RESULTS AND DISCUSSION

RESULTS

The analyzed data from all experiments most of them yield good results as expected in the experimental hypothesis. Some experiment that does not yields or given a proper result may be from the experiment design or the available instruments that did not match the experiment procedure. The experiment results are summarized as follow.

1. Experiment set 1 Electrical Characteristics

1.1 Experiment 1.1 Frequency characteristics of the OSA controller

From table 2 and 3 show frequency stability of high voltage ramp observed at 0.25 Hz, 0.5 Hz, 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz, and amplitude of 250 V, 200 V, 150 V, and 100 V respectively. Standard deviation of the mean is lower than 0.5% of average frequency. This value comparatively small and less than that claimed in its specification. But, if compare to some brand name such as Pi Scientific, 0.5% is rather high for metrological work.

1.2 Experiment 1.2 Amplitude characteristics of the OSA controller

From table 4 the amplitude stability of high voltage ramp observed at 0.25 Hz, 0.5 Hz, 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz, and amplitude of 250 V, 200 V, 150 V, and 100 V respectively. The data analysis shows that unbiased standard uncertainty (standard deviation of the mean) is less than 0.1% of each value of average amplitude. This value is also less than that claimed in its specification but it is rather high for metrological work.

1.3 Experiment 1.3 Linearity of the ramp signal

From table 5 and 6 the percentage of nonlinearity is 0.482% with unbiased uncertainty of 0.032%. This value is too small!

1.4 Experiment 1.4 Harmonic distortion of ramp signal.

From table 7 the *THD%* is about 1.2%, this does not agree to experiment 1.3. Note that shape of harmonic peak did not look like it should be, when compare to computer simulation result. They are two possible answers. First, the simulation ramp signal is some difference compare to the real signal, such as the fall down slope. The second, the ramp generator in the controller model 251 effected some modulation that caused side band frequency as seen in figure 36.

1.5 Experiment 2.1 Sensitivity and input range of the controller model 251 amplifier.

Result of experiment 2.1 is not as expected, may be from stability and noisy at low frequency of function generator. From table 8 the average static sensitivity is 20.65 with unbiased standard uncertainty 1.13. This value is far from specification. The improvement of procedure and instruments are required.

1.6 Experiment 2.2 Frequency response to 3 dB cutoff of the amplifier.

From figure 43 the response graph 3 dB cutoff frequency of the signal amplifier, is around 35 kHz. This value far difference from specification 80 kHz. It may be from bad stability and noise low signal amplitude of the function generator. The improvement of experiment procedure and instruments are required.

1.7 Experiment 3.1 Unexposed I-V characteristics

From figure 44 the unexposed I-V characteristics plotted compare to HM-6042. The curve indicated that the PIN 125DPL has threshold voltage about 0.65 V the same as typical silicon diode.

1.8 Experiment 3.2 Exposed I-V characteristics.

This experiment does not yield any result. The curve is the same as experiment 3.1. Note that, the diode leakage current (I_d at V_d that lower than 0.5 V) has some difference, but HM-6042 cannot measure.

2. Experiment set 2 The OSA Characteristics

2.1 Experiment 4.1 Etalon cavity extension & co-efficient.

In practical, the etalon extension coefficient is less importance than the repeatability of linear extension motion when linear ramp voltage was applied. How ever, etalon extension coefficient is more convenient to evaluate and its standard uncertainty can indicate repeatability of linear extension motion. From table 9 the extension coefficient is 3.605 nm/V with unbiased standard deviation 0.012 nm/V (or 0.34%) at effective degree of freedom 57. This value is in the same order of that claimed in its specification, 4 nm/V.

2.2 Experiment 4.2 Evaluation of Finesse @ 632.8 nm.

Finesse is the necessary parameter in many measurements that use OSA. The value from experiments in difference condition is 201.5 with unbiased standard uncertainty 0.8 at effective degree of freedom 112. This value is very close to 200 that claimed in its specification. But much difference if compare to the OSA certificate (367.2 at 632.8 nm). This difference may be from alignment or measurement method. The most possible influence is from HeNe laser, its frequency is not perfectly stabilized.

3. Experiment set 3 Wavelength Measurement

3.1 Experiment 5.1 Wavelength measurement of LHRP-0151 Laser

HeNe laser model LHRP-0151 with 632 nm nominal wavelength output was used in the experiment.. By shining the laser beam into the OSA head and read the output from oscilloscope screen. The measured wavelength is 634.3 nm which deviated from 632.8 nm with 17.4 nm unbiased expand uncertainty. The result was averaged from two measurements, so it does not accurate.

3.2 Experiment 5.2 Wavelength measurement of LHRP-0051 Laser

HeNe laser model LHRP-0051 with 543 nm nominal wavelength output was used in the experiment. The measured wavelength is 511.7 nm with 119.3 nm unbiased expand uncertainty. This wavelength is at the sensitivity margin of the OSA. The transmit output peak is very small and noisy. The measured data is collected from only one measurement, so the result does not reliable enough.

3.3 Experiment 5.3 Measure Wavelength of Laser diode (630 nm)

Laser pointer with 650 nm nominal wavelength output was used in the experiment. The measurement can not be done due to the instability of the output. This comes from the heat liberated form diode junction and lack off heat sink so the laser cavity length is varied.

DISCUSSION

The experiments procedure used in this research is proposed to investigate some physical characteristics of the OSA and the instruments. Method in the procedure only aimed to evaluate some parameters and depended on test instruments availability, so that, this may not be a standard procedure using in standard metrology laboratory. After trial and error many experiments and methods are abandoned. The experiment procedures in this paper are portion that yield some result.

The experiment set 1, Electrical characteristic: Most experiment results indicate that the Electrical characteristic such as those of the ramp generator and its scanning stability are qualified or better than that claimed by its specification. The average uncertainty is about 1%, except some experiment which may be caused from defect of the function generator.

Some experiments do not give an expected result for example an experiment on gain and responsivity characteristics of PIN 125DPL photodiode, required improvement of test method and instruments. The experiment should cover both continuous and pulse.

The experiment set 2, Optical characteristics: The methods and results seem reliable but more data and condition are suggested for improvement. In order to get a standard performance of the OSA the calibration of reference laser source is required. Some reference such as wavelength of others spectral source measured by others instrument that available is suggested.

Some parameters that cannot be calculate properly, such as the exact cavity length, the FSR, may be caused from limitation of instruments or the improper methodology applied. Although, the result is not good enough but if the calibrated laser source is available, the reliable value of important parameter is possible to calculate.

Experiment set 3, Wavelength measurement: Method using for wavelength measurement in this experiment is adapted and simplified from many literatures. The measurement results show wavelength uncertainty is rather high. Because of the detector damaged or sensitivity degenerate after characteristics test so, only few measurements are done and it is unable to repeat the experiment. Though, some guide such as from ISO handbook III LWS section 5.12 (esa ISO) by using some interoperation technique, may improve the measurement uncertainty.

Method of wavelength measurement used in thesis is not recommended by CIPM. This suggestion is recently found in some documents. The method that now widely used is called Comb Technique. This technique employs grating to the Faby-Perot interferometer to generate the ‘optical ruler’ which is claimed the measurement uncertainty to 10^{-12} or better. However, the OSA model 240 is a very fine instrument and widely used, but some standard document such as IEC PAS 62129 (Calibration of Optical Spectrum Analyzers) and other normative document related are needed.

CONCLUSION

The OSA model 240 and adjunct instruments that available in Photonic Metrology Laboratory at Department of Physics were purchased under The Government-World Bank Project (in year 2003) in order to develop academic strength in the field of Physics and related subject. The project was proposed to the Department to develop some subjects. Photonic Metrology and Laboratory in Photonic Metrology are new courses developed according to the aim of that project. Photonic Metrology is an interdisciplinary subject that employs another three groups of subject, Photometry, Spectroscopy and Interfero-metry. These three subjects are included many of Optical Metrology and the related such as Optical Frequency Standard, Length Standard, etc. So, Wavelength Measurement is the basic knowledge or backbone in this subject.

