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Product Specification

Fabry-Perot Etalon based Wavelength Lockers

Revision 9.0



Optoplex Corporation

April 21, 2025

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1. INTRODUCTION

Athermal Fabry-Perot Wavelength Locker

Optoplex's Athermal Fabry-Perot Wavelength Locker is a thermally stable, etalon-based device that can be widely used in wavelength monitoring or ITU-grid channel locking in DWDM systems, laser stabilization for tunable laser, optical power and network monitoring. The wavelength locker has a wide capture range and excellent wavelength accuracy. A built-in thermistor can be used to calibrate out residue thermal effects when even higher wavelength accuracy is required or for a very narrow-FSR locker. The key optical component of the wavelength locker is an Etalon which is made in-house with Optoplex's proven technology in thin-film optical coating and optical contact.



Figure 1.1, Photo of a 25GHz Wavelength Locker

Key Features and Benefits

- Athermal design
- C+L-band coverage by a single device
- Extremely low temperature dependence
- High wavelength accuracy
- Periodical locking covers all channels
- Built-in thermistor for better locking accuracy
- Telcordia GR-468 & 1221 compliant

Applications

- Precision laser locking for DWDM and ultra DWDM transmitter
- Wavelength monitoring
- Laser stabilization for tunable laser module
- DWDM channel frequency and optical power monitoring

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2. MODELS AND PART NUMBERS

2.1 List of Standard Part Numbers

Currently, Optoplex offers the wavelength locker products with FSR (free-spectral range) from 200, 100, 50, 25 down to 12.5GHz, for different wavelength bands including C-, L-, C+L, O-band and 1064nm.

[Table 2.1](#) below shows the models and part numbers of the wavelength lockers available at Optoplex.

[Table 2.1](#) Models and Part Numbers

#	FSR ¹⁾	WVL Band	Lockpoint at ITU	#	Lockpoint Off-ITU	
			MPN		MPN	Off ITU (GHz)
1	12.5	C-Band	WL-CACXXS100	1a	WL-CACXXS101	3.125
2	12.5	L-Band	WL-LACXXS110	2a	WL-LACXXS111	3.125
3	12.5	C+L Band	WL-TACXXS120	3a	WL-TACXXS121	3.125
4	12.5	O-Band	WL-QACXXS130	4a	WL-QACXXS131	3.125
5	12.5	1064nm	WL-AACXXS140	5a	WL-AACXXS141	3.125
6	25	C-Band	WL-C0CXXS200	6a	WL-C0CXXS201	6.25
7	25	L-Band	WL-L0CXXS210	7a	WL-L0CXXS211	6.25
8	25	C+L Band	WL-T0CXXS220	8a	WL-T0CXXS221	6.25
9	25	O-Band	WL-Q0CXXS230	9a	WL-Q0CXXS231	6.25
10	25	1064nm	WL-A0CXXS240	10a	WL-A0CXXS241	6.25
11	50	C-Band	WL-C1CXXS300	11a	WL-C1CXXS301	12.5
12	50	L-Band	WL-L1CXXS310	12a	WL-L1CXXS311	12.5
13	50	C+L Band	WL-T1CXXS320	13a	WL-T1CXXS321	12.5
14	50	O-Band	WL-Q1CXXS330	14a	WL-Q1CXXS331	12.5
15	50	1064nm	WL-A1CXXS340	15a	WL-A1CXXS341	12.5
16	100	C-Band	WL-C2CXXS400	16a	WL-C2CXXS401	25
17	100	L-Band	WL-L2CXXS410	17a	WL-L2CXXS411	25

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18	100	C+L Band	WL-T2CXXS420
19	100	O-Band	WL-Q2CXXS430
20	100	1064nm	WL-A2CXXS440

18a	WL-T2CXXS421	25
19a	WL-Q2CXXS431	25
20a	WL-A2CXXS441	25

21	200	C-Band	WL-C3CXXS500
22	200	L-Band	WL-L3CXXS510
23	200	C+L Band	WL-T3CXXS520
24	200	O-Band	WL-Q3CXXS530
25	200	1064nm	WL-A3CXXS540

21a	WL-C3CXXS501	50
22a	WL-L3CXXS511	50
23a	WL-T3CXXS521	50
24a	WL-Q3CXXS531	50
25a	WL-A3CXXS541	50

26	300	C-Band	WL-C4CXXS500
27	300	L-Band	WL-L4CXXS510
28	300	C+L Band	WL-T4CXXS520
29	300	O-Band	WL-Q4CXXS530
30	300	1064nm	WL-A4CXXS540

26a	WL-C4CXXS601	75
27a	WL-L4CXXS611	75
28a	WL-T4CXXS621	75
29a	WL-Q4CXXS631	75
30a	WL-A4CXXS641	75

Notes:

- 1) For 12.5GHz wavelength locker, the operating temperature range is 15C ~ 35C to guarantee the performance in Table 5.1.
- 2) All other FRS' in -5C ~ +65C.

