MZM Laser Synthesizer Development

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D. Kubo (Hardware/Test)
R. Srinivasan (Software/Test)
M. Chen (Technical Management)
H. Kiuchi (NAOJ, MZM-LS Developer/Technical Consultant)

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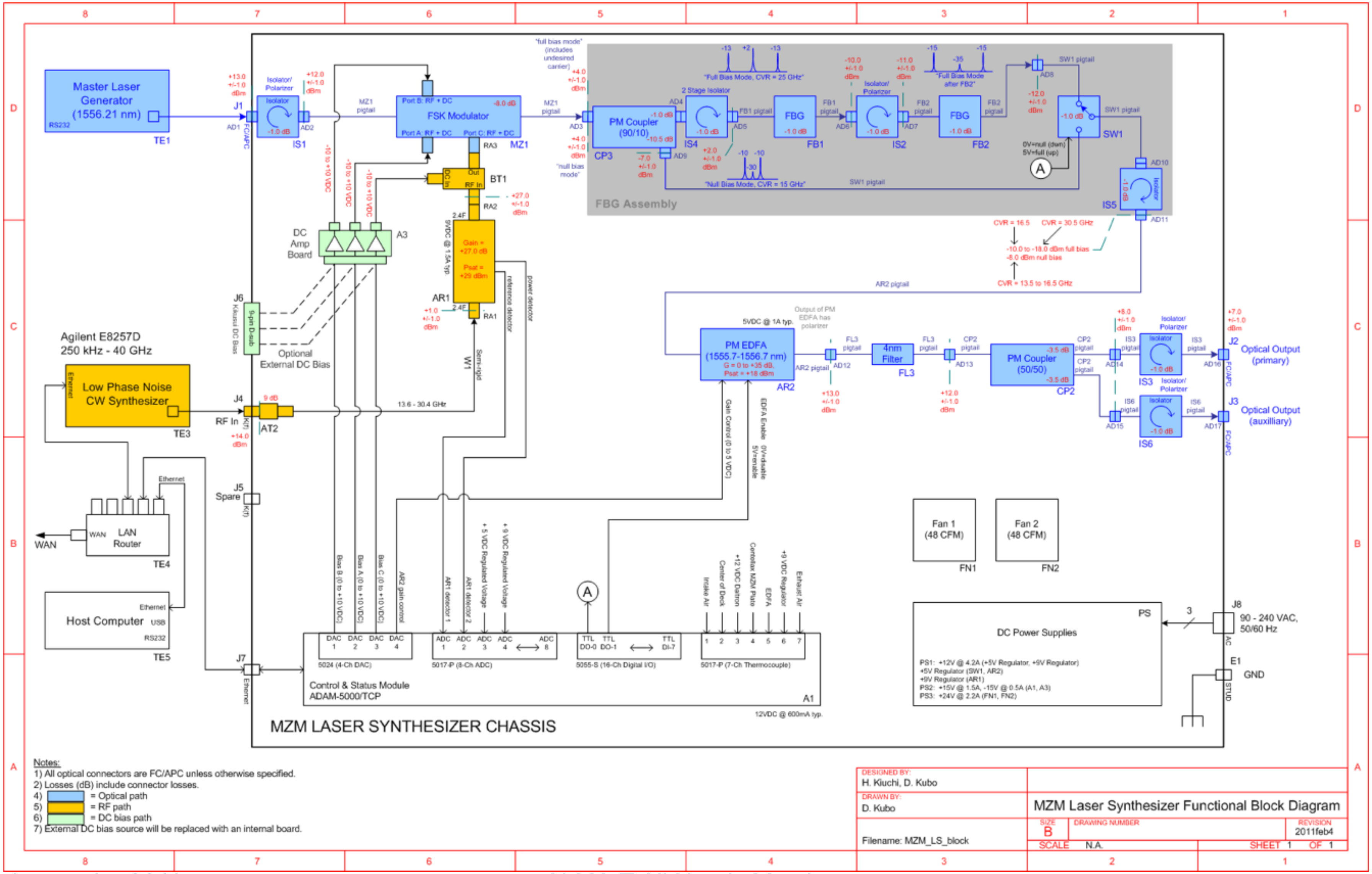
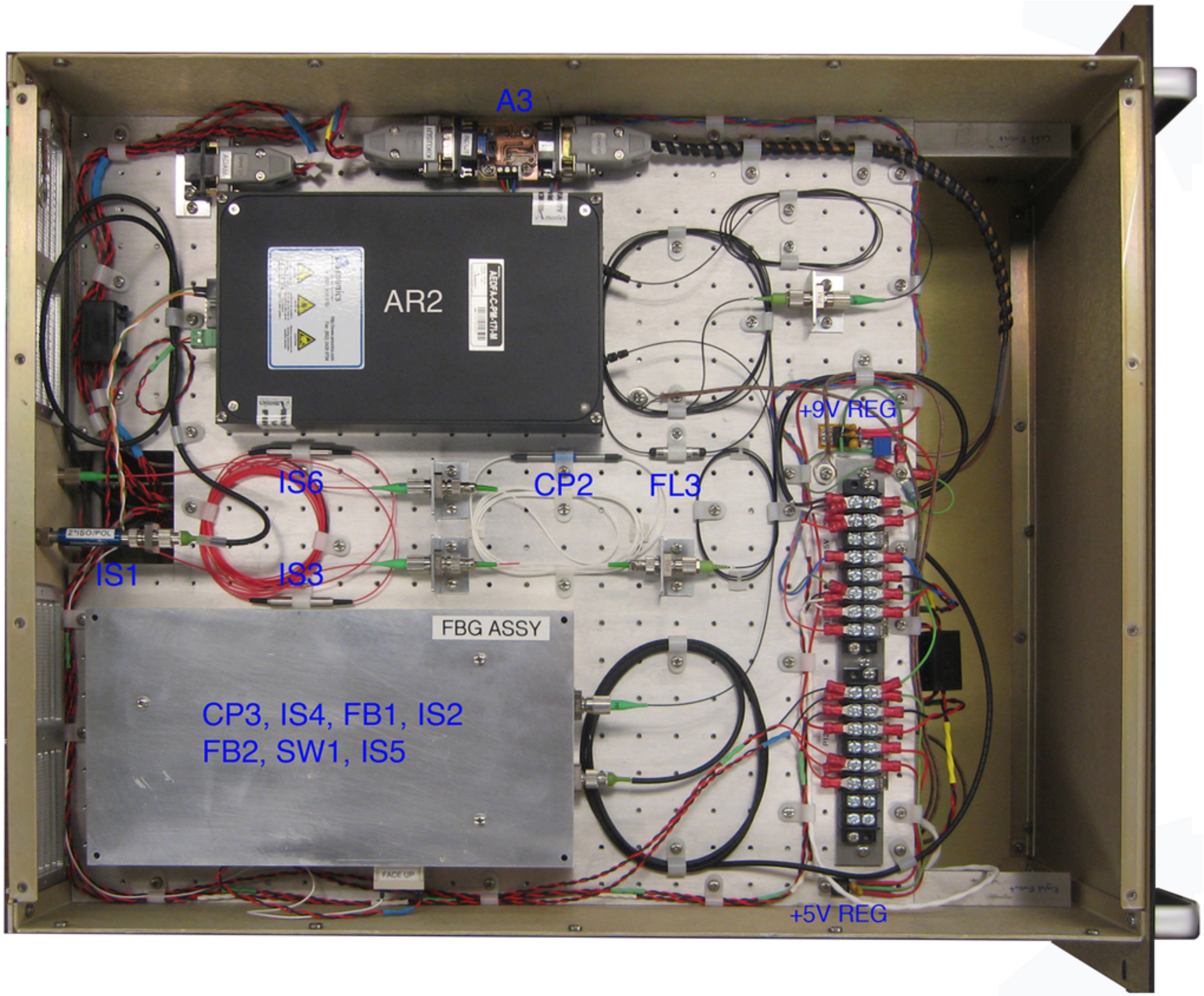


MZM Laser Synthesizer



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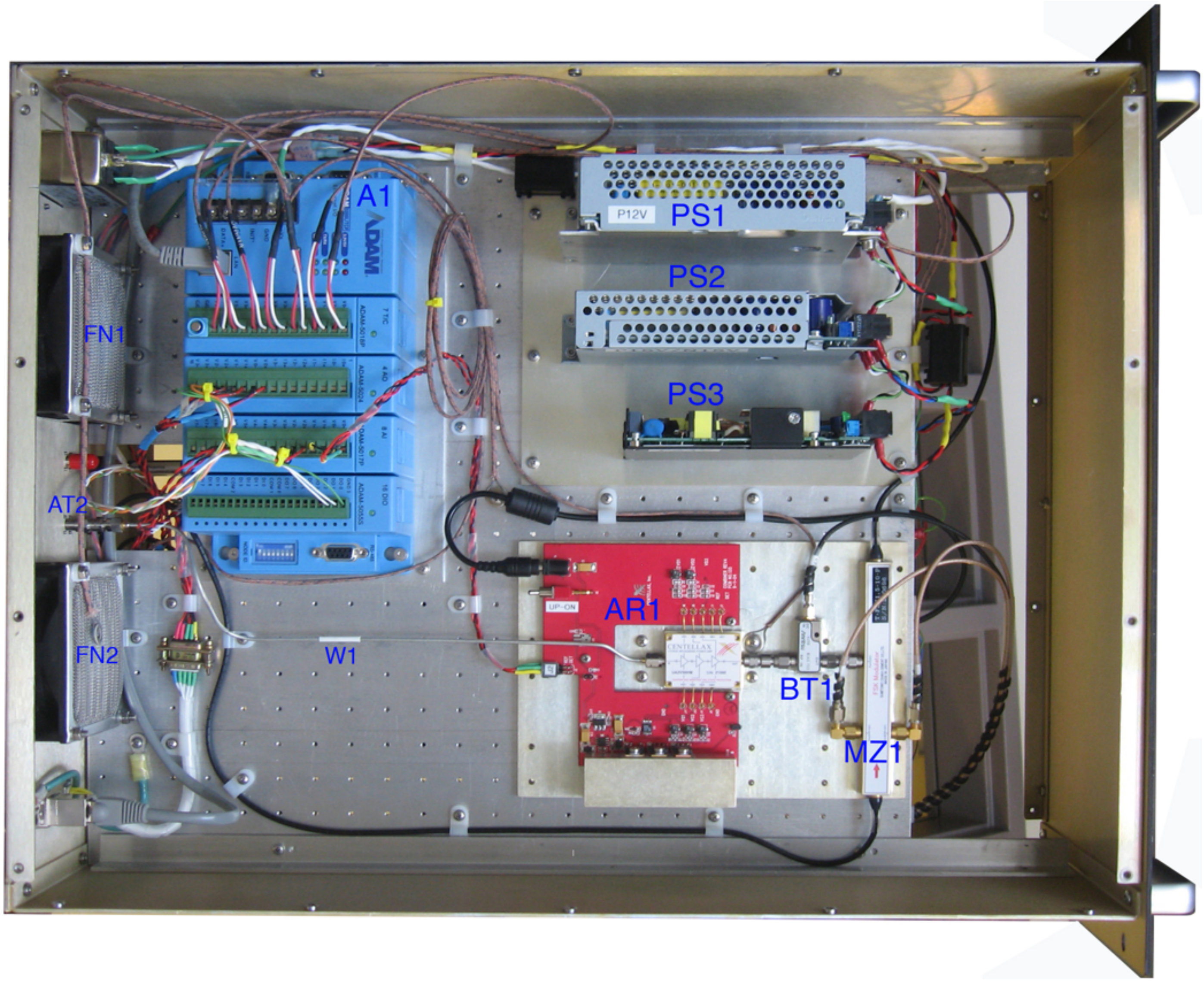
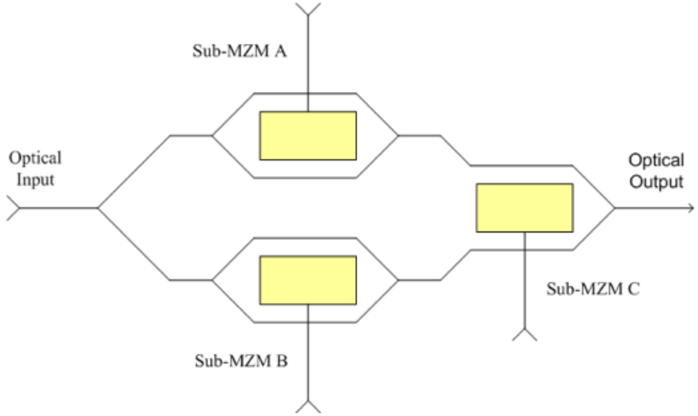
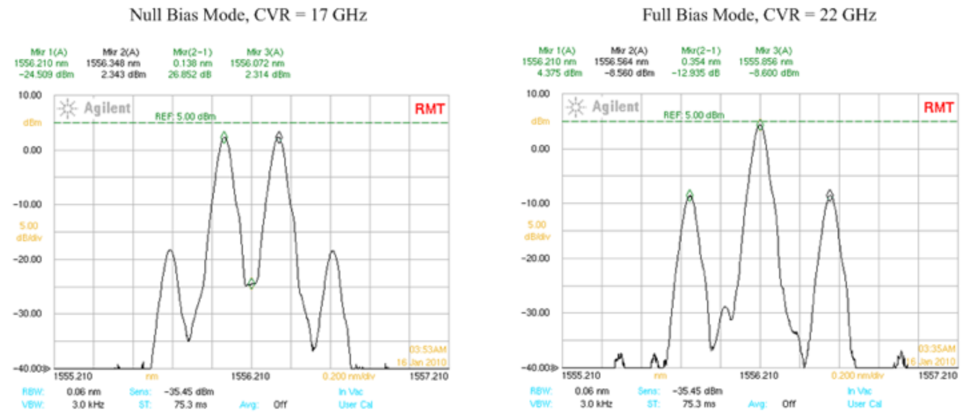


