Quantifying Uncertainty Contributions For Fibre Optic Power Meter Calibrations

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Abstract

This paper discusses the determination of uncertainty contributions when performing a power responsivity calibration for a fibre optic power meter. Only selected uncertainty contributors are looked at in detail. It is not always possible to measure or isolate an uncertainty contribution to quantify it completely. The effects of fibre flexing and connector tightening at wavelengths 1310 nm and 1550 nm are investigated in more detail to determine their contributions to the uncertainty of measurement.

1. Introduction

A fibre optic power meter calibration has several uncertainty contributors associated with it. In order to assign a realistic uncertainty to the calibration result it is necessary to realistically estimate the magnitude of each uncertainty contributor. Two contributors that are of interest during a fibre optic power meter calibration are the effect of connector-tightening and the effect of fibre flexing. This paper reports on empirical measurements that we performed to quantify these two uncertainty contributors, the methods we used and the results thereof. It was done only for standard single mode fibre with FC connectors, and using a 1310 nm and a 1550 nm Fabry Perot laser (FP laser).

2. The calibration set-up and procedure

Generally the uncertainty contributions for fibre optic power meter measurements must be identified and understood in the context of the calibration procedure. Figure 1 shows the set-up.

[†] During the period over which part the work reported on in this paper was performed, the co-author was associated with NMISA. He also assisted with the drafting of this paper.

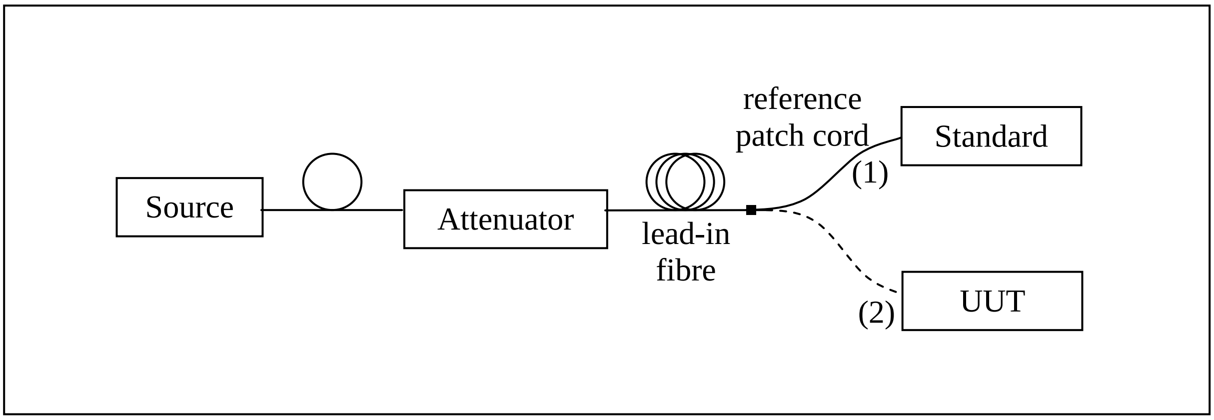

Figure 1. Measurement setup for the calibration of an optical power meter/photodiode.

The measurement or calibration procedure in short is as follows.
A source of the required wavelength, in this case 1310 nm, or 1550 nm, is fed to the fibre optic power meter (standard or unit under test (UUT)) via an attenuator. The attenuator serves to reduce back-reflections into the source and to set the power to the desired level. In Figure 1 the patch cord, alternatively feeding into the standard or UUT is labelled “reference patch cord”. It is preferred to use a patch cord with a ceramic fibre tip (not metal fibre tip) to reduce the effect reflections have between the fibre tip and the detector of the power meter. A long length of lead-in fibre can also be connected between the attenuator and the reference patch cord to reduce changes in coherence effects, resulting from variations in back-reflections and polarisation due to flexing of the patch cord when it is moved between standard and UUT.

When the measurement setup is complete and ready to perform measurements, there should be as little change as possible in the setup, eg. flexing and moving of the fibre, changing of any item in the measurement setup. Such changes may cause a change in the power level detected by the detector, and will cause calibration errors or larger uncertainties.

3. Possible uncertainty contributors

With the measurement setup defined, possible uncertainty contributions can be identified. See Figure 2 for a fish bone diagram that shows uncertainty contributions of the standard and UUT associated with the calibration.