2.2 Part Number Description

For example,

- 50GHz FSR Etalon, C-Band, Lockpoint at ITU, SM Fiber, No Connector
- P/N: WL-C1CXXS300

Type of Connectors

In the P/N, “XX” = xx, no connector

- = FA: FC/APC
- = FC: FC/UPC
- = LA: LC/APC
- = LC: LC/UPC
- = SC: SC/UPC
- = MU: MU connector

Type of Fiber:

For instance, WL-A3CXXS540

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“S” = SM Fiber

“P” = PM Fiber

2.3 ITU-Grids

- 100GHz ITU-grids, see [Table 2.2](#).
- For 50GHz, On-ITU means that between two adjacent 100GHz channels, inserting a 50GHz channel at the middle.
- Similarly, for 25GHz, on-ITU means that a 25GHz channel is inserted between two adjacent 50GHz channels at the middle.
- So on for 12.5GHz, on-ITU means that a 12.5GHz channels is inserted between two adjacent 25GHz channels at the middle.
- For 200GHz channels, please specify if the odd or the even 100GHz channels required.

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Table 2.2, 100GHz and 50GHz C-Band ITU Grids

100GHz ITU Ch#	WVL (nm)	50GHz ITU Freq. (THz)	100GHz ITU Ch#	WVL (nm)	50GHz ITU Freq. (THz)	100GHz ITU Ch#	WVL (nm)	50GHz ITU Freq. (THz)	100GHz ITU Ch#	WVL (nm)	50GHz ITU Freq. (THz)
1	1577.03	190.1		1563.45	191.75	34	1550.12	193.4		1537.00	195.05
	1576.61	190.15	18	1563.05	191.8		1549.72	193.45	51	1536.61	195.1
2	1576.20	190.2		1562.64	191.85	35	1549.32	193.5		1536.22	195.15
	1575.78	190.25	19	1562.23	191.9		1548.91	193.55	52	1535.82	195.2
3	1575.37	190.3		1561.83	191.95	36	1548.51	193.6		1535.43	195.25
	1574.95	190.35	20	1561.42	192		1548.11	193.65	53	1535.04	195.3
4	1574.54	190.4		1561.01	192.05	37	1547.72	193.7		1534.64	195.35
	1574.13	190.45	21	1560.61	192.1		1547.32	193.75	54	1534.25	195.4
5	1573.71	190.5		1560.20	192.15	38	1546.92	193.8		1533.86	195.45
	1573.30	190.55	22	1559.79	192.2		1546.52	193.85	55	1533.47	195.5
6	1572.89	190.6		1559.39	192.25	39	1546.12	193.9		1533.07	195.55
	1572.48	190.65	23	1558.98	192.3		1545.72	193.95	56	1532.68	195.6
7	1572.06	190.7		1558.58	192.35	40	1545.32	194		1532.29	195.65
	1571.65	190.75	24	1558.17	192.4		1544.92	194.05	57	1531.90	195.7
8	1571.24	190.8		1557.77	192.45	41	1544.53	194.1		1531.51	195.75
	1570.83	190.85	25	1557.36	192.5		1544.13	194.15	58	1531.12	195.8
9	1570.42	190.9		1556.96	192.55	42	1543.73	194.2		1530.72	195.85
	1570.00	190.95	26	1556.55	192.6		1543.33	194.25	59	1530.33	195.9
10	1569.59	191		1556.15	192.65	43	1542.94	194.3		1529.94	195.95
	1569.18	191.05	27	1555.75	192.7		1542.54	194.35	60	1529.55	196
11	1568.77	191.1		1555.34	192.75	44	1542.14	194.4		1529.16	196.05
	1568.36	191.15	28	1554.94	192.8		1541.75	194.45	61	1528.77	196.1
12	1567.95	191.2		1554.54	192.85	45	1541.35	194.5		1528.38	196.15
	1567.54	191.25	29	1554.13	192.9		1540.95	194.55	62	1527.99	196.2
13	1567.13	191.3		1553.73	192.95	46	1540.56	194.6		1527.60	196.25
	1566.72	191.35	30	1553.33	193		1540.16	194.65	63	1527.22	196.3
14	1566.31	191.4		1552.93	193.05	47	1539.77	194.7		1526.83	196.35
	1565.90	191.45	31	1552.52	193.1		1539.37	194.75	64	1526.44	196.4
15	1565.50	191.5		1552.12	193.15	48	1538.98	194.8		1526.05	196.45
	1565.09	191.55	32	1551.72	193.2		1538.58	194.85	65	1525.66	196.5
16	1564.68	191.6		1551.32	193.25	49	1538.19	194.9		1525.27	196.55
	1564.27	191.65	33	1550.92	193.3		1537.79	194.95	66	1524.89	196.6
17	1563.86	191.7		1550.52	193.35	50	1537.40	195		1524.50	196.65
Standard Range			Extended Range								

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3. DESCRIPTION

3.1 Functional Diagram

This document provides specifications for an athermal Fabry-Perot wavelength locker with different FSR (GHz, See [Table 1.1](#)) free spectral ranges. The device serves as a calibrated frequency discriminator for controlling the wavelength of a DFB laser to any ITU channel in the C-band on a specific channel grid (refer to [Table 1.1](#)). As such, the frequency discriminating function of the device must retain its initial relationship to the ITU grid over life. A highly simplified block diagram is shown in [Fig. 3.1](#).