The literature review in former part of this thesis points out that the realization of meter according to CIPM recommendation is possible by three methods. One method that generally used and widely applied is wavelength measurement by the instrument called ‘Interferometer’. Since 1983, thousands of researches working for scientific development have brought numbers of new techniques for accurate wavelength measurement. Today more recommendations and measurement conditions are added by CIPM in order to regulate and generalize the international standard of Meter Realization.

There are many types of interferometer invented since Young’s Double Slit experiment in 1805. The famous one was the Michelson’s double beam interferometer invented in 1887. However, the application of Faby-Perot interferometer for wavelength measurement is a high accuracy method with low operation cost when compare with other method of the same accuracy level.

The Materials and Methods in this thesis are about instruments and procedure of experiments to investigate the physical properties of the OSA and the adjunct instruments such as the controller, the detector and light source available. Also, some measuring instruments are included. The conclusion of this good instrument is ‘it is suitable for generally fine spectral measurement but may not be good enough for some metrological work such as reference wavelength that requires the uncertainty less than 10^{-9}.

However, the experiments for testing source of uncertainty of the OSA need much improvement and more data are required. In order to reach capable of international standard for wavelength calibration, standard and reference material are required, also, more investigation on standard and normative documents such as time frequency standard, the comb technique, must be done.

Though today, interferometry and application of Fabry-Perot interferometer are not popular among the Thai scientists but in the near future, I believe that, it may be an important technique and be widely used in many area such as industrial, agriculture and military.

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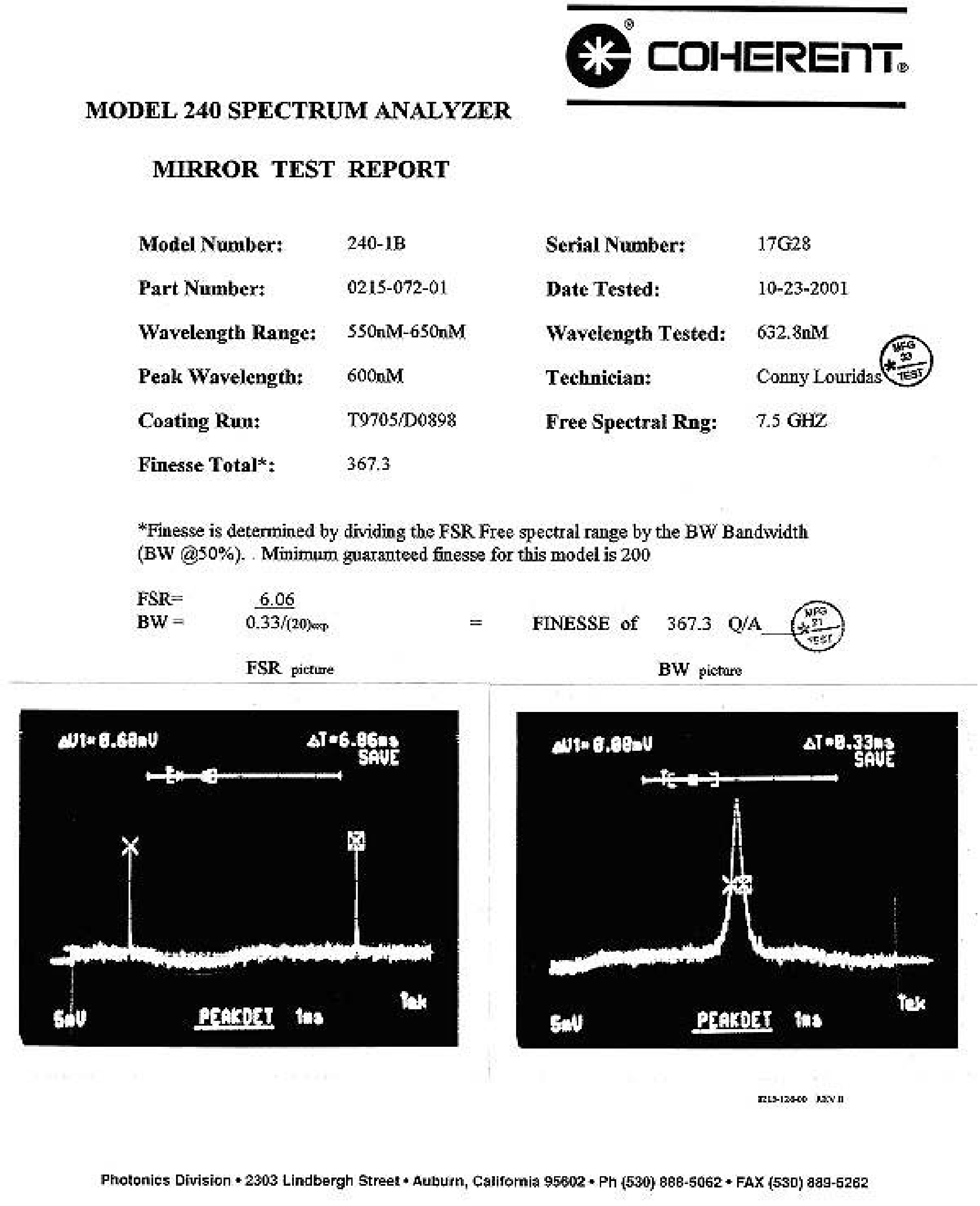
APPENDICIES

APPENDIX A

Spectral Information,
Instruments Specification and test certificate

APPENDIX A1



COHERENT

MODEL 240 SPECTRUM ANALYZER

MIRROR TEST REPORT

Model Number:	240-1B	**Serial Number:**	17G28
Part Number:	0215-072-01	**Date Tested:**	10-23-2001
Wavelength Range:	550nM-650nM	**Wavelength Tested:**	632.8nM
Peak Wavelength:	600nM	**Technician:**	Conny Louridas
Coating Run:	T9705/D0898	**Free Spectral Rng:**	7.5 GHZ
Finesse Total*:	367.3		

MFG 20 TEST

*Finesse is determined by dividing the FSR Free spectral range by the BW Bandwidth (BW @50%). . Minimum guaranteed finesse for this model is 200

