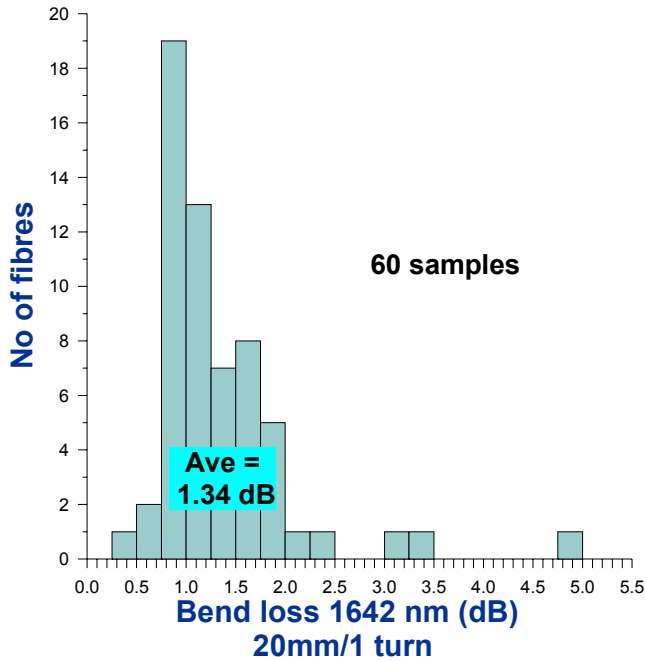


Figure 7: Bend loss statistics at 1642 nm.

For this test, the average bend losses at 1621 nm are approximately 2.3 times larger than the average bend losses at 1550 nm, which is in good agreement with the ratio (2x) between the test limits for the two wavelengths in G.657 (Table 1).

Additionally, we find that the average ratio between the bend losses at 1642 nm and 1621 nm is approximately 1.2.

### 3.3 MAC number dependence

#### 3.3.1 30 mm diameter-10 turns

In Figure 8 and Figure 9 are shown the bend losses at 1550 nm and 1621nm, respectively, as a function of MAC number, for 30 mm bending diameter and 10 turns.

It is evident from Figure 8 as well as Figure 9 that the bend losses tend to increase with increasing MAC number. Linear fits to the data are shown indicating the calculated increase rates according to the theory.

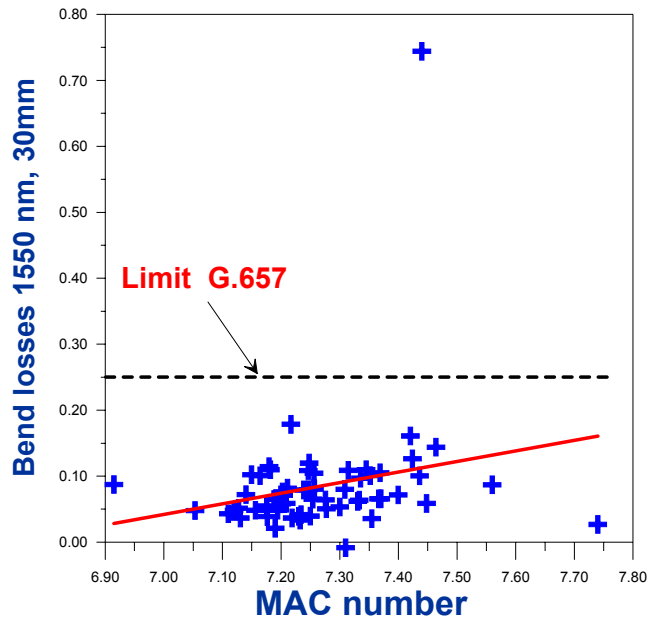


Figure 8: 1550 nm bend losses vs. MAC number-30 mm 10 turns.

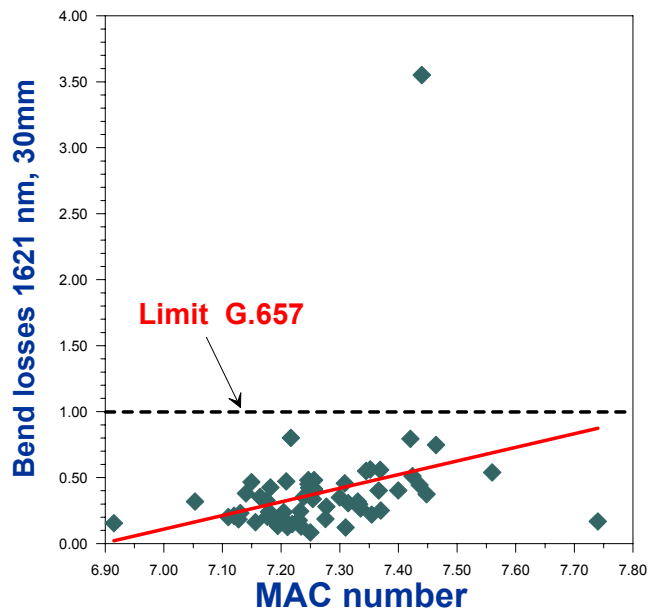


Figure 9: 1621 nm bend losses vs. MAC number-30mm 10 turns.

