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# A European Investigation of Cut-off Wavelength Measurements

**European Project Group***

## Abstract
*A european intercomparison between 10 laboratories of cut-off wavelength measurements has demonstrated that full implementation of the Reference Test Method (RTM) can provide an accuracy of ± 5 nm. However worse agreement was obtained when measuring dispersion shifted fibres. The accuracy of measurements of weakly guided fibres is limited by the sensitivity of the propagation of the $LP_{11}$ mode in the cladding of the fibre to the bending conditions introduced by the RTM. Some commercial systems are shown to measure a low cut-off wavelength for dispersion shifted fibres compared to a full implementation of the RTM.*

## Background
The cut-off wavelength of an optical fibre is the wavelength above which a fibre will only guide a single mode. Its precise determination is important in order to maximise the performance of systems which operate close to the potential limit of the optical fibre. An earlier COST 217 intercomparison of singlemode fibre cut-off wavelength [1,2] revealed the poor agreement between European laboratories in determining this parameter. The aim of this intercomparison was to investigate improvements in the measurement of cut-off wavelength using techniques which were highlighted in a study of the causes of anomalies in cut-off wavelength measurements [3]. The project consisted of a comparison of the results of cut-off wavelength measurements performed by 10 European laboratories.

An additional aim was to compare measurements of cut-off wavelength obtained from laboratory instrumentation with measurements obtained from commercial instrumentation. It was hoped to identify:-

- systematic differences in the repeatability of measurements performed under different techniques.
- systematic uncertainties associated with the use of commercial test equipment.

This aspect of the intercomparison was of particular interest, because the most commonly used piece of commercial test equipment does not fully implement the RTM. In particular, it incorporates an additional three quarter turn of diameter greater than 28 cm in the fibre under test. Studies of the variation of cut-off with deployment of the fibre have identified that for some fibre types, this additional loop may change the measured cut-off wavelength.

## Measurements
Four types of fibre were selected for the comparison: Matched cladding, Depressed cladding fibre, Dispersion shifted fibre and Erbium doped fibre. For each participant in the intercomparison, a prepared 2 m sample was provided of each fibre type to be measured. Prior to circulation, each sample for each participant was measured for cut-off wavelength in order to provide a control for the intercomparison. It should be noted that the fibres samples were taken from consecutive lengths from a given spool. No systematic variation in cut-off wavelength was observed with position of sample in the spool.

Each participant was asked to measure each fibre using the transmitted power technique [4] with two launch conditions: open beam overfill launch and multimode fibre launch. The reference power was obtained from the fibre under test by using a mode filter which comprised of one 6 cm diameter loop of the fibre. Care was taken not to disturb the launch between reference power and transmitted power configuration.

In general, the open beam launch is likely to produce a larger variation in experimental conditions between participants. Although all participants comply with the RTM in respect of overfill of both core and NA at launch, there will be variations between participants in the following: the uniformity of launch spot, the size of launch spot, the NA of launch conditions, the positioning of launch spot.

To investigate the possible improvement in measurement repeatability associated with common launch conditions, a multimode launch kit was circulated with the fibres. This multimode launch consisted of a three metre length of 50/125 graded index multimode fibre into which radiation was launched. A mode scrambler consisting of twenty turns of 20 mm diameter ensured that all modes in the launch fibre were uniformly excited. The fibre was then butt coupled to the fibre under test., via a temporary splice. This splice ensured the repeatable positioning of the launch fibre relative to the fibre under test. The same measurement conditions were specified for the multimode fibre launch, with the additional specification that the butt joint was not disturbed between configurations.

In both cases, participants were requested not to cleave the fibre under test, as precise cleaves had already been performed on the circulated fibres.

## Results of the intercomparison and discussion

The results of the intercomparison are summarised in table 1 and table 2. Table 1 presents results for both fibre guide and commercial instrumentation using an open beam launch configuration. Table 2 provides the same information, but for a multimode fibre launch.