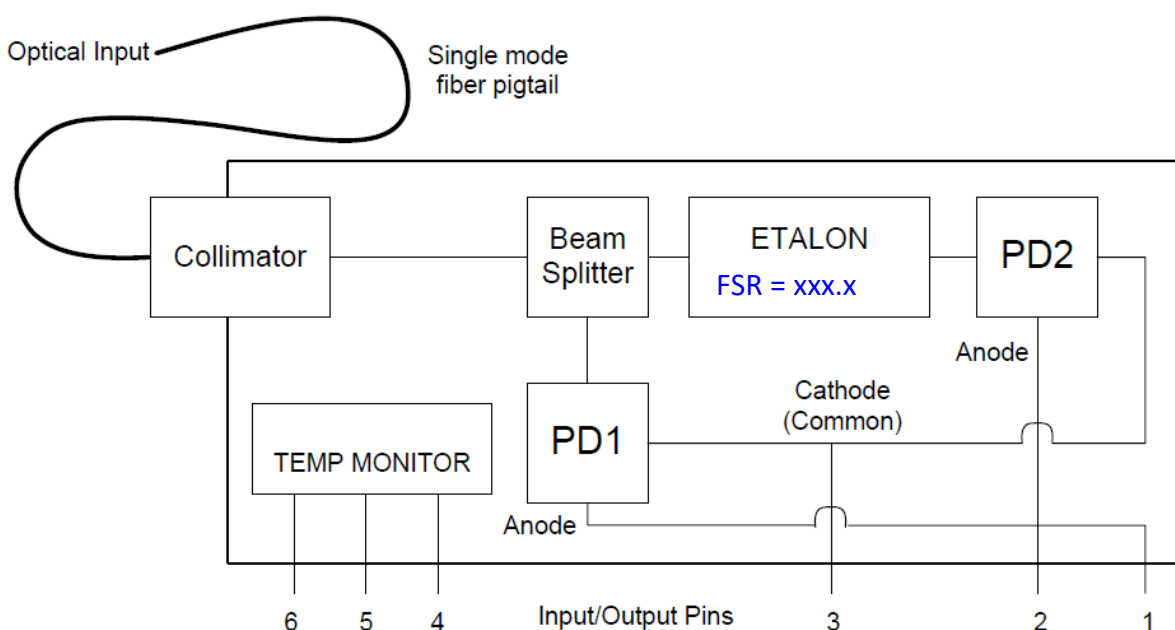


Figure 3.1, Block Diagram

Hermetically sealed package with single mode fiber input, and 6 electrical input/output pins.

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3.2 Abbreviations

Table 3.1, Abbreviations used in this document:

Abbreviations	Description
BOL	Beginning of Life
EOL	End of Life
CR	Contrast Ratio
FSR	Free spectral range
FPWL	Fabry-Perot wavelength locker
Id	Dark current (of photodiode)
SOP	State of polarization
T _{case}	Case temperature
T _{op}	Operating temperature
T _{store}	Storage temperature
TBD	To Be Determined

3.3 Related Documents

This list refers to the latest revisions of these documents, unless otherwise stated.

Table 3.2, List of applicable documents

Document Number	Description
ITU-T G.692	Optical interfaces for multichannel systems with optical amplifiers
Telcordia GR-468-CORE	Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment
Telcordia GR-1221-CORE	Generic Reliability Assurance Requirements for Passive Optical Components
ITU-T G.694.1	Spectral grids for WDM applications: DWDM frequency grid

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4. ABSOLUTE MAXIMUM RATINGS AND OPERATING CONDITIONS

4.1 Absolute Maximum Ratings

Absolute maximum ratings are intended to be conditions to which a device can be subjected for short periods of time (per Telcordia GR-63-CORE, Par. 4.1.2, Note 2) without permanent decrease in performance or reliability. The exception is case storage temperature, for which extended periods of time must be acceptable.

Table 4.1, Absolute Maximum Ratings

Parameter	Min.	Max.	Unit
Case storage temperature	-40	85	°C
Maximum optical power handling		10.0	dBm
Fiber bend radius	25		mm
Package lead soldering (250°C)		10	Sec
Fiber tensile load (10 sec. Max.)		5.0	N
ESD threshold (HBM)		300	V
Mounting screw torque (#2-56 screws)	0.07	TBD	N.m

4.2 Operating Conditions

Table 4.2, Operating Conditions

Parameter	Min.	Max.	Unit
Case operating temperature ²⁾	-5	65	°C
Rate of change of case temperature during operation		25	°C/min
Input power	-25	7	dBm
Relative humidity, at 40°C non-condensing	5	95	%
External pressure (dry inert gas)		60	psi

NOTES:

- 1) If the package is hermetically sealed, the device shall be tested for gross and fine leaks. (Helium gas leak rate < 4.0 x 10⁻⁹ ATM-cc/s). Helium gas may be allowed inside the package.
- 2) **For 12.5GHz FSR wavelength locker, the normal operating temperature range is 15 ~ 35C, this is due to its large the F-P cavity and the locker is relatively sensitive to temperature.**

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5. ELECTRICAL AND OPTICAL CHARACTERISTICS

5.1 Performance Specifications

The parameters described in the table below apply over the entire case temperature operating range as defined in [Table 5.1](#), unless otherwise stated. Furthermore, all specifications apply over the entire life of the product unless explicitly indicated to pertain to beginning of life.