MZM Laser Synthesizer

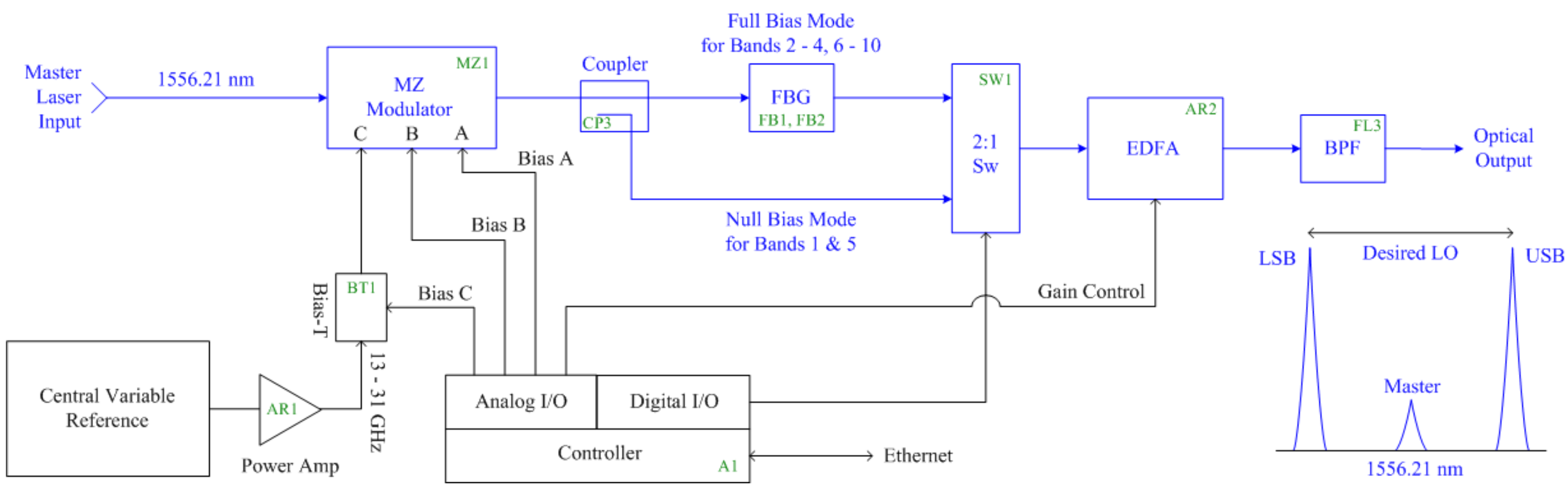
- Simplified Description of MZM-LS



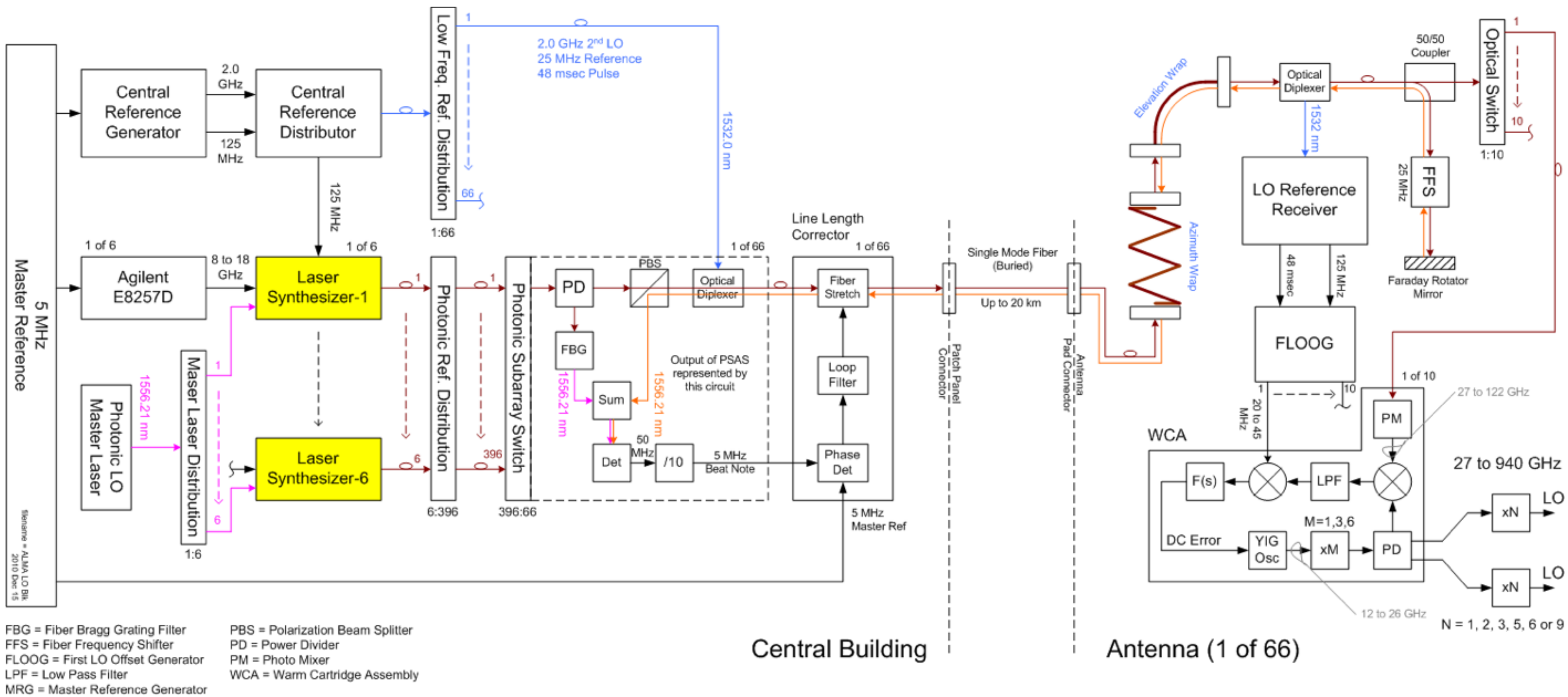
Sumitomo LiNbO3 MZ Modulator



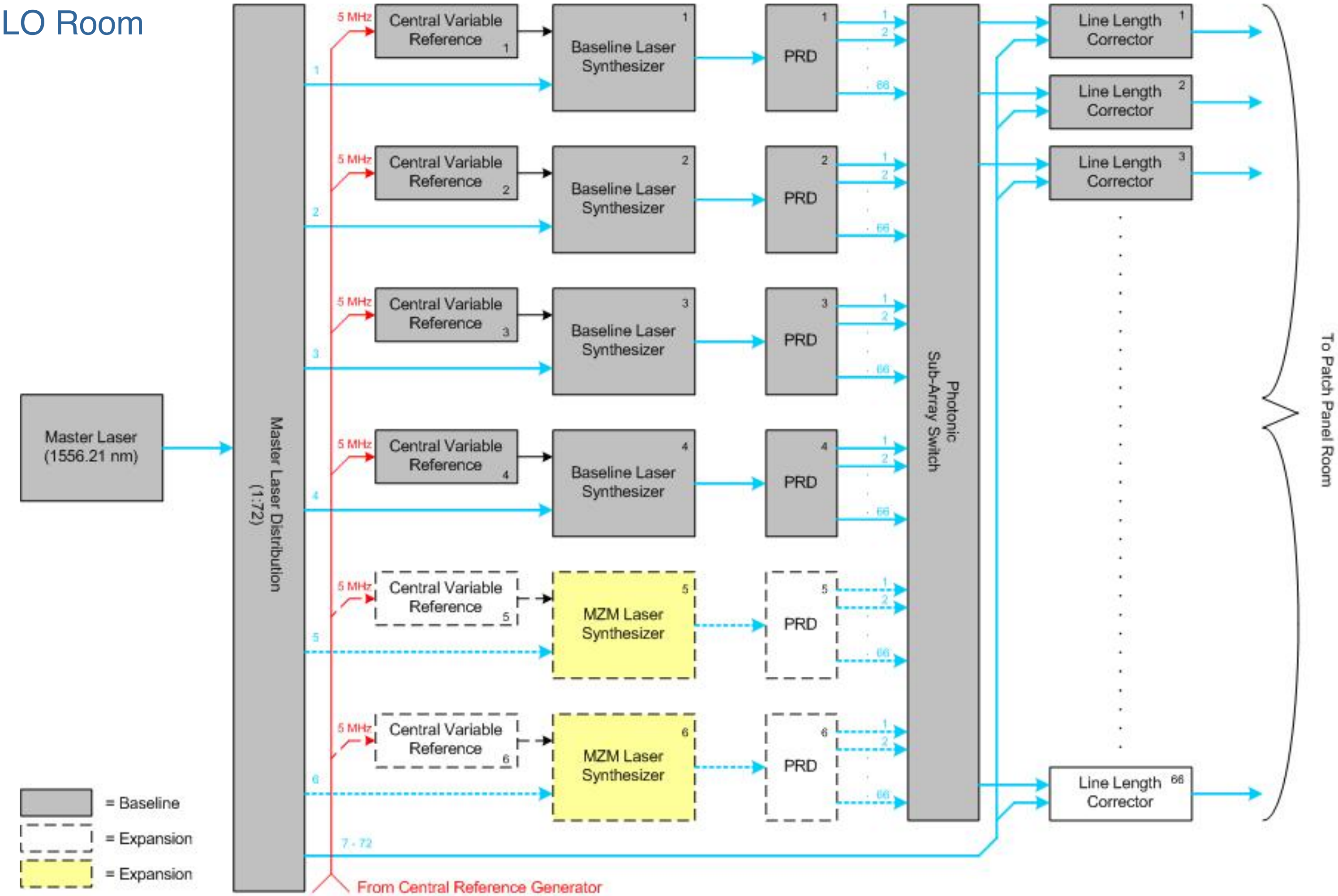
Optical Output Spectra from MZ Modulator



- Laser Synthesizer Application for ALMA Project

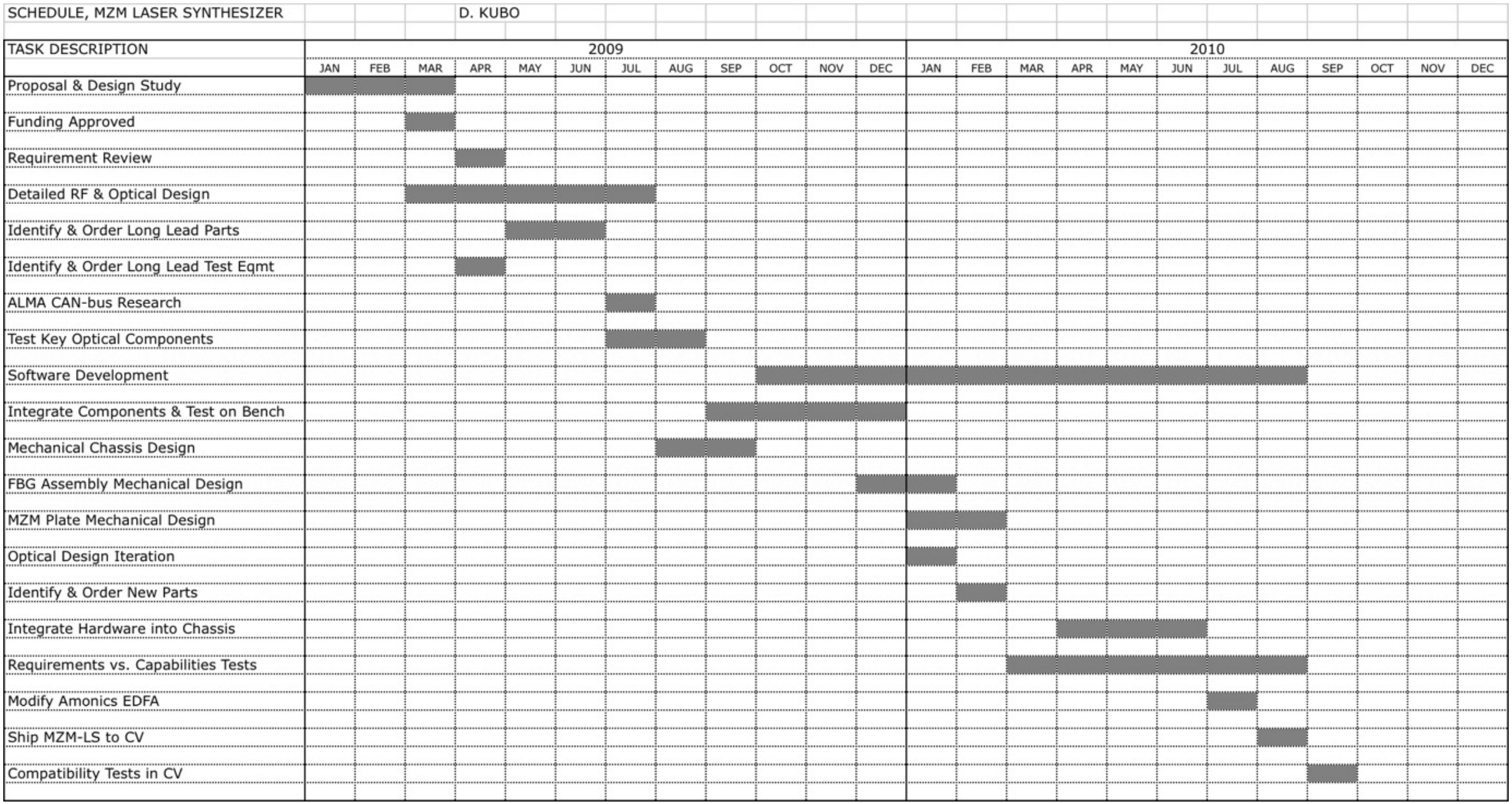


- MZM-LS Application for ALMA Project (continued)
  - Diagram of LO Room



MZM Laser Synthesizer

- Schedule



MZM Laser Synthesizer

- Material Costs
  - $54.1k USD
  - Does not include:
    - Spares
    - Test equipment

BOM, MZM LASER SYNTHESIZER		2011 FEBRUARY 8	D. KUBO				
ITEM	DESCRIPTION	PART NO.	SUPPLIER	REF. DES.	QTY/ ASSY	$/EA. (USD)	TOTAL $ (USD)
1	PM EDFA, gain +35 dB, Psat +18 dBm	AEDFA-C-PM-17I-M	Amonics	AR2	1	$11,500	$11,500
2	RF power amplifier, 2 - 50 GHz, P1dBc +27 dBm	TA2U50HA	Centellax	AR1	1	$9,568	$9,568
3	Optical Modulator	T.FSX1.5-10-P-FA	Sumitomo Osaka Cement	MZ1	1	$9,500	$9,500
4	PM isolator/polarizer, notail	NISO-D-15-PP2-FC/APC	General Photonics	IS1, IS2, IS4, IS5	4	$940	$3,760
5	PM Fiber Bragg Grating filter, custom	AT-FBGT3FXC4545 REV.00	Avensys	FB1, FB2	2	$1,250	$2,500
6	PM optical bandpass filter	BPF1556.2-3.2n/2c-P/FA	Optoquest	FL3	1	$2,250	$2,250
7	PM SPDT switch, pigtail	Custom	Leoni	SW1	1	$2,082	$2,082
8	FBG assembly, custom	-	Bear Machinery, Inc	-	1	$1,500	$1,500
9	PM isolator/polarizer, pigtail	ISO-S-15-PP2-FC/APC-90	General Photonics	IS3, IS6	2	$710	$1,420
10	Centellax/MZM plate, custom	-	Bear Machinery, Inc	-	1	$1,150	$1,150
11	Bias-T, 0.1 - 40 GHz, K-connector	K250	Anritsu	BT1	1	$1,065	$1,065
12	PM coupler, notail, 90/10	NPMC-12-F-15-10/90-FC/APC	General Photonics	CP3	1	$945	$945
13	PM FC/APC to FC/APC adapter	ADAFC2-PMN	Thorlabs	AD1 - AD17	17	$47	$799
14	Deck plate, custom	-	Dayton Jackson Machine Works	-	1	$640	$640
15	PM coupler, pigtail, 50/50	PM-C-12-F-15-50/50-FC/APC	General Photonics	CP2	1	$625	$625
16	Rear panel fabrication service	-	Dayton Jackson Machine Works	-	1	$500	$500
17	Miscellaneous	-	-	-	1	$500	$500
18	Front panel fabrication service	-	Bear Machinery, Inc	-	1	$445	$445
19	Ethernet controller, 4-slot	ADAM-5000/TCP-AE	Advantech	A1	1	$365	$365
20	Plug-in module, DAC	ADAM-5024	Advantech	A1-A2	1	$285	$285
21	Plug-in module, thermistor	ADAM-5016-P	Advantech	A1-A1	1	$270	$270
22	Plug-in module, ADC	ADAM-5017-P	Advantech	A1-A3	1	$250	$250
23	DC power supply, +12 VDC, low noise	HFS50-12	Daitron	PS1	1	$205	$205
24	DC power supply, +/-15 VDC, low noise	HFD30-15	Daitron	PS2	1	$195	$195
25	Blank chassis, EMI, 19 x 22 x 8.75"	14-19225A	Par-metal	-	1	$165	$165
26	Power supply plate	-	Bear Machinery, Inc	-	1	$165	$165
27	ADAM plate	-	Bear Machinery, Inc	-	1	$165	$165
28	Exhaust vent plate, custom	-	Dayton Jackson Machine Works	-	2	$75	$150
29	Attenuator, 6 dB, DC - 40 GHz, 2.9(m/f)	40AH2W-06	Aeroflex	AT2	1	$125	$125
30	Plug-in module, Digital I/O	ADAM-5055-S	Advantech	A1-A4	1	$120	$120
31	Thermocouple	A6-2	Nanmac Corporation	-	7	$16	$112
32	DC power supply, +24 VDC	RTW24-2R2	TDK/Lambda	PS3	1	$110	$110
33	K connector (f/f), 4-hole flange, DC - 40 GHz	5344	Aeroflex	J4, J5	2	$54	$108
34	DC amplifier, gain 2 V/V, -5 V offset, custom	Custom	ASIAA	A3	1	$100	$100
35	RF adapter, 2.4(m) to 2.9(f), DC - 40 GHz	5153	Aeroflex	-	1	$90	$90
36	Semirigid coax cable, 2.92(m) to 1.85(m), 15"	-	RFCoax, Inc.	W1	1	$88	$88
37	FC/APC connector bracket	-	Jackson Machine Works	-	4	$15	$60
38	Angle bracket, deck plate support	-	Dayton Jackson Machine Works	-	2	$28	$56
39	DC fan, +24 VDC, 92 mm, 48 CFM	965-0346 (Allied Electronics)	Globe Motors	FN1, FN2	2	$20	$40
40	RF adapter, 2.9(m) to 2.9(m), DC - 40 GHz	5171	Aeroflex	-	1	$38	$38
41	+9 VDC regulator assembly	LM350T + caps + pot	ASIAA	-	1	$20	$20
42	DC terminal block assembly	-	ASIAA	-	1	$20	$20
43	Mesh guard, 92 mm	592-2122 (Allied Electronics)	Orion	-	4	$4	$16
44	EMI line filter, switch, fuse	689-4318 (Allied Electronics)	Allied	J8	1	$14	$14
45	Ethernet connector, bulkhead, EMI shielded	ECF504-SC5E	L-com Global	J7	1	$11	$11
46	+5 VDC regulator assembly	LM7805 + caps	ASIAA	-	1	$5	$5
47	Subminiature D-connector, 9-pin	-	-	J6	1	$5	$5
48	Ground stud	-	-	E1	1	$5	$5
	TOTAL						**$54,107**

- Chassis Description
  - Dimensions 19 x 22 x 8.75” (W x D x H), excluding front panel handles and rear panel connectors
  - Rack mountable
  - Weight 42 LBS (19 kg) with covers installed
  - EMI Chassis (Par-metal Products Inc.)
  - All components mounted onto a fixed aluminum deck plate (16.625 x 18.0 x 0.25 inches)
    - 483 M3 tapped holes
    - 20 mm spacing
  - Power dissipation 58 W
  - Forced air cooled

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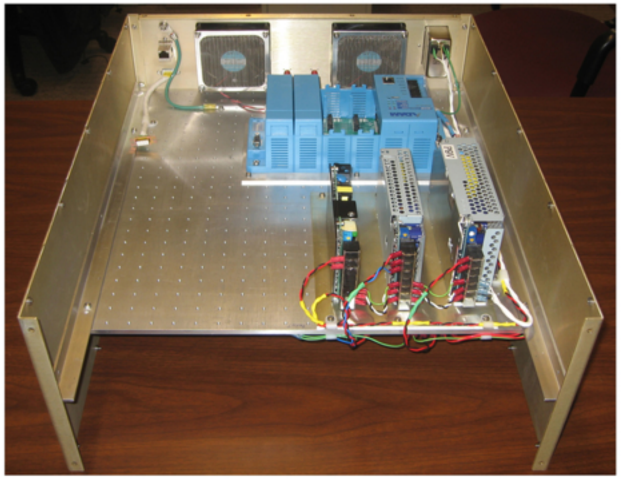
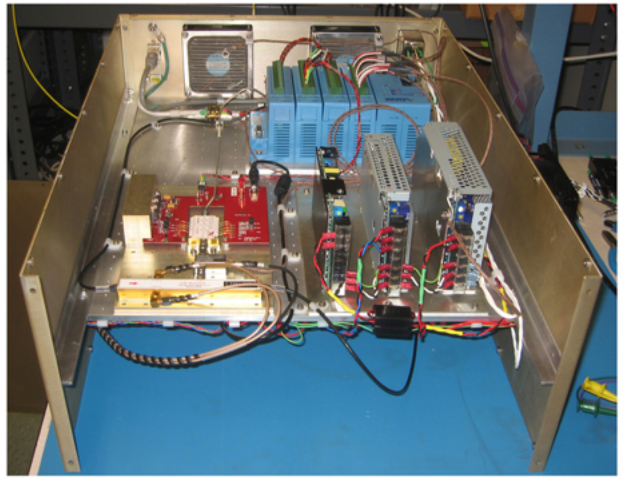
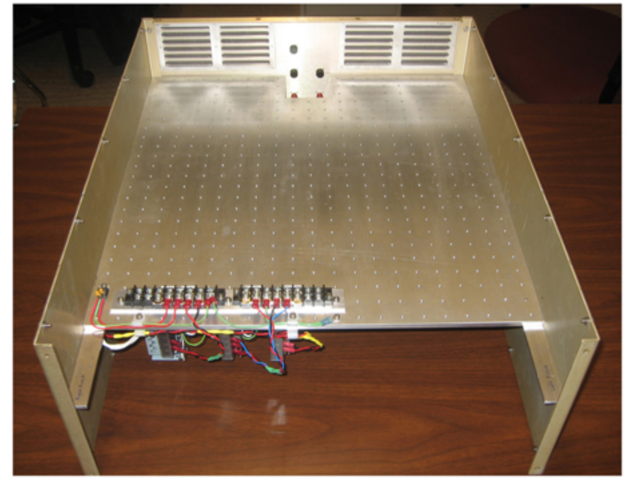
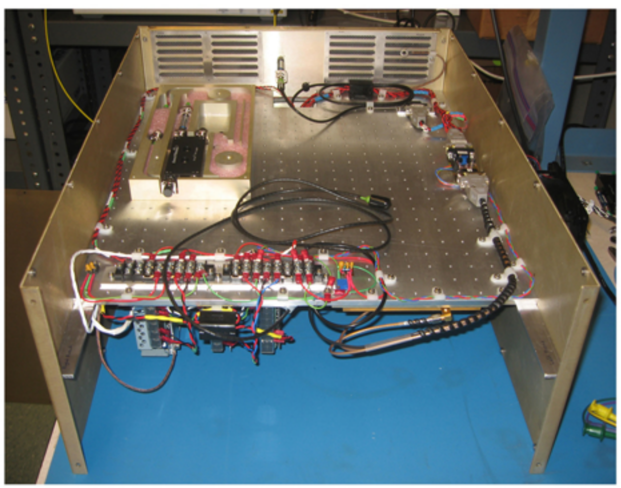
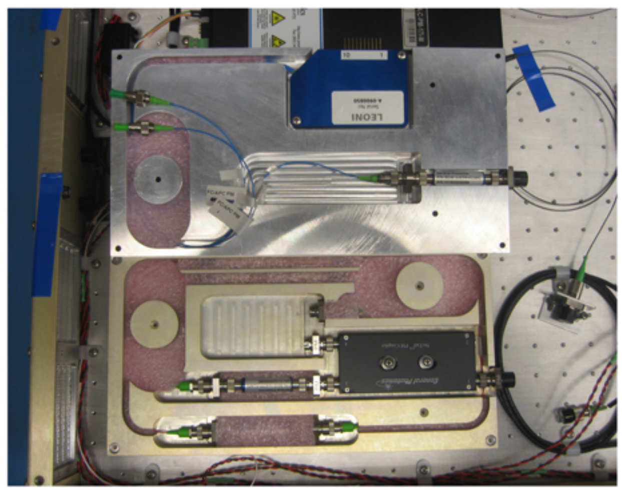
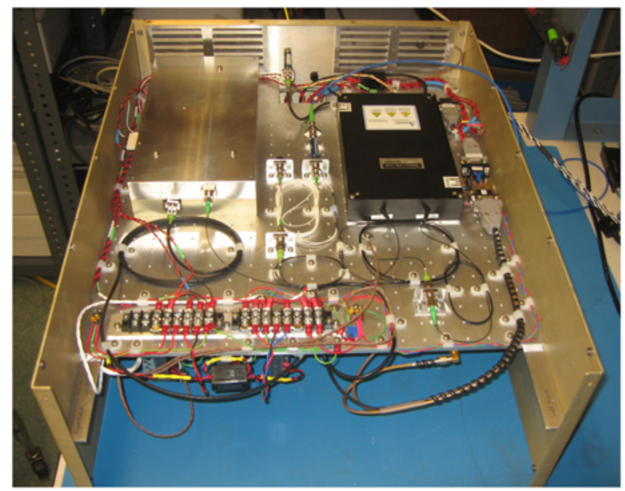
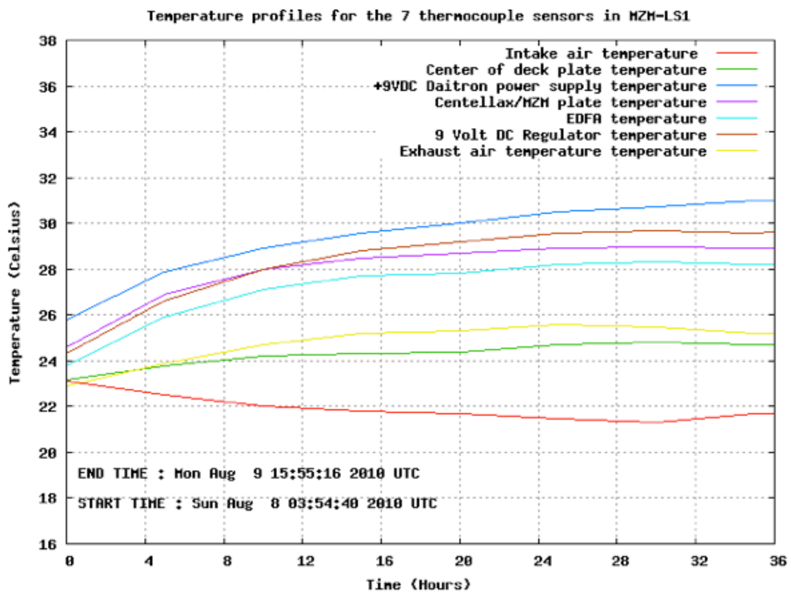
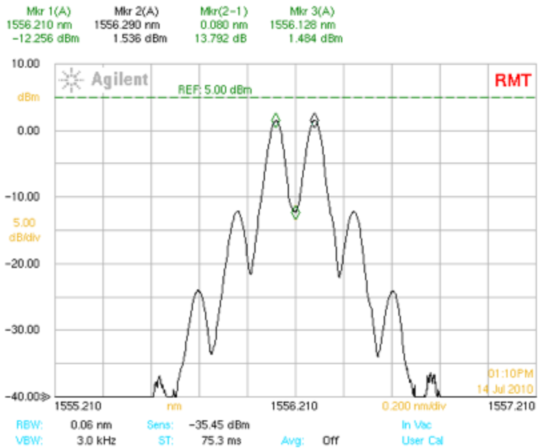
- Chassis Assembly

