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High Power Fibre Optic Calibration
Nordtest project 1654-03

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Abstract

Three Nordic National Metrology Institutes (NMIs) and one company participated in the Nordtest project no 1634-03 High Power Fibre Optic Calibration.

The project was successful and the service of calibrating high power fibre optic detectors can now be offered by the three NMIs. Each of the NMIs has established traceability to their own national standards for optical power.

The NMIs used the same method for generating high power by using a medium power diode laser that in turn was amplified by an Erbium Doped Fibre Amplifier.

A comparison of fibre optic power measurements in the power range from 1 mW up to 200 mW was made in October 2003 at the HUT Metrology Research Institute. Fibre optic power was compared at 1 mW level using low power detectors calibrated at an uncertainty level of 0,75% - 1,5 % (k=2). Results show deviations from average within the respective measurement uncertainties.

Linearity was tested for three high power detectors, one from each laboratory, in the range from 5 mW to 200 mW. All three detectors were linear within 1 % over the whole range.

The high power detector comparison was performed in the power range from 5 mW to 200 mW. Four detectors were compared. Results show that the largest deviation from the mean is 1,4 % well within the measurement uncertainty of the respective laboratory. Uncertainty for the high power detector at power levels from 5 mW and up to 200 mW is estimated to lie between 1,3 and 3 % for the three laboratories, respectively.

Based on the experience gained, the participants produced a Nordtest Method that describes measurement procedures that can be used to calibrate fibre optic power meters up to 200 mW power levels.

Key words: fibre optic, fibre optic power, calibration, fibre amplifier, detector, laser

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Preface

This is a report on the Nordtest project no 1634-03 “High Fibre Optic Power calibration”. The report describes the generation of, detector calibration at and a comparison at high fibre optic power levels ranging from 5 mW to 200 mW.

High Fibre Optic Powers are generated and transmitted through fibre optic communication systems. These systems can be local area networks in buildings or cities or they can be long haul intercontinental network. The high powers are generated either through several channels in each fibre and/or at high power in each channel. A standard fibre optic laser usually provides less than 1 mW of power without amplification. Therefore, there is need to accurately measure high fibre optic powers as well as study the effect of high power levels in fibre optic network.

Summary

Three Nordic National Metrology Institutes (NMIs) and one company participated in the Nordtest project no 1634-03 High Power Fibre Optic Calibration.

The project was successful and the service of calibrating high power fibre optic detectors can now be offered by the three NMIs. Each of the NMIs has established traceability to their own national standards for optical power.

The NMIs used the same method for generating high power by using a medium power diode laser that in turn was amplified by an Erbium Doped Fibre Amplifier.

A comparison of fibre optic power measurements in the power range from 1 mW up to 200 mW was made in October 2003 at the HUT Metrology Research Institute. Fibre optic power was compared at 1 mW level using low power detectors calibrated at an uncertainty level of 0,75% - 1,5 % (k=2). Results show deviations from average within the respective measurement uncertainties.

Linearity was tested for three high power detectors, one from each laboratory, in the range from 5 mW to 200 mW. All three detectors were linear within 1 % over the whole range.

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Sammanfattning

Tre nordiska nationella metrologiinstitut (NMI) deltog i Nordtest projektet 1634-03 ”High Power Fibre Optic Calibration”.

Alla tre instituten löste sin egen spårbarhet till nationella normaler.

Kalibrering av fiberoptiska detektorer upp till 200 mW kan nu erbjudas kunder av alla tre deltagande NMI:erna.

Metoder for generering av höga fiberoptiska effekter undersöktes.

Ickelinjära effekter ansågs inte spela någon roll för mätningarna så länge som mätningarna kunde repeteras och den optiska effekten genereras med tillfredställande brusfaktor. Höga effekter ökade behovet av rena fiberändar och komponenter som delare kunde öka bruset.

Hög fiberoptisk effekt genererades med en EDFA (Erbium Doped Fibre Amplifier) och en avstämbar laser eller DFB laser som i signal som skall förstärkas. Bruset kan minska om man använder en DFB laser istället för en avstämbar laser beroende på den större koherensen på den senare. Insignalens nivå var omkring 0,1 mW till 0,8 mW för bästa OSNR (Optical Signal to Noise Ratio).