Table 5.1, Optical Performance Specifications of Wavelength Lockers

#	Parameters	Unit	12.5GHz	25GHz	50GHz	100GHz	200GHz	Test Report
1	Wavelength /Frequency Range	nm /THz	C-Band: 1525 ~ 1568 / 196.585 ~ 191.194					x
2			L-Band: 1568 ~ 1606 / 191.194 ~ 186.670					
3			C+L Band: 1525 ~ 1606 / 196.585 ~ 186.670					
4			O-Band: 1260 ~ 1360 / 237.931 ~ 220.435					
5			1064nm: 1044 ~ 1084 / 287.258 ~ 276.561					
6	FSR (Free-Spectral Range)	GHz	12.5	25	50	100	200	x
7	FSR Accuracy	GHz	±0.2	±0.3	±0.5	±1.0	±1.0	x
8	Ideal Lockpoint (ILP) Frequency	THz	By Default, at ITIU. Off-ITU option available. See P/N Table					x
9	Contrast Ratio (CR)	dB	4 ~ 8	4 ~ 8	4 ~ 8	4 ~ 8	4 ~ 8	/
10	Ideal Lockpoint (ILP), CR/2	/	CR/2	CR/2	CR/2	CR/2	CR/2	/
11	Lockpoint Frequency Accuracy	GHz	±1.5	±1.5	±1.5	±1.5	±1.5	x
12	Responsivity Ratio at Lockpoint, αdB	dB	+/-1.25	+/-1.25	+/-1.25	+/-1.25	+/-1.25	x
13	Etalon Slope at ILP	dB/GHz	~ 2	~ 1	~ 0.5	~ 0.25	~ 0.125	/
14	Min. Blue Capture Range	GHz	~5	~10	~20	~40	~80	/
15	Polarization Dependent ILP Frequency Accuracy	GHz	0.6	0.6	0.6	0.6	0.6	x
16	PD Responsivity (Reference, PD1)	A/W	0.1 ~ 0.6	0.1 ~ 0.6	0.1 ~ 0.6	0.1 ~ 0.6	0.1 ~ 0.6	x
17	PD Responsivity (Etalon, PD2)	A/W	0.1 ~ 0.8	0.1 ~ 0.8	0.1 ~ 0.8	0.1 ~ 0.8	0.1 ~ 0.8	x
18	Optical Return Loss (ORL), Min.	dB	30	30	30	30	30	x

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19	PD1 Dark Current (@5V Reverse Bias, 25C)	nA	1	1	1	1	1	x
20	PD2 Dark Current (@5V Reverse Bias, 25C)	nA	1	1	1	1	1	x
21	Temperature Sensor Supply Voltage	V	4 ~ 10	4 ~ 10	4 ~ 10	4 ~ 10	4 ~ 10	/
22	Temperature Sensor Monitor	mA/C	7 ~ 13	7 ~ 13	7 ~ 13	7 ~ 13	7 ~ 13	/

Notes:

x: will be measured and reported

/: Guaranteed by design, or ideal number for reference (illustration only).

5.2 Parameter Definitions

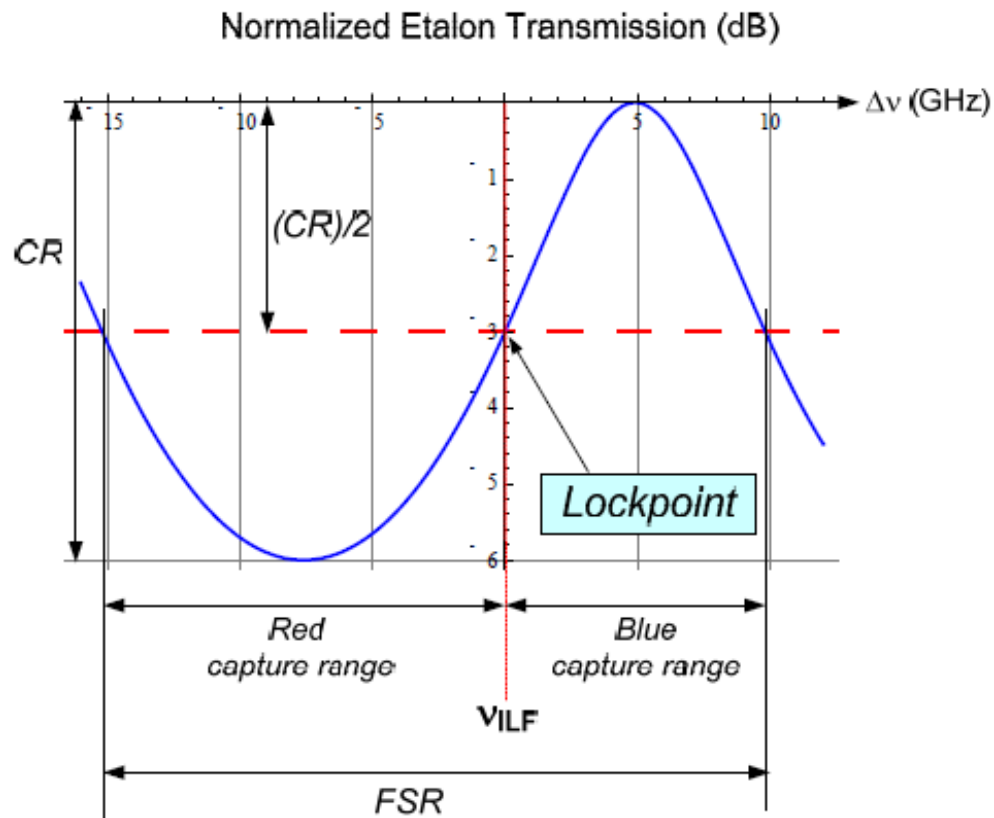


Figure 5.1, Contrast ratio, lockpoint, and capture range for a 25GHz Wavelength Locker, for illustration only

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Contrast Ratio (CR)

The difference (in dB) between the maximum and minimum transmission values of the etalon in a [25 GHz](#) frequency range defines the local contrast ratio for the etalon in the vicinity of the ITU frequency point that is contained in the selected [25GHz](#) interval. (using 25GHz as an example, similarly for other FSRs).