FSR= 6.06
BW = 0.33/(20)exp. = FINESSE of 367.3 Q/A MFG 21 TEST

FSR picture

BW picture

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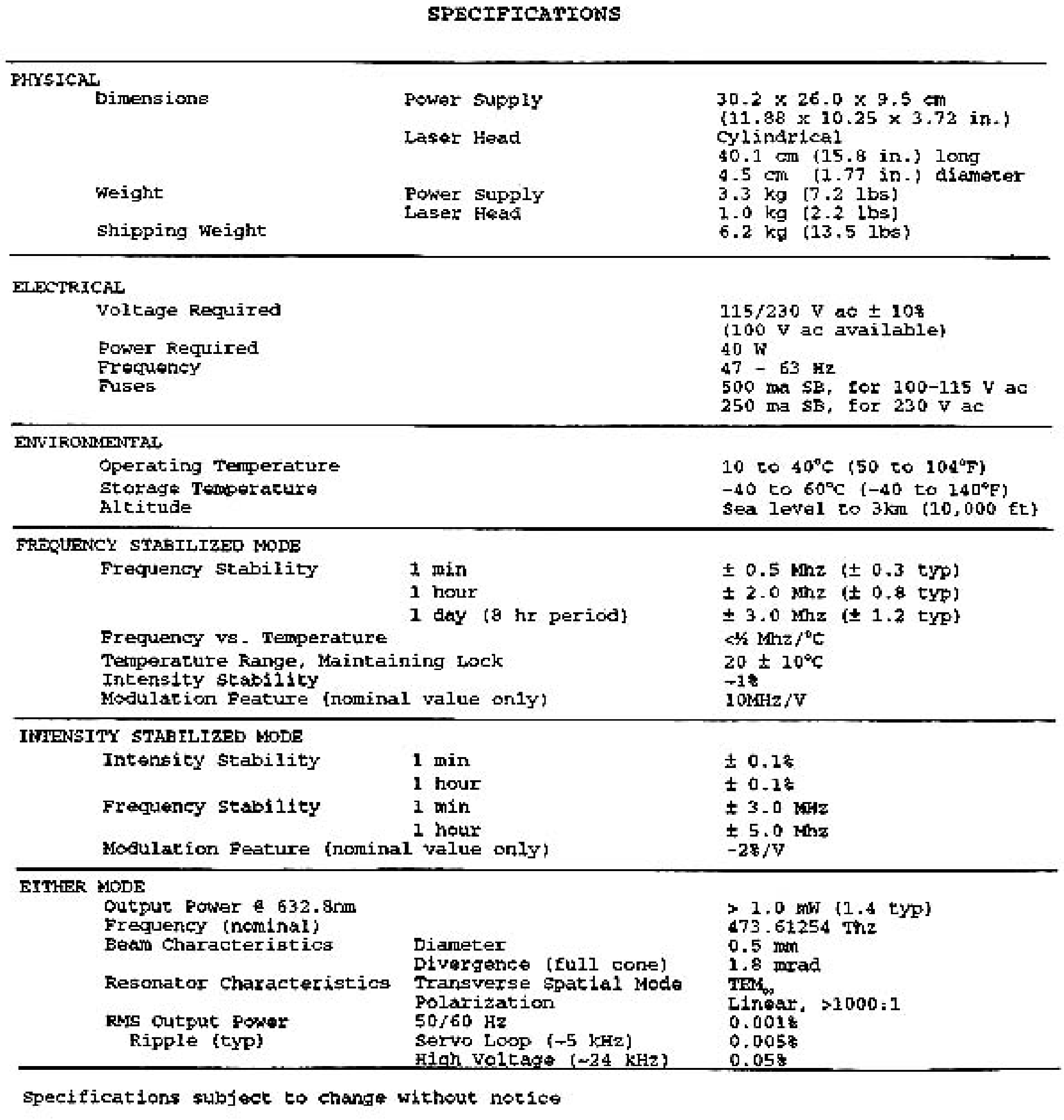
Appendix Figure A1 Test certificate of the OSA model 240

Source: Coherent Auburn Group. 1982.

APPENDIX A2



SPECIFICATIONS

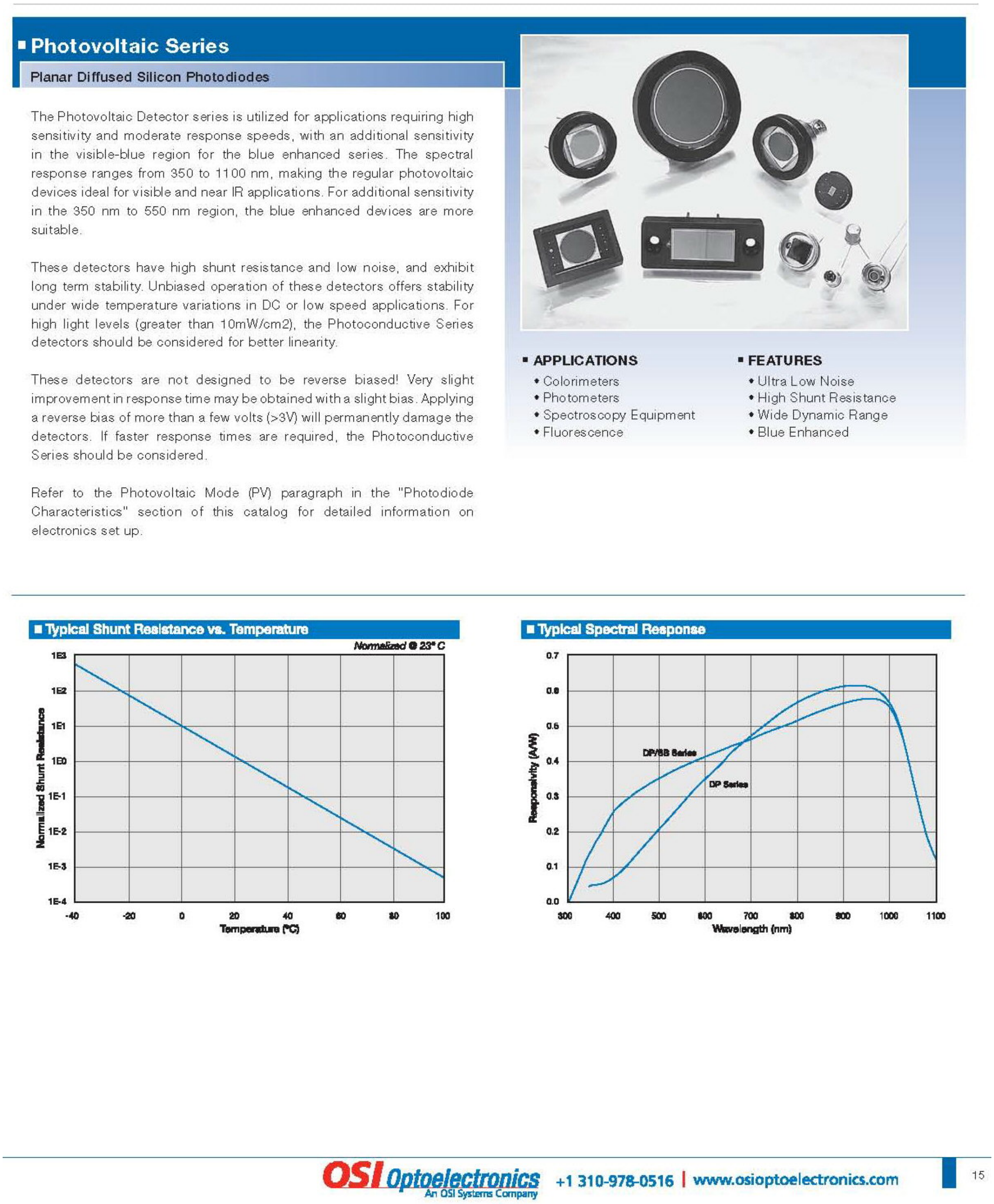
PHYSICAL		
Dimensions	Power Supply	30.2 x 26.0 x 9.5 cm (11.88 x 10.25 x 3.72 in.)
	Laser Head	Cylindrical 40.1 cm (15.8 in.) long 4.5 cm (1.77 in.) diameter
Weight	Power Supply	3.3 kg (7.2 lbs)
	Laser Head	1.0 kg (2.2 lbs)
Shipping Weight		6.2 kg (13.5 lbs)
ELECTRICAL		
Voltage Required		115/230 V ac ± 10% (100 V ac available)
Power Required		40 W
Frequency		47 - 63 Hz
Fuses		500 ma SB, for 100-115 V ac 250 ma SB, for 230 V ac
ENVIRONMENTAL		
Operating Temperature		10 to 40°C (50 to 104°F)
Storage Temperature		-40 to 60°C (-40 to 140°F)
Altitude		Sea level to 3km (10,000 ft)
FREQUENCY STABILIZED MODE		
Frequency Stability	1 min	± 0.5 Mhz (± 0.3 typ)
	1 hour	± 2.0 Mhz (± 0.8 typ)
	1 day (8 hr period)	± 3.0 Mhz (± 1.2 typ)
Frequency vs. Temperature		<½ Mhz/°C
Temperature Range, Maintaining Lock		20 ± 10°C
Intensity Stability		~1%
Modulation Feature (nominal value only)		10MHz/V
INTENSITY STABILIZED MODE		
Intensity Stability	1 min	± 0.1%
	1 hour	± 0.1%
Frequency Stability	1 min	± 3.0 MHz
	1 hour	± 5.0 Mhz
Modulation Feature (nominal value only)		-2%/V
EITHER MODE		
Output Power @ 632.8nm		> 1.0 mW (1.4 typ)
Frequency (nominal)		473.61254 Thz
Beam Characteristics	Diameter	0.5 mm
	Divergence (full cone)	1.8 mrad
Resonator Characteristics	Transverse Spatial Mode	TEM_{00}
	Polarization	Linear, >1000:1
RMS Output Power Ripple (typ)	50/60 Hz	0.001%
	Servo Loop (~5 kHz)	0.005%
	High Voltage (~24 kHz)	0.05%

Specifications subject to change without notice

Appendix Figure A2 Specification of SP117 632.8 nm stabilized HeNe Laser

Source: Spectra-Physics (1997)

APPENDIX A3



▪ Photovoltaic Series

Planar Diffused Silicon Photodiodes

The Photovoltaic Detector series is utilized for applications requiring high sensitivity and moderate response speeds, with an additional sensitivity in the visible-blue region for the blue enhanced series. The spectral response ranges from 350 to 1100 nm, making the regular photovoltaic devices ideal for visible and near IR applications. For additional sensitivity in the 350 nm to 550 nm region, the blue enhanced devices are more suitable.