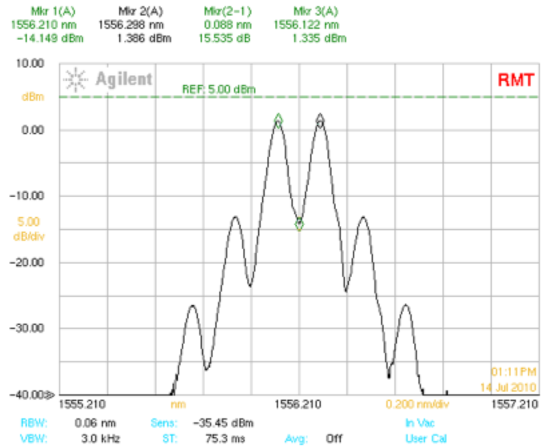







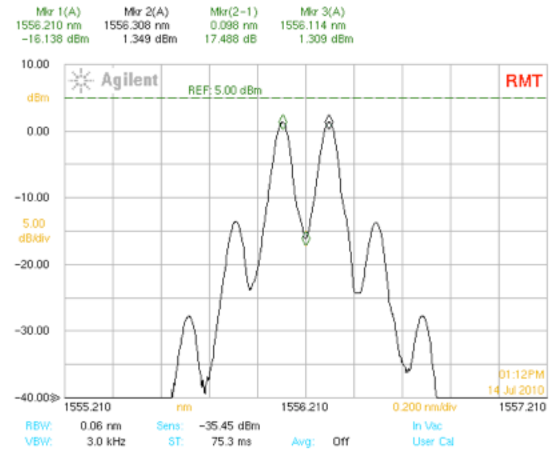
- Thermal Design
  - 2 x 48 CFM fans powered from dedicated +24 VDC TDK/Lambda supply
  - Fixed aluminum deck plate provides large thermal reference mass
  - Observe an exhaust vs. intake air temperature difference of ~4 degrees C at sea level



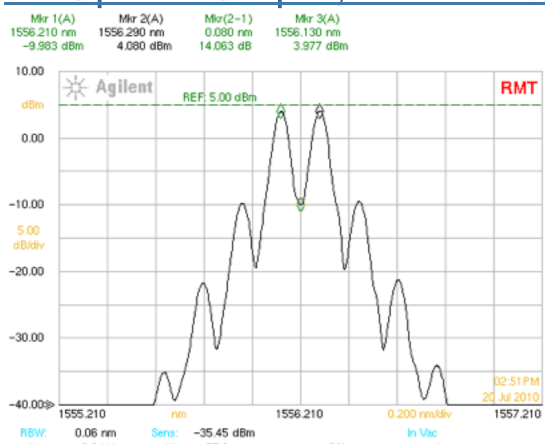
- MZ1 Optical Output, **Null Bias** Mode

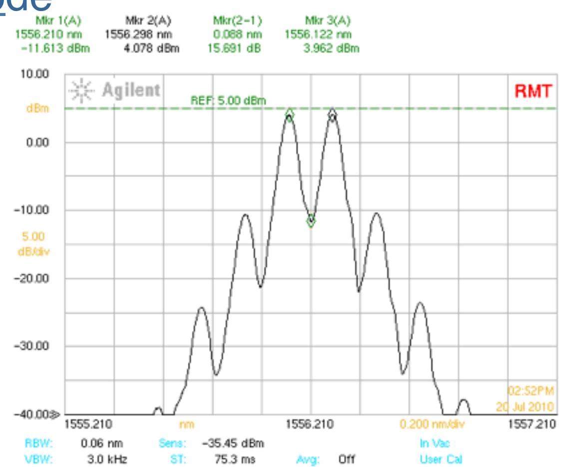


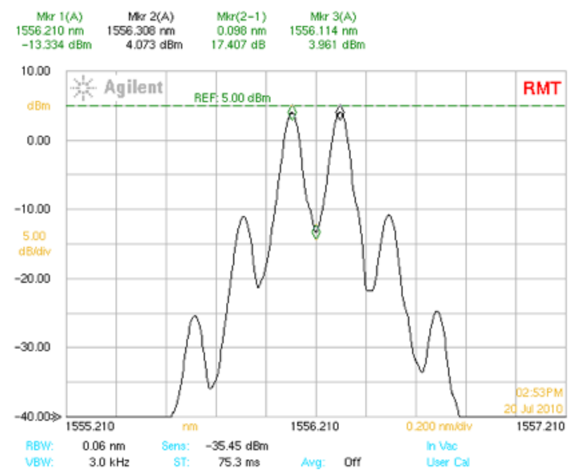




- J2 Optical Output, **Null Bias** Mode

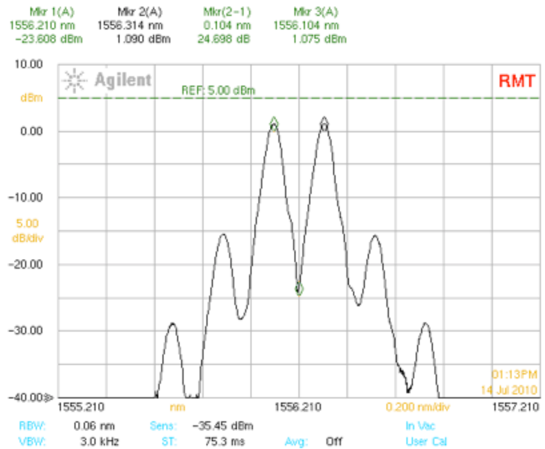


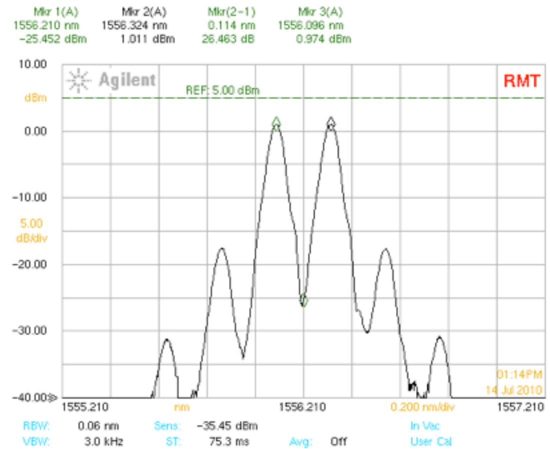


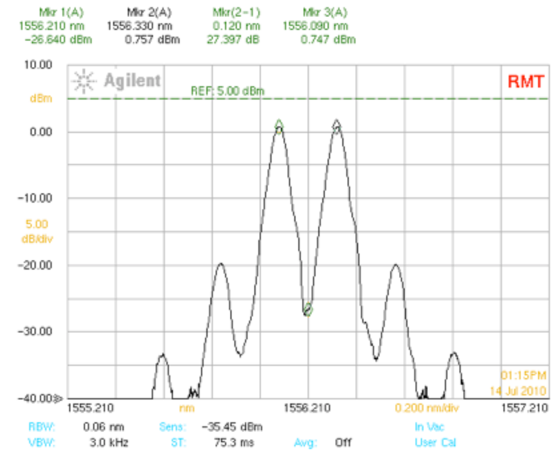


CVR = 10.0 GHz (LO = 20.0 GHz) | CVR = 11.0 GHz (LO = 22.0 GHz) | CVR = 12.0 GHz (LO = 24.0 GHz)

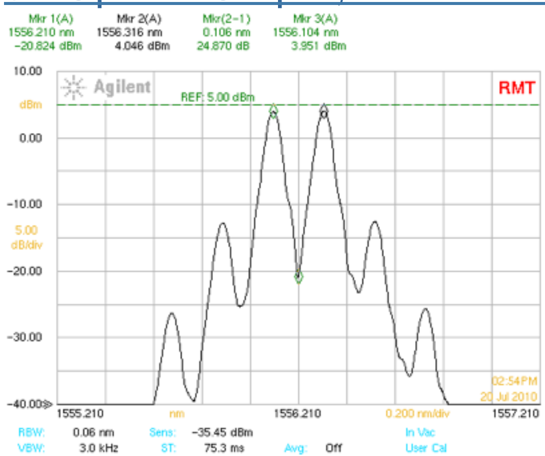
- MZ1 Optical Output, **Null Bias** Mode

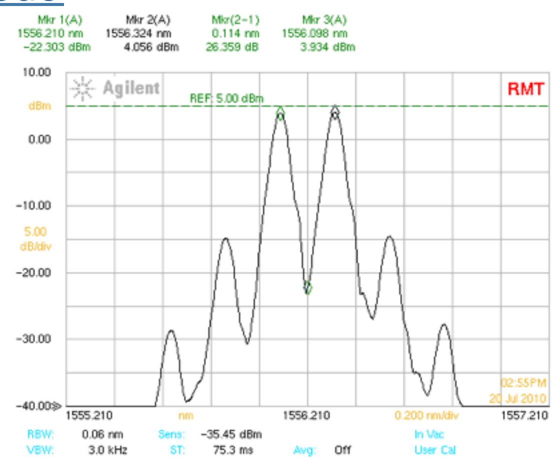


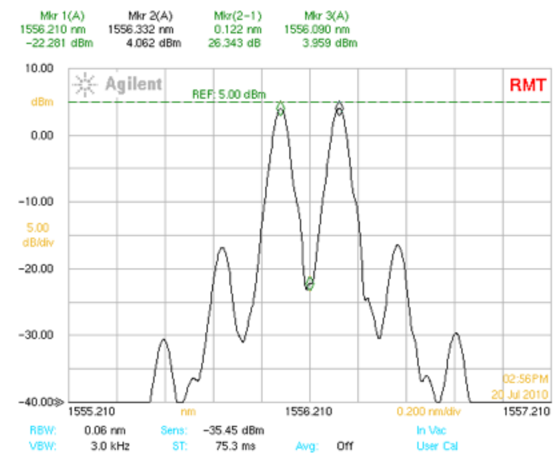




- J2 Optical Output, **Null Bias** Mode

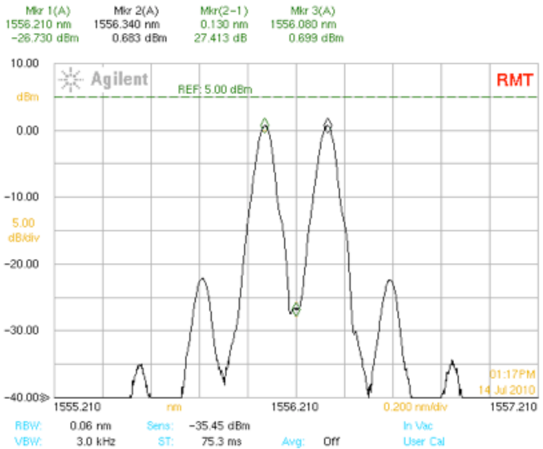


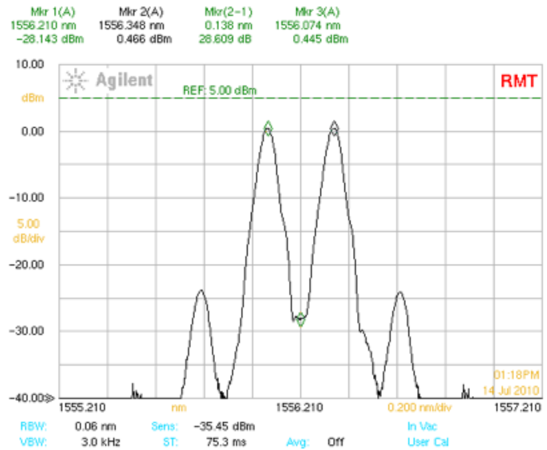




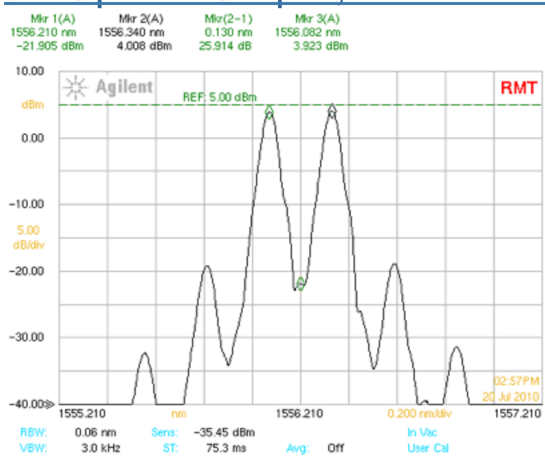
CVR = 13.0 GHz (LO = 26.0 GHz) | CVR = 14.0 GHz (LO = 28.0 GHz) | CVR = 15.0 GHz (LO = 30.0 GHz)

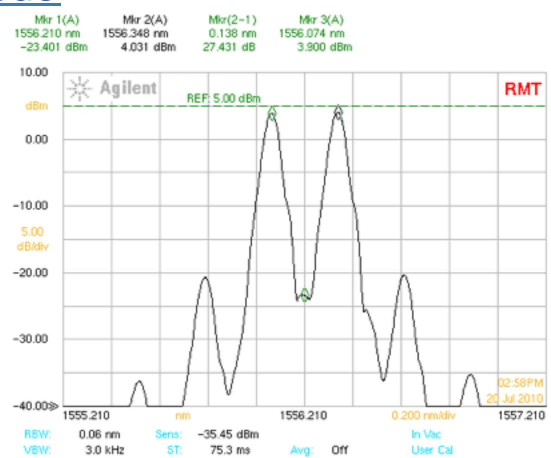
- MZ1 Optical Output, **Null Bias** Mode





- J2 Optical Output, **Null Bias** Mode

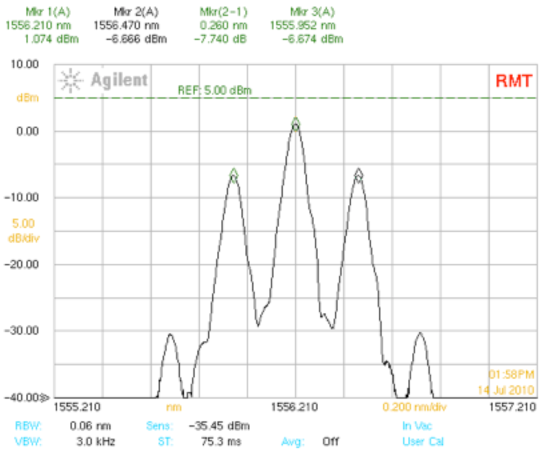


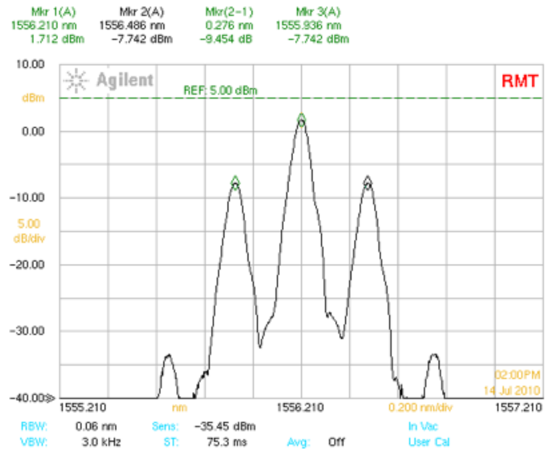


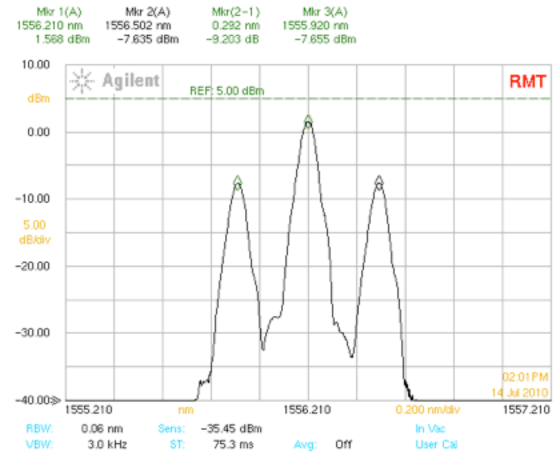
CVR = 16.0 GHz (LO = 32.0 GHz) CVR = 17.0 GHz (LO = 34.0 GHz)

MZM Laser Synthesizer

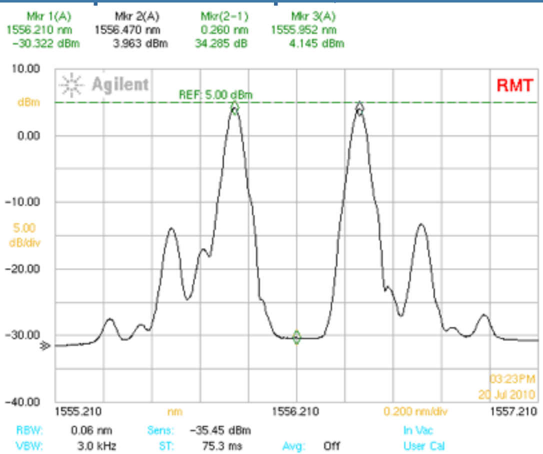
- MZ1 Optical Output, **Full Bias** Mode