Capture Range

The frequency difference between adjacent points with the same etalon transmission value as at the local ITU frequency is defined as the Red capture range (in the direction of lower optical frequencies) or the Blue capture range (in the direction of higher optical frequencies). By design (choice of sign of slope and range of allowed values), the Blue capture range will be smaller than the Red capture range. The minimum acceptable capture range is specified in [Table 5.1](#), for different FSRs, and it refers to the smallest allowable Blue capture range.

Ideal Lock Frequency (ILF)

By default, the ILF is aligned at ITU. For the definitions of the ITU for different FSRs, refer to Section 2.2 and [Table 2.2](#).

Ideal lockpoint (ILP)

Ideally, at ITU channels, $PD2/PD1 = 1$ midway between the peak and the valley of the etalon transfer function in dB. Ideally, the $ILP = CR/2$.

Responsivity Ratio at Lockpoint (αdB)

Ratio (in dB) of photocurrents $PD2/PD1$ on ITU channels.

Etalon slope at ILF Freq (Slope, dB/GHz)

At all ITU wavelengths on [25 GHz](#) (for instance) grid in specified wavelength range. 25GHz as an example, others similar.

Lockpoint Frequency Accuracy (LPFA)

The drift with respect to the BOL value. The drift includes the change over operating temperature range (without temperature compensation), all SOP, and aging.

Polarization Dependent Accuracy (PDAcc)

Peak to peak frequency shift for fixed photocurrent ratio, over all SOP at any ITU wavelength on [25 GHz](#) (for instance) grid in specified wavelength range, at fixed case temperature

PD 1 Responsivity (Reference PD)

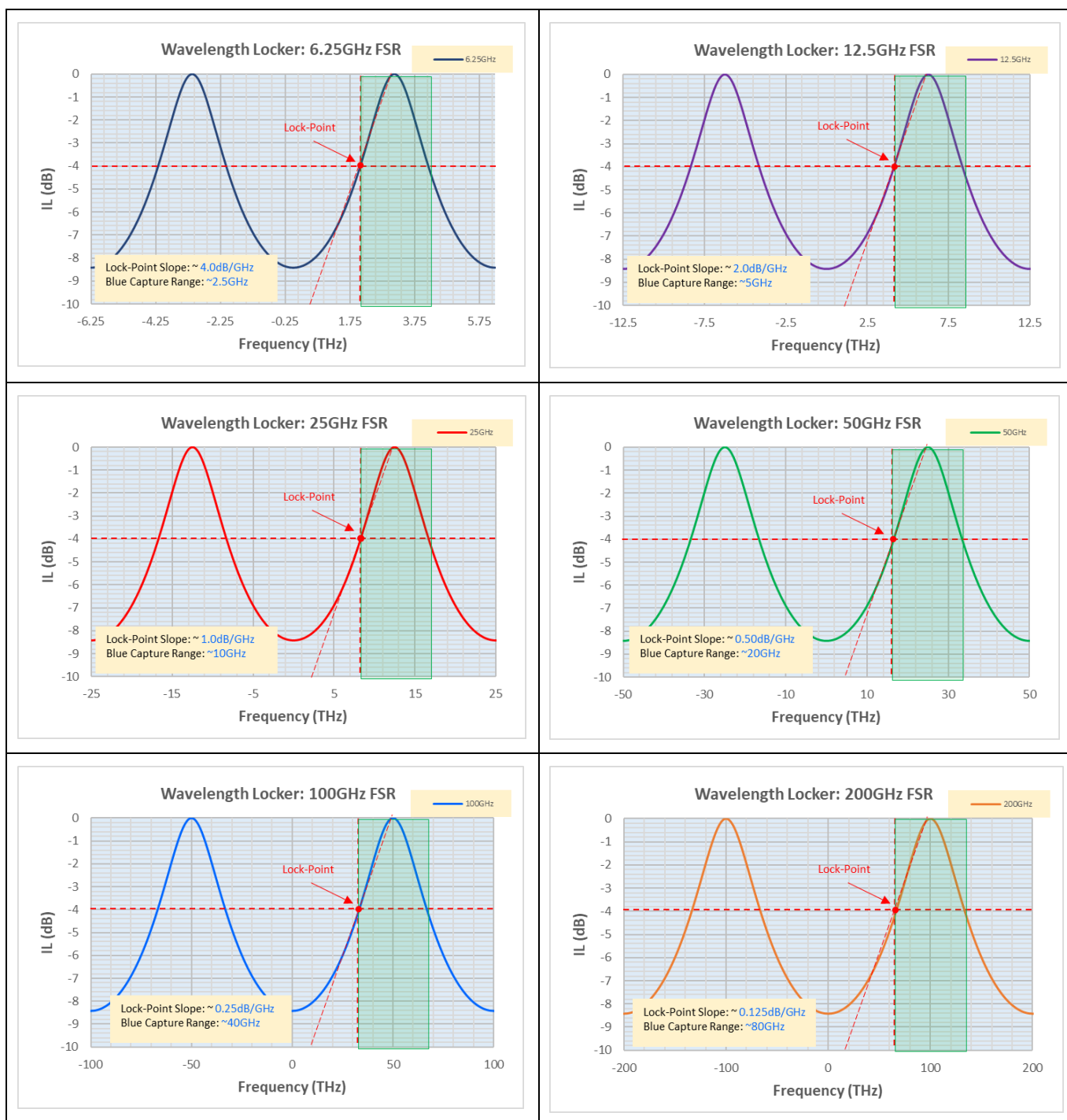
Note: actual range will be restricted by spec for αdB

