Bi-Lateral Comparison between NIS-Egypt and NMISA-South Africa for the Calibration of an Optical Spectrum Analyzer

Osama Terra, Hatem Hussein, Adriaan Van Brakel

***Abstract*—**Dense wavelength division multiplexing (DWDM) technology requires tight specification and therefore measurement of wavelength accuracy and stability of the telecommunication lasers. Thus, calibration of the used Optical Spectrum Analyzers (OSAs) that are used to measure wavelength is of a great importance. Proficiency testing must be performed on such measuring activity to insure the accuracy of the measurement results. In this paper, a new comparison scheme is introduced to test the performance of such calibrations. This comparison scheme is implemented between NIS-Egypt and NMISA-South Africa for the calibration of the wavelength scale of an OSA. Both institutes employ reference gas cell to calibrate OSA according to the standard IEC/ BS EN 62129 (2006). The result of this comparison is compiled in this paper.

***Keywords*—**OSA calibration, HCN gas cell, DWDM technology, wavelength measurement.

I. Introduction

FIBER optical communication is still rapidly developing with the constant introduction of newer technologies to increase the communications bandwidth. The most widely used new technology is the DWDM [1]. DWDM requires tight specification and therefore measurement of wavelength accuracy and stability of communication lasers. This specification is required because of precise channel allocation and detection requirements. Up to 80 different laser wavelengths (optical channels within wavelength range of 1520-1570 nm) can be used in DWDM. This increases the communication bandwidth from about 1 Gb/s to about 100 Gb/s, which allows high speed data transmission.

OSAs are widely used to measure the absolute wavelength and spectral purity of laser sources which are used in DWDM. Calibration of OSA is necessary to ensure accurate measurement of laser characteristics. Characterization of laser sources is not only important for DWDM systems, but also for other telecommunication applications. For example, laser spectral purity determines the chromatic dispersion in an optical communication system and hence the bandwidth. Therefore, it is important to calibrate OSAs to assure its accurate measurements. The standard IEC/BS EN 62129 (2006) describes different methods for the calibration of an OSA [2]. One of the methods that can be easily implemented for the calibration of OSA is the use of a reference gas cell. The most commonly used reference gas cells in the telecommunication wavelength region are Hydrogen cyanide (carbon isotope 13) ($H^{13}C^{14}N$) in the wavelength range 1522-1577 nm, Hydrogen cyanide (carbon isotope 12) ($H^{12}C^{14}N$) in the wavelength range 1514-1570 nm, carbon monoxide (carbon isotope 12) ($^{12}C^{16}O$) in the wavelength range from 1560–1595 nm, and carbon monoxide (carbon isotope 13) ($^{13}C^{16}O$) in the wavelength range from 1595–1630 nm.

In this paper, a comparison has been made between NIS-Egypt and NMISA-South Africa for the calibration of the OSA wavelength scale. The calibration has been performed using reference gas cell according to the standard IEC/ BS EN 62129 (2006).

II. Background about OSA

The main block of a grating-based OSA is a monochromator [3]. Fig. 1 shows a basic configuration of a monochromator. The monochromator has a planar diffraction grating and two concave mirrors. The incident light from the optical fiber is made parallel by a collimating mirror, and diffracted at the diffraction grating. Then, this light reflects on a focusing mirror and dispersively forms a spectrum on the slit plane. Only the light with the intended wavelength will be focused at the slit and can pass through it.

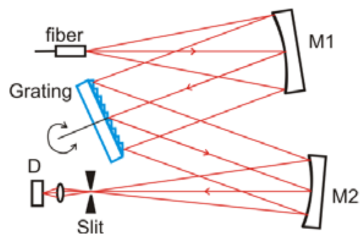

Fig. 1 Monochromator configuration, M1: collimating mirror, M2 focusing mirror, D: photodetector

The relation between the grating angle and wavelength has to be accurately determined and regularly calibrated for the accurate determination of the wavelength. Due to the nonlinearity of the grating rotation, this relation is not linear and therefore calibration over the whole intended wavelength range is required.