En detektorsfär var undersökt för eventuell degradering på grund av de höga effekterna. Ingen degradering kunde noteras.

En jämförelse mellan de tre instituten gjordes oktober 2003 vid HUT på det Nationella Mättekniska Institut

Fiberoptisk effekt jämfördes vid 1 mW med detektorer som var kalibrerade med en noggrannhet på ca 0,75 - 1,5 % (k=2). Resultatet visar avvikelser från medel väl inom mätosäkerheten.

Linjäriteten mättes för tre detektorer, en från varje laboratorium, från 5 mW till 200 mW. Alla tre detektorerna var linjära inom 1 % over hela effektintervallet.

En jämförelse gjordes från 5 mW till 200 mW för fyra detektorer. Resultaten visar en största avvikelse på 1,4 %. Även här var resultaten väl inom mätosäkerheten som var mellan 1,3 och 3 % för de respektive instituten

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1 Purpose of the project

This is a report on the Nordtest project no 1634-03 “High Fibre Optic Power calibration”. The project dealt with generation of, measurement of, detector calibration at, and detector comparison and validation of the calibration methods at fibre optic powers from 1 mW to 200 mW.

The results obtained justify that the service of calibrating high power fibre optic detectors be offered by all three NMIs.

High fibre optic power levels are generated and transmitted through fibre optic communication systems both in local area network as well as in long haul network. The high power levels are generated and transmitted through either many channels in every fibre or by using a high power level in a single channel.

In order to measure accurately the high power transmitted in the networks, it is necessary to use detectors / power meters that are calibrated and have traceability to national standards.

1.1 Participating laboratories

Three Nordic NMIs (National Measurement Institutes) participated in project HPFOC (High Power Fibre Optic Calibration). The NMIs are HUT (Helsinki University of Technology), DFM (Danish Institute of Fundamental Metrology) and SP (Swedish National Testing and Research Institute).

2 Introduction

A comparison of high fibre optic power detectors was the main goal of the project. Before the comparison could take place problems concerning production of and measurement at high fibre optic power levels and traceability to national standards had to be solved by all participating laboratories.

Within the last decade there has been a considerable improvement in the lasers and the optical fibres used in optical telecommunication. The power emitted by the lasers has increased dramatically and the attenuation of the fibres has decreased both leading to higher power being transmitted through optical fibre links. This has lead to an increased demand for absolute power calibrations at higher power levels, typically up to a few 100 mW. Currently no accredited laboratory offers absolute calibration at these high power levels, however, some are currently performing research into problems associated with doing this including how to make the measurements traceable to the radiometric primary standard, the cryogenic radiometer. Among these is the National Physical Laboratory in England. The three institutes involved in the project reported on here all have primary radiometric standards making a good basis for such a project. All three institutes already provide power calibration in the fibre optic windows at power levels up to a few mW. The project is a natural extension of the services for fibre optic power provided by these institutes.

In order to obtain the best calibration result a power meter must be calibrated at the power levels and wavelengths at which it is going to be used. One of the problems associated with measurements at high power levels is the traceability to the primary standards at such high power levels. The transfer is performed in several steps requiring transfer detectors operating at high power levels. Traceability is solved for each laboratory.

3 Investigations

A detailed characterization of detectors with respect to their response at a chosen wavelength and at high power levels is required. The effects of non-linearity produced in the fibres have been considered and found to be negligible at the power levels used and at the estimated uncertainty levels found in this work.

High fibre optic power levels were produced using tuneable lasers or DFB (Distribute Feed Back) single wavelength lasers as input to fibre optic amplifiers, Erbium Doped Fibre Amplifier (EDFAs). Optical noise produced in the systems can be different using either laser due to different coherence levels from the two laser types. It was found that there was no need to filter out the EDFA pump laser signal. One reason for that is that the pump wavelengths are in ranges that are naturally attenuated by the fibre itself. Since the power densities will be very high the contacts need to be perfect and clean in order not to cause destruction of the fibre ends. No special optics in front of detectors was used. One integrating sphere (HUT) was investigated with respect to possible response changes due to surface deterioration under long exposure time. No such effects were found. Optic power signal stability was investigated for different measurement set-ups. To keep fibre optic splitters and contacts at a minimum is a good habit in order to minimise spurious signals. It is often necessary to use attenuators or isolators in order to stop back reflections that can influence the source and cause an increase in optical noise.