These detectors have high shunt resistance and low noise, and exhibit long term stability. Unbiased operation of these detectors offers stability under wide temperature variations in DC or low speed applications. For high light levels (greater than 10mW/cm2), the Photoconductive Series detectors should be considered for better linearity.

These detectors are not designed to be reverse biased! Very slight improvement in response time may be obtained with a slight bias. Applying a reverse bias of more than a few volts (>3V) will permanently damage the detectors. If faster response times are required, the Photoconductive Series should be considered.

Refer to the Photovoltaic Mode (PV) paragraph in the "Photodiode Characteristics" section of this catalog for detailed information on electronics set up.

▪ **APPLICATIONS**

- Colorimeters
- Photometers
- Spectroscopy Equipment
- Fluorescence

▪ **FEATURES**

- Ultra Low Noise
- High Shunt Resistance
- Wide Dynamic Range
- Blue Enhanced

▪ **Typical Shunt Resistance vs. Temperature**

▪ **Typical Spectral Response**

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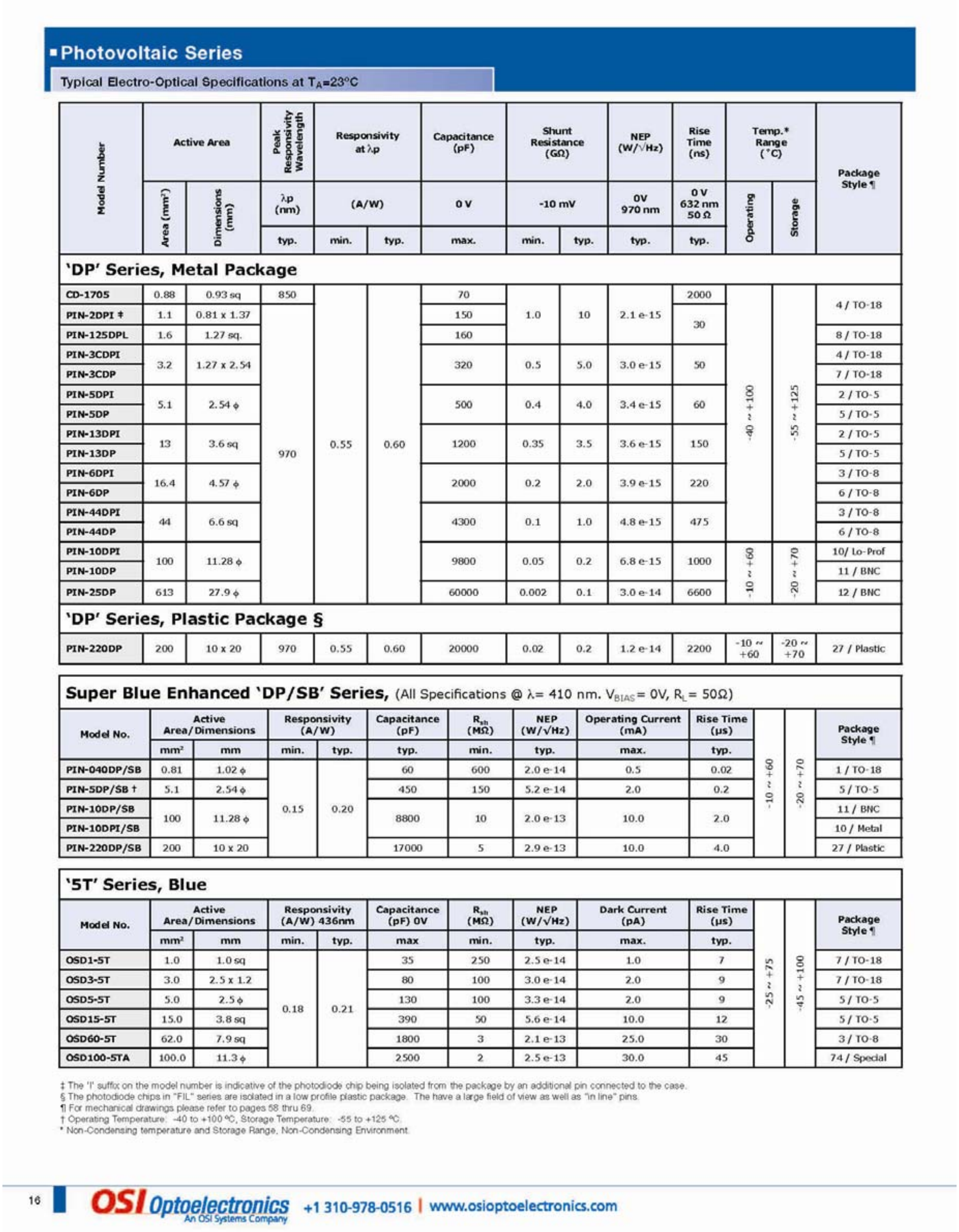
Appendix Figure A3 Scanned page 1 of the specification of UDT photo-voltaic series.

Source: OSI-Optoelectronics. (2006)



Photovoltaic Series

Typical Electro-Optical Specifications at T_A=23°C

Model Number	Active Area		Peak Responsivity Wavelength	Responsivity at λp		Capacitance (pF)	Shunt Resistance (GΩ)		NEP (W/√Hz)	Rise Time (ns)	Temp.* Range (°C)		Package Style ¶
	Area (mm^2)	Dimensions (mm)	λp (nm)	(A/W)		0 V	-10 mV		0V 970 nm	0 V 632 nm 50 Ω	Operating	Storage	
			typ.	min.	typ.	max.	min.	typ.	typ.	typ.			
'DP' Series, Metal Package													
CD-1705	0.88	0.93 sq	850	0.55	0.60	70	1.0	10	2.1 e-15	2000	-40 ~ +100	-55 ~ +125	4 / TO-18
PIN-2DPI ‡	1.1	0.81 x 1.37	970			150				30			
PIN-125DPL	1.6	1.27 sq.				160							8 / TO-18
PIN-3CDPI	3.2	1.27 x 2.54				320	0.5	5.0	3.0 e-15	50			4 / TO-18
PIN-3CDP													7 / TO-18
PIN-5DPI	5.1	2.54 ϕ				500	0.4	4.0	3.4 e-15	60			2 / TO-5
PIN-5DP													5 / TO-5
PIN-13DPI	13	3.6 sq				1200	0.35	3.5	3.6 e-15	150			2 / TO-5
PIN-13DP													5 / TO-5
PIN-6DPI	16.4	4.57 ϕ				2000	0.2	2.0	3.9 e-15	220			3 / TO-8
PIN-6DP													6 / TO-8
PIN-44DPI	44	6.6 sq				4300	0.1	1.0	4.8 e-15	475			3 / TO-8
PIN-44DP													6 / TO-8
PIN-10DPI	100	11.28 ϕ				9800	0.05	0.2	6.8 e-15	1000	-10 ~ +60	-20 ~ +70	10/ Lo-Prof
PIN-10DP													11 / BNC
PIN-25DP	613	27.9 ϕ				60000	0.002	0.1	3.0 e-14	6600			12 / BNC
'DP' Series, Plastic Package §													
PIN-220DP	200	10 x 20	970	0.55	0.60	20000	0.02	0.2	1.2 e-14	2200	-10 ~ +60	-20 ~ +70	27 / Plastic

Super Blue Enhanced 'DP/SB' Series, (All Specifications @ λ= 410 nm. V_{BIAS}= 0V, R_L= 50Ω)

