

RESULTS AND EXPERIENCES FROM HIGH FIBRE OPTIC POWER CALIBRATION COMPARISON

Resultats et Experiences de Comparison Etalonnage de Puissance Elevé dans le Fibre Optique

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Abstract

In this article we discuss the results and experiences of a Nordic comparison [1], in fibre optic power calibrations from 1 mW to 200 mW. The standards used by TKK and DFM were spectralon coated integrating spheres, equipped with InGaAs (TKK) and Ge (DFM) photodiodes, respectively, while SP used a thermopile detector. The most significant sources of uncertainty in the calibrations include the noise of the EDFA (Erbium Doped Fibre Amplifier), the uncertainty of the reference detector, linearity of and repeatability in the set-up. The expanded measurement uncertainties of the calibrations at 200 mW are 1,3 % for TKK, 2,8 % for SP and 1,3 % for DFM.

Résumé

Dans cette article les resultats et experiences de comparison Etalonnage de puissance elevé dans le fibre optique à 1 mW de 200 mW [1] sont montré. Les participants sont trois Laboratoires Nationaux Nordique, SP de Suède, TKK de Finlande et DFM de Danemark. TKK et DFM sont utilisé spheres couché à la interieur avec spectralon. Les spheres sont equipé avec detectores InGaAs (TKK) et Ge (DFM). SP fait la comparaison en utilisant un detector de thermocouple. Les raison significatifes d'incertitude de mesure incluse le bruit d'EDFA (Erbium Doped Fibre Amplifier), l'incertitude de mesure de la detector de reference, le linearité et la reproductibilité dans le « set-up » experimental. D'incertitude de mesure dans ca comparaison à 200 mW sont estimé à 1.3 % de TKK, 2.8 % de SP et 1.3 % de DFM.

Introduction

High fibre optic power levels are generated and transmitted through fibre optic communication systems both in local area networks as well as in long haul networks. In order to measure accurately the high power transmitted in the networks, it is necessary to use detectors / power meters that are calibrated and are traceable to national standards.

Within the past 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 leading to higher power 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 hundreds of milliwatts.

The three institutes involved in this work all have primary radiometric standards and perform power calibrations in the fibre optic windows, thus providing a good basis for a comparison.

The best measurements result of a power meter is obtained when it is calibrated at the power levels and wavelengths at which it is going to be used. One of the obstacles associated with measurements at high power levels is the traceability to the primary standards. The transfer is performed in several steps requiring transfer detectors operating at high power levels.

Traceability

A traceability chain is an unbroken chain of comparisons, all having stated uncertainties, ensuring that a measurement result is related to references at higher levels, ending at a primary national standard [2]. As an example of traceability for high fibre optic power the SP case is presented below. At SP traceability for fibre optic power is based on a Cryogenic absolute radiometer (uncertainty level: 0,02 %) a silicon trap detector (633 nm, 0,5 mW uncertainty level: 0,08 %) via a spectral flat electrical substitution absolute radiometer (1550 nm, 0,5 mW, uncertainty level: 0,3 %) a temperature stabilised Ge detector (1550 nm, up to 1,5 mW, uncertainty level: 1,5 %) to a high power thermopile detector (1550 nm, up to 200 mW, uncertainty level: 2,8%).

Experimental

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 obtained using tuneable lasers or DFB(Distributed 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 when using lasers with different coherence levels. It was found that there was no need to filter out the EDFA pump laser signals. 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

fibres contacts need to be perfect and clean in order not to cause destruction of the fibre ends. One integrating sphere (TKK) was investigated with respect to possible response changes due to surface deterioration under long exposure time. No such effects were found. Optical 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 isolators in order to stop back reflections that can influence the source and cause an increase in optical noise.

EDFA characterisation

The SNR (signal-to-noise-ratio) of the radiation from the EDFAs was determined as a function of background and peak power levels of the output signal at 1550 nm. It was concluded (1) that increasing the input power level increases the SNR and thus reduces the measurement uncertainty and (2) increasing the gain decreases the SNR and thus increases the measurement uncertainty. It was found that the best control of the EDFA was obtained when using signal 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 was around 25-30 dB. The out-of-band radiation causes small additional uncertainty to the measurements. This additional component is estimated in Table 1. The values have been calculated by taking the integrated power ratio between background (without the peak power) and with only the desired peak power.