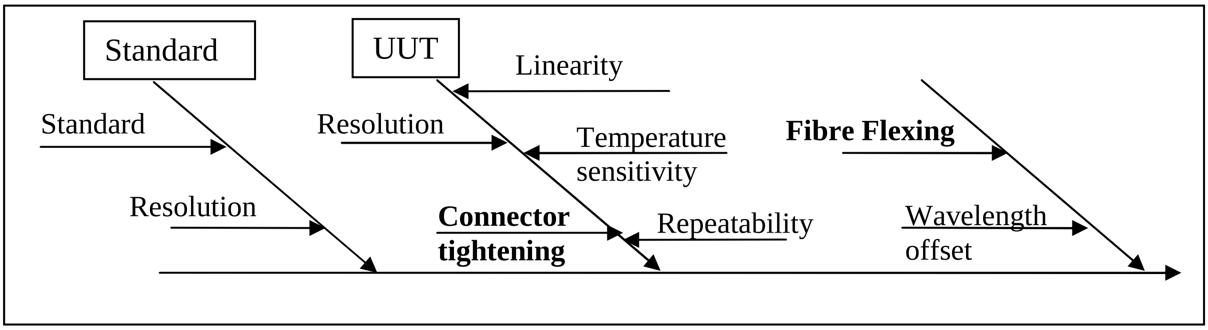

Figure 2. Fish bone diagram of the uncertainty contributors

Most of these uncertainty contributions can either be obtained from a calibration certificate, specifications, or empirical measurements.

In the next two sections details are given on how to determine the uncertainty contributions related to connector tightening and fibre flexing from empirical measurements.

4. Methods and results

4.1 Connector tightening effect

To empirically quantify the effect of connector tightening, two readings are taken at each measurement, which for briefness are labelled “tight” and “un-tight”. A “tight” connection is when the fibre connector is tightened such that it is finger-tight (cannot be turned anymore, but not forced). An “un-tight” connection is when the ferrule is inserted and tightened just until the fibre tip is not able to move inside the connector. The difference between the “tight” and “un-tight” measurements is then taken as the connector-tightening effect.

Ten measurements (“tight” and “un-tight”) at each wavelength were performed with minimal or no flexing of the fibre. FP lasers of nominal wavelengths 1310 nm and 1550 nm were used and the patch cord (single mode) that was used for the power measurements had an FC connector with ceramic tip. The maximum difference between a tight and an un-tight power reading were calculated as a percentage of the total input power as displayed on the power meter. The results are given in Table 1. In the past much larger effects than the 0,012% reported in the table, have been observed, probably owing to a connector end and adapter that exhibited a particularly bad effect in this regard.

Table 1. Connector tightening effects, taken as uncertainty contributions. A selected patch cord (single mode) with FC-connector (ceramic ferrule), was used.

Wavelength [nm]	Uncertainty contribution [%]
1310 nm FP laser	0,012
1550 nm FP laser	0,012

Our experience has shown that the magnitude of the connector-tightening effect differs when tested using different patch cords (i.e. with the same connector type), presumably because of variations between the individual connectors. It was therefore necessary to select one with a smaller connector tightening effect. Therefore, for calibration work, a particular patch cord and one particular end of it is used to connect the standard and UUT. This serves as reference patch cord with one end considered as the reference connector.

The causes of the connector-tightening effects have not been investigated. One potential cause, when the connector is tighter, is more strain on the connector tip, leading to micro bending and deformation, influencing optical polarisation and reflections. Another potential effect that was initially considered, occurs when the connector is not tightened enough (is too loose). In this case gross misalignment of the fibre core with the aperture of the power meter’s fibre optic port can occur, such that it blocks off part of the radiation emerging from the fibre tip. However with experience in experimentally estimating the connector-tightening effect, we came to the conclusion that measurements where the connector is so loose, are not representative, and should not be part of an uncertainty – such gross looseness can be avoided. The “un-tight” situation discussed above should therefore not be interpreted as gross “looseness” of the connection.

It is possible that the connector-tightening effect contains a small contribution accounted for as part of the overall repeatability of the optical power meter calibration, but without better characterisation and understanding of the effect it is considered appropriate to account for the connector-tightening effect as an independent uncertainty contributor.

4.2 Fibre flexing

The method to empirically quantify the effect that flexing (movement) of the fibre has on the output power was determined by connecting an optical fibre to a power meter head and performing controlled movements of the head (displacements and rotations) to emulate flexing representative of the situation when the fibre end is interchanged between a standard and a UUT fibre optic power meter. By just moving the head, connector tightening effects are avoided.