Model No.	Active Area/Dimensions		Responsivity (A/W)		Capacitance (pF)	R_{sh} (MΩ)	NEP (W/√Hz)	Operating Current (mA)	Rise Time (μs)			Package Style ¶
	mm^2	mm	min.	typ.	typ.	min.	typ.	max.	typ.			
PIN-040DP/SB	0.81	1.02 ϕ	0.15	0.20	60	600	2.0 e-14	0.5	0.02	-10 ~ +60	-20 ~ +70	1 / TO-18
PIN-5DP/SB †	5.1	2.54 ϕ			450	150	5.2 e-14	2.0	0.2			5 / TO-5
PIN-10DP/SB	100	11.28 ϕ			8800	10	2.0 e-13	10.0	2.0			11 / BNC
PIN-10DPI/SB												10 / Metal
PIN-220DP/SB	200	10 x 20			17000	5	2.9 e-13	10.0	4.0			27 / Plastic

'5T' Series, Blue

Model No.	Active Area/Dimensions		Responsivity (A/W) 436nm		Capacitance (pF) 0V	R_{sh} (MΩ)	NEP (W/√Hz)	Dark Current (pA)	Rise Time (μs)			Package Style ¶
	mm^2	mm	min.	typ.	max	min.	typ.	max.	typ.			
OSD1-5T	1.0	1.0 sq	0.18	0.21	35	250	2.5 e-14	1.0	7	-25 ~ +75	-45 ~ +100	7 / TO-18
OSD3-5T	3.0	2.5 x 1.2			80	100	3.0 e-14	2.0	9			7 / TO-18
OSD5-5T	5.0	2.5 ϕ			130	100	3.3 e-14	2.0	9			5 / TO-5
OSD15-5T	15.0	3.8 sq			390	50	5.6 e-14	10.0	12			5 / TO-5
OSD60-5T	62.0	7.9 sq			1800	3	2.1 e-13	25.0	30			3 / TO-8
OSD100-5TA	100.0	11.3 ϕ			2500	2	2.5 e-13	30.0	45			74 / Special

‡ The 'I' suffix on the model number is indicative of the photodiode chip being isolated from the package by an additional pin connected to the case.
§ The photodiode chips in "FIL" series are isolated in a low profile plastic package. The have a large field of view as well as "in line" pins.
¶ For mechanical drawings please refer to pages 58 thru 69.
† Operating Temperature: -40 to +100 °C, Storage Temperature: -55 to +125 °C.
* Non-Condensing temperature and Storage Range, Non-Condensing Environment.

Appendix Figure A4 Scanned page 2 of the Specification of UDT photo-voltaic series that show specification of PIN 125DPL.

Source: OSI-Optoelectronics. (2006)

APPENDIX A4

Some Radiation Recommended by CIPM

Appendix Table A1 List of recommended radiations, 1983, for radiation of lasers stabilized by saturated absorption.

Absorbing molecule	Transition	Component	ν [MHz]	λ [fm]	10^9 u_{rel}
CH_4	ν_3, P(7)	$F_2^{(2)}$	88 376 181.608	3 392 231 397.0	0.13
$^{127}I_2$	17-1, P(62)	o	520 206 808.51	576 294 760.27	0.6
$^{127}I_2$	17-5, R(127)	I	473 612 214.8	632 991 398.1	1.0
$^{127}I_2$	9-2, R(47)	o	489 880 355.1	611 970 769.8	1.1
$^{127}I_2$	43-0, P(13)	a_3	582 490 603.6	514 673 466.2	1.3

Note

In this list, the values of the frequency ν and of the wavelength λ should be related exactly by the relation $\lambda\nu = c_o$ with c_o = 299 792 458 m/s but the values of λ are rounded.

Radiation of lasers stabilized by saturated absorption. As a footnote: “Each of these radiations can be replaced, without degrading the accuracy, by a radiation corresponding to another component of the same transition or by another radiation, when the frequency difference is known with sufficient accuracy...” u_{rel} means: estimated overall relative uncertainty, the threefold standard deviation.

Source: Bayer-Helms (1991)

Appendix Table A2 List of recommended radiations of Spectral Lamps.

Atom	Transition	λ [pm]	u_{rel}
^{86}Kr	$2p_9 - 5d'_4$	645 807.20	$2 \cdot 10^{-8}$
	$2p_8 - 5d_4$	642 280.06	
	$1s_3 - 3p_{10}$	565 112.86	
	$1s_4 - 3p_8$	450 361.62	
^{198}Hg	$6^1P_1 - 6^1D_2$	579 226.83	$5 \cdot 10^{-8}$
	$6^1P_1 - 6^3D_2$	577 119.83	
	$6^3P_2 - 7^3S_2$	546 227.05	
	$6^3P_1 - 7^3S_1$	435 956.24	
^{114}Cd	$5^1P_1 - 5^1D_2$ *^{2}	644 024.80	$7 \cdot 10^{-8}$ (the red Cd line)
	$5^3P_2 - 6^3S_1$	508 723.79	
	$5^3P_1 - 6^3S_1$	480 125.21	
	$5^3P_0 - 6^3S_1$	467 945.81	

Note

1. Radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the atom ^{86}Kr. The value λ = 605 780 210 fm, $u_{rel} = 4 \cdot 10^{-9}$ *^{1}, applies to the radiation emitted by a lamp operated under the conditions recommended by the CIPM.

2. Radiations of the atoms ^{86}Kr, ^{198}Hg and ^{114}Cd recommended by the CIPM in 1963.

3. *^{1} The realization uncertainty of the metre definition from 1960 with the 8^6Kr standard lamp has been quoted originally to be 10^{-8} relative only. According to further experiments and experiences it could be reduced to $4 \cdot 10^{-9}$. The meaning of quoted uncertainty values has been stated more precisely to be the threefold standard deviation here.

4. *^{2} A misprint occurred in the classification in.

Source: Bayer-Helms (1991)

APPENDIX A5

Appendix table A3 Possible spectrum of He-Ne laser.

(1) Output Wavelength	(2) HeNe Laser Name	(3) Perceived Beam Color	(4) Lasing Transition	(5) Typical Gain (%/m)		(6) Maximum Power (mW)	
543.5 nm	Green	Green	3s2->2p10	0.52	0.59	2	(5)
594.1 nm	Yellow	Orange-Yellow	3s2->2p8	0.5	0.67	7	(10)
604.6 nm		Orange	3s2->2p7	0.6	1.0	3	
611.9 nm	Orange	Red-Orange	3s2->2p6	1.7	2.0	7	
629.4 nm		Orange-Red	3s2->2p5	1.9	2.0		
632.8 nm	Red	" "	3s2->2p4	10.0	10.0	75	(200)
635.2 nm		" "	3s2->2p3	1.0	1.25		
640.1 nm		Red	3s2->2p2	4.3	2.0	2	
730.5 nm	Border	Infra-Red	3s2->2p1	1.2	1.25	0.3	
886.5 nm		" "	2s2->2p10	1.2	1.25	0.3	
1,029.8 nm	Near-IR	Invisible	2s2->2p8	N.A.			
1,062.3 nm	" "	" "	2s2->2p7	N.A.			
1,079.8 nm	" "	" "	2s3->2p7	N.A.			
1,084.4 nm	" "	" "	2s2->2p6	N.A.			
1,140.9 nm	" "	" "	2s2->2p5	N.A.			
1,152.3 nm	" "	" "	2s2->2p4	N.A.		1.5	
1,161.4 nm	" "	" "	2s3->2p5	N.A.			
1,176.7 nm	" "	" "	2s2->2p2	N.A.			
1,198.5 nm	" "	" "	2s3->2p2	N.A.			
1,395.0 nm	" "	" "	2s2->2p?	N.A.		0.5	
1,523.1 nm	" "	" "	2s2->2p1	N.A.		1.0	
3,391.3 nm	Mid-IR	" "	3s2->3p4	N.A.	440.0	24	

Notes:

1. Output Wavelength is approximate. In addition to slight variations due to actual lasing conditions (single mode, multimode, doppler broadening, etc.), some references don't even agree on some of these values to the 4 or 5 significant digits shown.

