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Overview of wavelength scale calibration methods for optical spectrum analysers

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Introduction

The requirements for Dense Wavelength Division Multiplexing (DWDM) are increasing the required wavelength accuracy for Optical Spectrum Analysers (OSA), a versatile instrument for measuring optical power as a function of wavelength. The ITU has defined a uniform grid of optical frequencies (100/200 GHz, centred at 193.1 THz, corresponding to 0.8 nm and 1.6 nm respectively) for these systems. However, there is also interest in operation with a non-uniform grid spacing as this will reduce the effect of four-wave mixing¹, based on a 25 GHz grid with a minimum separation of 125 GHz. The measurement accuracy required to support these systems exceeds the specifications of the present generation of instruments.

Because of their widespread industrial use, the diversity of applications and the mechanical nature of the design there is considerable interest in OSA calibration. To meet this industrial need, we are developing calibration techniques for these instruments and participating in the International Electrotechnical Commission (IEC) working group to standardise procedures for OSA calibration.

In this paper a range of calibration methods will be outlined with supporting measurement examples.

Parameters affecting the wavelength scale accuracy

An OSA is essentially a sophisticated monochromator coupled to a detector and display. Systematic errors will depend on the instrument design but may include contributions due to the positioning of the grating and component wear.

Environmental effects such as temperature and pressure will also affect the measurements but the latter effect is expected to be small (± 12 pm at 1550 nm). Although the air pressure effect is small, vacuum wavelengths should be quoted as these are independent of the environmental conditions.

Wavelength scale calibration methods and measurement results

Measurements have been performed on two commercially available Optical Spectrum Analysers to illustrate these calibration methods. Typically, an uncalibrated OSA will have an accuracy of ± 1 nm or less but this can be improved by nearly two orders of magnitude by calibration and the use of atomic or molecular references. The most appropriate calibration method depends on the accuracy and operating range required. The results may require additional processing to apply the correction factors. The main calibration methods are as follows:

1. Single point measurement:

A known reference wavelength local to the wavelength of interest is used to provide a traceable reference point. Key commands to provide this type of calibration may be provided in the instrument. The advantage of this method is simplicity but the accuracy of the calibration will depend on the separation between the calibration and operating points as there is insufficient data to correct for wavelength scale errors. Although a commercial instrument may specify ± 0.2 nm over the whole operating range, in practice the accuracy for measurements within the same optical fibre window will be higher.

Measurements of a tuneable laser (1300 nm) and a DFB laser locked to a Krypton Opto-galvanic transition at 1547.825 nm^{2,3} were made using an OSA and wavemeter. The results are shown in table 1.

Table 1. Single point calibration to DFB locked to Kr OG transition			
λ_{Wm} (nm)	λ_{OSA} (nm)	$\lambda_{Wm} - \lambda_{OSA}$ (pm)	Comments
1547.826	1547.350	476	No calibration applied
1547.826	1547.873	-47	Calibration applied using internal routine
1319.986	1320.193	-207	Measurement at 1320

These results illustrate that the single point calibration will provide an acceptable calibration close to the measurement point. However, the difference between the results at the two wavelengths is 160 pm.

2. Multiple reference sources:

A discharge lamp, series of lasers/tuneable laser(s) and wavemeter or etalon calibration artefact are used to give multiple measurement points. This approach has the advantage that the wavelength offset, wavelength scaling and any long period nonlinearities can be corrected. The correction factor can be calculated and applied at the measurement wavelength. In this case only a few reference wavelengths have been used spread over a wide wavelength range. It is appropriate to describe the wavelength deviation by

$$\Delta\lambda_{OSA}(\lambda_{OSA}) = \Delta S \cdot \lambda_{OSA} + \Delta\lambda_o$$

where ΔS is the scale factor, which ideally should be zero, and $\Delta\lambda_o$ is an offset which again ideally should be zero. The relationship between the measured wavelength and the true vacuum wavelength is given by:

$$\lambda_{vac}(\lambda_{OSA}) = \lambda_{OSA} + \Delta\lambda_{OSA} + \xi(\lambda_{OSA})$$

where λ_{vac} is the vacuum wavelength and the term ξ represents an additional error which is instrument dependent.

A high-intensity Krypton discharge lamp gives at least eight lines with sufficient power to calibrate the OSA over the range 1180-1680 nm. The measured results are shown in Figure 1.

The calculated slope (ΔS) and intercept ($\Delta\lambda_o$) were -1.753×10^{-4} and -332 pm respectively. The wavelength uncertainty, based on the uncertainty of the reference lines and the deviation from the was ± 27.3 pm. However, the true deviation from this fit may be higher because the reference points are widely spaced.