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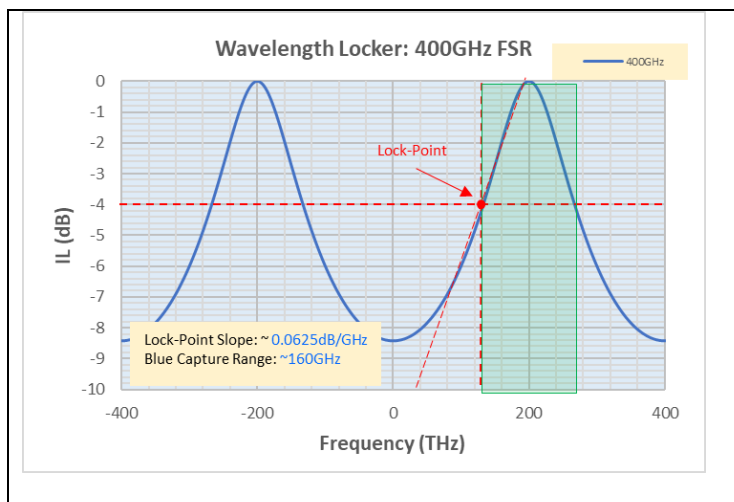
PD 2 Responsivity (Etalon PD)

Etalon responsivity at ITU grid points, across C-band (for instance), over all conditions

5.3 Simulated Spectra (Ideal Situation, for Reference only)



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Notes:

- 1) By default, the etalon mirror reflection coating is 45%. So the CR (contrast ratio) is about 8dB. Custom design with different R% is available upon request, Usually some NRE is required, Contact Optoplex for details.
- 2) For easy review, normalized frequency is used for x-axis.
- 3) The simulated spectra here are for ideal situation (IL =0 dB and both PDs have the same responsivities)
- 4) The lock-point frequency position, by default, is usually set at ITU-grid. We can align it at any position that the customer wants.
- 5) There are for illustrations purpose only.

The actual IL of an etalon spectrum depends on the FSR, the coating (mirror reflection coating accuracy), the fiber input/output coupling loss as well as others (optics surface quality, light beam quality) and the PD's responsivity, ...