Figure 3 shows the different positions, as well as the rotation of the head’s optical axis at which readings were taken. In Figure 3 the displacement distance is indicated as *d*. Two sets of measurements were performed, each at 1310 nm and 1550 nm (using FP lasers), one set “typical” and one set “extreme”. For the purpose of these measurements the “typical” displacement *d* was defined as about 8 cm and “extreme” displacement defined as about 15 cm.

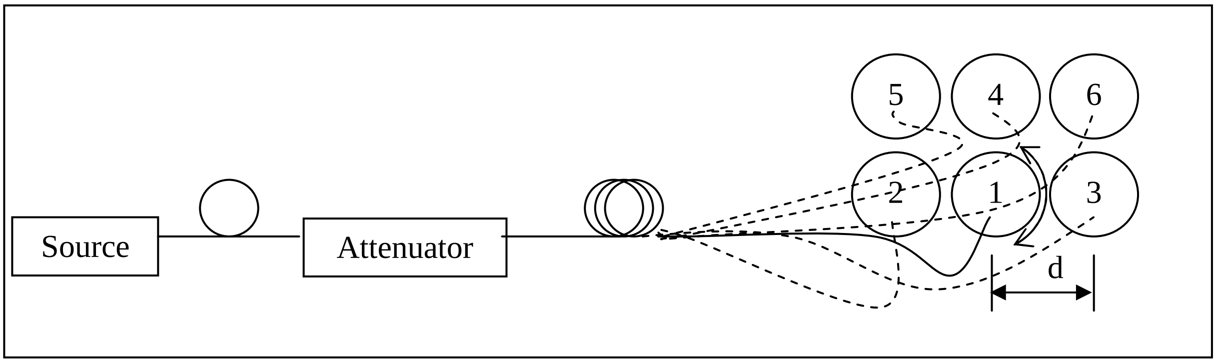

Figure 3. Optical head positions and rotation to emulate the effect of fibre flexing during typical fibre optic power meter calibrations.

Table 2 lists the uncertainty contributions (the magnitude of the effect) calculated from the measured results.

Table 2. Results for fibre flexing

Wavelength	Position	Uncertainty contribution [%]
1310 nm FP laser	“Typical”	0,062
1310 nm FP laser	“Extreme”	0,105
1550 nm FP laser	“Typical”	0,052
1550 nm FP laser	“Extreme”	0,112

The results in Table 2 indicate that when the fibre is being bent and moved more, the effect that the flexing has on the power readings, increases drastically. This can be due to micro and macro bending, resulting in variations in losses and polarisation effects, etc.

It should be noted that our optical power meter calibration procedure requires that the optical heads of the standard and the UUT are placed side-by-side, as close as practically possible, and with their optical axes roughly parallel to one another to reduce the effect of fibre flexing when interchanging from one detector head to another. Excessive flexing and moving of the fibre can cause differences in the radiant power emerging from the fibre, causing the standard and the UUT to be exposed to different power levels and will thus increase the uncertainty of measurement.

It should be possible to reduce the effect of fibre flexing by using a reference patch cord made from so-called bend-insensitive fibre that has become available over the past few years. [1] and [2] are two typical manufacturers.

5. Discussion and Conclusion

Empirical measurements have been performed to quantify the effects of connector-tightening and fibre flexing on fibre optic power meter calibrations, for the use of standard single mode fibre with FP connectors. These results can serve to assign associated uncertainties for the two particular contributions. The contribution associated with connector tightening was 0,012%, and the contribution associated with fibre flexing ranged from about 0,06% to 0,12%, at both, 1310 nm and 1550 nm. This needs to be seen in the context of our claimed measurement capability (MC) of 1,5% for our fibre optic power meter calibrations.

The benefits of using a reference patch cord to reduce these two uncertainty contributions have been mentioned, e.g. a reference patch cord made of bend-insensitive fibre.

It is acknowledged that the effect of connector tightening may vary for different lasers (depending on wavelength, bandwidth, mode distribution and coherence length), different optical heads (detector types), different optical fibres, connector types and connector end ferrule materials and may also be affected by the quality and manufacturing tolerances of the fibre tip and adapter.

It is also acknowledged that the effect of fibre flexing may vary due to the factors mentioned in the previous paragraph and need to be quantified for those cases.

6. References

1. Corning - http://www.corning.com/opticalfiber/
2. Stocker Yale - http://www.stockeryale.com/o/fiber/bi_fiber.htm