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High Power Fibre Optic Calibration

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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 service of calibrating high power fibre optic detectors can now be offered from all three NMIs.
Traceability was solved for each NMI to the National standard for optical power.
Methods for generation of high fibre optic powers were developed.
Comparisons of fibre optic powers from 1 mW up to 200 mW were done in October 2003 at HUT Metrology Institute.
Fibre optic power was compared at 1 mW using low power detectors calibrated at an uncertainty level of 1,5 % (k=2). Results show deviations from average at the largest 0,71 % well within the measurement uncertainty.
Linearity was tested for three high power detectors, one from each laboratory, from 5 mW to 200 mW. All three detectors were linear within 1 % over the whole interval.
High power detector comparison was performed with powers from 5 mW to 200 mW for four detectors. Results show deviations at the largest 1,6 % well within the measurement uncertainty. Uncertainty for the high power detector at power levels from 5 mW and up to 200 mW is estimated to below 3 %.

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

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The company North Light Optronics AB that showed interest in the project and gave advice in the high power generation.
HUT hosted the comparison that took place October 6-8 2003.

Preface

This report is the outcomes from Nordtest project no 1634-03 High Fibre Optic Power calibrations also with purpose of being able to calibrate an optical spectrum analyser at high powers.
The report is about the generation, calibration and a comparison of high fibre optic powers.
High Fibre Optic Powers are generated and transported in the fibre optic communication systems. Those systems most often send around cities or long howl. The high powers are generated either through very many channels in every fibre and/or the high power in each channel. A normal not amplified fibre optic laser channel has below 1 mW of power.
In both cases there is need to know more about the effect of high powers in fibres and how to measure high fibre optic powers.
This project deals with generation, measurement, and calibration and through a comparison validation of the calibration methods of fibre optic powers from 1 mW to 200 mW.

Summary

Three Nordic National Metrology Institutes and one company participated in the Nordtest project no 1634-03 High Power Fibre Optic Calibration.
The service of calibrating high power fibre optic detectors can now be offered from all three NMIs.
Traceability was solved for each laboratory to the National standard for optical power.
Methods for generation of high fibre optic powers were developed.
Non-linearities were considered to play minor role as long as the set-up could generate repeatable and stable powers. High powers increase the demand for clean fibre ends. Components, such as splitters, in the optical set-up can increase the noise.
High fibre optic power was generated using EDFA (Erbium Doped Fibre Amplifier) with tuneable laser or DFB laser as input signal to be amplified. It was noted that using a tuneable laser could increase noise compared to when using a DFB laser. Input power levels for best OSNR (Optical Signal to Noise Ratio) was about 0,1 mW – 0,8 mW.
A detector sphere was irradiated for checking degradation caused by high powers. No such effects were noted.
Comparisons for fibre optic powers from 1 mW up to 200 mW were completed in October 2003 at HUT Metrology Institute.
Fibre optic power was compared at 1 mW using power detectors calibrated at an uncertainty level below 1,5 % (k=2). Results show deviations from average at the largest 0,71 % well within the measurement uncertainty.
Linearity was tested for three high power detectors, one from each laboratory, from 5 mW to 200 mW. All three detectors were linear within 1 % over the whole power interval.
High power detector comparison was performed with powers from 5 mW to 200 mW for four detectors. Results show deviations at the largest 1,6 % well within the measurement uncertainty. Uncertainty for the high power detector at power levels from 5 mW and up to 200 mW is estimated to below 3 %(k=2).

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 1,5 %(k=2). Resultatet visar avvikelser från medel som störst 0,71 % vilket är 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 1,6 %. Även här var resultaten väl inom mätosäkerheten som var på 3 %.

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1 Purpose of the project

This report is the outcomes from Nordtest project no 1634-03 High Fibre Optic Power calibration. This project dealt with generation, measurement, calibration, and through a comparison, validation of the calibration methods of fibre optic powers from 1 mW to 200 mW.
The service of calibrating high power fibre optic detectors can now be offered from all three NMIs.
High Fibre Optic Powers are generated and transported in the fibre optic communication systems that send around cities or long howl. The high powers are generated either through very many channels in every fibre and/or the high power in each channel.
In order to measure how high powers are transported in the systems calibrated detectors traceable to national standards are needed.