**Table 1: Results of open beam launch measurements**

| Fibre: | NPL1 - DC cut-off nm | NPL2 - MC cut-off nm | NPL3 - DS cut-off nm | NPL4 - Er cut-off nm |
|---|---|---|---|---|
| Laboratory system participant: | | | | |
| A | 1272.0 | 1240.0 | 1148.0 | 864.0 |
| B | 1279.0 | 1247.0 | 1152.3 | 866.5 |
| C | 1269.0 | 1229.0 | 1165.0 | 864.0 |
| D | 1276.9 | 1245.2 | 1138.2 | 869.1 |
| E | 1276.7 | 1243.4 | 1164.1 | 861.2 |
| F | 1274.5 | 1245.0 | | 863.9 |
| Mean | 1274.7 | 1241.6 | 1153.5 | 864.8 |
| SEOM | 1.5 | 2.7 | 5.0 | 1.1 |
| $\sigma_{n-1}$ | 3.6 | 6.6 | 11.3 | 2.7 |
| Commercial system participant: | | | | |
| G | 1270.0 | 1246.0 | 1137.0 | 855.0 |
| H | 1268.0 | 1240.0 | 1130.0 | 860.0 |
| C | 1274.0 | 1233.0 | 1132.0 | 865.0 |
| I | 1276.8 | 1233.6 | 1124.0 | 855.7 |
| J | 1275.6 | 1247.0 | 1159.0 | 868.8 |
| Mean | 1272.9 | 1239.9 | 1136.4 | 860.9 |
| SEOM | 1.6 | 2.9 | 6.0 | 2.7 |
| $\sigma_{n-1}$ | 3.6 | 6.5 | 13.4 | 6.0 |
| All Systems: | | | | |
| **Mean** | **1273.9** | **1240.8** | **1145.0** | **863.0** |
| **SEOM** | **1.1** | **1.9** | **4.7** | **1.4** |
| $\sigma_{n-1}$ | 3.6 | 6.3 | 14.7 | 4.6 |

### Reproducibility of results

For the results for the open beam launch (Table 1), the overall reproducibility for NPL1, the depressed clad fibre is 3.6 nm. This is consistent with the pre-intercomparison work which identified DC fibre as being the most reproducible fibre to measure. Reproducibility for NPL2, the matched clad fibre is 6.3 nm. The reproducibility of measurements for the erbium doped fibre, NPL4, is 4.6 nm. This is despite difficulties experienced by some participants in launching power into the fibre because of its small core size. The reproducibility for NPL3, the dispersion shifted fibre is poor, only 15 nm.

**Table 2: Results of multimode fibre butt-couple launch**

| | NPL1 - DC cut-off nm | NPL2 - MC cut-off nm | NPL3 - DS cut-off nm | NPL4 - Er cut-off nm |
|---|---|---|---|---|
| Laboratory system participant: | | | | |
| A | 1274.0 | 1232.0 | 1136.0 | 864.0 |
| B | | | | |
| C | 1269.0 | 1233.0 | 1158.0 | 864.0 |
| D | 1266.4 | 1236.2 | 1133.6 | 865.4 |
| E | | 1232.0 | 1132.0 | |
| F | 1270.9 | 1242.0 | 1133.5 | |
| Mean | 1270.1 | 1235.0 | 1138.6 | 864.5 |
| SEOM | 1.6 | 1.9 | 4.9 | 0.5 |
| $\sigma_{n-1}$ | 3.2 | 4.2 | 10.9 | 0.8 |
| Commercial system participant: | | | | |
| G | 1268.0 | 1239.0 | 1131.0 | |
| H | 1272.0 | 1248.4 | 1143.2 | 858.4 |
| C | | | | |
| I | 1267.4 | 1228.4 | 1116.4 | 856.6 |
| J | 1274.7 | 1239.0 | 1143.1 | 865.9 |
| Mean | 1270.5 | 1238.7 | 1133.4 | 860.3 |
| SEOM | 1.8 | 4.1 | 6.4 | 2.5 |
| $\sigma_{n-1}$ | 3.6 | 8.2 | 12.8 | 4.3 |
| **All Systems:** | | | | |
| **Mean** | **1270.3** | **1236.7** | **1136.3** | **862.4** |
| **SEOM** | **1.1** | **2.0** | **3.8** | **1.6** |
| $\sigma_{n-1}$ | 3.1 | 6.0 | 11.3 | 3.9 |