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III. Reference Gas Cells

Both NIS and NMISA employ reference gas cells to calibrate the wavelength scale of an OSA according to the standard IEC/BS EN 62129 (2006) [2]. However, NIS uses Hydrogen Cyanide ($H^{13}C^{14}N$) gas cell that covers the wavelength range 1530-1557 nm, while NMISA uses a gas mixture from Hydrogen-Cyanide 12 ($H^{12}C^{14}N$) and Carbon-Monoxide 12 ($^{12}C^{16}O$) that covers the wavelength range 1515 -1995 nm. The absorption lines with wavelengths from 1530-1560 nm are selected for the comparison. Table I shows the gas cells absorption lines that will be used for OSA calibration as reported by the manufacturer and measured by the others [4], [5].

TABLE I
The Wavelengths of the Gas Cells Absorption Lines that Will Be Used for OSA Calibration

$H^{13}C^{14}N$		$H^{12}C^{14}N$	
R branch Wavelength (nm)	P branch Wavelength (nm)	R branch Wavelength (nm)	P branch Wavelength (nm)
1533.14868	1534.52984	1533.14868	1534.52984
1532.47395	1535.23629	1532.47395	1535.23629
1531.80978	1535.95333	1531.80978	1535.95333
1531.15613	1536.68095	1531.15613	1536.68095
1530.51304	1537.41922	1530.51304	1537.41922
	1538.16813		1538.16813
	1538.92767		1538.92767
	1539.69784		1539.69784
	1540.47871		1540.47871
	1541.27025		1541.27025
	1542.07248		1542.07248
	1542.88542		1542.88542
	1543.70908		1543.70908
	1544.54348		1544.54348
	1545.38859		1545.38859
	1546.24448		1546.24448
	1547.11115		1547.11115
	1547.9886		1547.9886
	1548.87683		1548.87683
	1549.7759		1549.7759
	1550.68579		1550.68579
	1551.60651		1551.60651
	1552.53809		1552.53809
	1553.48054		1553.48054
	1554.43387		1554.43387
	1555.3981		1555.3981
	1556.37324		1556.37324
	1557.3593		1557.3593
	1558.35631		1558.35631
	1559.36426		1559.36426

IV. Transfer Standard

The transfer standard was an OSA purchased from Yokogawa with model AQ6370C. This OSA has a wavelength range of 600-1700 nm with resolution of 0.02 nm. Since OSA is heavy and contains optical component that cannot be easily transferred, the OSA is kept at NMISA while the reference absorption cell and the broadband source (the calibration system) of NIS are transferred to NMISA. This means that, the same OSA will be calibrated using NIS and NMISA participants in the comparison at NMISA.

V. OSA Wavelength Scale Calibration

Reference gas cells are used to calibrate OSA. At NIS, the carbon 13 isotope of the Hydrogen Cyanide ($H^{13}C^{14}N$) gas cell is used. The cell is purchased from *Traid technology* with specified gas pressure at 23 C of 100 Torr ± 5%, HCN purity of 98%, temperature dependence < 0.0001nm/°C and wavelength accuracy of ± 0.0003 nm (1 sigma). In order to probe these absorption lines, an Erbium-doped fiber amplifier (EDFA) (QAMnet-gEDFA-17-2) is used as a broadband source. The EDFA emits a broad spectrum over the wavelength range (1530-1560 nm) with power > -30 dBm/nm.

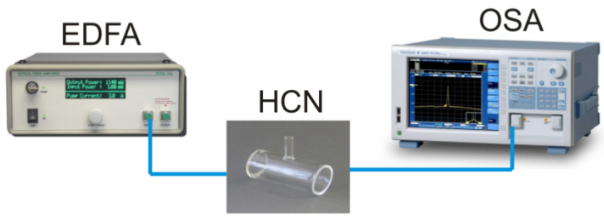

Fig. 2 OSA calibration setup using H13CN reference gas cell

At NMISA, the carbon 12 isotope of the Hydrogen Cyanide ($H^{12}C^{14}N$) gas cell is used. A super luminescent diode (SLED) (EXFO (FSL2200SCL)) is used as a broadband source which has the wavelength range from 1460 nm to 1625 nm and power of more than – 30 dB.