Table 1. Relative background levels as a 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%

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 of the detectors, an integrating sphere, was investigated by TKK 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 levels 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%.

Non linearity in the optical set-up

Non-linearity is of considerable concern in fibre optic networks 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 the 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 measurements.

Comparison

1. Comparison at the low power level. Low power detectors were compared at 1 mW and 1,5 mW. Detectors numbered 0, 2, 3 and 4.) 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 the 5mW – 200 mW calibration.

Detectors 0 and 1 were a cooled Ge detector and a thermopile detector respectively, from SP. Detectors 2 and 3 were a plain InGaAs photodiode and a 50 mm diameter integrating sphere with an InGaAs detector, respectively, from TKK. Detectors 4 and 5 were a 50 mm diameter integrating sphere with a Ge detector and a 100 mm diameter integrating sphere with a Ge detector respectively, from DFM.

Results

Results at 1 mW power level

The results of fibre optic power measurements at 1 mW are presented in Figure 1. 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 expanded uncertainties, at these levels, for the different institutes, are 1,55% (SP) 0,9% (TKK) 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 TKK deviates +0,43% from the reference value, DFM deviates -0,47% and SP deviates +0.03%.

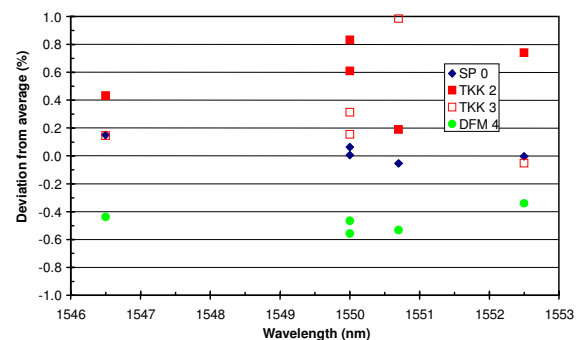


Figure 1. Comparison results for the 1 mW power level. Values are given as relative deviations of the measured power from the average of the power measured by the three institutes.

Results at 5 mW – 200 mW power levels

The results of the comparison of detectors at power levels from 5 mW to 200 mW are shown in Figure 2. All values used for generating Figure 2 are shown in numerical form in Table 2.

The expanded uncertainties for the different institutes are 1,95% (SP up to 8 mW) 2,84% (SP up to 200 mW) 1,3% (TKK) 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 $\pm 1,5\%$ from the reference value. It can be noted that on average TKK deviates $-0,05\%$ from the reference value, DFM deviates $+0,13\%$ and SP deviates $-0,32\%$.

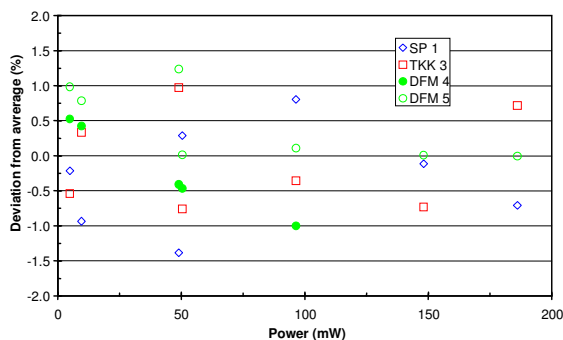


Figure 2. Comparison of detectors at high power levels. Values are given as relative deviations of the measured power from the average of the power measured by the three institutes.

Table 2. Deviation from average measured powers when comparing detectors with the fibre-end substitution method.

Power [mW]	Deviation from average [%]			
	SP 1	TKK 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

Linearity

It was observed that SP 1, TKK 3 and DFM 5 detectors are linear within 1 % from 5 mW to 200 mW. The linearity correction is a value, with which the optical power measured with the detector needs to be divided in order to obtain the lowest uncertainty of the responsivity at the power level of the calibration [3].

Recommendations

It is recommended that high power fibre optic detectors be calibrated once a year, traceable to national standards. Stability and linearity checks of detectors 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.

Summary

The outcome of this comparison is that the service of calibrating high power fibre optic detectors can now be

offered by all three NMIs participating. Each of the NMIs has established traceability to their own national standards of optical power. The NMIs used the same method for generating high power by using a medium power monochromatic diode laser in the 1550 nm wavelength range 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 TKK 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.

Acknowledgments

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References

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