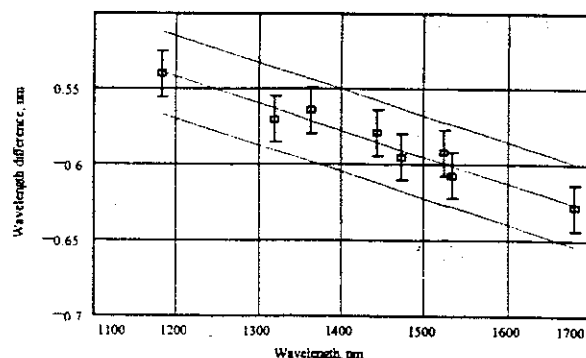


Figure 1 Calibration of OSA using Krypton emission lines

This paucity of data points can be overcome by using a wavelength calibrator. This device comprises of a temperature stabilised air spaced etalon, used in reflection. The wavelength response contains well defined null points, which can be measured with a broadband source - such as a LED - and are independent of the source wavelength characteristic. Although this device is not an absolute reference the null spacing can be calibrated and the null position can be locked to a reference. The normalised response of a calibrator with

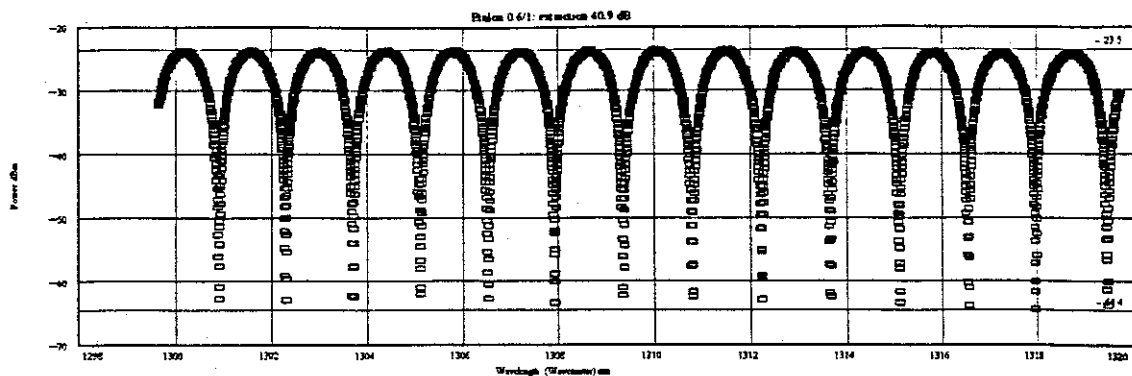


Figure 2 Etalon wavelength calibrator measured with an external-cavity tuneable diode-laser. Null extinction ratio 40.9 dB

a nominal null spacing of 250 GHz, measured with a tuneable external-cavity laser is shown in figure 2.

3. Highest accuracy measurements

To obtain the highest accuracies it is necessary to have detailed knowledge of the instrument nonlinearities, good environmental control and access to locally held traceable wavelength standards. Under these conditions the accuracy achievable may be better than ± 20 pm. The disadvantage of this approach is that the volume of calibration data is high and the results will need additional processing.

Measurements of the instrument over the operating range with a tuneable laser and calibrated wavemeter are necessary to determine the nonlinearities and long-term measurement of the OSA together with the environmental conditions are needed to determine the instrument stability.

Temperature effects

The effect of environmental conditions have been measured using the Kr locked DFB laser. Two measurement runs of 55 and 14 hours respectively were made using two commercial OSAs. Figures 3 and 4 show the variation of the temperature and wavelength respectively.

The rapid temperature variations are due to the laboratory environmental controls. These variations show a correlation peak with the wavelength variations at a delay of 23 minutes.

The second measurement run was performed overnight when the temperature conditions would be more stable. The parametric results are shown in Figure 5. The starting positions for the measurements have been marked.

As expected, there is a clear correlation between the temperature and OSA wavelength and the locked

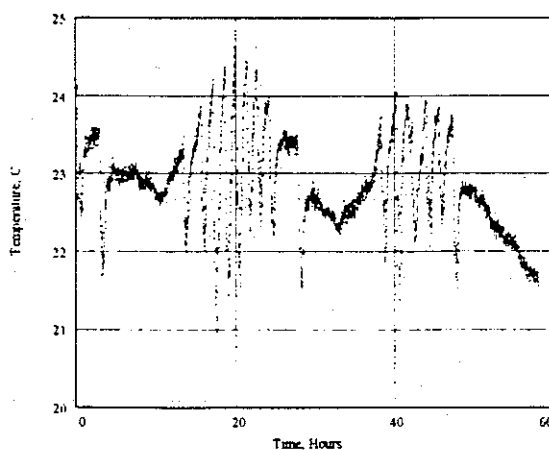


Figure 3 Run 1 Temperature vs time

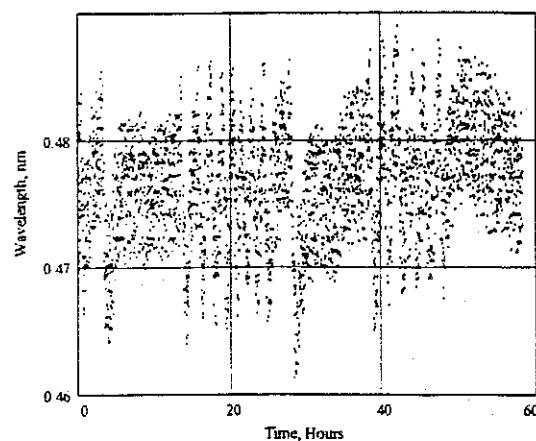


Figure 4 Run 1 Wavelength error vs time

reference source variation is insignificant. The OSA temperature coefficient was calculated as -14 pm/C .