1.1 Participating laboratories

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

2 Introduction

A comparison of high fibre optic powers was the main goal of the project. Before a comparison could take place problems regarding production and measurement of high fibre optic power and traceability to national standards needed 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 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. Some of the problems associated with measurements at high power levels are 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 behaviour at correct wavelength and at high power levels is required. Effects of non-linearity produced in the fibres have been considered to be a neglectable effect on the detector measurement result. The problem producing high fibre optic power was been solved by with tuneable laser or DFB laser (Distribute Feed Back single wavelength laser) as input to fibre optic amplifier so called EDFA, Erbium Doped Fibre Amplifier. A tuneable laser can be tuned to wavelengths in a wide interval in contrast to a DFB laser that stayes at the one wavelength it is one tuned into. Optical noise produced in the system could be different using either laser due to different coherences from the two laser types which effects the optical set-up. No need to filter out the pump laser signal was found. One reason for that is that pump powers are in wavelength ranges that are very attenuated by the fibre itself. Since the power densities will be very high the contacts need to be perfect and clean not to cause destruction at fibre ends. No special optics in front of detectors was used. One sphere (HUT) was investigated for changes under long time exposure of high powers. No such effects were found. Optic power signal stability was investigated for different measurement set-ups. To keep fibre optic splitters and contacts to a minimum is a good advice. Attenuators and or isolators can stop back reflections that influence the source, which will decrease optical noise.

3.1 EDFA characterisation

SNR (signal-to-noise-ratio) of input to output power was calculated from measurements at 1550 nm where different input powers were used and for different mode of operation. Concluding that 0,1 mW to 1 mW is good power levels, power level control was somewhat better and that no filtering of the pump power laser signals were needed. Typical SNR good values were around 25-30 dB.

3.2 Detector characterisation

A detailed characterization of detectors with respect to their behaviour at correct wavelength and at correct power levels is required. Three detectors where tested for linearity from 5 mW to 200 mW. One sphere was investigated by HUT for changes under long time exposure of high powers.

3.2.1 Linearity measurements

Three detectors where tested for linearity from 5 mW to 200 mW.
Results show linear behaviour within 1 % for all three detectors.

Linearity was measured for the high power detectors using set-up in figure 1 below.

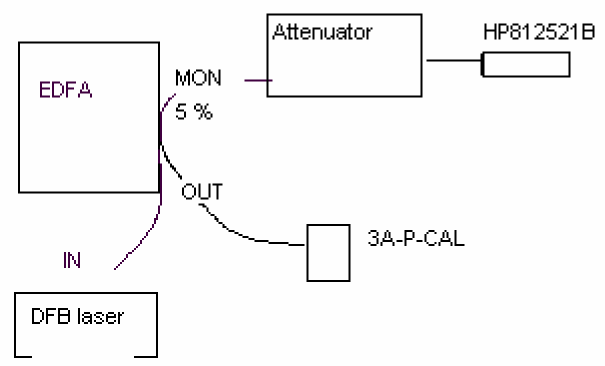

Figure 1: set-up for linearity measurement test of high power detectors. 3A-P-CAL is example of the SP detector representing the high power detector to be characterised.

3.2.2 Long time high power exposure of sphere detector

One sphere was investigated by HUT for changes under long time exposure of high powers. No such effects were found.

3.3 Optical set-up

The problem producing high fibre optic power was been solved with tuneable laser or DFB laser as input to fibre optic amplifier so called EDFA, Erbium Doped Fibre Amplifier. No need to filter out the pump laser signal was found. One reason is that pump powers are in wavelength ranges that are very attenuated by the fibre itself. Since the power densities will be very high the contacts need to be perfect and clean not to cause destruction at fibre ends. No special optics in front of detectors was used.
Optic power signal stability was investigated for different measurement set-ups. To keep fibre optic splitters and contacts to a minimum is a good advice. Attenuators and or isolators can stop back reflections that influence the source, which will decrease optical noise.

3.3.1 Non-linearity in optical set-up

Non-linearity in optical set-up was considered to play a minor role as long as the signal stayed stable long enough to make the measurement.

4 Result from Comparison

The comparison was done in three steps

1. 1 mW

Low power detectors were compared at 1 mW and 1,5 mW. 0, 2, 3 and 4 was used in the low power comparison.

2. Connecting between detectors in steps from 5 mW up to 200 mW

1,3,4 and 5 were used in the high power comparison.