3.1 EDFA characterisation

The SNR (signal-to-noise-ratio) of the radiation from the EDFAs were determined as a function of input and output power levels at 1550 nm. It was concluded (1) that increasing the input power level increases the SNR and thus reduces the measurement error and (2) increasing the gain decreases the SNR and thus increases the measurement error. It was found that the best control of the EDFA was obtained when using pump power levels in the range 0,1 mW (-10 dBm) to 1 mW (0 dBm). In addition, no filtering of the pump power laser beam was needed at this input power level. Typical SNR were around 25-30 dB. Figure 1 shows an example of the characterisation measurements. The out-of-band radiation causes additional uncertainty to the measurements. This additional component is estimated in Table 1. Values have been calculated by taking the ratio of the integrated signal outside the signal band to the desired peak power.

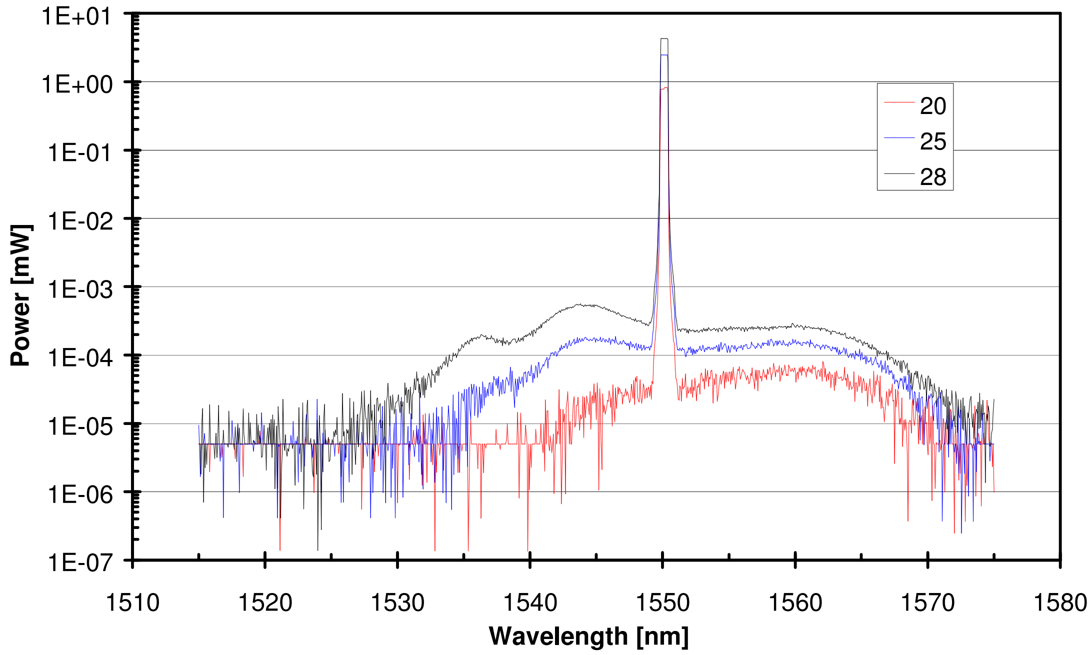

Figure 1. Output spectrum of the EDFA. Input power is 0 dBm. Output is in dBm's as indicated in the figure legend.

Table 1. SNR as function of input and output power levels.

Pin \ Pout [dBm]	28	25	20
0	0.20%	0.14%	0.13%
-5	0.42%	0.31%	0.25%
-10	1.62%	1.03%	0.69%
-15	7.58%	4.79%	2.69%

3.2 Detector characterisation

The institutes made a detailed characterization of their detectors including determination of responsivities at chosen wavelengths and power levels. Three of the detectors were tested for linearity from 5 mW to 200 mW. One the detectors, an integrating sphere, was investigated by HUT with respect to possible changes of the inner surface due to long time exposure at high power levels. The inner surface of the sphere, coated with Spectralon, was irradiated at 200 mW power level for 20 h. During this period, no change in the responsivity of the sphere detector could be noted. The standard deviation of the responsivities measured was 0.15%.