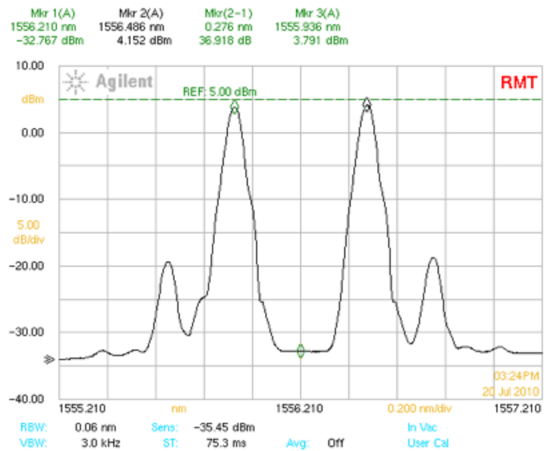




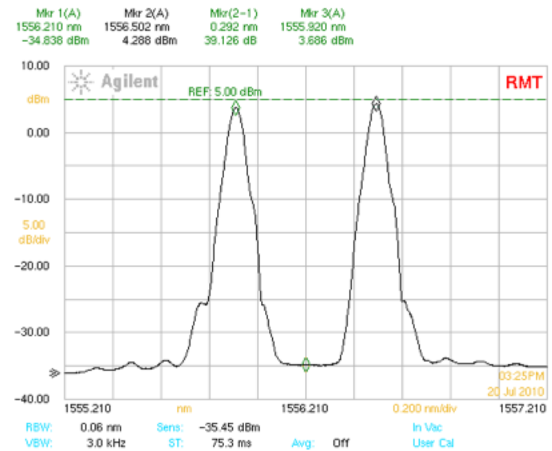
- J2 Optical Output, **Full Bias** Mode



CVR = 16.0 GHz (LO = 64.0 GHz)

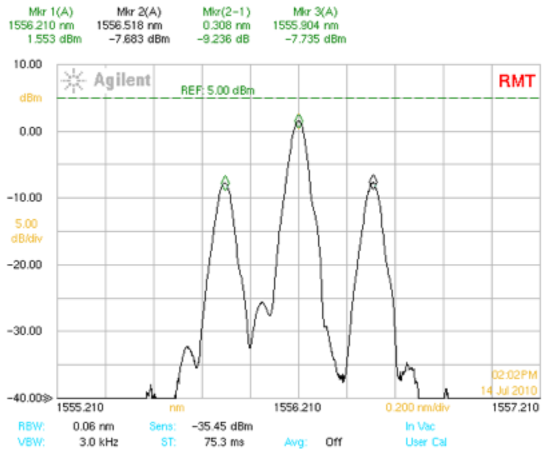


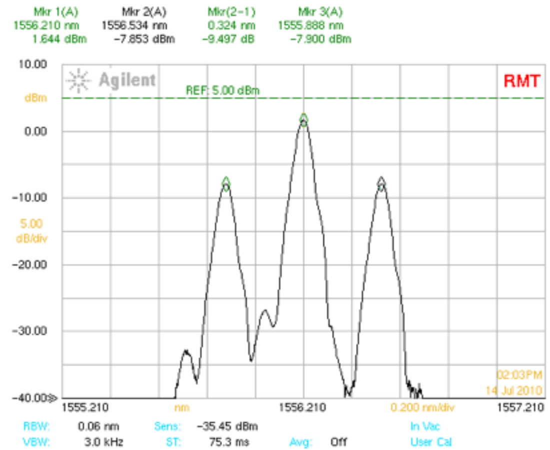
CVR = 17.0 GHz (LO = 68.0 GHz)

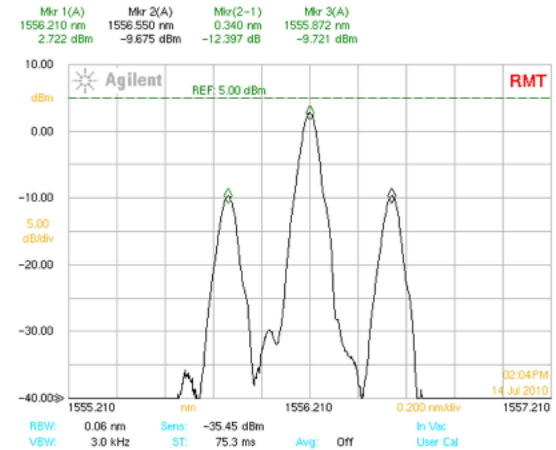


CVR = 18.0 GHz (LO = 72.0 GHz)

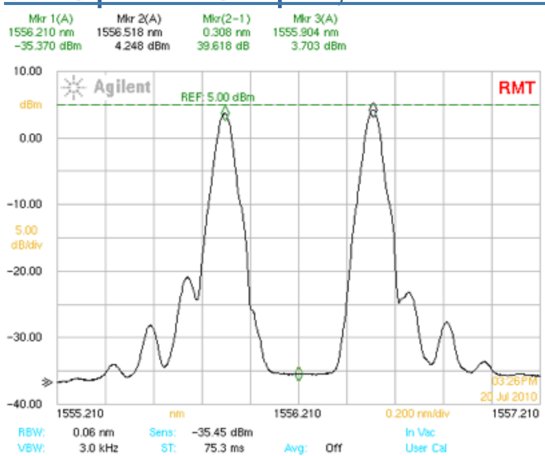
- MZ1 Optical Output, **Full Bias** Mode



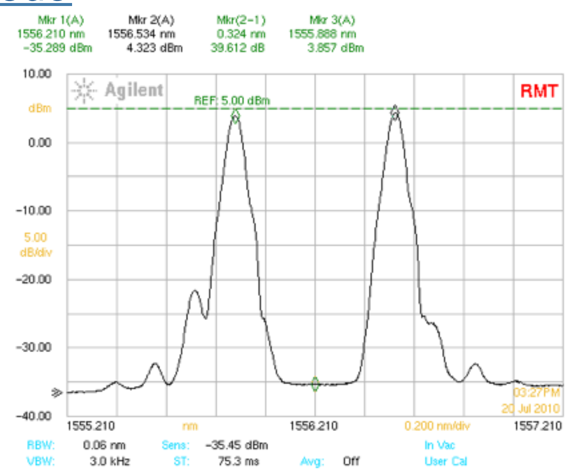




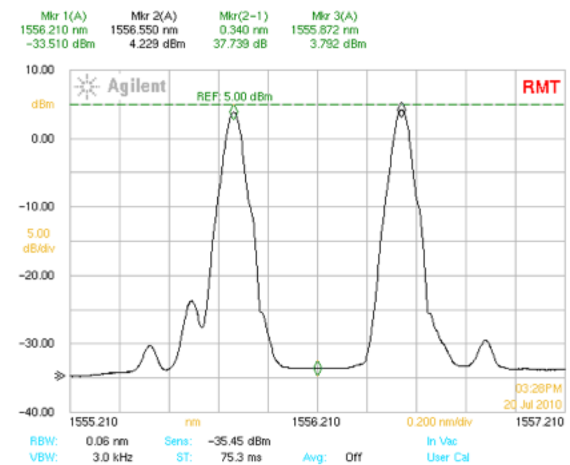
- J2 Optical Output, **Full Bias** Mode



CVR = 19.0 GHz (LO = 76.0 GHz)



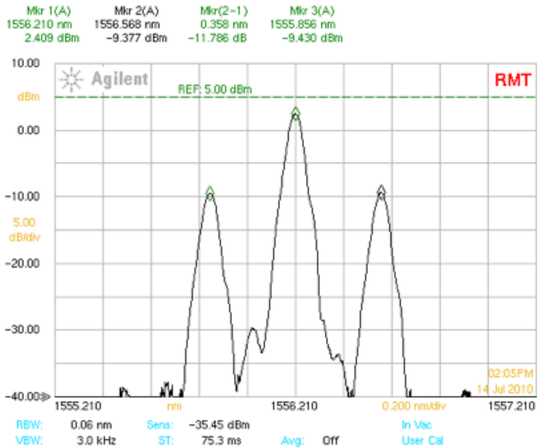
CVR = 20.0 GHz (LO = 80.0 GHz)

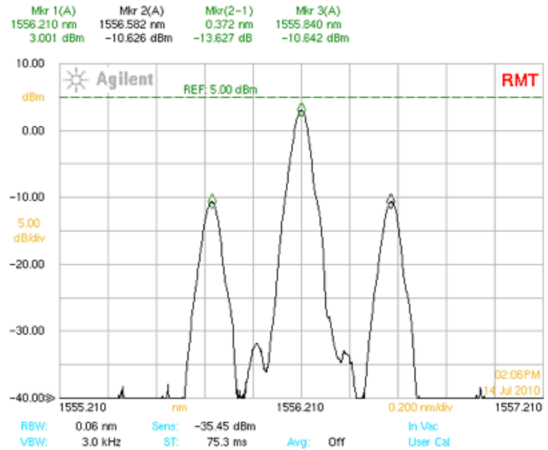


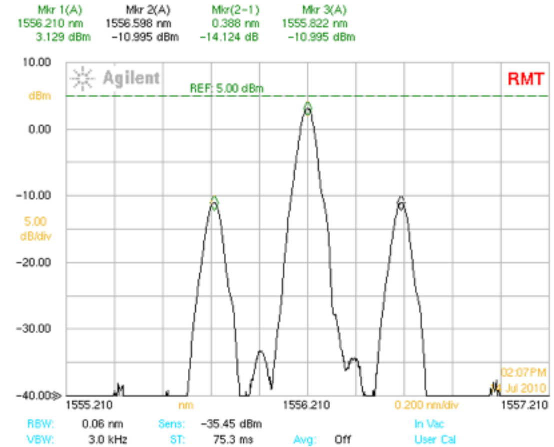
CVR = 21.0 GHz (LO = 84.0 GHz)

MZM Laser Synthesizer

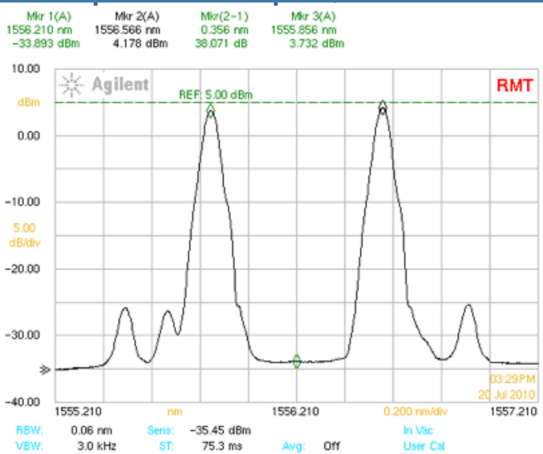
- MZ1 Optical Output, **Full Bias** Mode



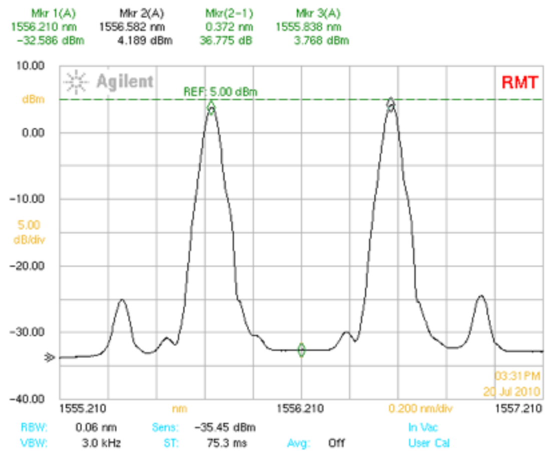




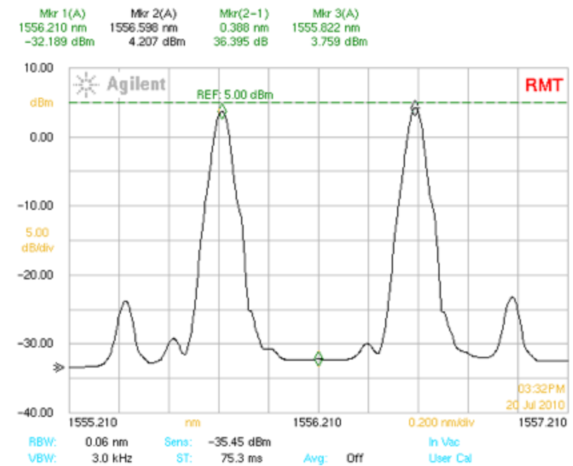
- J2 Optical Output, **Full Bias** Mode



CVR = 22.0 GHz (LO = 88.0 GHz)

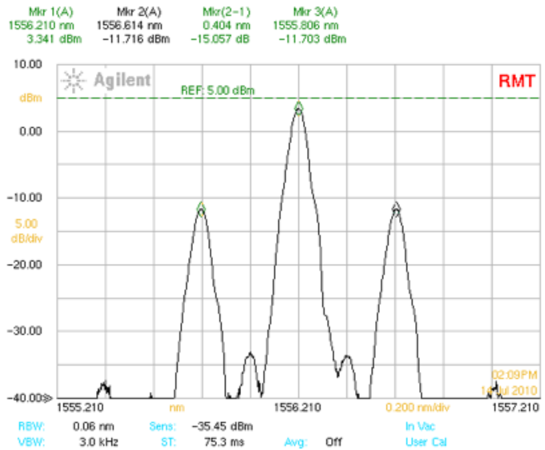


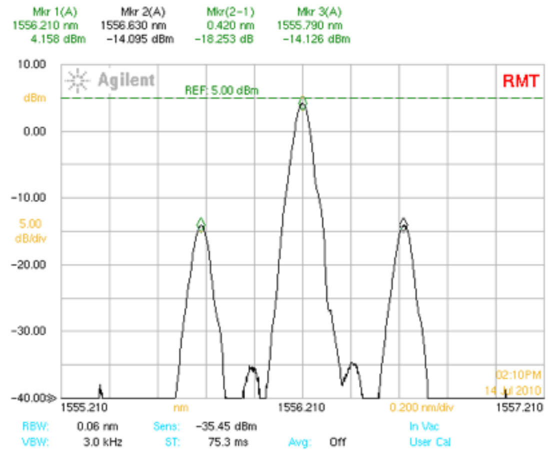
CVR = 23.0 GHz (LO = 92.0 GHz)

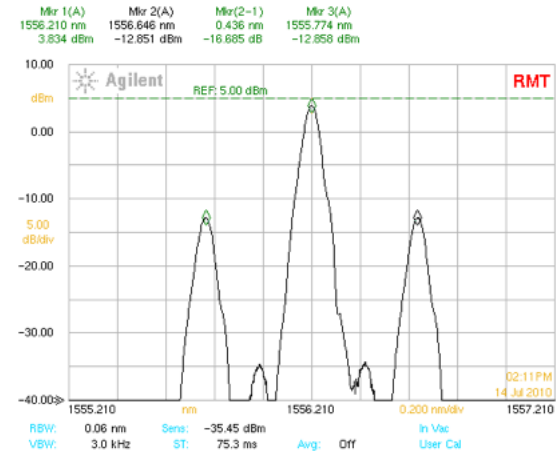


CVR = 24.0 GHz (LO = 96.0 GHz)

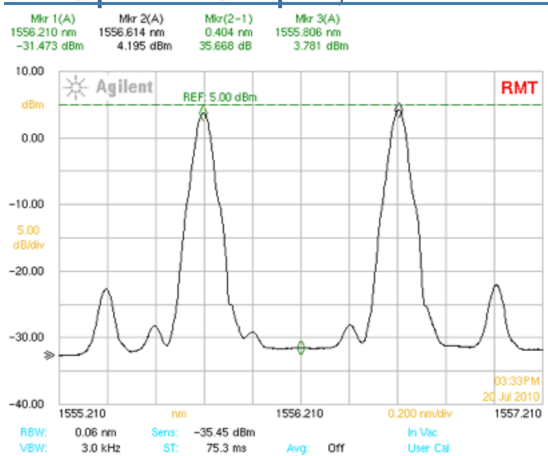
- MZ1 Optical Output, **Full Bias** Mode



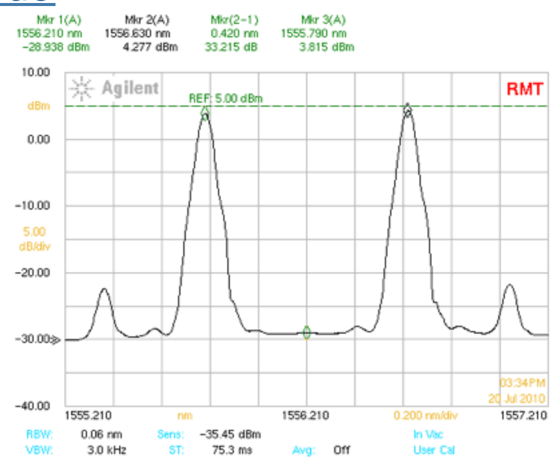




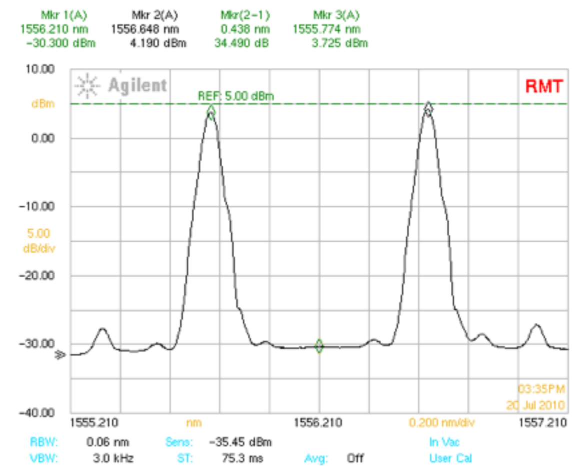
- J2 Optical Output, **Full Bias** Mode



CVR = 25.0 GHz (LO = 100.0 GHz)

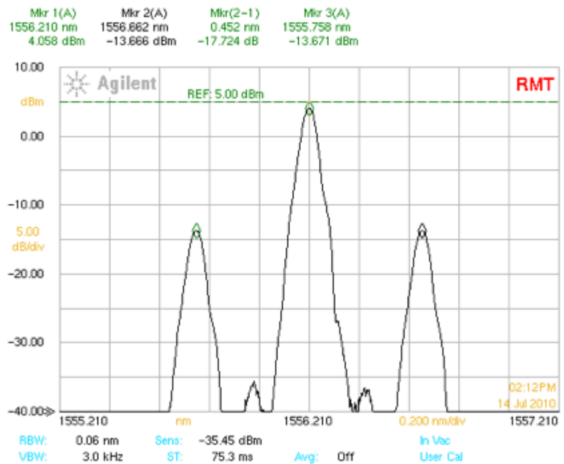


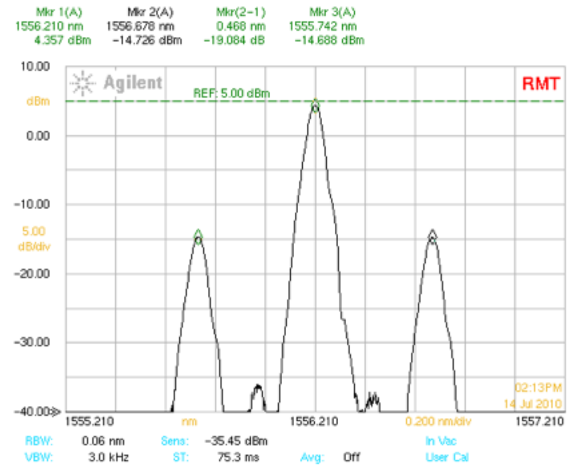
CVR = 26.0 GHz (LO = 104.0 GHz)

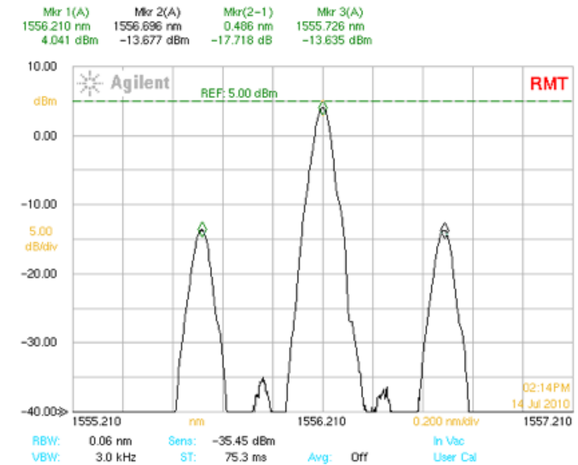


CVR = 27.0 GHz (LO = 108.0 GHz)