#### 3.3.2 20 mm diameter-1 turn

Figure 10 and Figure 11 show the bend losses at 1550 nm and 1621 nm, respectively, as a function of MAC number, for 20 mm bending diameter and 1 turn.

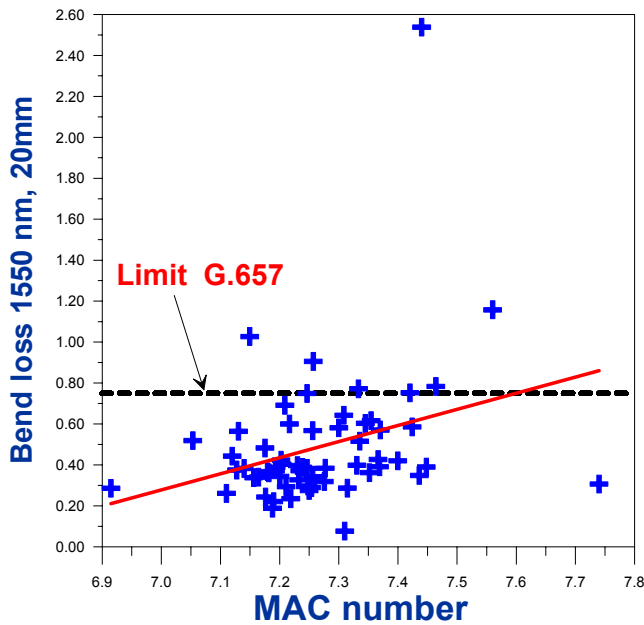


Figure 10: 1550 nm bend losses vs. MAC number- 20 mm 1 turn.

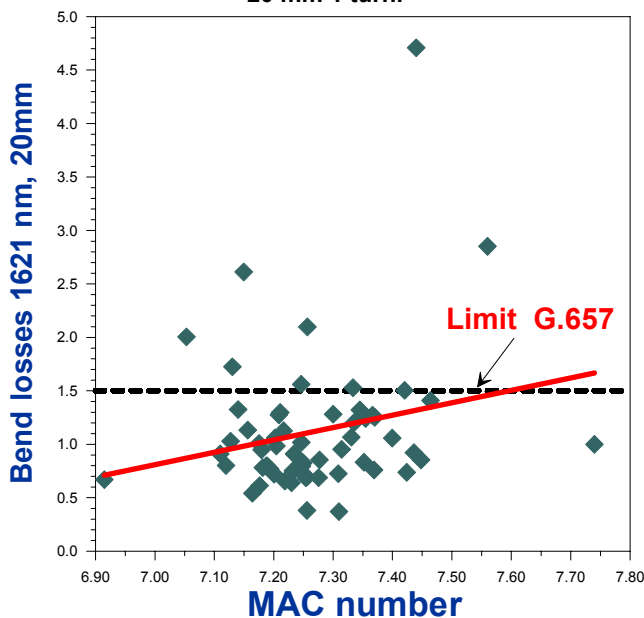


Figure 11: 1621 nm bend losses vs. MAC number- 20 mm 1 turn.

Again, it is evident from Figure 10 and Figure 11 that the bend losses tend to increase with increasing MAC number. Linear fits to the data are shown indicating the calculated increase rates.

The calculated bend loss increase with MAC number is more pronounced for this test than for the 30 mm-10 turn test. Also, the spread in the data set is higher.

## 4. Discussion

The data variations in all the tests may result from different factors. The Mack values for the different fibres are taken to be the value given by the fibre manufacturer for the fibre spool used in the test cable. Obviously, the MAC-number for the actual fibre length under test may vary from that value, since the MAC value could vary along the fibre spool length. Also the detailed winding of the fibre around the mandrel could cause some variation of the bending loss.

The spread seems in all tests to be larger for the higher MAC numbers than for the medium and lower MAC values. However, there are only limited data with high MAC values to support this assumption.