3.2.1 Linearity measurements

Three detectors were tested for linearity from 5 mW to 200 mW. The results show linear behaviour within 1 % for all three detectors. Linearity was measured using set-up shown in Figure 2.

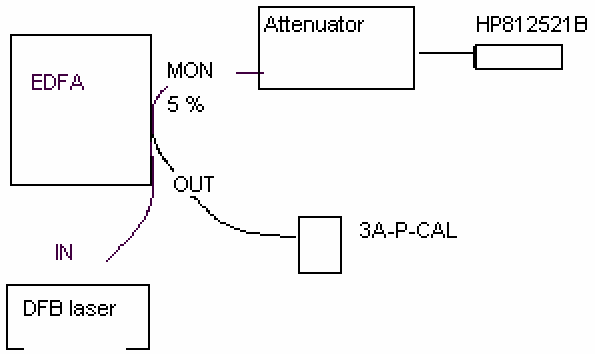

Figure 2. The set-up used for linearity measurement of high power detectors. The 3A-P-CAL is a SP high fibre optic power detector and HP812521B is the SP linearity standard detector. Radiation from a DFB laser was used as optical input to the EDFA.

3.3 Optical set-up

An example of the optical set-up for high fibre optic power calibration can be seen in Figure 2 above. When a comparison is performed the fibre optic connector at “OUT” is connected to the various detectors. The laser could be any type operating in the EDFA active wavelength range. The use of a tuneable laser allows for adjustment of the wavelength in the 1550 nm region while the use of a DFB laser often produced less noise in the set-up. The “MON” out-put was used to check the linearity. An attenuator was needed for high power levels if the reference detector has an upper limit below 10 mW (5 % of 200 mW).

3.3.1 Non-linearity in optical set-up

Non-linearity is of considerable concern in fibre optics network and experimental set-ups. The phenomenon is enhanced at higher power levels and in fibres with low attenuation, both of which are the tendencies in present day fibre optic systems. Although, at fibre optic power levels of 200 mW, non-linear phenomena occur, it was found that for single power measurements it was not possible to observe an effect on the detectors as long as no changes were made to the set-up during the measurement.

4 Results of the comparisons

The comparisons were made in three steps

1. Comparison at the 1 mW power level

   Low power detectors were compared at 1 mW and 1,5 mW. The detectors numbered 0, 2, 3 and 4 (Table 2) were used.

2. Comparison in the range from 5 mW to 200 mW

   Detectors 1, 3, 4 and 5 were used.

3. Linearity measurements from 5 mW – 200 mW

   Linearity measurements were performed for detectors 1, 3 and 4. The linearity was used to correct the responsivities in step 2 above by division.

Table 2. Detectors used in the comparison.

Detector no:	Laboratory:	Detector
0	SP	Cooled germanium
1	SP	Thermopile, 3A-P-CAL
2	HUT	FOPM-1, Plain InGaAs photodiode.
3	HUT	50 mm dia. Integrating sphere with InGaAs detector
4	DFM	JS11, 50 mm dia. integrating sphere with Ge detector
5	DFM	LPM40, 100 mm dia. integrating sphere with Ge detector

4.1 Results at the 1 mW power level

Fibre optic power detectors were compared at the 1 mW power level. The results are presented in Figure 3. Measurements were conducted at four different wavelengths – 1546,5, 1550,0, 1550,7 and 1552,5 nm. At 1550,0 nm, the comparison was repeated at the 1,5 mW power level. The uncertainties for the different institutes are 1,55% (SP) 1,20% (HUT) and 0,75 % (DFM). All results are well within these uncertainties. Comparing the measurements at 1,5 mW and 1 mW levels made at 1550 nm, it is noted that for each detector the deviation is at the most 0,2 %. This is a measure of the repeatability of the measurement set-up. It can be noted that on average HUT deviates +0,43% from the reference value, DFM deviates -0,47% and SP deviates +0.03%.