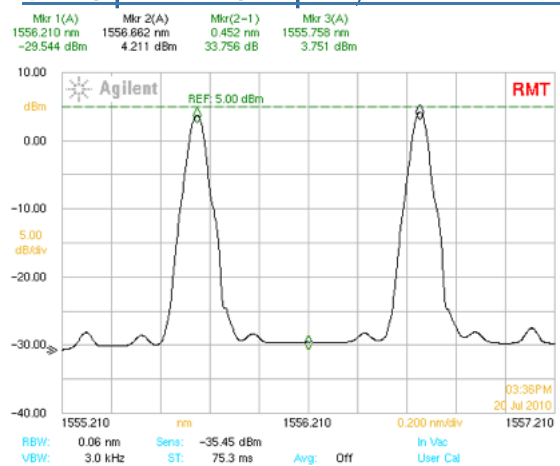
- MZ1 Optical Output, **Full Bias** Mode



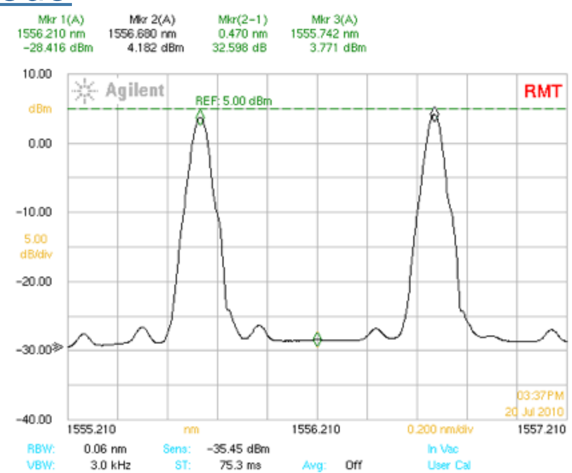




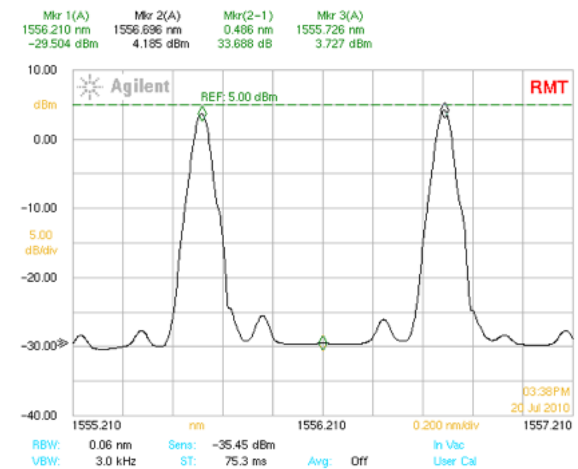
- J2 Optical Output, **Full Bias** Mode



CVR = 28.0 GHz (LO = 112.0 GHz)

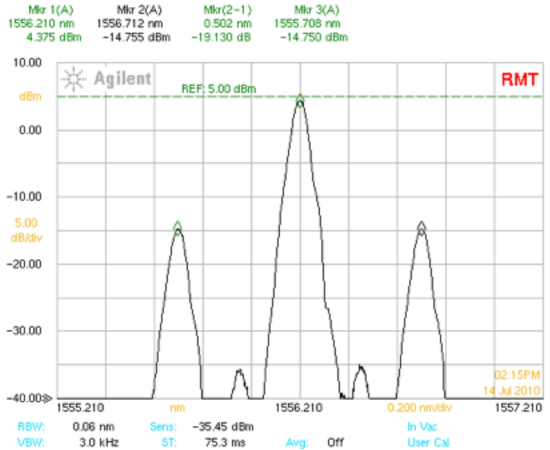


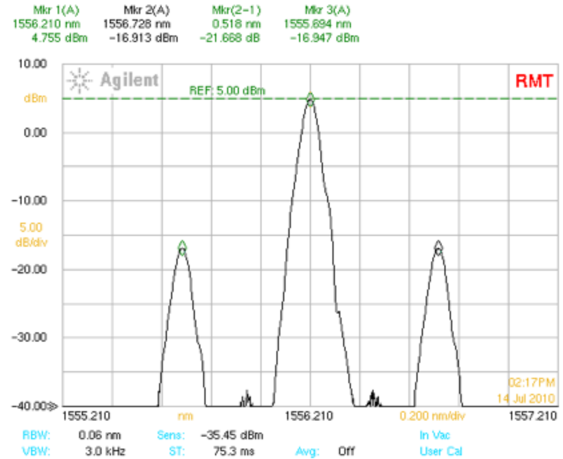
CVR = 29.0 GHz (LO = 116.0 GHz)

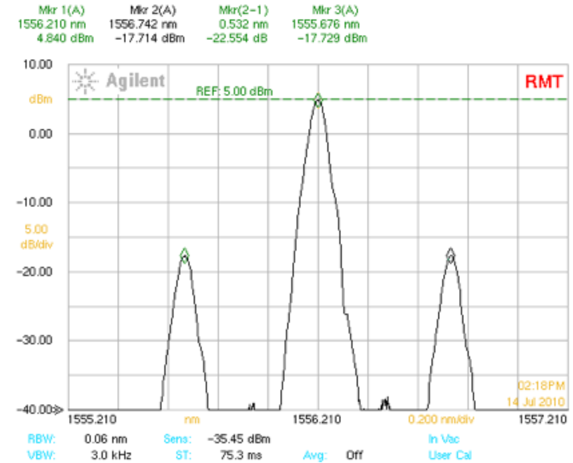


CVR = 30.0 GHz (LO = 120.0 GHz)

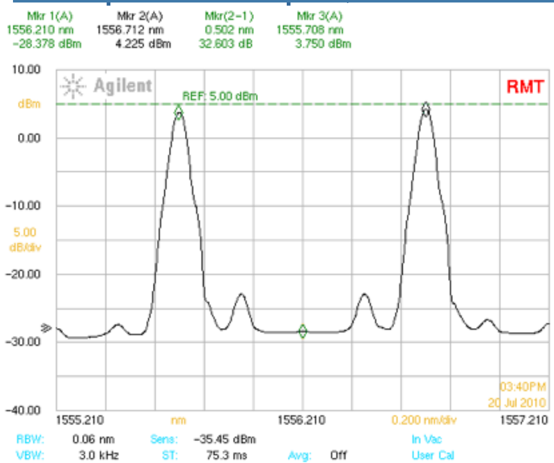
- MZ1 Optical Output, **Full Bias** Mode



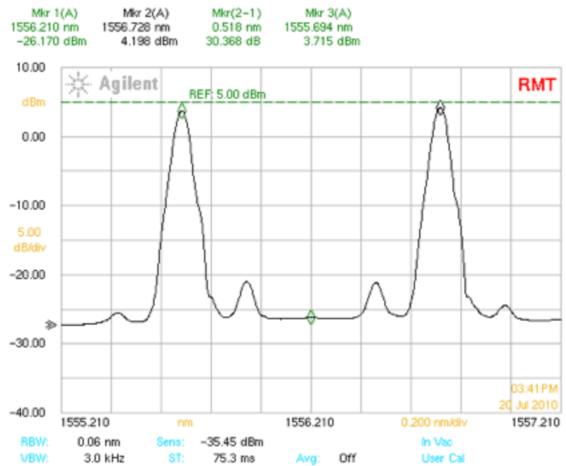




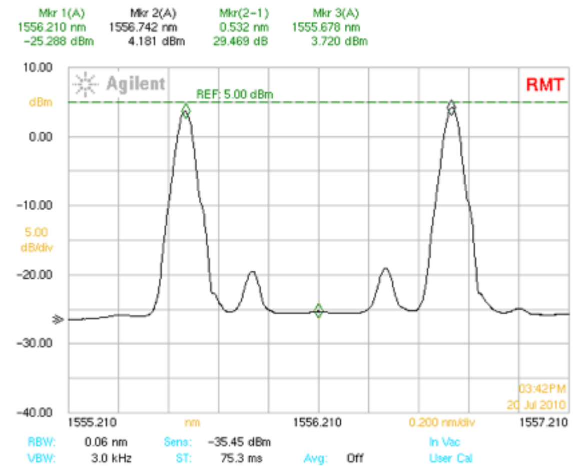
- J2 Optical Output, **Full Bias** Mode



CVR = 31.0 GHz (LO = 112.0 GHz)

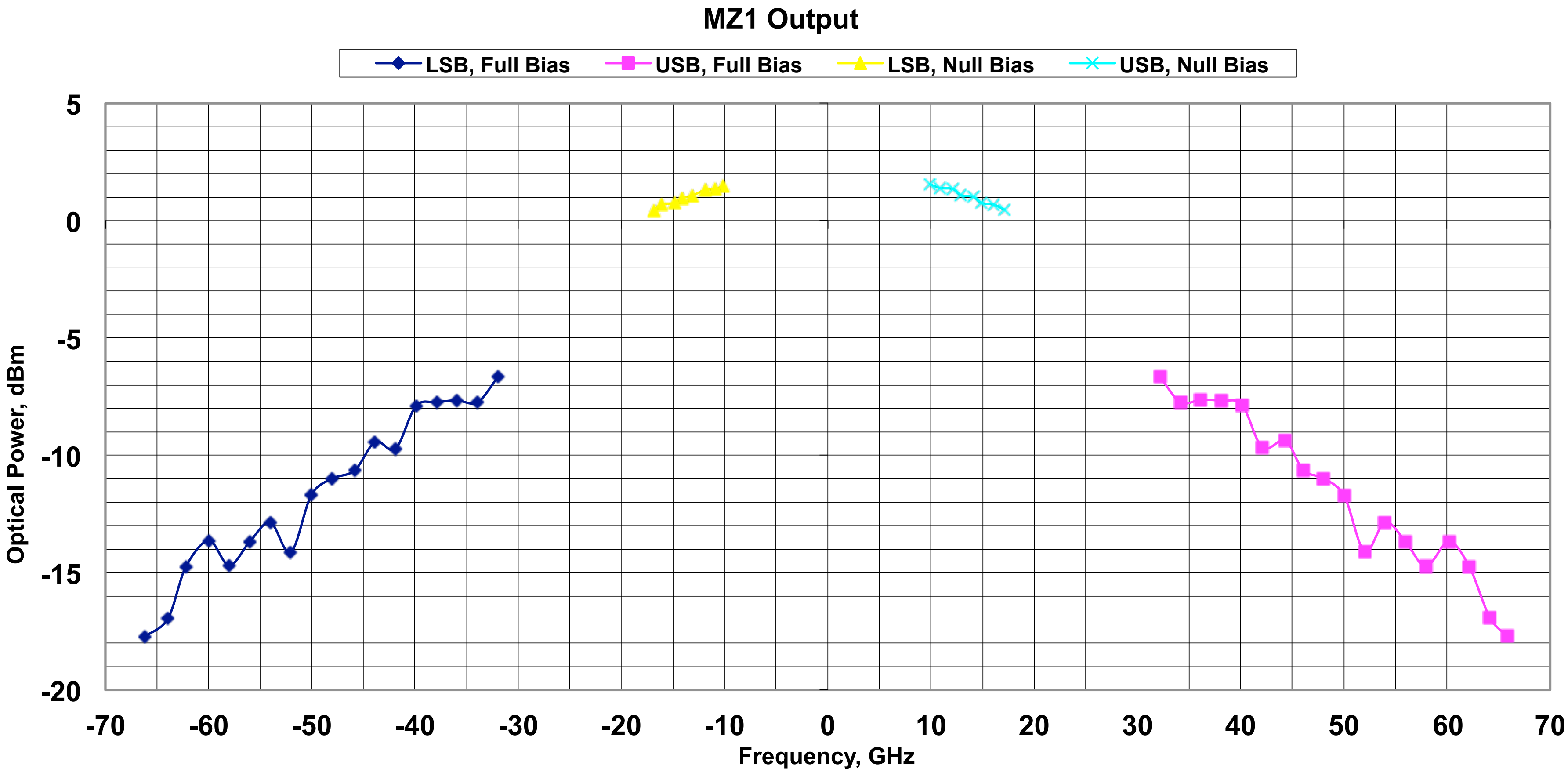


CVR = 32.0 GHz (LO = 116.0 GHz)

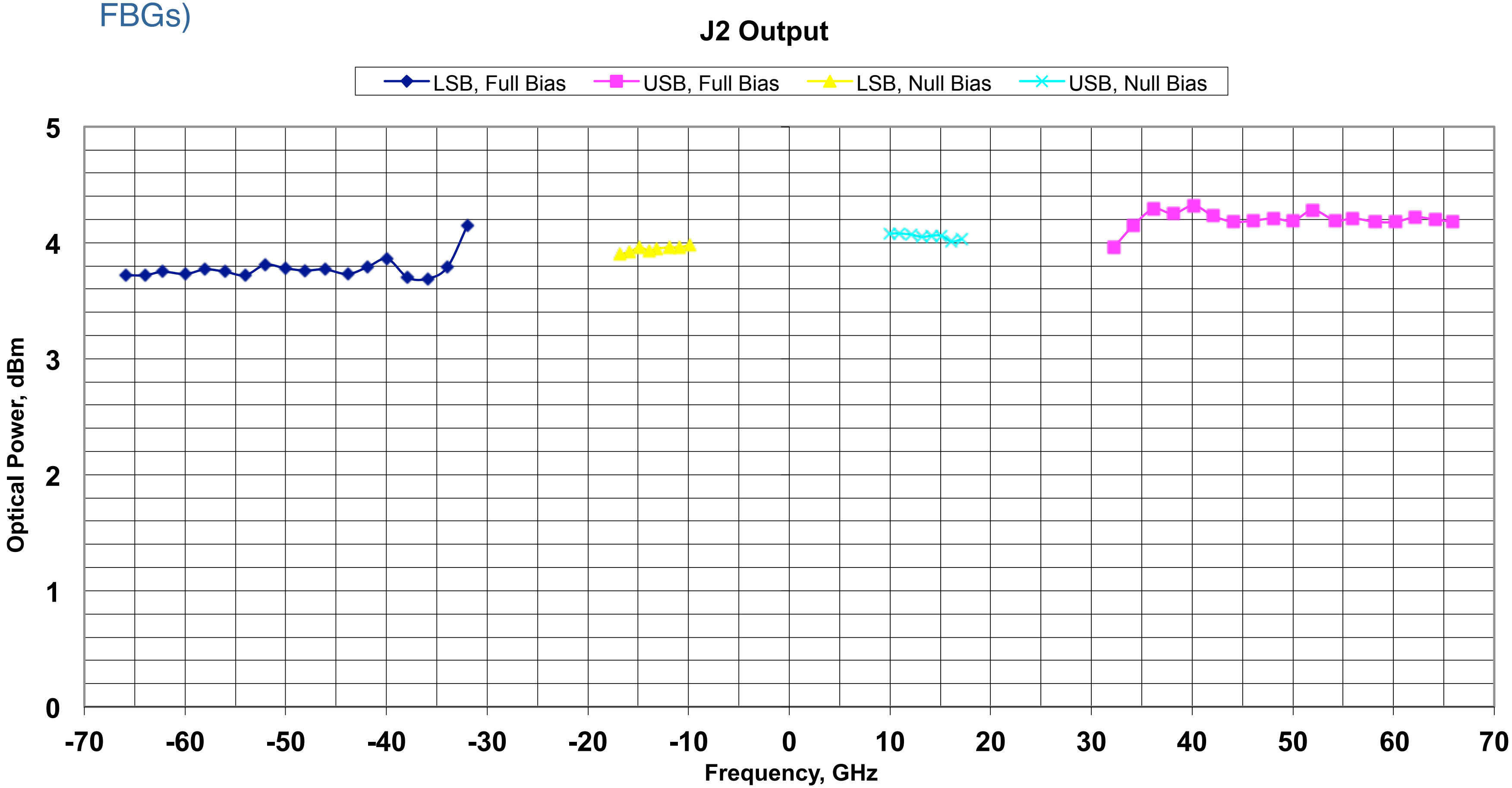


CVR = 33.0 GHz (LO = 120.0 GHz)

- Plot of MZ1 Optical Output Power vs. Offset Frequency
  - 0 GHz represents 1556.21 nm master laser (192.642,702 THz)
  - MZ1 modulation efficiency reduces with increasing RF frequency

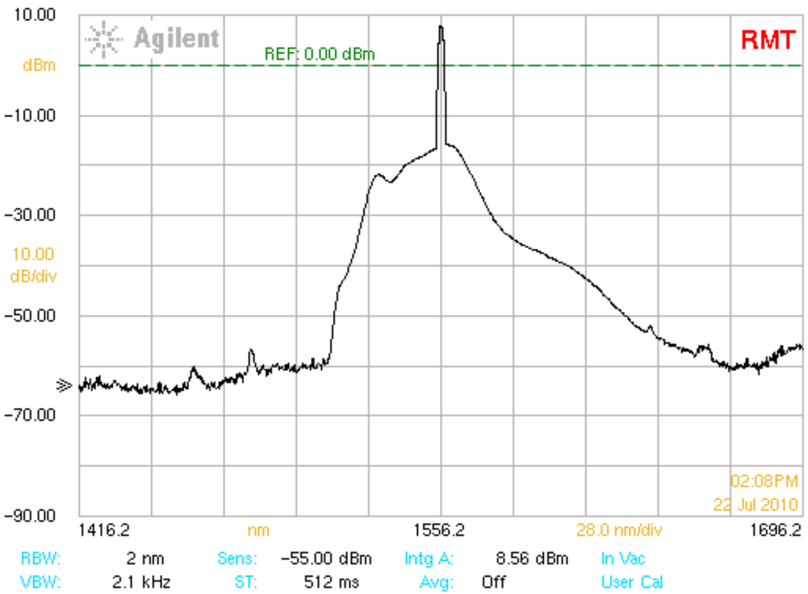


- Plot of J2 Final Optical Output Power vs. Optical Frequency
  - AR2 EDFA gain is adjusted to compensate for MZ1 frequency roll-off
    - Upward/downward tails at +/- 32.5 GHz were caused by FBGs and are no longer present (replaced FBGs)

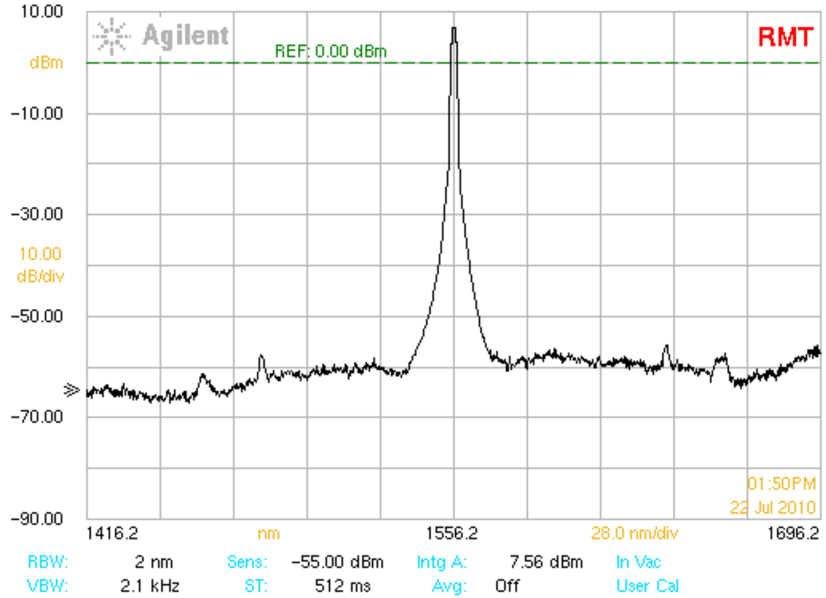


- EDFA Output Noise Pedestal Characterization at J3 (identical to J2)
  - FL3 optical filter removes ~80% of the EDFA ASE noise
    - Remaining ASE noise pedestal accounts for approximately -13 dBm
    - Desired tones +7 dBm, undesired noise -13 dBm → optical SNR ~20 dB

Output without FL3 (CVR = 25 GHz)