3. Linearity from 5 mW – 200 mW

Linearity was measured for detectors 1, 3 and 4. The linearity was used to correct the responsivities in step 2 above.

Detector no:	Laboratory:	Detector short
0	SP	Cooled germanium
1	SP	3A-P-CAL
2	HUT	FOPM-1
3	HUT	Sphere
4	DFM	JS11
5	DFM	LPM40

Table 1: Detector numbered as presented in the results and used in figures.

4.1 Results from comparison at 1 mW

Fibre optic power was compared at 1 mW. Results are presented in Figure 2 below. SP and DFM participated with one detector each- and HUT with two detectors. Figure 1 shows results for deviation from average for 1,5 mW at 1550 nm and for 1 mW for 1546,5 nm, 1550 nm, 1550,7 nm and 1552,5 nm. The comparison showed agreement within uncertainty of 1 %. Studying results for 1,5 mW and 1 mW for 1550 nm it is noted that all four detectors was deviated the most 0,2 % with itself. This could be viewed as a measure of the repeatability of the measurement set-up. It can be noted that HUT is on average a little high in their responsivities and DFM a little low.

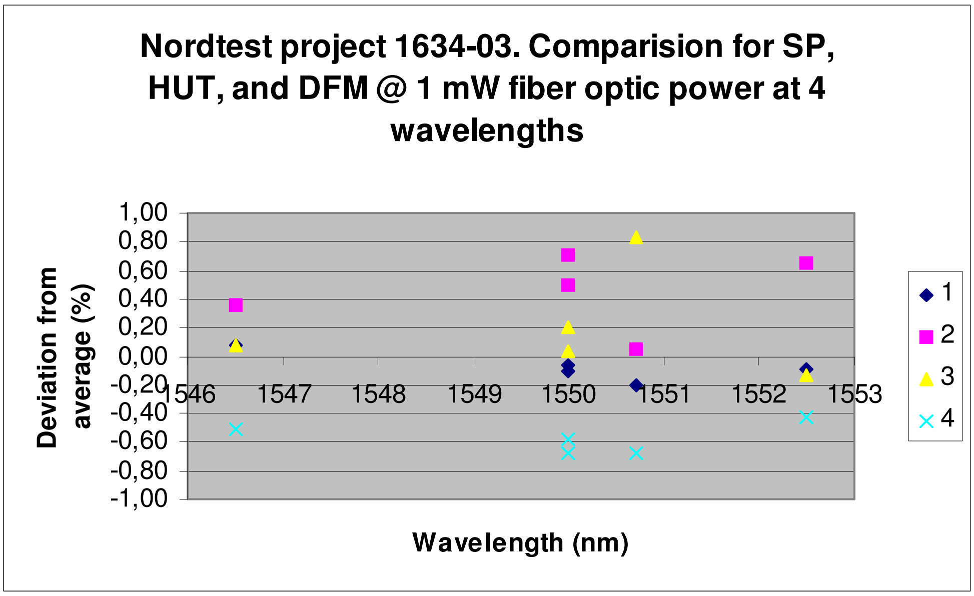

Figure 2: Deviation from average for 1,5 mW at 1550 nm and for 1 mW for 1546,5 nm, 1550 nm, 1550,7 nm and 1552,5 nm are shown for four detectors.

4.2 Results from comparison from 5 mW to 200 mW

High power comparison

Result from comparison of power from 5 mW to 200 mW can be studied in figure 3 below. The method is fibre optic connection substitution back and forth between all four detectors. The largest deviation, around 1,6 % from average measured powers, is noted for HUT sphere at 150 mW. DFM participated with two detectors JS11 and LPM40. Largest deviation for DFM were 1,2 % from average. For SP detector the largest deviation was around 1,5 % from average. All measurement results are within uncertainty of the project goal i.e. 3 %.