In summary, we have noted that the 30 mm-10 turn test at 1550 nm and 1621 nm has 1 of 60 fibres (2%) outside the G.657 limits. Also, we have registered that the 20 mm-1 turn test at 1550 nm has 7 of 60 fibres (12 %) outside the G.657 limits, while the 20 mm-1 turn test at 1621 nm has 9 of 60 fibres (15 %) outside the G.657 limits.

It is possible to reduce the number of fibres falling outside the G.657 limits by selecting fibres with an upper limit for the MAC number.

If we choose an upper limit of 7.40 for the MAC number, it would reduce considerably the number of bend test fallouts for the investigated fibres. In this case, the 30 mm-10 turn test at 1550 nm and 1621 nm will have zero of 52 fibres (0 %) outside the G.657 limits. Furthermore, the 20 mm-1 turn test at 1550 nm will then have only 3 of 52 fibres (6 %) outside the G.657 limits, while the 20 mm-1 turn test at 1621 nm will have only 6 of 52 fibres (11 %) outside the G.657 limits.

In addition, we get rid of the fibres with the highest bend losses.

It should be noted that more than 97 % of the fibres in a typical G.652D distribution (Fig.1), would have MAC values less than 7.40, indicating that this is a weak selection.

Finally, it is evident that all outage percentages would have been lower if the distribution of MAC-numbers in the investigated fibres had been similar to the typical distribution of MAC-numbers in G.652D fibres.

## 5. Conclusions

We have performed the macro bend tests given in G.657, class A fibres, on 60 samples of G.652D fibres and investigated their detailed macro bend loss performance relative to the G.657 test limits. The MAC numbers of the test fibres have been in the upper range of MAC values that could typically be found in current G.652D fibres, and thus the number of fibres with expected poor bending properties in our sample selection is higher than normal.

For the 30 mm-10 turn test, we have found that approximately 2 % of the investigated fibres were outside the test limits at 1621 nm as well as at 1550 nm. We also show that the average bend losses at 1621 nm are approximately 4.5 times larger than the average bend losses at 1550 nm while the ratio between the bend losses at 1642 nm and 1621 nm is found to be approximately 1.5.

For the 20 mm-1 turn test, the bend losses are generally higher. Here, 12 % and 15 % of the investigated fibres at 1550 nm and 1621 nm, respectively, were outside the test limits. Furthermore, at 1621 nm the bend losses are approximately 2.3 times larger than the average bend losses at 1550 nm while the average ratio between the bend losses at 1642 nm and 1621 nm is approximately 1.2.

From the measurement data we have found evidence for a trend that the bend losses increase linearly with increasing MAC number.

If we choose an upper limit of 7.40 for the MAC number, which is a weak selection in the typical G.652D distribution, zero percent of the investigated fibres were outside the test limits in the 30 mm-10 turn test, and only 6 % and 11 % of the investigated fibres at 1550 nm and 1621 nm, respectively, were outside the test limits in the 20 mm-1 turn test.

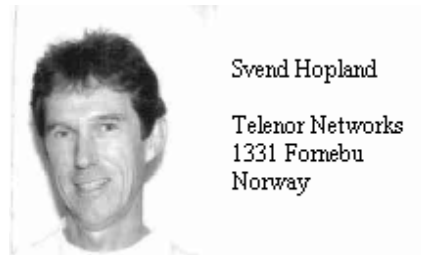
All outage percentages would have been lower if the distribution of MAC-numbers in the investigated fibres had been similar to the typical distribution of MAC-numbers in G.652D fibres.

## 6. Acknowledgments

Great thanks to Idar Gangsø (now retired), who have performed the measurements. Without his skilfulness and enthusiastic work, this investigation would not have been possible.

## 7. References

- [1] ITU-T Recommendation G.657: "Characteristics of a bending loss insensitive single mode optical fibre and cable for the access network".
- [2] IEC standard 60793-1-47: "Measurement methods and test procedures-Macrobending loss"



Svend Hopland is chief engineer on optical fibre cables and fibre transmission in Telenor Norway Technology. He graduated from the Norwegian Institute of Technology in 1985 with a PhD on optical fibres and joined Telenor in 1986. He is responsible for submarine cables and fibre and fibre cable specifications in Telenor. He has developed an advanced method for installing underwater cables in the difficult sub sea terrain along the Norwegian coast. He has done extensive investigations on hydrogen generation in installed underwater cables and he has pioneered field measurements on wide spectrum fibre cable link losses. In his spare time he enjoys among other things cycling and soccer playing.