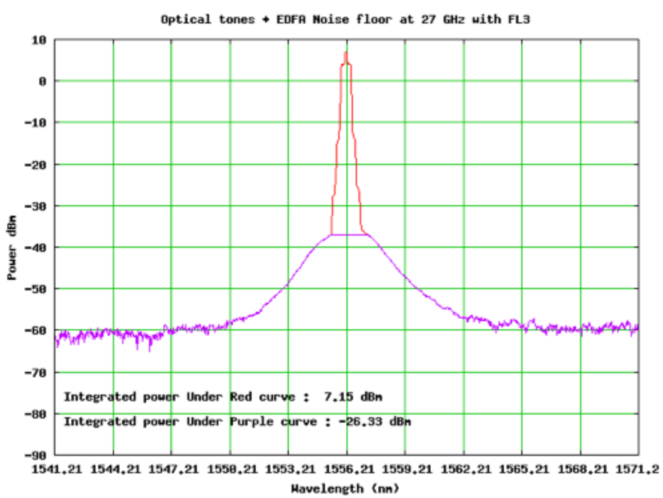


Output with FL3

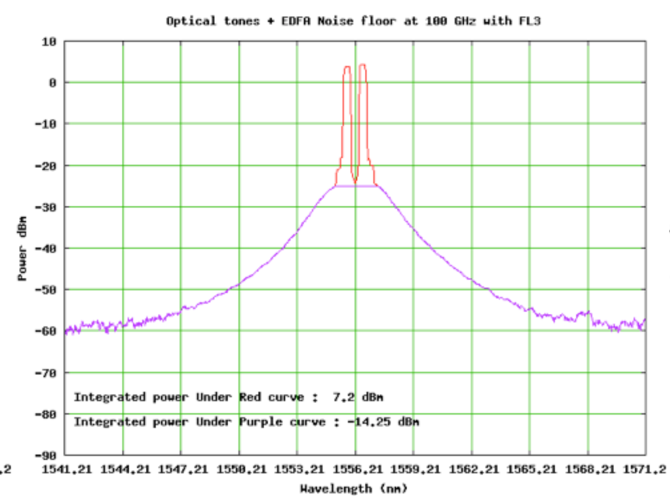


- EDFA Output Noise Pedestal Characterization (continued)
  - Comparison of output SNR at 27, 100, and 124 GHz
  - Higher EDFA gain is required at higher LO frequencies
    - Results in lower SNR at higher LO frequencies
    - Worst case optical SNR is 18 dB (spec is 10 dB)

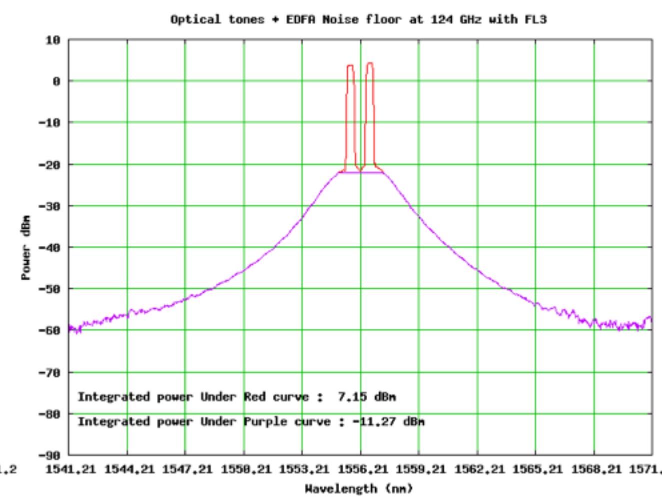
SNR = 33 dB @ LO = 27 GHz



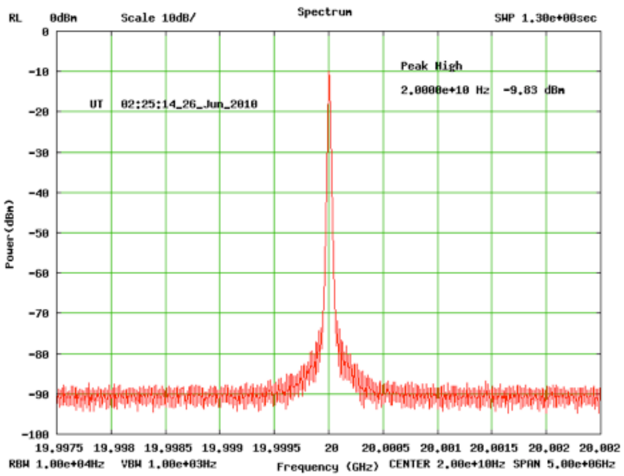
SNR = 21 dB @ LO = 100 GHz

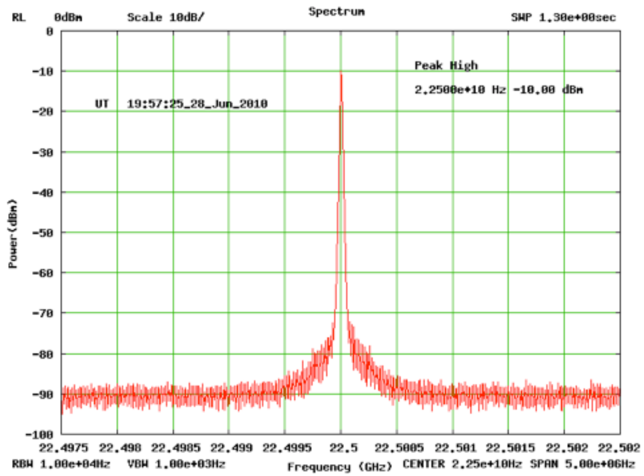


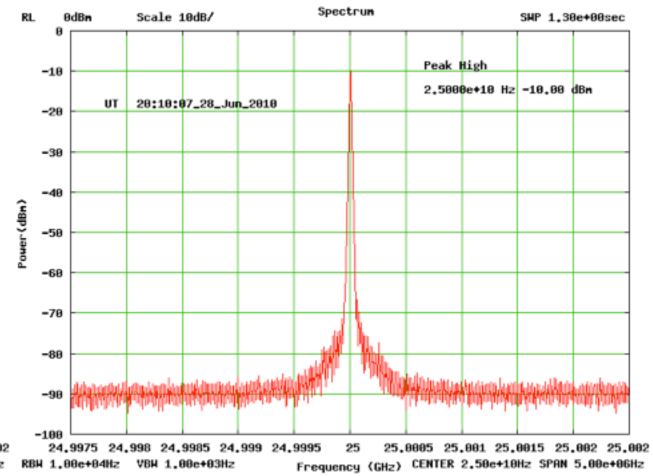
SNR = 18 dB @ LO = 124 GHz



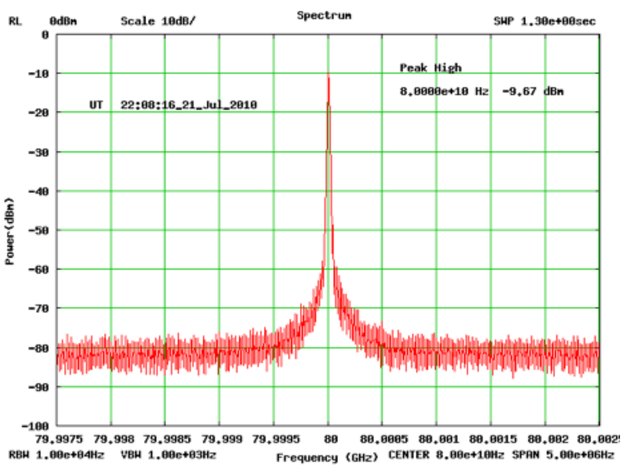
- CVR Spectral Response (5 MHz span)

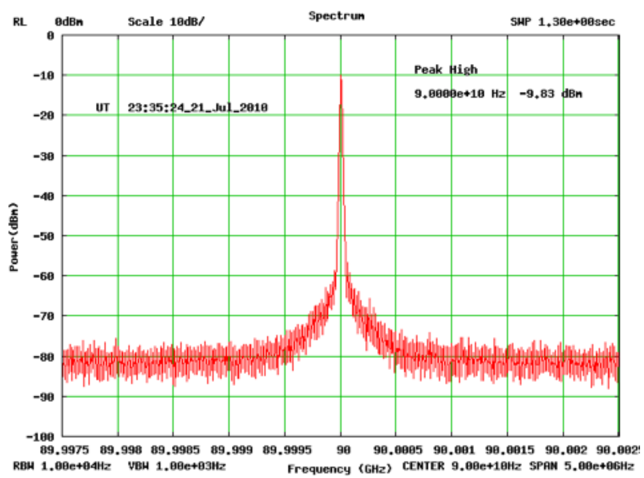


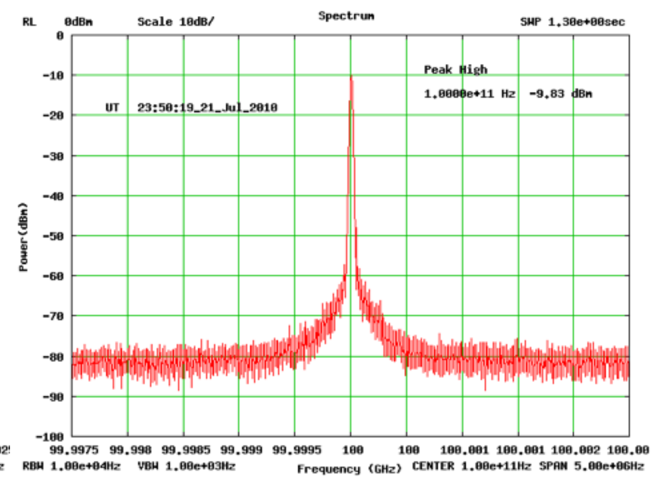




- Photomixer Spectral Response (5 MHz span)



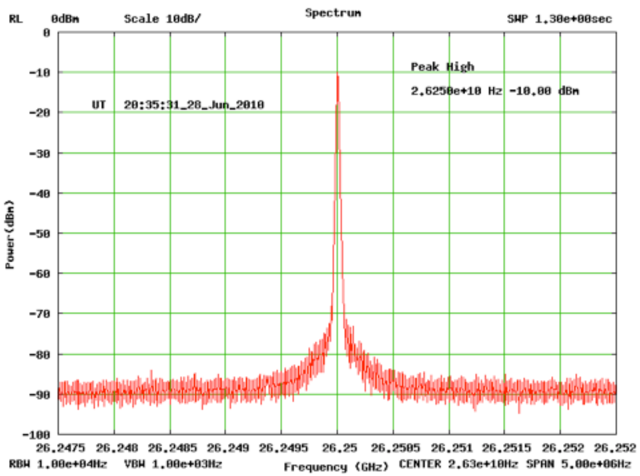




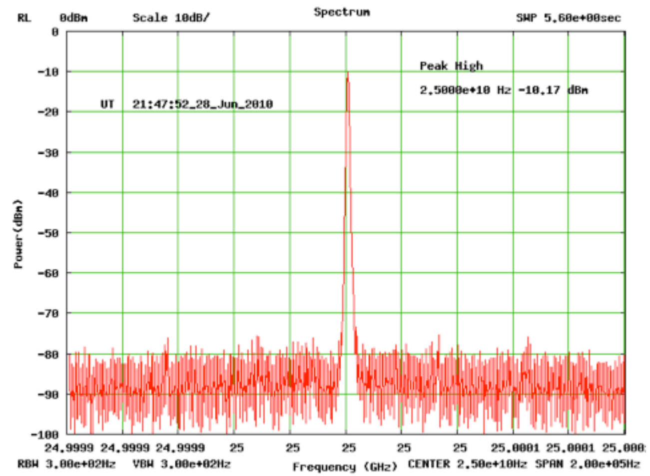
CVR = 20.0 GHz, PM = 80.0 GHz | CVR = 22.5 GHz, PM = 90.0 GHz | CVR = 25.0 GHz, PM = 100.0 GHz

MZM Laser Synthesizer

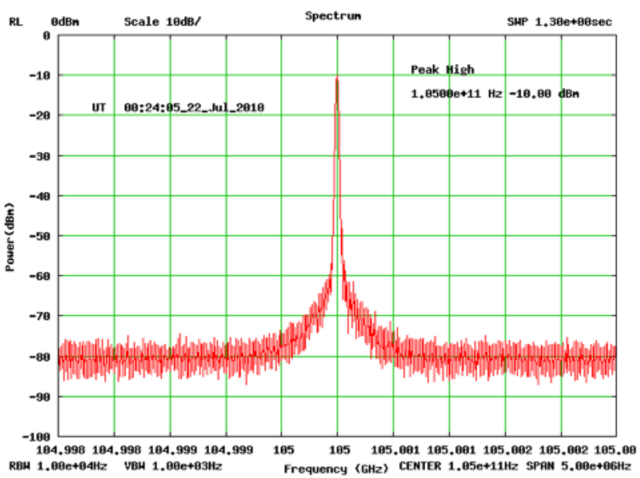
- CVR Spectral Response (5 MHz span)



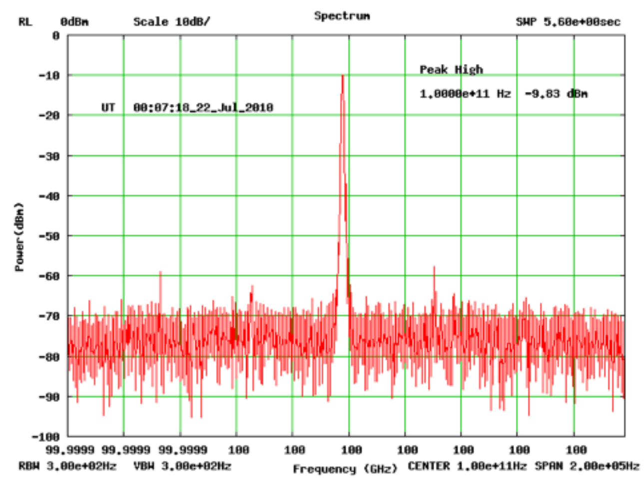
(200 kHz span)



- Photomixer Spectral Response (5 MHz span)



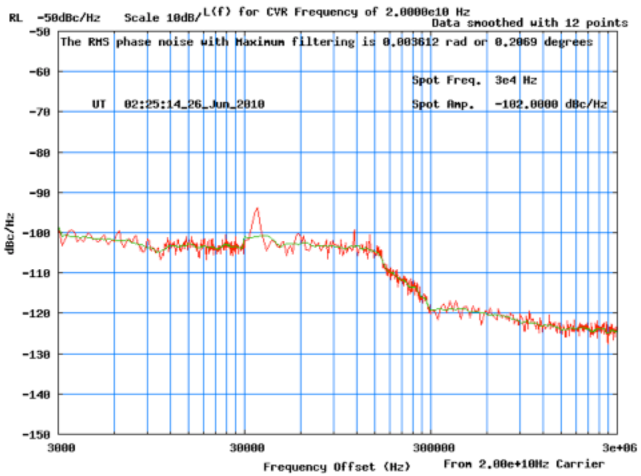
(200 kHz span)

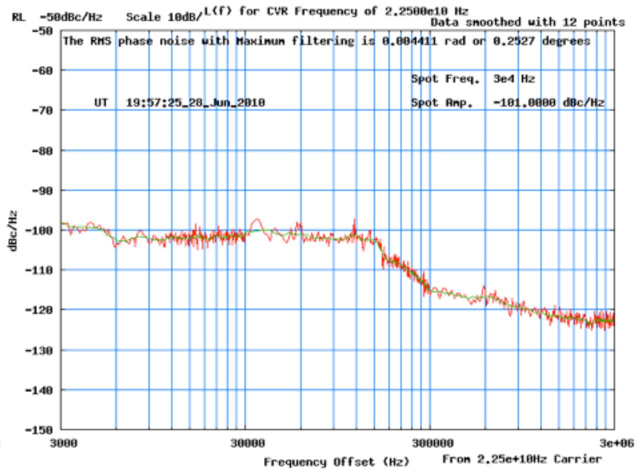


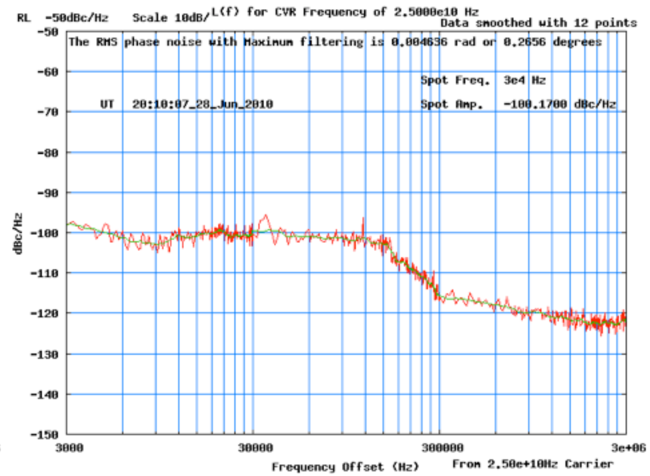
CVR = 26.250 GHz, PM = 105.000 GHz

CVR = 25.0 GHz, PM = 100.0 GHz

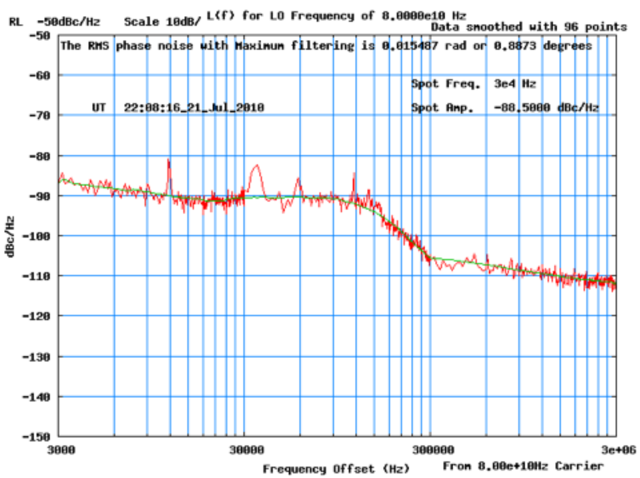
- CVR L(f) Phase Noise

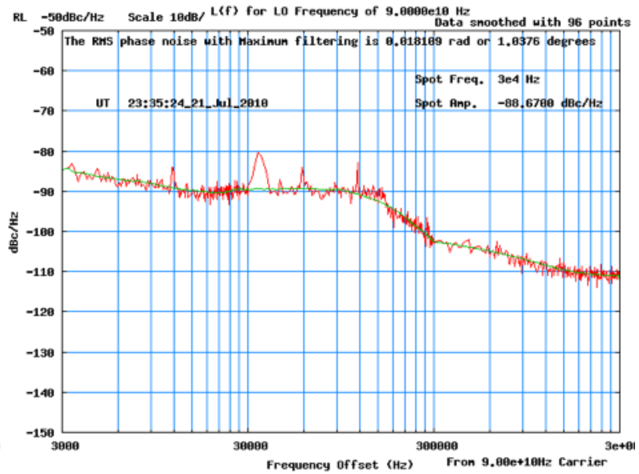


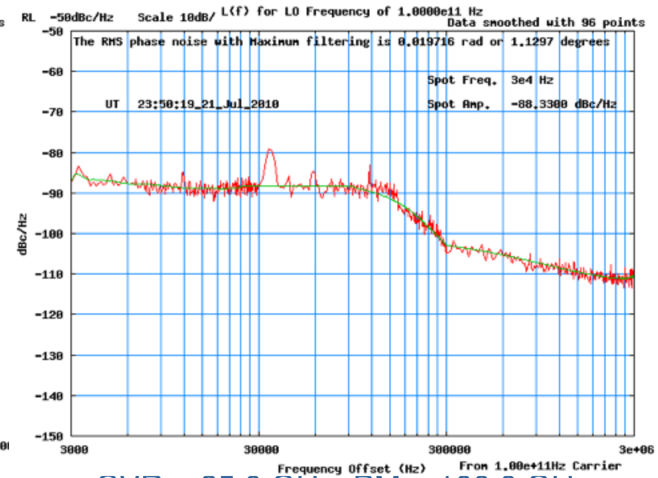




- Photomixer L(f) Phase Noise



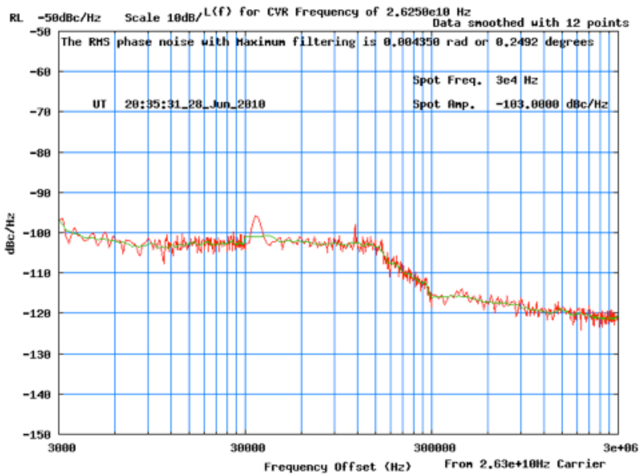




CVR = 20.0 GHz, PM = 80.0 GHz | CVR = 22.5 GHz, PM = 90.0 GHz | CVR = 25.0 GHz, PM = 100.0 GHz

MZM Laser Synthesizer

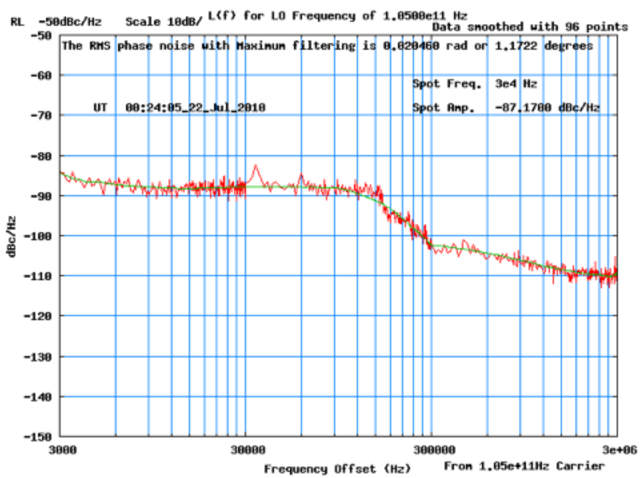
- CVR L(f) Phase Noise



Total RMS integrated phase noise (3 kHz - 3 MHz):