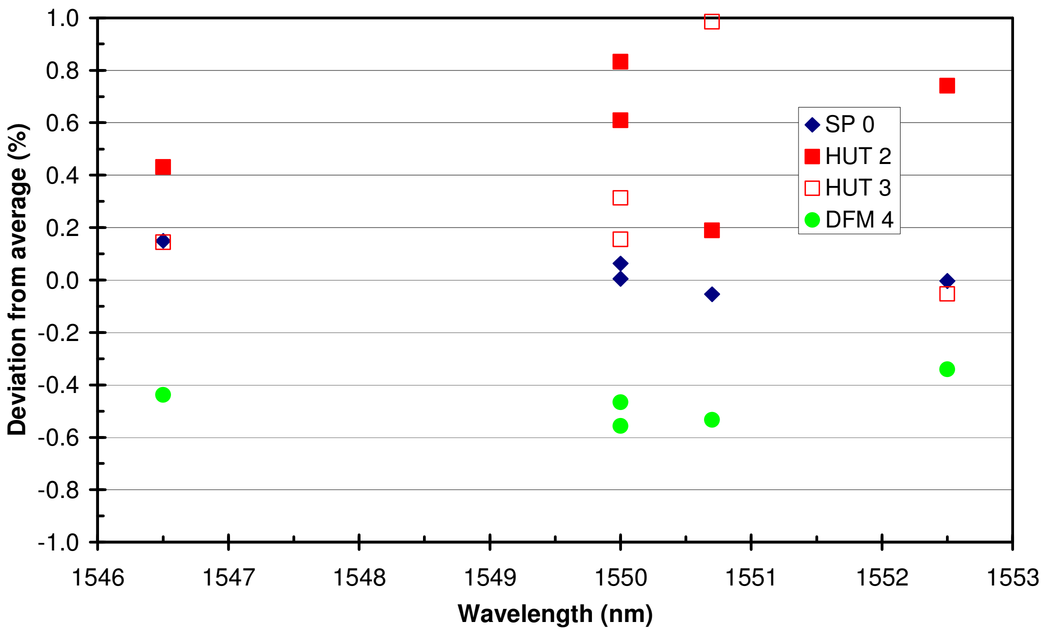

Figure 3. Comparison results for the 1 mW power level. Values are given as relative deviations of the measured power from the average of the power measured by the three institutes.

4.2 Results of the comparison from 5 mW to 200 mW

The results of the comparison of detectors at power levels from 5 mW to 200 mW are shown in Figure 4. All values used for generating Figure 4 are shown in numerical form in Table 3.

The uncertainties for the different institutes are 1,95% (SP up to 8 mW) 2,84% (SP up to 200 mW) 1,5% (HUT) and 1,3% (DFM). All results are within these uncertainties. Results at the 50 mW power level are not reliable. It appears that at one or both of the two measurements at this power level, the optical power of the laser changed abruptly during the measurement sequence. Despite the problems at this power level, all results are within ±1,5% from the reference value. It can be noted that on average HUT deviates -0,05% from the reference value, DFM deviates +0,13% and SP deviates -0.32%.