2. HeNe Laser Name is what would be likely to be found in a catalog or spec sheet. All those that have an entry in this column are readily available commercially.

3. Perceived Beam Color is how it would appear when spread out and projected onto a white screen. Of course, depending on the revision level of your eyeballs, this may vary someone from individual to individual.

4. Lasing Transition uses the so-called "Paschen Notation" and indicates the electron shells of the neon atom energy states between which the stimulated emission takes place.

5.Typical Gain (%/m) shows the percent increase in light intensity due to stimulated emission at this wavelength inside the laser tube's bore. This is the single pass gain and will be affected by tube construction, gas fill ratio and pressure, discharge current, and other factors. The first column is from various sources. The second column is from Hecht, "The Laser Guide Book".

6. Gain at 1,523 nm may be similar to that of 543.5 nm - about 0.5%/m. Gain at 3,391 nm is by far the highest of any - possibly more than 100%/m. I know of one particular HeNe laser operating at this wavelength that used an OC with a reflectivity of only 60% with a bore less than 0.4 m long.

Source: Goldwasser (2005)

APPENDIX B

Experiments procedure

APPENDIX B1

Experiments Set 1 Procedure

Experiment 1.1 Frequency characteristics of the OSA controller.

Objective

1. Measure frequency range and resolution.
2. Observe the rise time range and stability.

Literature: See topic Material & Method section 1.1 & 1.3

From specification, Rise Time of Ramp is 10 ms to 5 s at tolerance of ±10%. Fall Time of Ramp is 10 ms at tolerance of ±10% and expects to be constant.

Experimental hypothesis (From user manual,)

1. The frequency range can approximate from rise time. It may span from 0.2 Hz to 50 Hz with uncertainty better than ±10%.
2. Rise time span from 10 ms to 5 s with uncertainty better than ±10%.

Instruments

1. OSA controller model 251 (UUT.)
2. DSO (TDS 220)

Procedure

1. Use the TDS 220 to measure frequency span and rise time.
2. Warm up the OSA controller model 251 and TDS 220 for 30 minute.
3. Observe maximum and minimum of the frequency span and rise time.
4. Observe the tuning point or frequency range that cause in stability
5. Observe frequency and period stability at 0.25 Hz, 0.5 Hz, 1.0 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz. in 1 hour, at amplitude 250 V, 200 V, 150 V, 100 V, and 50 V.
6. Measure frequency, period, and rise time. Calculate fall time and duty cycle.

7. Evaluate mean frequency and period and the uncertainties associated at 95% confidence.

Experiment 1.2 Amplitude characteristics of the OSA controller.

Objective

1. Measure Amplitude range and resolution.
2. Observe the Amplitude stability.

Literature: See topic Material & Method section 1.1 & 1.3

Experimental hypothesis (From user manual,)

1. The Amplitude range span from 0 V to 250 V with unknown tolerance. The resolution of controllable incrimination voltage is observed.
2. The amplitude stability is not specify, but expected to be better than 1%.

Instruments

1. OSA controller model 251 (UUT.)
2. DSO (TDS 220)

Procedure

1. Observe maximum and minimum peak to peak amplitude
2. Use sampling frequency at 0.25 Hz, 0.5 Hz, 1.0 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz.
3. Use the TDS 220 to measure the peak to peak amplitude at zero DC offset.
4. Use sampling amplitude at (1, 2.5, 5, 10, 25, 50, 100, 250) V for each frequency. Observe the amplitude voltage range that cause instability or uncontrollable.
5. Observe minimum peak compare 0 V.
6. Evaluate mean amplitude voltage range at each step and the uncertainties associated at 95% confidence.

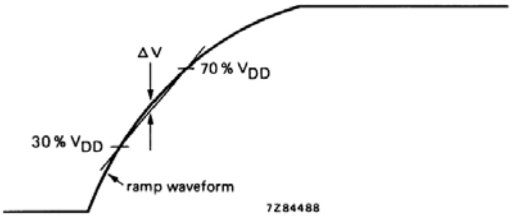
Experiment 1.3 Linearity of ramp signal.

Objective

Measure the linearity of ramp signal.

Literature

Since, there is no exact definition of linearity of the ramp signal on any standard documents. Only one found form HEF4750V data sheet (Philips Semiconductor 1995).



Linearity = $\frac{\Delta V}{1/2\ V_{DD}} \times 100\%$.

Fig.16 Definition of the ramp linearity at full swing.
ΔV is the maximum deviation of the ramp waveform to the straight line, which joins the 30% V_{DD} and 70% V_{DD} points.

Appendix figure B1 Measurement definition of ramp linearity

In case of extreme linearity so we change the full swing span from 10% V_{DD} to 90% V_{DD}.

Equation: $$\text{Linearity} = \frac{\Delta V}{0.5V_{DD}}$$

Linearity is property of signal like “error”. Its uncertainty is not defined.

Experimental hypothesis (From user manual,)

The ramp linearity is less than 1.5%.

Instruments

1. OSA controller model 251 (UUT.)
2. DSO (TDS 220)

Procedure

1. Use sampling frequency at 0.25 Hz, 0.5 Hz, 1.0 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz.
2. Use sampling amplitude at 5 V, 10 V, 25 V, 50 V, 100 V, 150 V, 200 V, 250V for each frequency.
3. Observe ramp voltage and time at 10% V_{DD}, and 90% V_{DD} at each frequency.
4. Evaluate average linearity (or non-linearity) at each amplitude value over the frequency range.

Experiment 1.4 DC offset characteristics.

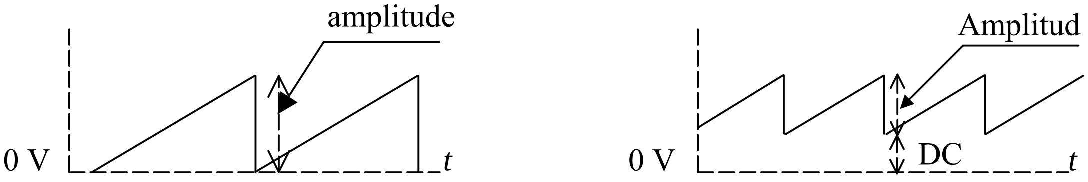
Objective

1. Measure DC offset range and resolution.
2. Observe DC offset stability.

Literature

DC offset is a DC voltage mix to ramp signal. Thus result is two cases. The first, DC voltage is added to the ramp signal. The peak voltage is increase and the peak to peak amplitude is the same. The second, DC voltage is mix in to the ramp signal. This case the peak voltage is the same but the peak to peak amplitude is previous peak voltage minus the DC offset. By this manner DC offset is not DC term of furier components.

A scanned FPI cavity some time needs to start scanning at specific length. The DC offset voltage applied to the piezo actuator elongate the cavity to this length. This mean that the extreme stability of DC offset is need.



Appendix figure B2 Zero Offset Ramp and Ramp with DC offset

Experimental hypothesis (From user manual,)

1. DC offset is 0 V to 200 V.
2. DC offset is stability is not specified, but expects to be better than 0.1%.

Instruments

1. OSA controller model 251 (UUT.)
2. DSO (TDS 220)

Procedure

1. Use the sampling test frequency at 0.25 Hz, 0.5 Hz, 1.0 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz.
2. Use the sampling amplitude or peak voltage at 50 V, 100 V, 250 for each frequency.
3. Select the sampling DC offset at 10 V, 25 V, 50 V, 100 V, 150 V and 200 V for each pair of amplitude-frequency.
4. Observe stability of DC offset voltage and other effect on amplitude and frequency.
5. Evaluate DC offset mean voltage at the sampling amplitude over a frequency range and the uncertainties associated at 95% confidence.