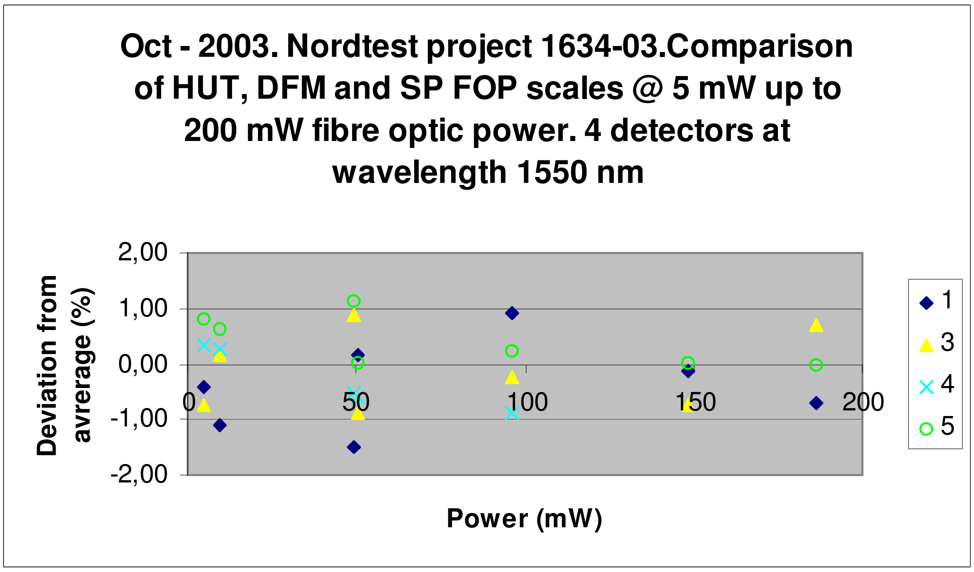

Figure 3: Comparison of powers with a method that changed connector before each measurement.

All values in Figure 3 can be studied in detail in Table 2.

Average	Deviation from average			
	SP	HUT	DFM	
	Detector 1	Detector 3	Detector 4	Detector 5
mW	%	%	%	%
4,83	-0,39	-0,77	0,35	0,81
9,57	-1,00	-0,08	0,36	0,72
49,0	-1,33	0,39	-0,35	1,29
50,4	0,37	-1,48	-0,38	0,01
96,3	1,00	-0,49	-0,81	0,30
147,4	0,34	-1,64		0,01
185,4	-0,31	-0,08		0,39

Table 2: Deviation from averaged measured powers when comparing detectors with fibre-end substitution method. The detectors can be viewed as randomly chosen. Largest deviation was 1,5 % within measurement uncertainty for high power measurement and within the measurement uncertainty for the goal of this project.

4.3 Linearity

Linearity measured for detector 1, 3 and 5 can be studied in figure 4, 5 and 6 below. Linear behaviour within 1 % can be noted for all three detectors.

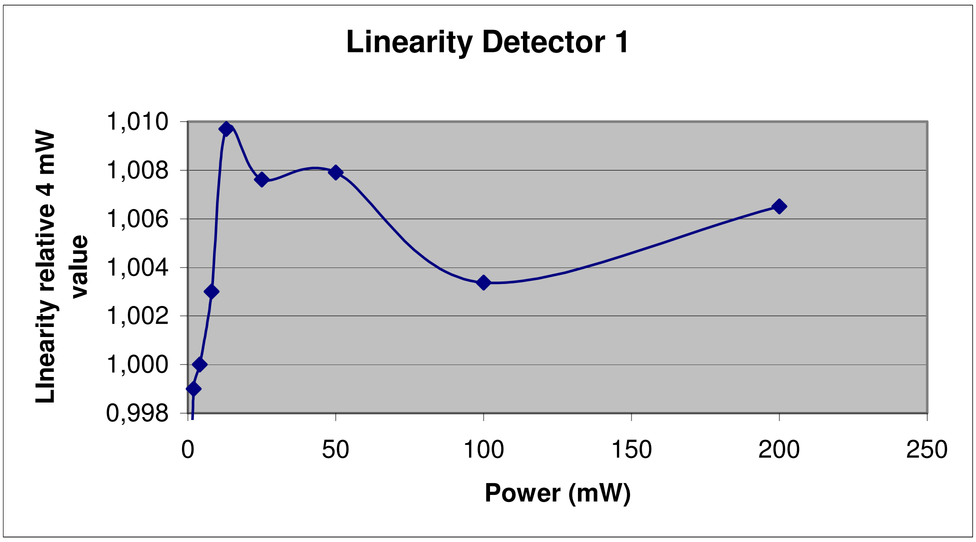

Figure 4: Linearity of detector 1 between 5 mw and 200 mw the linearity is within 1 %.

Linearity measured detector 3 from 6 mW up to 220 mW can be studied in Figure 5. The values are normalised against 6 mW values. Results show linear behaviour within 1 % from value at 6 mW.