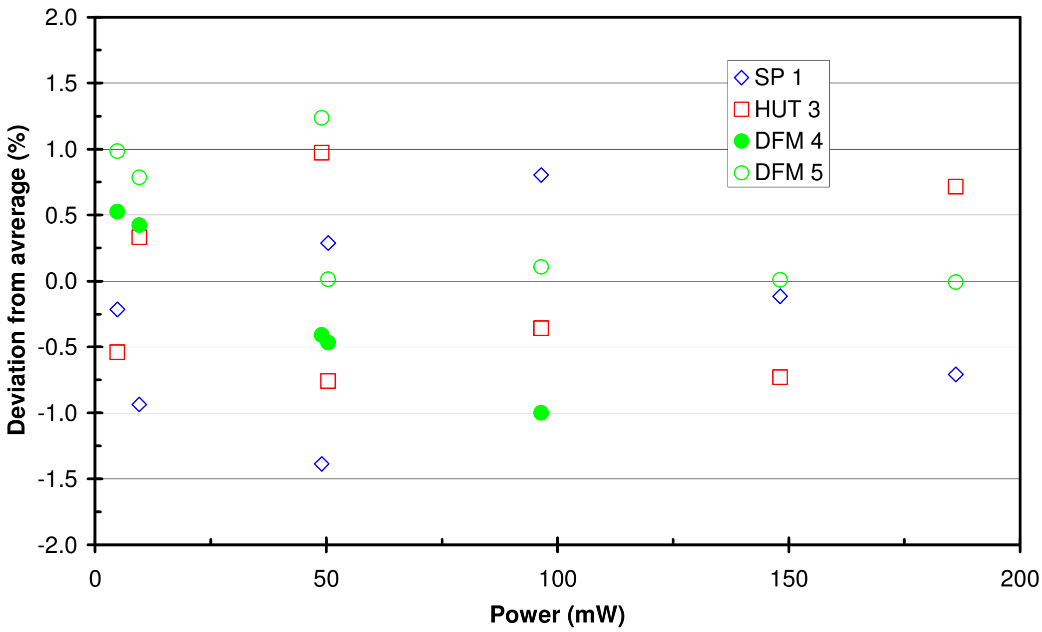

Figure 4. Comparison of detectors at high power levels. Values are given as relative deviations of the measured power from the average of the power measured by the three institutes.

Table 3. Deviation from averaged measured powers when comparing detectors with fibre-end substitution method.

Power [mW]	Deviation from average [%] SP 1	HUT 3	DFM 4	DFM 5
4.82	-0.22	-0.54	0.53	0.98
9.56	-0.94	0.33	0.42	0.79
48.99	-1.39	0.97	-0.41	1.24
50.42	0.29	-0.76	-0.47	0.01
96.47	0.80	-0.36	-1.00	0.11
148.11	-0.11	-0.73		0.01
186.14	-0.71	0.72		-0.01

4.3 Linearity measurements

The results of the linearity measurements for detectors 1, 3 and 5 can be seen in Figure 5, Figure 6. and Figure 7. It was observed that all three detectors are linear within 1 %. The linearity correction is a value, with which the optical power measured with the detector needs to be divided in order to obtain the calibrated responsivity at the reference level.

The curves have been normalised to unity at 6,5 mW power level except for detector SP 1 where the values are normalised to the 4 mW level.

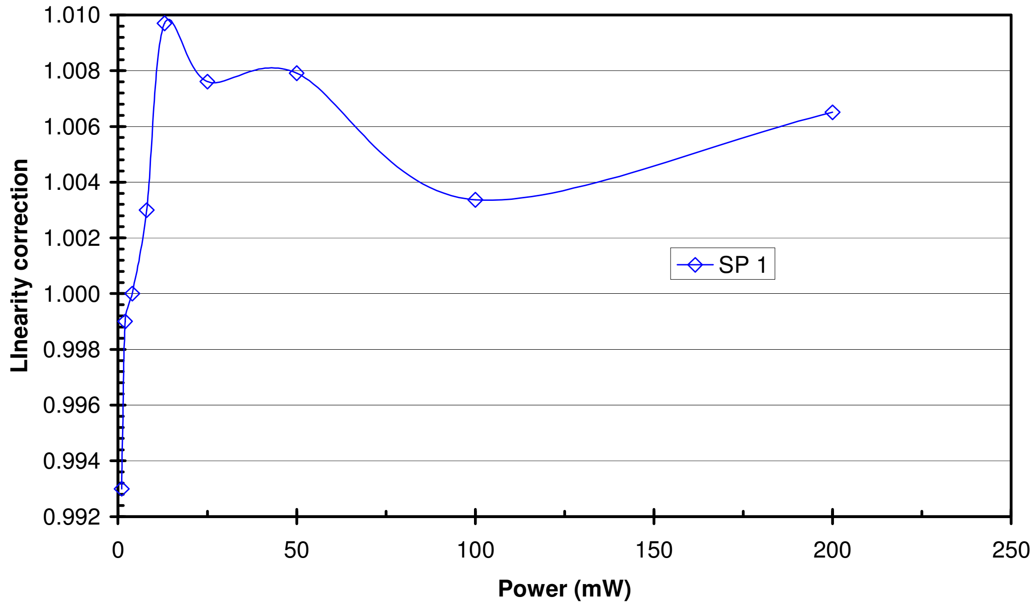

Figure 5. Linearity measurement of detector SP 1.