VI. Results

Initially, NIS calibration system ($H^{13}C^{14}N$ + EDFA) is used to calibrate OSA. The calibration results are shown in Table II. Table II shows that the maximum error over the whole range is 8.4 pm with standard deviation of 1.7 pm. Thereafter, NMISA calibration system ($H^{12}C^{14}N$ + SLED) is used to calibrate OSA. The calibration results are shown in Table III. Table III shows that the maximum error over the whole range is 8.5 pm with standard deviation of 1.7 pm.

Uncertainty evaluation of distance scale calibration at NIS

The uncertainties of measurements were calculated according to the GUM [6] and guidelines as stipulated in the standard EN 62129 (2006) [2]. There are two main sources of uncertainty contributing to the uncertainty in the wavelength scale calibration of an OSA, namely, the uncertainty in the reference gas cell absorption lines and the standard deviation of the values measured during the calibration. According to the manufacturer and by [4], [5], which states the absorption lines of the HCN at zero pressure and the wavelength pressure dependence which is about 2 MHz/Torr and the measurement uncertainties therein, an upper limit for the uncertainty in the wavelength of the absorption lines is chosen to be ±3 pm. The standard deviation from the calibration of the OSA according to section 6 is 1.7 pm for each cell. The combined uncertainty is then equal to ±3.4 pm. The expanded uncertainty at 95% is found to be ±6.8 pm.

TABLE II
OSA CALIBRATION WITH $H^{13}C^{14}N$ GAS CELL

R branch				P branch			
Label	OSA (nm)	HCN (nm)	dλ (pm)	Label	OSA (nm)	HCN (nm)	dλ (pm)
R20	1530.2986	1530.3061	7.5	P1	1543.1078	1543.1141	6.3
R19	1530.7806	1530.7856	5	P2	1543.8068	1543.8094	2.6
R18	1531.27	1531.7738	4.9	P3	1544.5126	1544.5147	2.1
R17	1531.77	1531.7738	3.8	P4	1545.226	1545.2300	4
R16	1532.277	1532.2825	5.5	P5	1545.9506	1545.9552	4.6
R15	1532.793	1532.8010	8	P6	1546.687	1546.6903	3.3
R 14	1533.3234	1533.3292	5.8	P7	1547.4344	1547.4353	0.9
R13	1533.8612	1533.8671	5.9	P8	1548.1862	1548.1904	4.2
R12	1534.4102	1534.4149	4.7	P9	1548.95	1548.9555	5.5
R11	1534.9686	1534.9724	3.8	P10	1549.7254	1549.7306	5.2
R10	1535.5338	1535.5397	5.9	P11	1550.5122	1550.5156	3.4
R9	1536.1084	1536.1168	8.4	P12	1551.305	1551.3106	5.6
R8	1536.6968	1536.7037	6.9	P13	1552.1088	1552.1156	6.8
R7	1537.2956	1537.3004	4.8	P14	1552.926	1552.9309	4.9
R6	1537.9028	1537.9067	3.9	P15	1553.7518	1553.7559	4.1
R5	1538.5164	1538.5233	6.9	P16	1554.5856	1554.5912	5.6
R4	1539.141	1539.1494	8.4	P17	1555.4306	1555.4365	5.9
R3	1539.7774	1539.7856	8.2	P18	1556.288	1556.2919	3.9
R2	1540.426	1540.4314	5.4	P19	1557.1538	1557.1573	3.5
R1	1541.0824	1541.0873	4.9	P20	1558.027	1558.0329	5.9
R0	1541.7462	1541.7530	6.8	P21	1558.913	1558.9185	5.5
				P22	1559.8112	1559.8143	3.1