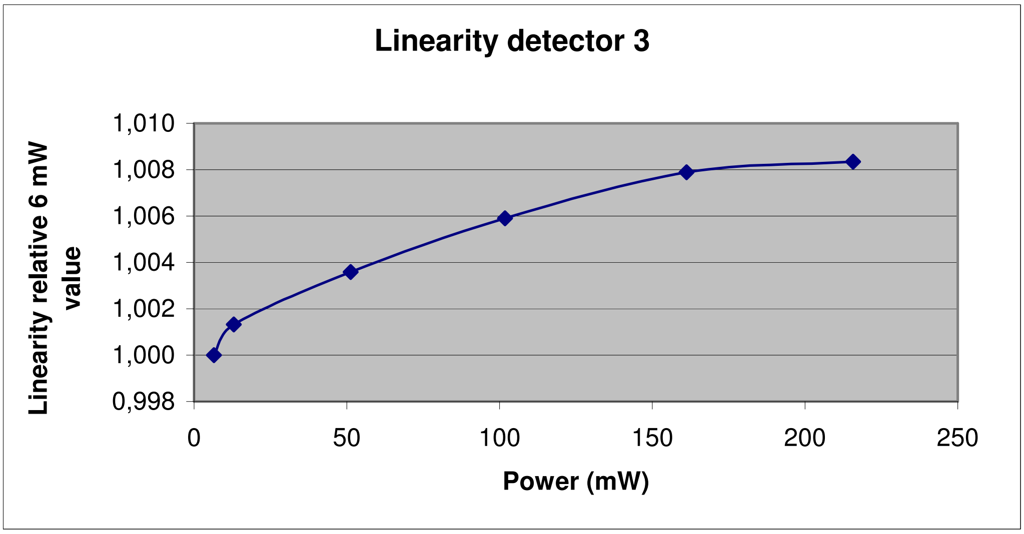

Figure 5: Linearity measured for detector 3.

Linearity measured for DFM detector 5 (LPM40) show linear behaviour within 1 % from value at 5 mW as can be studied in Figure 6 below.

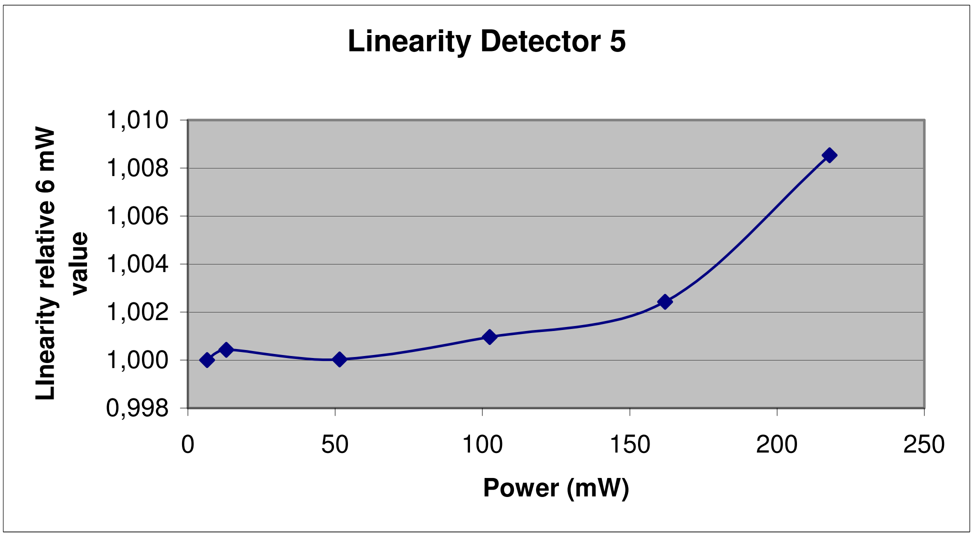

Figure 6: Linearity measured for detector 5. Linear behaviour within 0,2 % up to 150 mW and within 1 % up to 200 mW is shown.

4.4 Responsivities of High power detectors Oct-03

Absolut responsivities were measured at all three laboratories for detectors 1, 3 and 4 at power levels below 1 mW. At SP detector 1, was calibrated for absolute responsivity up to 8 mW against an electrical substitutional radiometer. From the linearity measurement the responsivities at higher powers were calculated. Measurement uncertainty was calculated according to next chapter.