The kink at the base of the results was due to the warm-up time of the OSA, approximately two hours.

Wavelength scale

A wavelength scan was performed over the range 1290-1320 nm at 1 pm increments using an external-cavity tunable laser and wavemeter to provide a wavelength reference. The results (Figure 6) show a periodic ripple with wavelength of approximately 40 pm peak to peak. This variation is too fine to be observed using the calibration artefact or other methods. The measurements were repeated four days later and position of the high-frequency ripples was unchanged. The low frequency variation is believed to be a temperature effect.

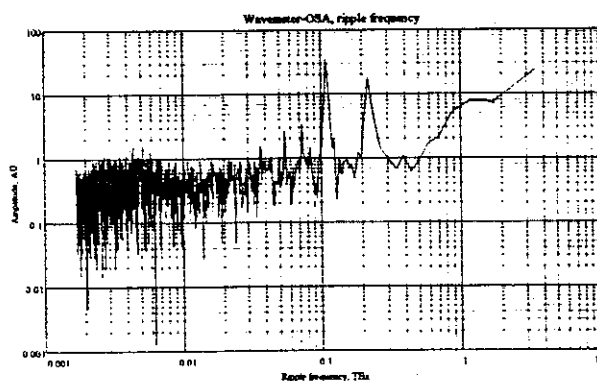
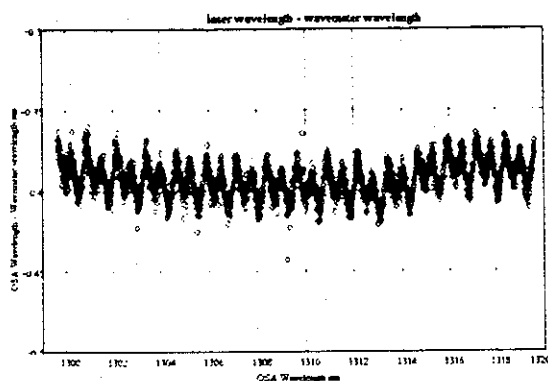
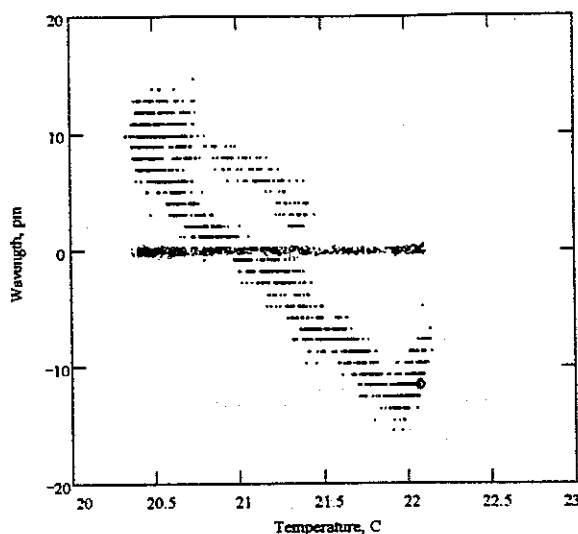


Figure 6 Variation of the wavelength correction as a function of wavelength

Figure 7 Fourier transform of the OSA wavelength corrections showing peaks at 108 and 217 GHz.

The results were analysed by Fourier techniques, to determine the period of the variations (Figure 7). These indicate two peaks at 108 and 217 GHz.

Summary and acknowledgement

Three calibration methods have been presented. To obtain the highest accuracies it is necessary to calibrate the instrument over the wavelength range of interest and have access to locally held absolute reference standards operating within the wavelength range of interest.

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References

1. F Forgheiei et al.: 'Reduction of Four-Wave mixing Crosstalk in WDM systems using unequally spaced channels', IEEE Photon. Technol. Lett. Vol. 6, pp.754-756, 1994.
2. UHP Fiser and C von Helmholt: 'Saturation and isotopic shift of the ^{84}Kr excited-state transition at 1547.825 nm', IEEE Photon. Technol. Lett., Measurements have been performed on two commercially available Optical Spectrum Analysers to illustrate these calibration methods. Vol. 7(1), pp. 65-67, 1995.
3. D J E Knight et al.: 'Frequency measurements on H_I and the Kr line at 1.548 μm ', Proc. EFTF'96, Brighton, UK March 5-7 1996.