- 20.0 GHz = 0.2069 deg.
- 22.5 GHz = 0.2527
- 25.0 GHz = 0.2656
- 26.25 GHz = 0.2492

- Photomixer L(f) Phase Noise



CVR = 26.250 GHz, PM = 105.000 GHz

Total RMS integrated phase noise (3 kHz - 3 MHz):

- 80.0 GHz = 0.8873 deg.
- 90.0 GHz = 1.0376
- 100.0 GHz = 1.1297
- 105.0 GHz = 1.1722

- Calculation of MZM-LS Residual Phase Noise

$$\Phi_{total} = [(4*\Phi_{CVR})^2 + (\Phi_{ALS})^2]^{0.5} \;\; \text{-->} \;\; \Phi_{ALS} = [(\Phi_{total})^2 - (4*\Phi_{CVR})^2]^{0.5}$$

Frequency (GHz)		Integrated Phase Noise, RMS (3 kHz - 3 MHz)			
CVR	Photomixer	Total (deg)	CVR (deg)	MZM-LS (deg)	MZM-LS (fsec)
20.000	80.000	0.8873	0.2069	**0.3200**	**11.11**
22.500	90.000	1.0376	0.2527	**0.2343**	**7.23**
25.000	100.000	1.1297	0.2656	**0.3841**	**10.67**
26.250	105.000	1.1722	0.2492	**0.6168**	**16.32**

- Specification

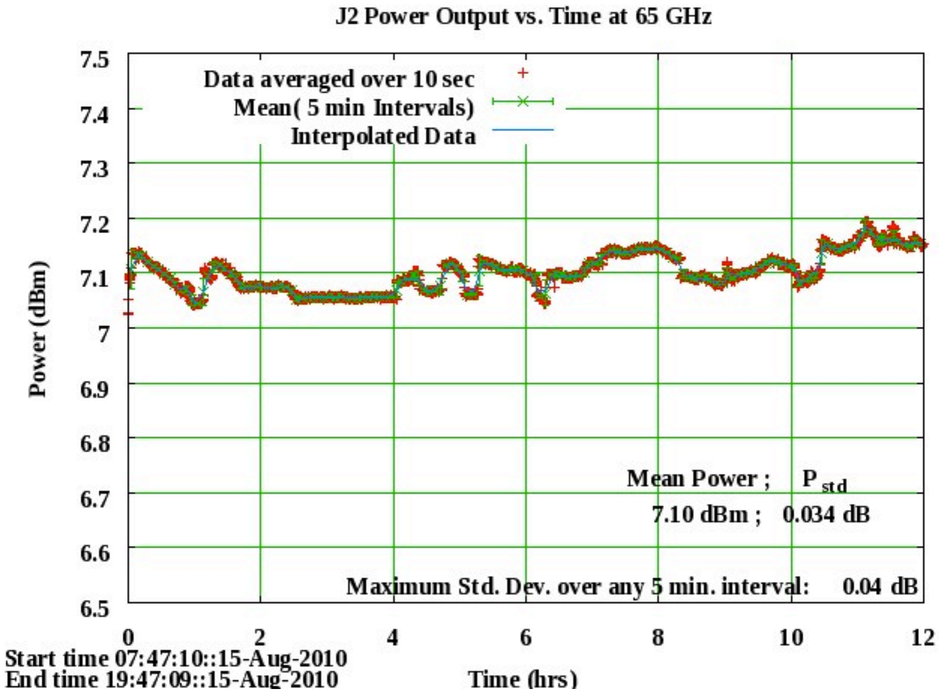
</= 50 fsec (</= 1.800 degrees @ 100.0 GHz), integrated from 1 Hz - 1 kHz

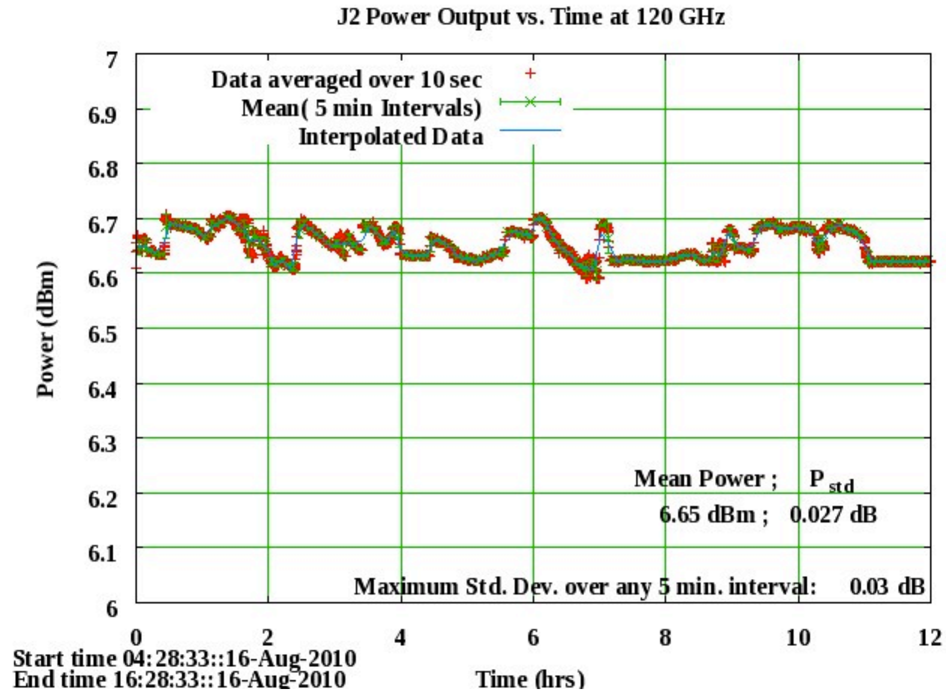
- Can’t measure below 3 kHz with test equipment in Hilo, will have to wait for tests in CV

</= 27 fsec (</= 0.972 degrees @ 100.0 GHz), integrated from 1 kHz - 1 MHz

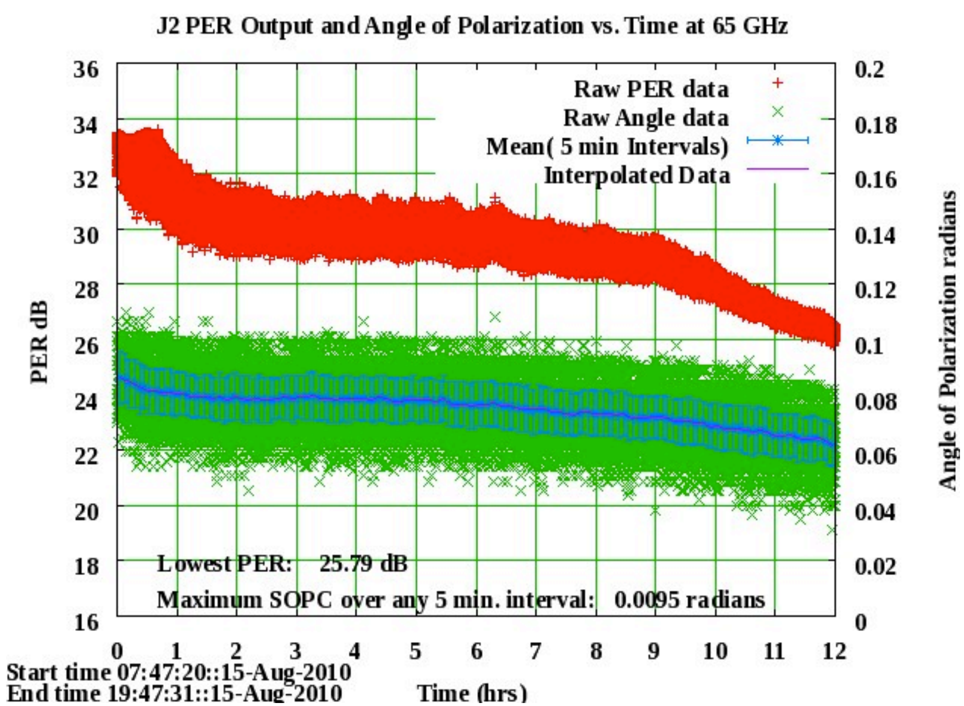
- Worst case measured value was 16.3 fsec seen at 105 GHz (3 kHz - 3 MHz)

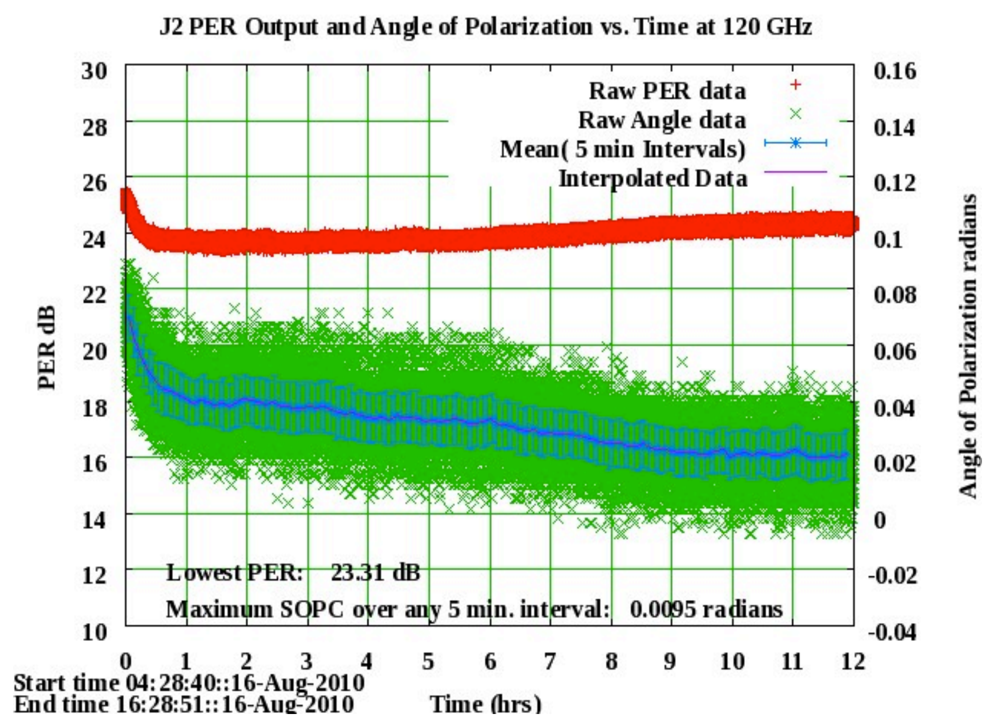
- J2 Optical Output Power Stability vs. Time
  - Plots below represent optical power output at 65 GHz and 120 GHz over a duration of 12 hours
  - Power stability spec is < 0.4 dB variation over any 300 second (5 minute) interval with samples averaged over 10 seconds
    - Measured maximum 1 sigma value of 0.04 dB → peak-to-peak value ~0.24 dB



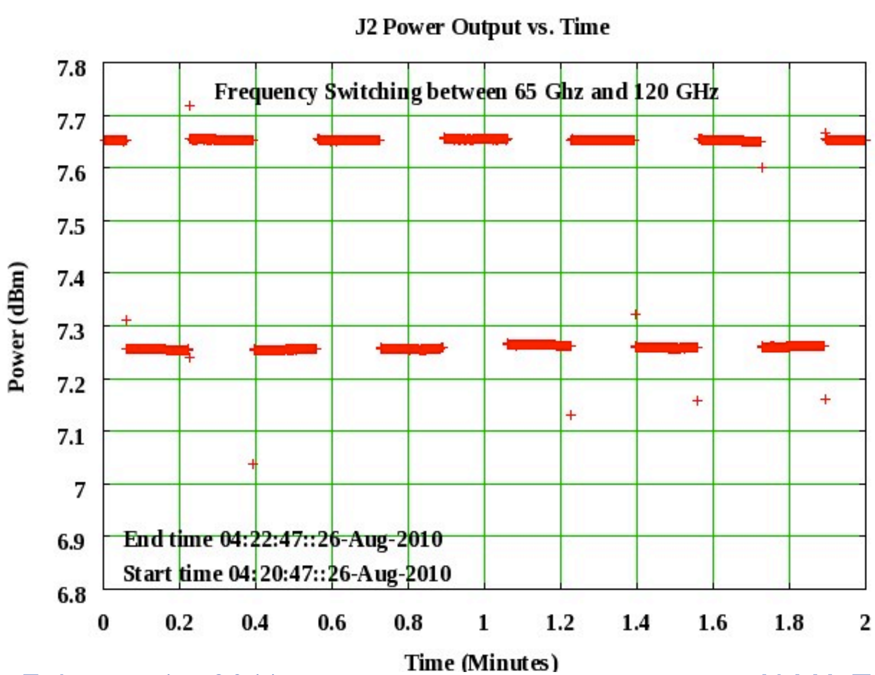


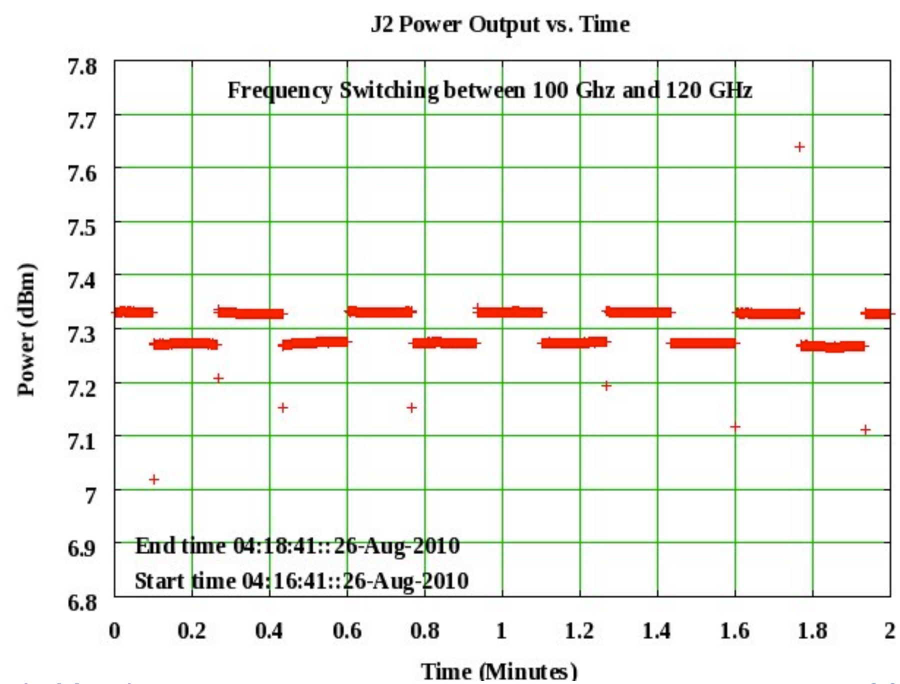
- J2 Optical Output PER & SOPC Stability vs. Time
  - Plots below represent optical PER & SOP output at 65 GHz and 120 GHz over a duration of 12 hours
  - PER (Polarization Extinction Ratio) spec is > 20 dB
    - Measured worst case value of 23.3 dB
  - SOPC (State of Polarization Change) spec is < +/- 0.01 radians RMS over any 300 second interval
    - Measured worst case value of +/- 0.0095 radians RMS



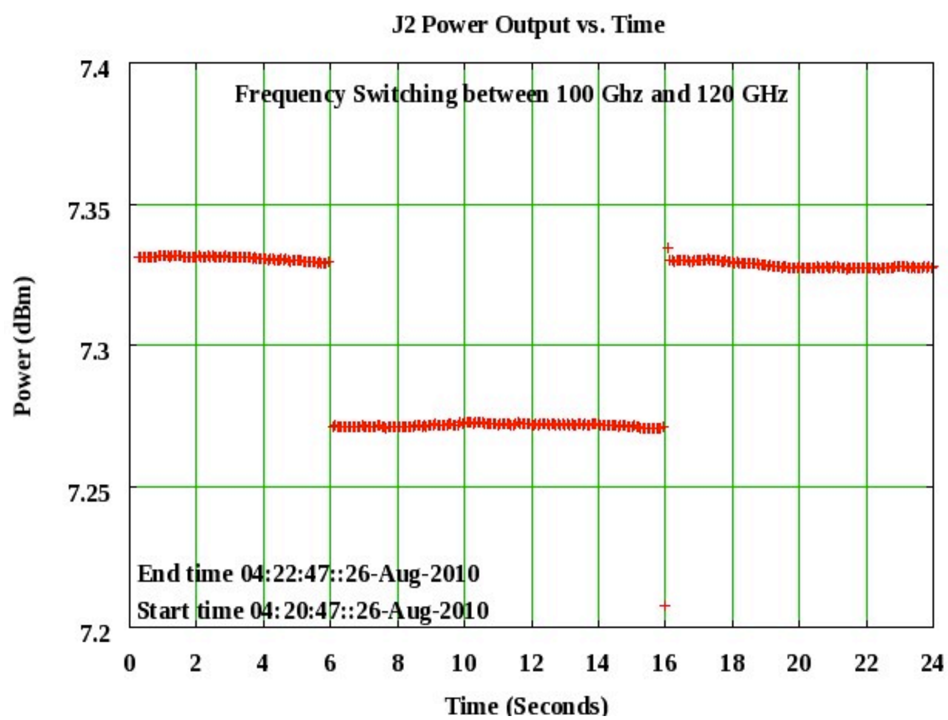


- Fast Frequency Switching Mode
  - Use an OzOptics optical power meter to indirectly measure the frequency switching time
  - 2 plots below represent 65/120 GHz and 100/120 GHz frequency switching
  - Imbalance in power at the 2 LO frequencies is due to non-flat response of MZ1 and AR1
    - For the 65/120 case there is ~7 dB power difference exiting MZ1 and is subsequently leveled to ~0.4 dB by dynamically adjusting the EDFA gain
    - For 100/120 GHz case there is ~2 dB difference exiting MZ1 which is leveled to ~0.1 dB