SP Detector 1				
mW	linearity	responsivity	stddev	Uncertainty
0,5	0,962	0,983	0,004	0,016
1	0,993	1,015	0,003	0,016
2	0,999	1,021	0,002	0,016
4	1	1,022	0,003	0,016
8	1,003	1,025	0,007	0,016
13	1,010	1,032	0,007	0,020
25	1,008	1,030	0,007	0,020
50	1,008	1,030	0,013	0,030
100	1,003	1,025	0,013	0,030
200	1,007	1,029	0,013	0,030

Table 3: Responsivities for SP detector 1. Responsivitieas were measured against an electrical substitutional radiometer up to 8 mW.

HUT Detector 3		
mW	linearity	responsivity
1	1,000	1,003
6,5	1,000	1,003
13	1,001	1,004
50	1,004	1,007
100	1,006	1,009
160	1,008	1,011
200	1,008	1,011

Table 4: Responsivities measured and calculated for HUT detector 3.

DFM Detector 5		
mW	linearity	responsivity
1	1,000	0,575
6,5	1,000	0,575
13	1,000	0,575
50	1,000	0,575
100	1,001	0,575
160	1,002	0,576
200	1,009	0,580

Table 5: Responsivities measured and calculated for DFM Detector 4.

5 Recommendations

High power fibre optic detectors are recommended to be recalibrated traceable to national standards once a year. Stability and linearity check of detector and the optical set-up are more important the higher the power. Special need for clean fibre ends in measurement set-up is needed. All electronic equipment should be put on 30 min before measurement. Precautions to high power should be taken using safety goggles whenever disconnecting fibre ends.

6 Conclusions

High power detector comparison was performed with powers from 5 mW to 200 mW for four detectors. Results show deviations at the largest 1,6 % well within the measurement uncertainty. Uncertainty for the high power detector at power levels from 5 mW and up to 200 mW is estimated to below 3 %.
High fibre optic power is produced with an EDFA (Erbium Doped Fibre Amplifier) with an input signal either from DFB lasers or from a tuneable laser (tuneable over about 100 nm in the 1550 nm range). The input signal was found to produce best SNR (signal-to-noise-ratio) in the range from about 0,1 mW to 0,8 mW. No trace of pump power lasers could be detected in the output signal. Also keeping splitters, connectors and extra optical components to a minimum and to be very careful to use clean fibre ends are good advice when stable high fibre optic power levels are needed. The traceability is solved in four steps. First three steps regards traceability to power levels in the 1-8 mW ranges going from cryogenic radiometers, trap detectors to low power thermoelectric detectors alternatively to an electrical substitution radiometer. Fourth step regards linearity measurements from 5 mW level up to 200 mW, where a cooled germanium detector is used as linear working normal. Linearity measurements showed that the high power detectors were linear within 1 % from 5 mW up to 220 mW.
Measurement uncertainties were estimated to 1,5 % for 1 mW power level and up to 3 % for 200 mW power level which is within the scope of this project.
The comparison at both 1 mW and for 5 mW to 200 mW showed results with deviation from average well within measurement uncertainty for all three laboratories.

7 Uncertainty

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

Object: -Low Fibre Optic power (1 mW) -High Fibre Optic Power (up to 8 mW alt. up to 200 mW)
Reference instrument: Electrial substitutional radiometer and/or germanium working standard

Type		Uncertainty		varians
		s		s²
Component A		0,7		0,49
Other power level, higher than 8 mW		1		1
Uncertainty calculation ,ei=student-t	sm			sm2
Component B	max fel (%)	faktor (%)	uj (%)2	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
Repeatability in FC/PC-kontakt	0,1	0,5774	0,0577	0,0033333
Reading of referensinstrument	0,2	0,5774	0,1155	0,0133333
Reading, last digit, object(high power)	0,1	2	0,2000	0,04
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
Linearity of germanium linearity working standard	0,2	0,5774	0,1155	0,0133333

Uncertanty budget	Wavelength nm	Power mW	Uncertainty (%)	
For low power (1 mW) calibration	1545-1555			k=2
Combined uncertainty:		1	0,777	1,554
For High power (up to 8 mW)				
Combined uncertainty:		2 to 8	0,973	1,946
For High power (up to 200 mW)				
Combined uncertainty:		4 to 200	1,417	2,835

Table 6: Uncertainty budget for SP power scale.

8 References

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