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6. MECHANICAL REQUIREMENTS

6.1 Device Outline

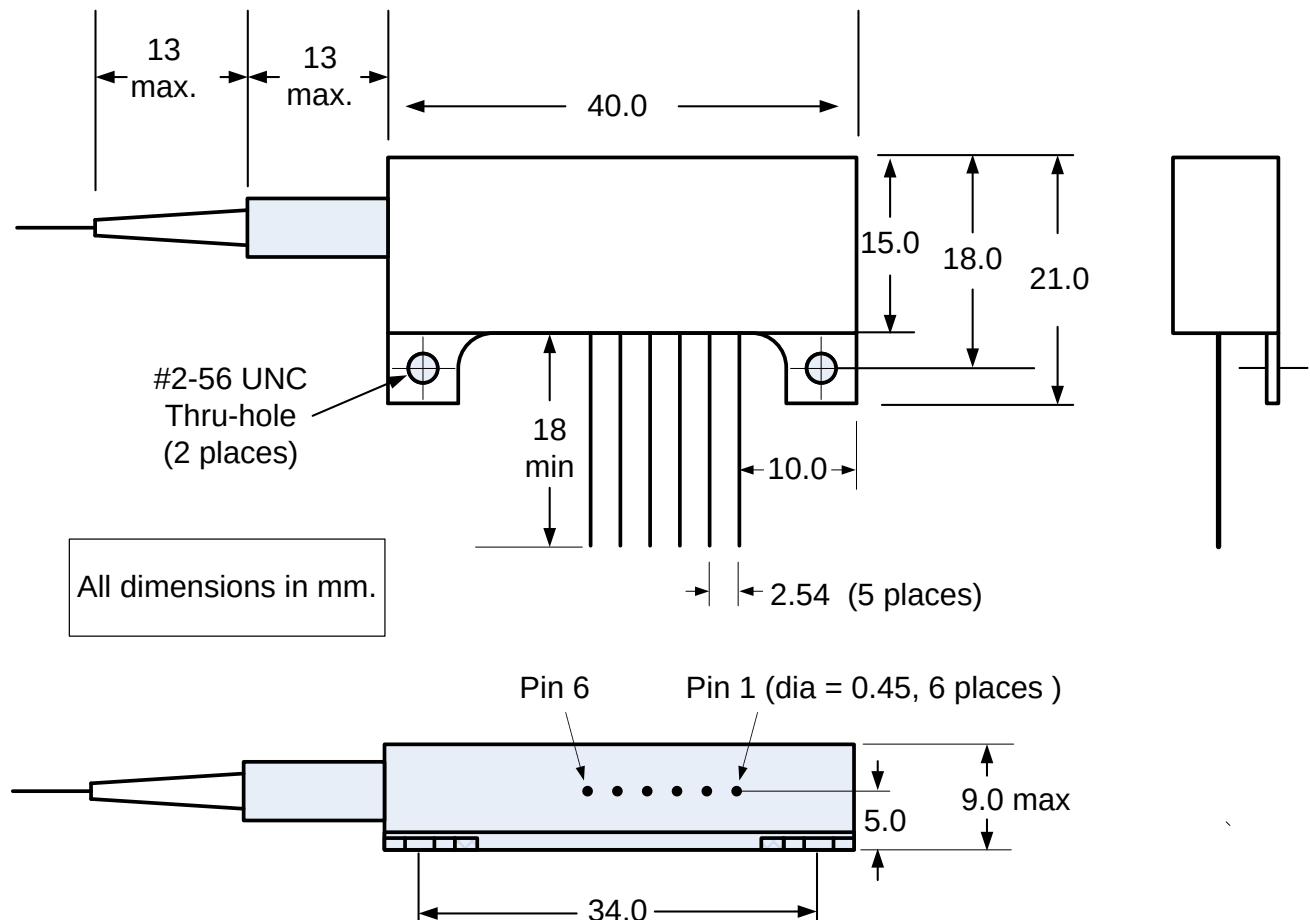


Figure 6.1, Package Outline

Notes:

- 12.5GHz (or smaller FSR) Wavelength Locker will have a larger package. Details will be added here later. Contact Optoplex for more details. Refer to Section 6.3 in Rev4.0
- For wavelength locker with a built-in monotonic filter (contact Optoplex for details), also using a larger package described in Section 6.3 in Rev4.0.

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6.2 PIN Assignment

Table 6.1, Package Pin Assignments

Pin #	Function	Notes
1	Photodiode 1 Anode	
2	Photodiode 2 Anode	
3	Photodiode 1 & 2 Common Cathode	
4	Temp. sensor voltage	Linear Active Thermistor (Microchip, MPN: MCP9701) Voltage Supply, $V_{DD} = 2.3 \sim 5.5V$
5	Temp. sensor output	
6	Temp. sensor ground	



MCP9700_Linear
Active Thermistor by I

6.3 12.5GHz Wavelength Locker * and Aerospace Grade Package

6.3.1 Mechanical Dimension

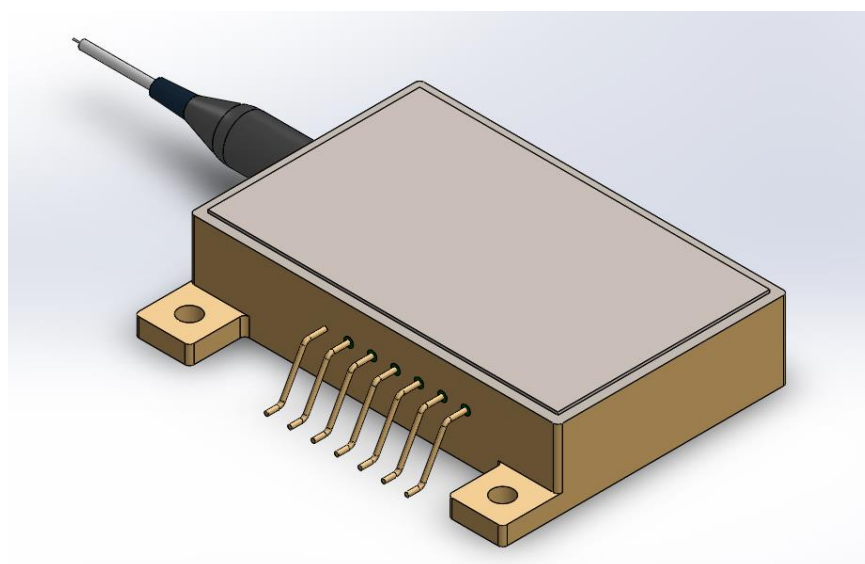


Figure 6.2, Package Outline of 12.5GHz FSR

The dimension of the package (excluding the mounting pads and the input collimator):

40 x 25 x 8.80mm

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*. Special Notes

- For FSR = 12.5GHz and smaller, using this package described in Section 6.3
- For wavelength locker with a built-in monotonic filter, use this package.
- For Aerospace-Grade products, regardless FSR, using this 40x25x8.80mm package as shown in Figure 6.3.