Experiment 1.5 Harmonic distortion of ramp signal

Objective

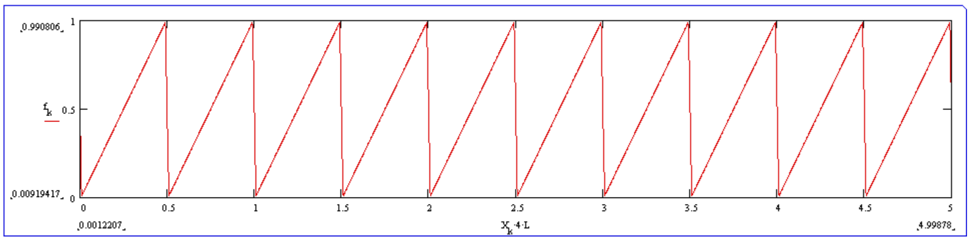
1. Measure the harmonic distortion of ramp signal.
2. Observe ramp spectrum of model 251 controller signal compare to computer FFT result of ideal ramp signal of the same frequency, amplitude and duty cycle.

Literature

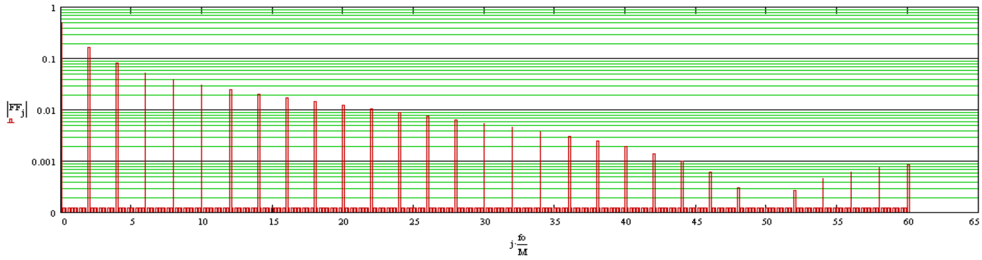
1. Harmonic distortion cause the signal shape distort from its regular shape. In case of audio frequency sinusoidal signal, the “True RMS” meter is introduced to measure voltage or current of the test signal compare to the reference signal. The

reference signal usually synthesized from very high definition signal synthesizer or arbitrary function synthesizer. If the signal is ramp wave form harmonic distortion is major cause of non-linearity. In case of small non-linearity the method in experiment 3 may unable to show the significant figure.

2. Small harmonic distortion is difficult to distinguish by method above. If we known exactly the desired ramp waveform. Spectrum Analyzer or Fast Fourier Analyzer able to analyze harmonics of the test signal compare to a reference signal or computerize Fourier transform of geometrical wave form.



Appendix figure B3 Ramp wave form of period 0.5 s, rise time 0.49 s, duty cycle 98%.



Appendix figure B4 FFT of the same ramp, show 30 peak harmonics form 300 components. First 11 and 22 harmonics which amplitude are over 0.01 and 0.001 respectively.

3. If we consider that the algebraic sum of fourier components arise from random noise tend to zero. The DC part is 0.5, then the modulus of infinite sum on harmonics of the complex amplitude is tending to 0.5. In practice, summation on limit range of harmonics may give result more than 0.5 i.e., before phase reversal point (f = 1/2*Tf).

To set comparison on the same condition. We adjust FFT analyzer to sampling 10 periods of the test ramp on the 4096 points time window. Consider the algebraic sum of the complex amplitude from the first harmonic to the first harmonic that magnitude less than 0.1 % of the test ramp.

Equation:

$$TDH_X = \frac{1}{0.5 \cdot V}\sqrt{\left(\sum_{p=1}^{q-1} FF_p\right)^2}$$

Where

V is the average amplitude of test ramp wave.

FF_p are complex amplitude of p^{th} harmonic of FFT of test ramp wave.

q-1 is the FFT term that $|FF_q|$ is less than $0.001V$.

$$TDH_{Ref} = \frac{1}{0.5 \cdot V_{ref}}\sqrt{\left(\sum_{p=1}^{q-1} FF_p\right)^2}$$

TDH_{Ref} is the total harmonic distortion of reference ramp wave of the same frequency, amplitude rise time and fall time.

$$TDH\% = \left(1 - \frac{TDH_X}{TDH_{ref}}\right) \times 100$$

$TDH\%$ is defined for Total Harmonics Distortion index that compare to the reference ramp wave form.

Experimental hypothesis (From user manual,)

The harmonic distortion is less than 1.00%.

Instruments

1. OSA controller model 251 (UUT.)
2. Real Time FFT analyzer (Tektonix 2642A)

Procedure

1. Use sampling frequency at 0.25 Hz, 0.5 Hz, 1.0 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz.

2. Use sampling amplitude at (1, 2.5, 5, 10, 25, 50, 100, 250) V for each frequency.
3. Use the 2642A to observe power and phase spectrum of the test ramp signal at each frequency and amplitude pair. Evaluate the TDH_{Ref}
4. Evaluate TDH_{Ref} from any mathematic software i.e., MathCAD.
5. Evaluate Total Harmonics Distortion index ($TDH\%$) of the test ramp wave compare to the correspondence reference ramp wave.

Experiment 2.1 Signal Amplifier Characteristics of the controller model 251

Objective

1. Measure D.C. sensitivity characteristic of ramp signal amplifier of 251 controller.
2. Measure the input range of ramp signal amplifier of 251 controller.

Literature

1. D.C. sensitivity is the ratio of output signal to input signal. This static charac-teristic can directly measure form output voltage which correspondence to assigned input voltage if the amplifier has D.C response.

2. Sensitivity characteristic can observe and measure by given a linear ramp signal of appropriate amplitude and frequency range. Then observe the simultaneous output such as linearity, saturation and other difference with the input signal shape.

3. Two methods above we also measure input range by observe saturation of the output signal.

4. Transfer characteristic is an I-V relation of output/input. Usually apply to sensor which may consider as current source or voltage source

Equation:

Voltage Sensitivity $$S_V = \left\langle \frac{\Delta V_O}{\Delta V_I} \right\rangle$$

ΔV_O is best linear span of output voltage range correspondence with

ΔV_I is best linear span of input voltage range.

Transfer Sensitivity $S_T = \left\langle \frac{\Delta V_O}{\Delta I_I} \right\rangle$

ΔI_I is best linear span of input current range.

Experimental hypothesis (From user manual,)

1. The sensitivity (or voltage gain) = 1000
2. Transfer characteristic:
    - 2.1 for current source ($Ri > 100$ kΩ) $V_O(\text{V}) = 50\ I_I(\text{A})$
    - 2.2 for voltage source ($Ri < 100$ Ω) $V_O(\text{V}) = 10^3$ v/v $I_I(\text{A})$

Instruments

1. OSA controller model 251 (UUT.)
2. Multimeter 8842A
3. DSO (TDS 220)
4. Arbitrary function generator AFG 5101
5. Digital multi-meter 33401A

Procedure

1. Set AFG 5101 to generate triangular signal at 5 Hz and 10 mV amplitude. Then feed to controller model 251 via the detector input channel.
2. Use the TDS 220 to observe the best linear span of output signal from the detector output channel compare to the correspondence input signal. Then calculate the average sensitivity.
3. Connect the DMM 33401A between AFG 5101 and the controller model 251. Set up the 33401A to ACmA mode (at 1 A range the resolution is 1 nA and uncertainty from specification is 1.00% of reading + 400 nA). The internal impedance of AFG 5101 is 50 Ω. This case the AFG 5101 is a voltage source with $Ri < 100$ Ω.
4. Use the TDS 220 to observe the best linear span of output signal from the detector output channel compare to the correspondence input signal. Then calculate the average Transfer sensitivity.

Experiment 2.2 Frequency response to 3 dB cutoff of the amplifier

Objective

1. Measure 3dB cutoff frequency of signal amplifier of 251 controller.
2. Observe the frequency response linearity of signal amplifier of 251 controller.

Literature

1. Any amplifiers always have specific frequency response. The preferred signal amplifiers must have a constant gain on broad frequency range.
2. Cutoff frequency is the frequency which the output signal is half power of the input signal or the voltage gain is $1/\sqrt{2}$.
3. There are many ways to study and observe frequency characteristics of signal amplifier. In this case a simple swept sine method is applied.

Experimental hypothesis (From user manual,)

The cutoff frequency is 80 KHz (typical).