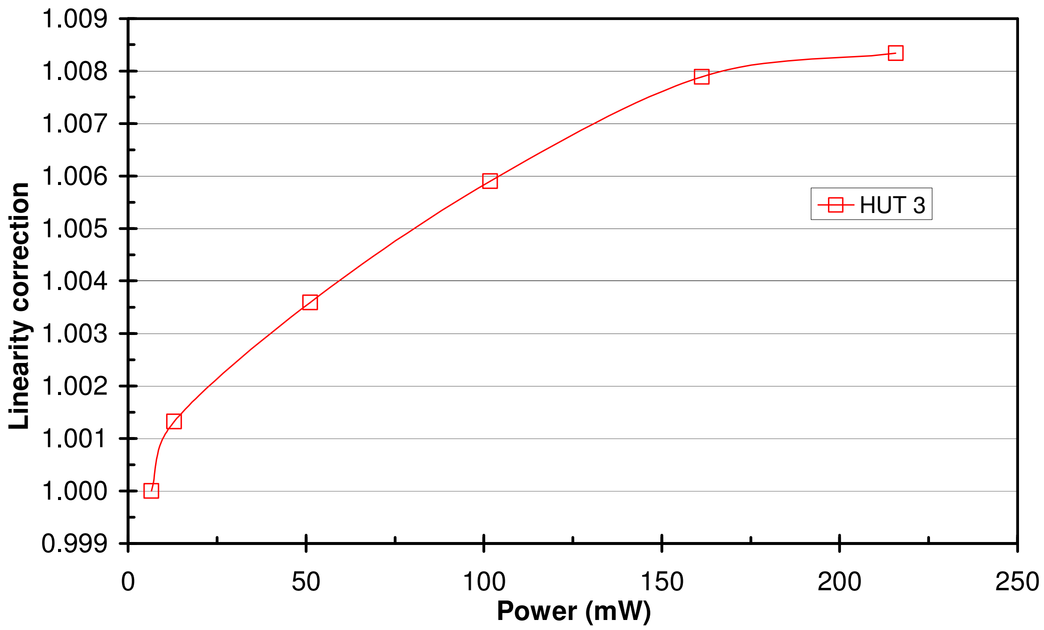

Figure 6. Linearity measurement of detector HUT 3.