TABLE III
OSA CALIBRATION WITH $H^{12}C^{14}N$ GAS CELL

R branch				P branch			
Label	OSA (nm)	HCN (nm)	dλ (pm)	Label	OSA (nm)	HCN (nm)	dλ (pm)
R4	1530.5058	1530.5130	7.2	P1	1534.5274	1534.5298	2.4
R3	1531.1512	1531.1561	4.9	P2	1535.2306	1535.2363	5.7
R2	1531.805	1531.8098	4.8	P3	1535.9476	1535.9533	5.7
R1	1532.467	1532.4740	7	P4	1536.675	1536.6809	5.9
R0	1533.1402	1533.1487	8.5	P5	1537.4162	1537.4192	3
				P6	1538.1646	1538.1681	3.5
				P7	1538.9238	1538.9277	3.9
				P8	1539.6912	1539.6978	6.6
				P9	1540.475	1540.4787	3.7
				P10	1541.268	1541.2703	2.3
				P11	1542.0682	1542.0725	4.3
				P12	1542.8806	1542.8854	4.8
				P13	1543.7066	1543.7091	2.5
				P14	1544.5402	1544.5435	3.3
				P15	1545.3838	1545.3886	4.8
				P16	1546.2394	1546.2445	5.1
				P17	1547.1082	1547.1112	3
				P18	1547.9852	1547.9886	3.4
				P19	1548.8716	1548.8768	5.2
				P20	1549.7716	1549.7759	4.3
				P21	1550.6848	1550.6858	1
				P22	1551.6036	1551.6065	2.9
				P23	1552.5334	1552.5381	4.7
				P24	1553.4778	1553.4805	2.7

VII. Measurements Compared

The average of the wavelength deviation (dλ) from Table II is compared to the average of that from Table III to evaluate the results of both institutes (NIS and NMISA). The comparison is given in Table IV.

TABLE IV
COMPARING NIS AND NMISA CALIBRATION RESULTS

Parameter		NIS	NMISA
Wavelength	Value	8.4 pm	8.5 pm
	Uncertainty	±6.8 pm	±6.8 pm

The wavelength calibration results are also plotted in Fig. 3.

Actually, the best way to compare the result is to use the normalized Error (En). The normalized error is calculated according to:

$$E_n = \frac{\lambda_{NIS} - \lambda_{NMISA}}{\sqrt{(U_{NIS}^2 + U_{NMISA}^2)}} \quad (1)$$

where λ_{NIS} , λ_{NMISA} are the wavelength measurement results by OSA at NIS and at NMISA, U_{NIS}, U_{NMISA} are the expanded uncertainty of the wavelength measurement by OSA at NIS and NMISA. But, since the transitions wavelengths are not matched, the reference values of the wavelengths from the publications are used. Therefore, the equation becomes:

$$E_n = \frac{(\lambda_{NIS} - \lambda_{R,NIS}) - (\lambda_{NMISA} - \lambda_{R,NMISA})}{\sqrt{(U_{NIS}^2 + U_{NMISA}^2)}} \quad (2)$$

where $\lambda_{R,NIS}$ is the reference value for the $H^{13}C^{14}N$ cell, and $\lambda_{R,NMISA}$ is the reference value for the $H^{12}C^{14}N$ cell. If both values were equal, (2) will be (1). Some transitions are chosen from Tables II and III that are near to each other and distributed along the wavelength range.