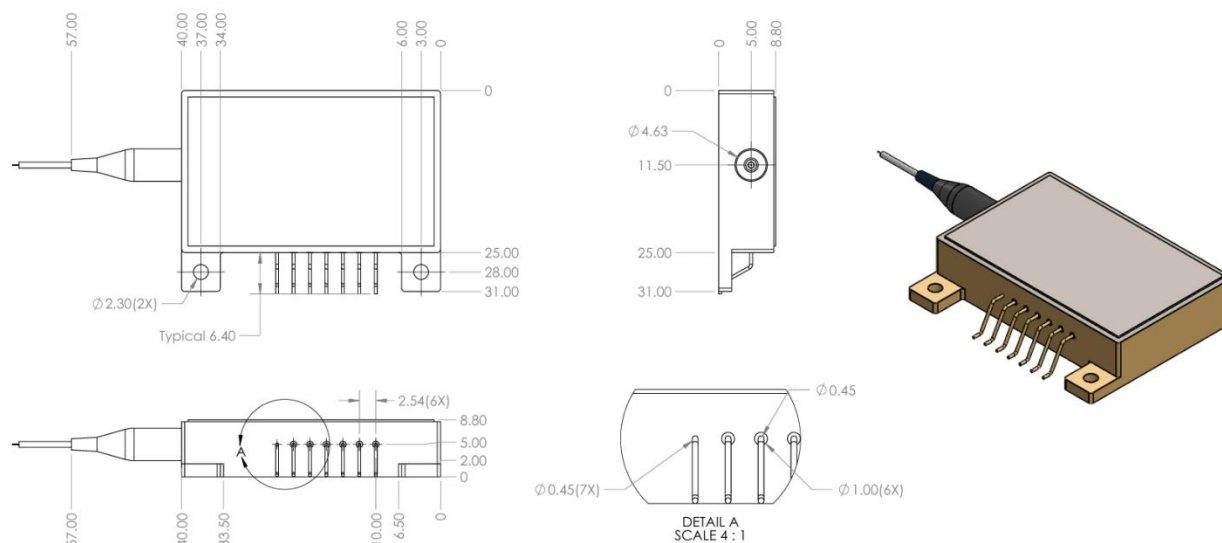


Figure 6.3, Mechanical Drawing of 12.5GHz FSR

6.3.2 PIN Assignment

Table 6.2, Package Pin Assignments of 12.5GHz FSR

Pin #	Function	Notes
1	Photodiode-1: Anode	
2	Photodiode-2: Anode	
3	Photodiode-3: Anode	
4	Photodiode 1, 2 & 3 Common Cathode	
5	Temp. sensor voltage	Linear Active Thermistor (Microchip, MPN: MCP9700) Voltage Supply, $V_{DD} = 2.3 \sim 5.5V$
6	Temp. sensor output	
7	Temp. sensor ground	



MCP9700_Linear
Active Thermistor by I

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6.4 Fiber Pigtail Characteristics

Table 6.3, Fiber Pigtail Characteristics

Characteristic	Description	Note
Optical Connector ^{a)}	Customer specific. See Section 2.2.	By default, no connector.
Type of Fiber	SMF-28+ or equivalent	
	Panda type PM Fiber or equivalent (PM 1550)	If choose PM fiber
Pigtail	250 μ m diameter bare fiber	By default, no connector.
	with 0.9mm loose tube ^{b)}	If with connector, see Section 2.2
PM Fiber Axis Alignment	A low axis aligned to the key	If choosing PM fiber with FC connector
Pigtail Length	1.0 +/- 0.1m	
Fiber Labeling	By default, the fiber pigtails shall have no labels or stickers attached in any form	Or customer specific
Notes: a) See Section 2.2. MU connector is NOT recommended. Popular ones are FC/APC, FC/UPC, LC/APC, LC/UPC, and SC/UPC. If choosing SC/APC, it may take longer leadtime. b) If choose to have connectors and bare fiber , please explicitly state in orders.		

7. RELIABILITY

By default, the standard product is qualified against Telcordia GR-648 for telecom applications.

Optoplex also offers military and aerospace-grade wavelength lockers, please contact Optoplex for more details.

8. ROHS COMPLIANCE

Product is compliant to the Directive 2002/95/EC of the European Parliament on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive). It is RoHS 6/6 compliant (lead-free).

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9. PRODUCT LABELING

Each device will be labeled with below information

Optoplex logo

Product description: [Wavelength Locker \(Product Description\)](#)

Manufacturer P/N: [WL-xxxxxxxxx](#)

Manufacturer S/N: CCCWLyyynnnn

Manufacturer S/N, in format of CCCWLSyynnnn, described below:

- CCC represents customer's code (assigned by Optoplex),
- [W](#) represents Wavelength Locker,
- L represents manufacturing location (F-Fremont CA, USA; S – Shanghai, China; W-Wuhan, China),
- yy represents manufacturing year,
- *nnnn* represents sequential number of the product.

10. ORDERING INFORMATION

According to your required wavelength band and FSR, Lockpoint at ITU or Off-ITU, choose the part number in [Table 2.1](#) (Section-2.1) matching your requirement.

Then specify which type of the optical connector you need, as defined by the two digits (“XX”) in the part number. Refer to “XX” definitions in Section 2.2.

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REVISION HISTORY

Revision	Date	Change History	Authored by	Approved by
1.0	3/30/2022	Consolidated the data sheets of all models and part numbers into a single document	Nick Xiao	Gary Wang
2.0	12/14/2022	Corrected typos Updated spec for 12.5GHz wavelength locker	Nick Xiao	Gary Wang
3.0	2/15/2023	Added Fiber Type in Section 2.2	Nick Xiao	Gary Wang
4.0	5/30/2023	Added Package mechanical drawings and Pin Assignment for 12.5GHz (and smaller FSR) in Section 6.3 Updated Table 6.3	Nick Xiao	Gary Wang
5.0	12/1/2023	Updated Table 2.1, standard ITU-offset is set to ITU + $\frac{1}{4}$ FSR. Added 300GHz FSR models to Table 2.1	Nick Xiao	Gary Wang
6.0	5/28/2024	Add a note to specify For Aerospace-Grade wavelength locker, the package shown in Figure 6.2, regardless of FSR.	Nick Xiao	Gary Wang
7.0	10/21/2024	Update Package mechanical drawings Figure 6.2 and Figure 6.3.	Nick Xiao	Gary Wang
8.0	3/19/2025	Correct the P/N of the thermistor. It should be MCP9701 (rather than MCP9700) in Table 6.2	Nancy Guo	James Pang
9.0	4/21/2025	Updated the Lock-point frequency slopes and the (blue) capture range in Tabel 5.1. Updated the simulation charts in Section 5.3	Nancy Guo	James Pang