Instruments

1. OSA controller model 251 (UUT.)
2. Multimeter 8842A
3. DSO (TDS 220)
4. Arbitrary function generator AFG 5101

Procedure

1. Set AFG 5101 to generate sine signal at 5 Hz and 10 mV amplitude. Then feed to controller model 251 via the detector input channel.
2. Use the TDS 220 to observe amplitude of output signal from the detector output channel compare to input signal. Then calculate the average voltage gain.
3. Change the input frequency form 1 Hz to 1 MHz in 1:2:5 step.

4. Redo item 3. from 50 kHz to 100 kHz by 2 kHz step and find the cutoff frequency.

Experiment 3.1 Unexposed I-V characteristic of photo diode sensor

Objective

1. Observe the Unexposed I-V characteristic of photo diode “PIN-125DPL”.
2. Measure the diode threshold voltage.

Literature

1. “PIN-125DPL” is a planar diffuse silicon photo diode designed for photo-voltaic application. This detector is utilized for applications requiring high sensitivity and moderate response speeds, with an additional sensitivity in the visible-blue region for the blue enhanced series. The spectral response ranges from 350 nm to 1100 nm. (cf. 1.1.3)

2. Since, this sensor detector is not designed to be reverse biased. The operation of this sensor in the OSA must be photovoltaic mode. This mode of operation the photo diode act like a solar cell. If no light expose on its junction we can find the junction voltage from I-V characteristics.

3. There are many ways to study I-V characteristics diodes. In this case, for convenient, we use a HM-6042 Curve Tracer to observe I-V diagram and measure the diode current and voltage simultaneously.

Experimental hypothesis (From user manual,)

The cutoff frequency is 80 KHz (typical).

Instruments

1. PIN-125DPL (UUT.)
2. Curve Tracer HM-6042

Procedure

1. Insert the “PIN-125DPL” PIN photo diode into test devices socket on the HM-6042. Cover the PIN-125DPL with small cap to shade it from surrounded light.

Appendix figure B5 Measurement of Diode Characteristic with HM6042

2. Push to lock the BIP/FET switch to FET/Diode mode. Set Pmax to 0.4 W. Set Imax and Vamx to 2 mA and 2 V respectively. Then push DUT button to start the test.
3. Push the cursor button and turn the control knob to read the diode current and voltage.
4. Record the diode current and voltage. Plot I-V diagram with program EXEL.

Experiment 3.2 Exposed I-V characteristic of photo diode sensor

Objective

1. Observe the exposed I-V characteristic of photo diode “PIN-125DPL”.
2. Measure the diode threshold voltage.

Literature

1. PIN-125DPL is a planar diffuse silicon photo diode designed for photo-voltaic application. The spectral response ranges from 350 nm to 1100 nm. (cf. 1.1.3) In this application we interest its sensitivity and characteristic at 632 nm and near by wavelength.

2. From specification, PIN-125DPL active area is 1.27 mm x 1.27 mm or 1.6 mm^2.

3. There are many ways to study I-V characteristics diodes. In this case, for convenient, we use a HM-6042 Curve Tracer to observe I-V diagram and measure the diode current and voltage simultaneously.

Experimental hypothesis (From user manual,)

-

Instruments

1. PIN-125DPL (UUT.)
2. Curve Tracer HM-6042
3. Stabilized HeNe Laser 632.8 nm
4. Neutral density filter set
5. Optical power meter

Procedure

1. After complete experiment 3.1, remove PIN-125DPL from test devices socket and install it into a socket with extension wire.
2. Align 632.8 nm HeNe Laser and neutral density filter set. Measure the Laser beam power with pass through neutral density filter with optical power meter.
3. Varies the density of the filter set from 0, 0.1 … to 0.5 and record the beam power.
4. Align laser beam on the PIN photo diode. Varies the density of the filter set from 0, 0.1 … to 0.5 and record the diode current and voltage. Plot I-V diagram with program EXEL.

APPENDIX B2

Experiments Set 2 Procedure

Experiment 4.1 Etalon cavity expansion & co-efficient

Objective

1. Observe stability of linear extension of the OSA cavity when high voltage linear ramp is applied.
2. Measure the extension coefficient of the OSA cavity.

Literature

1. The OSA is application of Faby-Perot interferometer. Detailed literature confer to section 4.5

2. One of Fabry-Perot cavity mirror is attached with a hollow cylindrical piezo actuator. If this piezo actuator is applied with a liner ramp voltage, the actuator is extended linearly dependent with the applied voltage. Linear ramp voltage is linearly increasing with time then the cavity length is linearly extended with time.

3. Practical extended motion of the actuator is linear over a short distance and limited applied voltage. A transfer function of piezo element electrically equivalent to RLC circuit that response to a limit range of frequency. Furier expression of linear ramp is odd harmonic span form fundamental to infinite. When practically ramp voltage is applied to special shape piezo actuator nonlinear response is occur in some frequency and voltage range.

Experimental hypothesis

The cavity expansion & co-efficient is 4 nm/V approximately.

Instruments

1. The OSA model 240 and the controller model 251.
2. Frequency stabilized HeNe laser model SP-117
3. DSO (TDS 220)
4. Multimeter 8842A

Procedure

1. Connect ‘Ramp Out’ channel from OSA controller model 251 to the OSA model 240 and TDS 220 via a 3 way BNC splitter.
2. Switch on the TDS 220, wait until it’s ready. Then switch on the OSA controller model 251.
3. Adjust the OSA controller model 251, set sweep expansion to x1, set amplitude to 250 V, se offset to 0 V, and set rise time to 5 s. Left it 30 minute for warm up.
4. Evaluate for α_t (nm/s), slope (V/s), and α_V (nm/V) with varying amplitude.
5. Adjust amplitude until see 6 successive interference peaks.
6. Measure time interval between the 6 peak (n = 5 intervals) as dT. Measure rise time record as T1. Measure amplitude voltage and record.
7. Observe 5 successive interference peaks. Do item 5 with n = 4.
8. Calculate α_t (nm/s), slope (V/s), and α_V (nm/V). Calculate average and standard diviation.
9. Adjust amplitude voltage until see 4 successive interference peaks. Do item 5 with n = 3. Then do item 7.
10. Adjust amplitude voltage until see 3 successive interference peaks. Do item 5 with n = 2. Then do item 7.
11. Evaluate for α_t (nm/s), slope (V/s), and α_V (nm/V) with varying rise time.
12. Adjust amplitude to 250 V and rise time to 5 s.
13. Do item 5 with n = 5 and 4. Then do item 7.
14. Adjust rise time to 7.5 s and 9 s then do item 5 with n = 5 and 4. Then do item 7.
15. Evaluate α_V (nm/V) and unbiased standard uncertainty.

Experiment 4.2 Evaluated the finesse @ 632.8 nm

Objective

1. Observe the FSR and FWHM from scope screen.
2. Measure the FSR and FWHM to evaluate Finesse

Literature

See section 5.7 and 5.9.

Experimental hypothesis

Finesse of the OSA is 367.3 at 632.8 nm wavelength.

Instruments

1. The OSA model 240 and the controller model 251.
2. Frequency stabilized HeNe laser model SP-117
3. DSO (TDS 220)
4. Multimeter 8842A

Procedure

1. Connect ‘Ramp Out’ channel from OSA controller model 251 to the OSA model 240 and TDS 220 via a 3 way BNC splitter.
2. Switch on the TDS 220, wait until it’s ready. Then switch on the OSA controller model 251.
3. Adjust the OSA controller model 251, set sweep expansion to x1, set amplitude to 250 V, se offset to 0 V, and set rise time to 5 s. Left it 30 minute for warm up.
4. Measure ramp amplitude, frequency and rise time.
5. Adjust sweep expansion until see only two peak. Measure separation between the two peaks. Record the FSR.
6. Adjust sweep expansion until see only one peak. Save the wave form.
7. Recall the saved form then adjusts time/div (zoom mode) and reposition, until see the peak as wide as possible. Record the FWHM.
8. Evaluate finesse and unbiased standard uncertainty.
9. Change the ramp amplitude to 150 V, 125 V and change rise time to 7.5 s and 9 s then repeat the experiments.

CIRRICULUM VITAE

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