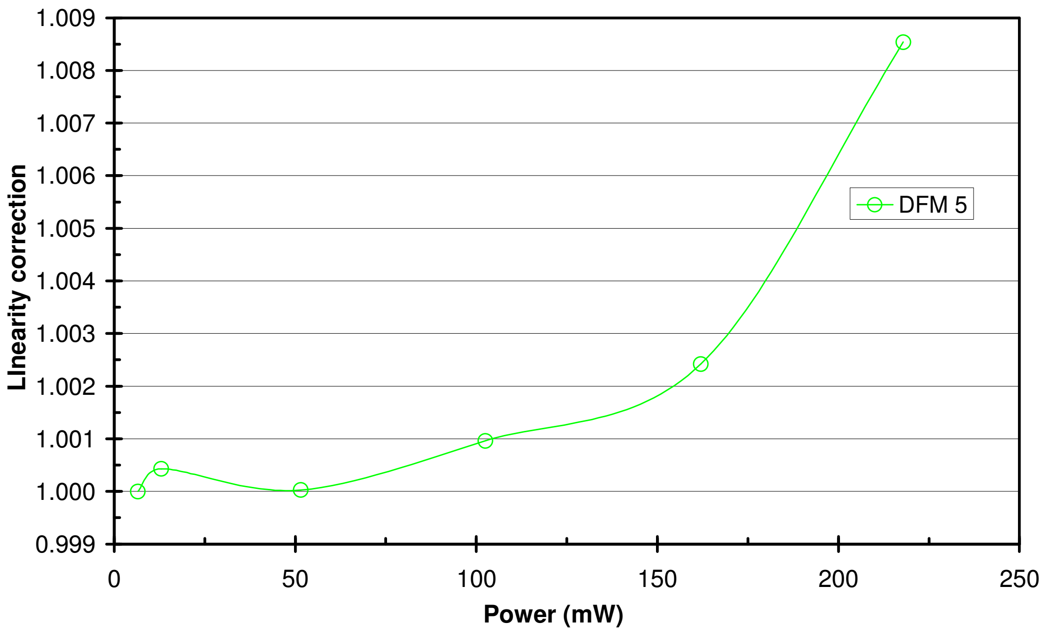

Figure 7. Linearity measurement of detector DFM 5.

5 Recommendations

It is recommended that high power fibre optic detectors be calibrated once a year, traceable to national standards. Stability and linearity check of detector and the optical set-up are more important the higher the power. There is a special need for maintaining clean fibre ends in high power measurements.Precautions to high power should be taken using safety goggles whenever disconnecting fibre ends.

6 Conclusions

A high power detector comparison was performed with power levels from 5 mW to 200 mW using four detectors. The results show that the largest deviation from the average value is not more than 1,4 %, well within the measurement uncertainty of the respective laboratory. Uncertainty for the high power detector at power levels from 5 mW and up to 200 mW is estimated to be below 3 %, the scope of this project.

The service of calibrating fibre optic power detectors up to 200 mW can now be offered by all three NMIs participating in this project.

High fibre optic power is produced with an EDFA with an input signal from either a DFB lasers or a tuneable laser. The input signal was found to produce best SNR with input power levels in the range from about 0,1 mW to 0,8 mW. No trace of pump power lasers (at 980 nm and 1400) could be detected in the output signal. By keeping splitters, connectors and other optical components to a minimum and by carefully cleaning fibre ends a good optical power stability can be obtained. All involved detectors are traceable to national primary standards. Linearity measurements from 5 mW level up to 200 mW, are performed against a known linear working standard. Linearity measurements showed that the high power detectors were linear within 1 % from 5 mW up to 220 mW. .

7 Uncertainty budget: an example

Below is an example of uncertainty budget calculated for SP power scale.

Table 6: Uncertainty budget for SP power scale.

Type			Uncertainty		varians
			s		s²
Component A	1 - 8 mW		0,5		0,25
	8 - 200 mW		1		1
Uncertainty calculation ,ei=student-t		sm			sm2
Component B		max fel (%)	faktor (%)	uj (%)	uj²
Calibration of the reference standard (at 0,3 mW)		0,3	2	0,15	0,0225
Linearity of the electrical subst. Rad. meter (up to 8 mW)		0,5	2	0,25	0,0625
Linearity of germanium working standard		0,2	0,5774	0,1155	0,0133333
Repeatability in FC/PC-kontakt		0,1	0,5774	0,0577	0,0033333
Reading of referensinstrument		0,1	0,5774	0,0577	0,0033333
Reading, reference instrument(high power)		0,2	2	0,4000	0,16
Geometrical difference between ref. and obj		0,4	0,5774	0,2309	0,0533333
Temperature dependance in set-up		0,05	0,5774	0,0289	0,0008333
Reflections in the systems		0,15	0,5774	0,0866	0,0075
Polarisation dep.		0,1	0,5774	0,0577	0,0033333
Wavelength of source corresponding to reference		0,14	0,5774	0,0808	0,0065333
Aging of reference standard		0,1	0,5774	0,0577	0,0033333
Temperature dependance in reference standard		0,2	0,5774	0,1155	0,0133333
Spectral correction		0,1	0,5774	0,0577	0,0033333

Uncertanty budget 1545-1555 nm	Wavelength nm	Power mW	Uncertainty (%)	
Germanium low power working standard			k=1	k=2
Combined uncertainty:	1545-1555	1	0,59	1,18
Thermopile high power working standard				
Combined uncertainty:	1530-1560	2 to 8	0,64	1,29
Thermopile high power working standard				
Combined uncertainty:	1530-1560	8 to 200	1,46	2,92

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