For the multimode launch, there is no significant improvement in the reproducibility of measurements across all participants for the matched cladding, depressed cladding and erbium doped fibres. However, the reproducibility of measurements of the dispersion shifted fibre, NPL3, improved from 15 nm to 11 nm. This highlights the sensitivity of cut-off wavelength of these types of fibre to launch condition. and the intercomparison indicates that improvement in the specification of launch in the RTM will improve the reproducibility of measurement for this fibre type.

Difficulties were experienced by some participants in realising the multimode launch conditions. In particular, periodic oscillations were observed in both the reference power plot and transmitted power plot using the multimode launch. The magnitude of these oscillations was reduced by inserting refractive index matching oil at the fibre butt joint. It is postulated that these effects are associated with interference effects caused by inter-reflections between the fibre ends.

For the matched clad fibre, this intercomparison shows a factor of two improvement in the reproducibility of measurement over those reported in the COST 217 intercomparison [3]. However, a similar improvement has not been observed for the dispersion shifted fibre.

**Comparison of commercial instrumentation with fibre guide results**

The open beam launch results for fibres NPL1 (depressed clad) and NPL2 (matched clad) show good agreement between measurements using both commercial equipment and the laboratory fibre guide set up. For NPL1 the difference in the mean of the results is 1.7 nm and for NPL 2, 1.7 nm. For NPL3 (dispersion shifted), there is a systematic difference between the two sets of measurements. In particular, there is a difference of nearly 20 nm between results obtained using Manufacturer 1, and those obtained using the fibre guide. This discrepancy may be associated with the extra 3/4 turn which is introduced in to the fibre when measuring using a Manufacturer 1 system. Results obtained using the Manufacturer 2 System agree well with those obtained from the fibre guide.

The multimode launch results for NPL3, the dispersion shifted fibre, show a reduction in the value of cut-off wavelength of 15 nm when measured using the laboratory systems. This lower value of cut-off wavelength is comparable with that measured by commercial instrumentation. In addition, there is an improvement in the reproducibility of measurements for participants using the laboratory systems. There is no associated improvement in the reproducibility for commercial instrumentation, nor is this improvement in reproducibility found in measurements of other fibre types. A smaller number of participants measured the cut-off wavelength using the multimode launch due to the interference effects outlined above. The apparent improvement in reproducibility may be a reflection on the reduced size of the data-set.

## Conclusions

The cut-off wavelength of most fibre types can be measured across Europe with an agreement of better than ± 5 nm, using both commercial and laboratory realisation of the RTM. This is a significant improvement over the agreement obtained in previous intercomparisons. There remains a problem measuring the cut-off wavelength of dispersion shifted fibres. This is critically affected by the way light is launched into the 2 m length of fibre.

There is a systematic difference in results obtained for dispersion shifted fibre between commercial and laboratory realisation of the RTM when using an open beam source. Some commercial instruments measure a low cut-off wavelength. This is attributed to the discrepancies in interpretation of the RTM in the deployment of the fibre for these instruments.

Multimode launch techniques can cause interference effects in the cut-off plots, which are reduced by using matching oil. The launch set-up provides a more consistent way of launching radiation into fibre.

Active fibres do not present a problem with regard to the measurement of cut-off wavelength. However, there can be some difficulty in coupling enough power into the small core of such fibres. This can cause signal to noise problems with measurements.

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