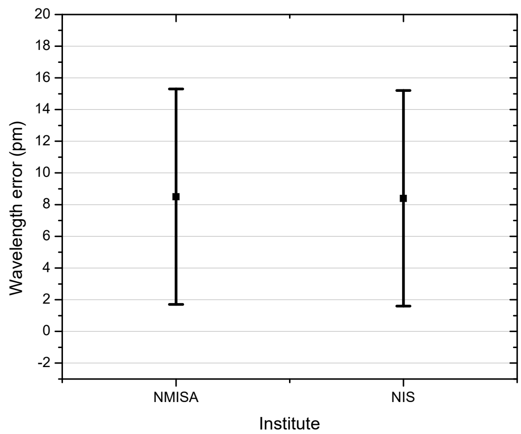

Fig. 3 Wavelength scale calibration comparison between NIS and NMISA for wavelength range 1530-1560 nm

TABLE V
CALCULATION OF THE NORMALIZED ERROR E_N

NIS ($H^{13}C^{14}N$)			NMISA ($H^{12}C^{14}N$)			En
OSA (nm)	HCN (nm)	dλ (pm)	OSA (nm)	HCN (nm)	dλ (pm)	
1530.2986	1530.3061	7.5	1530.5058	1530.5130	7.2	0.03
1531.77	1531.7738	3.8	1531.805	1531.8098	4.8	-0.10
1532.793	1532.8010	8	1532.467	1532.4740	7	0.10
1534.4102	1534.4149	4.7	1534.5274	1534.5298	2.4	0.24
1536.1084	1536.1168	8.4	1535.9476	1535.9533	5.7	0.28
1536.6968	1536.7037	6.9	1536.675	1536.6809	5.9	0.10
1537.2956	1537.3004	4.8	1537.4162	1537.4192	3	0.19
1538.5164	1538.5233	6.9	1538.1646	1538.1681	3.5	0.35
1539.7774	1539.7856	8.2	1539.6912	1539.6978	6.6	0.17
1540.426	1540.4314	5.4	1540.475	1540.4787	3.7	0.18
1543.8068	1543.8094	2.6	1543.7066	1543.7091	2.5	0.01
1544.5126	1544.5147	2.1	1544.5402	1544.5435	3.3	-0.12
1545.226	1545.2300	4	1545.3838	1545.3886	4.8	-0.08
1548.1862	1548.1904	4.2	1547.9852	1547.9886	3.4	0.08
1548.95	1548.9555	5.5	1548.8716	1548.8768	5.2	0.03
1549.7254	1549.7306	5.2	1549.7716	1549.7759	4.3	0.09
1550.5122	1550.5156	3.4	1550.6848	1550.6858	1	0.25
1551.305	1551.3106	5.6	1551.6036	1551.6065	2.9	0.28
1552.926	1552.9309	4.9	1552.5334	1552.5381	4.7	0.02
1553.7518	1553.7559	4.1	1553.4778	1553.4805	2.7	0.15

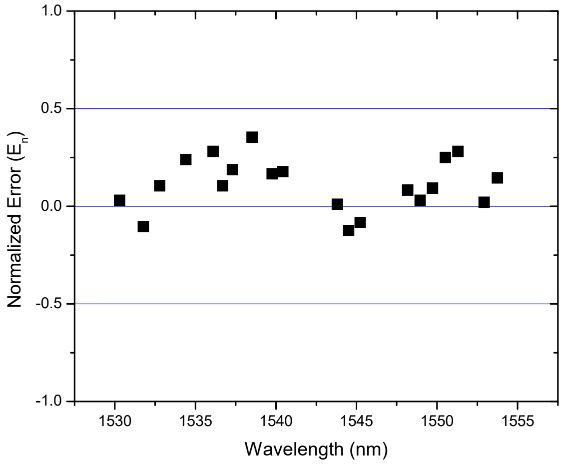

Fig. 4 Normalized Error E_n for comparison of both institute results

VIII. Conclusion

A bi-lateral comparison between NIS-Egypt and NMISA-South Africa in the calibration of the wavelength scale of OSA has been conducted. A transfer OSA has been calibrated by both institutes, NIS and NMISA for the wavelength scales using their respective standards according to the IEC/EN standard 62129 (2006). Good agreement is found between the results from both institutes which lie within the uncertainty limits of the OSA.

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