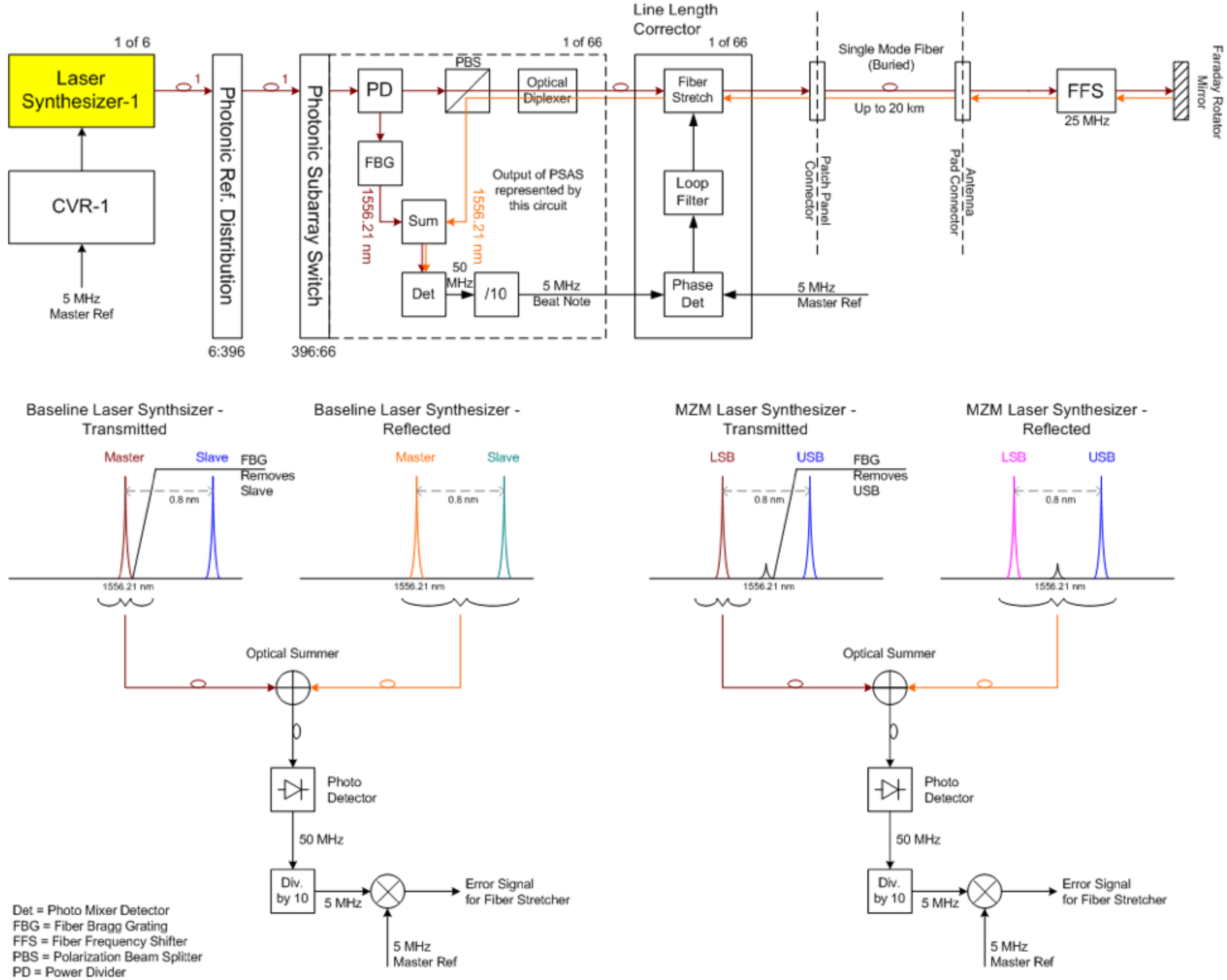


- Fast Frequency Switching Mode (continued)
  - Closer time span look at 100/120 GHz frequency switching
    - Power meter sample rate is 15 samples/second (67 msec per data point)
    - Based on the sample rate it appears that the switching time is no greater than 2 sample times or 133 msec (spec is < 500 msec, goal is 100 msec)

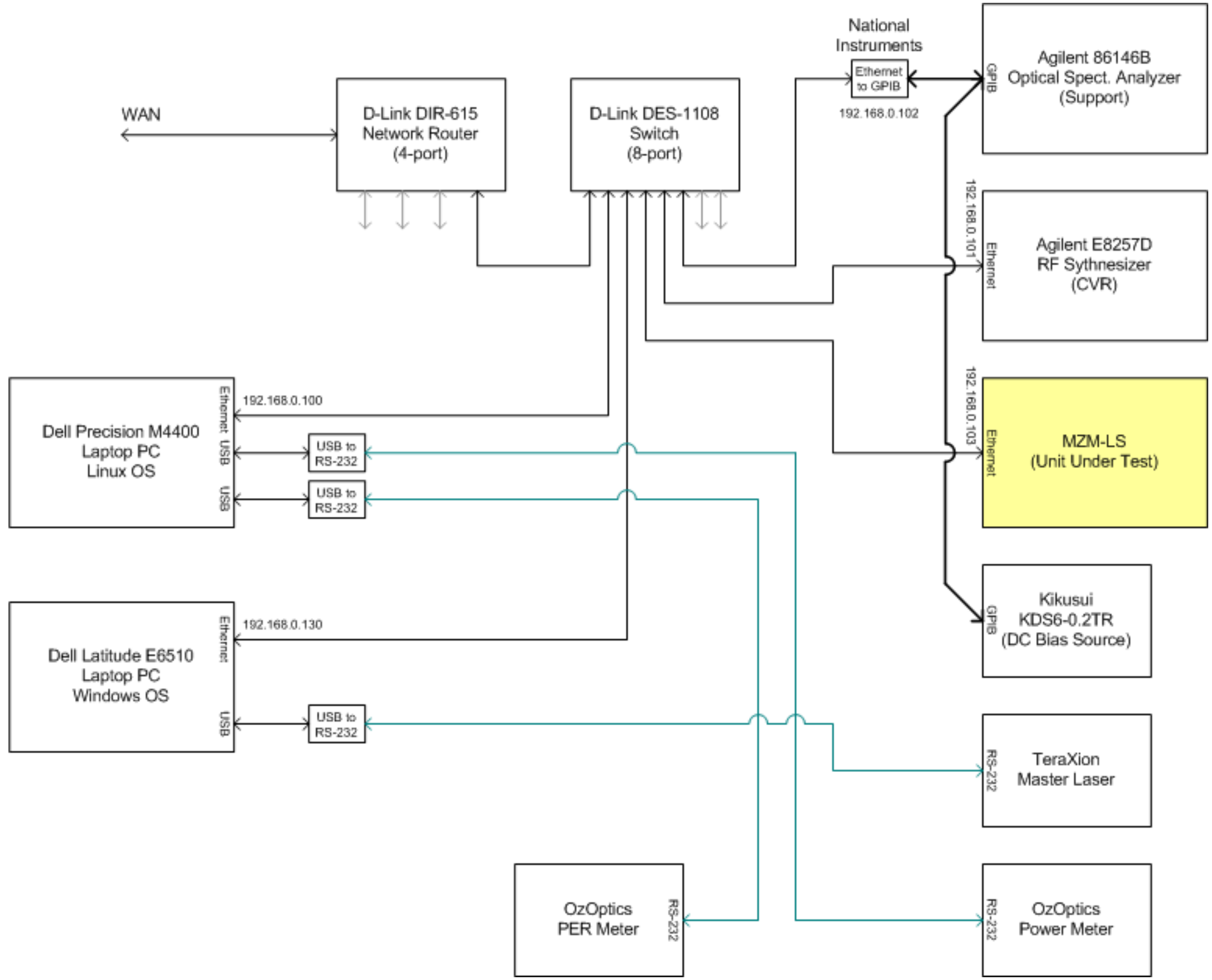


MZM Laser Synthesizer

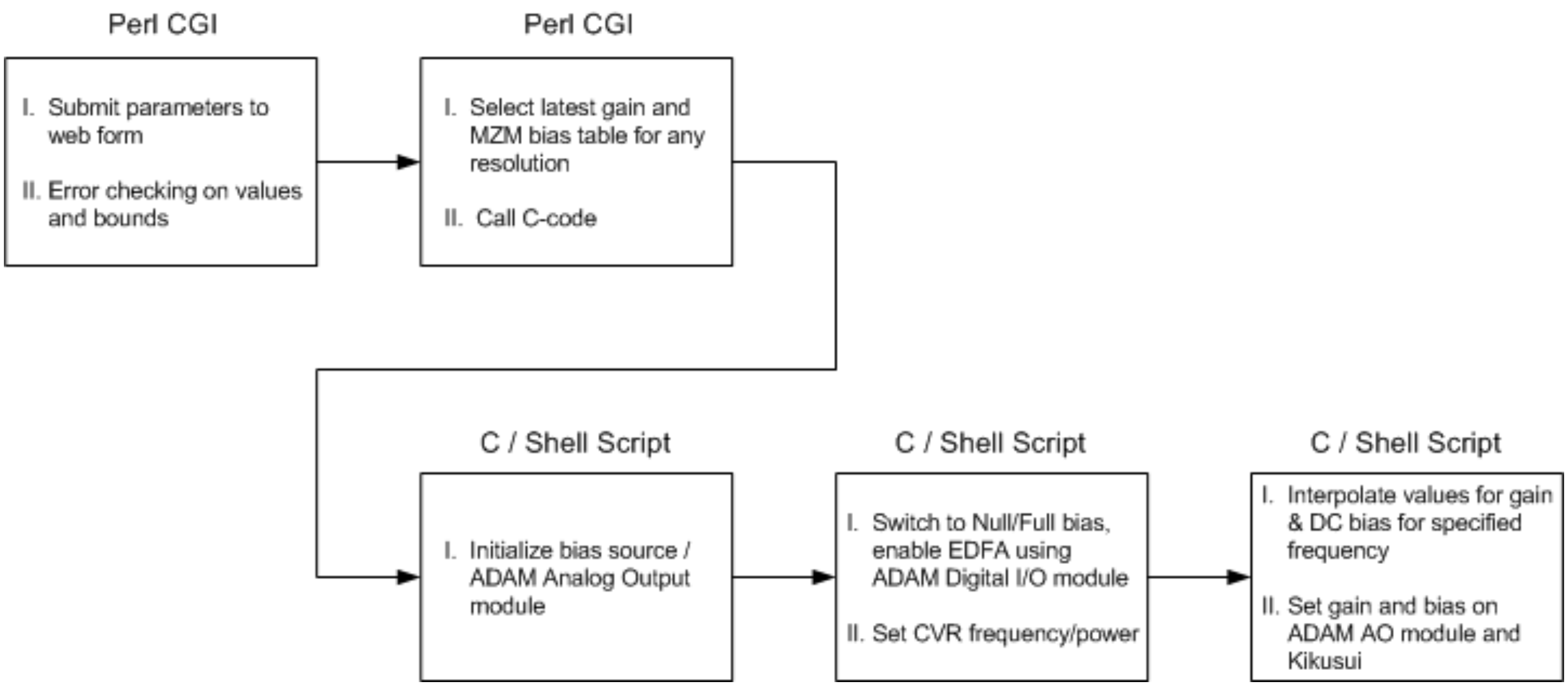
- Issue with Line Length Corrector in Fast Frequency Switching Mode
  - Abrupt change in CVR (Agilent E8257D) frequency causes momentary dropout of RF signal
    - Results in momentary dropout of optical tones
    - Loss of lock for LLC
  - One possible solution is the re-introduction of the Master Laser after the MZM-LS
    - Tests at CV confirms that this works
    - 3rd optical tone may impact the lock reliability of the WCAs



- Instrument Communication Interconnect Diagram

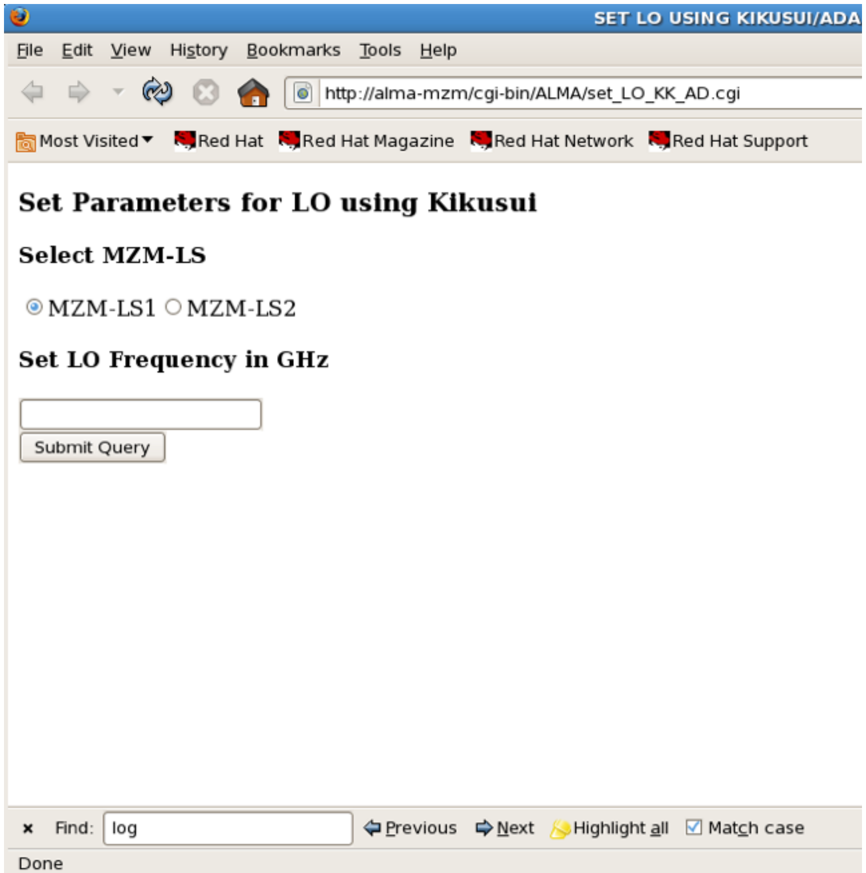


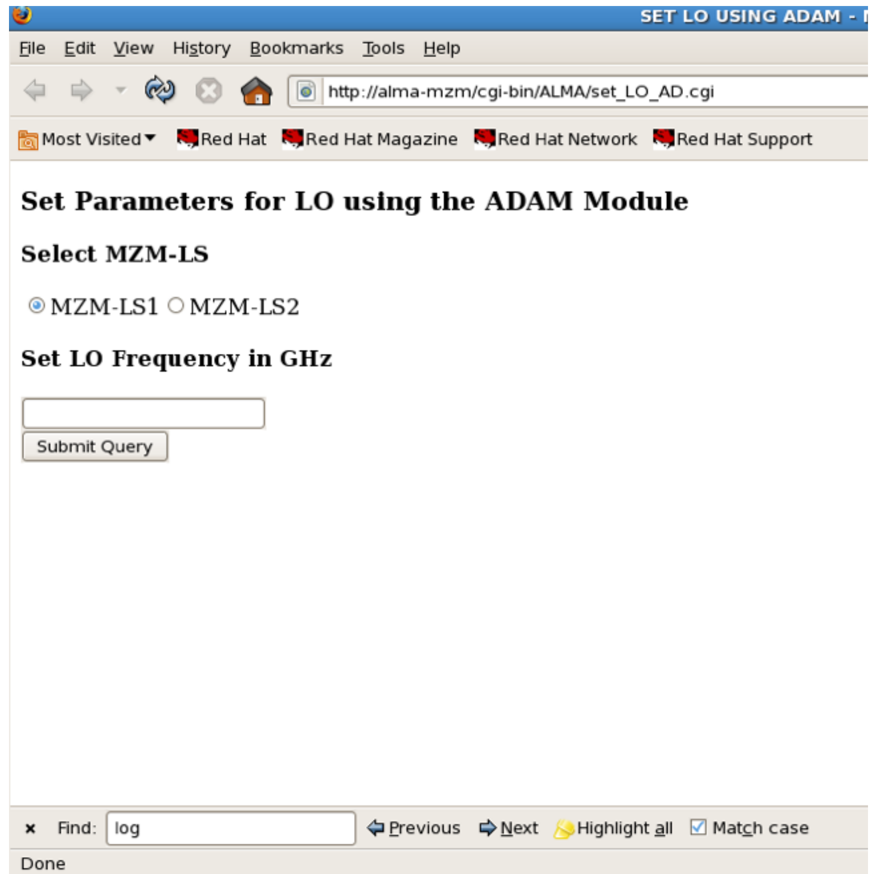
- Software Flow Diagram
  - Each stage collects instrument read-back which is logged
  - Unresponsive instruments create appropriate error messages which terminates the program



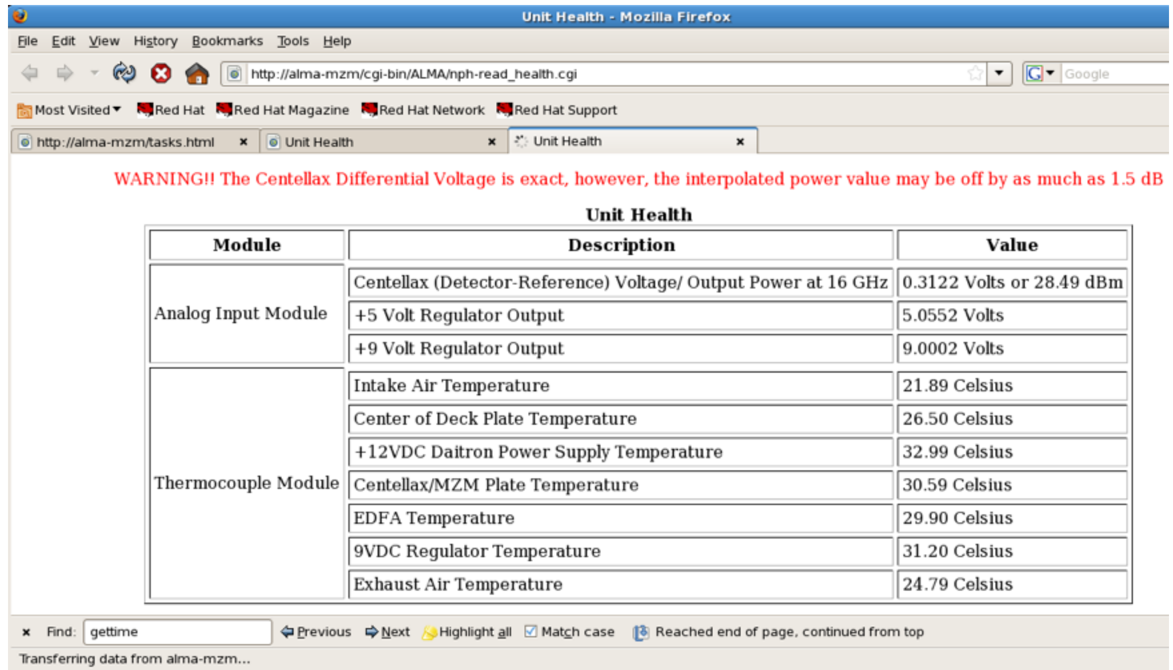
- MZM-LS Control Window
  - Main window is shown below

- MZM-LS Control Window (continued)
  - MZM DC bias can be controlled by either the external Kikusui unit or the internal ADAM unit
    - Must swap internal 9-pin D-sub connectors to switch between the 2 bias sources





- MZM-LS Control Window (continued)
  - Health page monitors 2 regulated voltage values (+5 and +9 VDC) and 7 temperature values



Module	Description	Value
Analog Input Module	Centellax (Detector-Reference) Voltage/ Output Power at 16 GHz	0.3122 Volts or 28.49 dBm
	+5 Volt Regulator Output	5.0552 Volts
	+9 Volt Regulator Output	9.0002 Volts
Thermocouple Module	Intake Air Temperature	21.89 Celsius
	Center of Deck Plate Temperature	26.50 Celsius
	+12VDC Daitron Power Supply Temperature	32.99 Celsius
	Centellax/MZM Plate Temperature	30.59 Celsius
	EDFA Temperature	29.90 Celsius
	9VDC Regulator Temperature	31.20 Celsius
	Exhaust Air Temperature	24.79 Celsius

- Summary
  - Residual phase noise performance of MZM Laser Synthesizer is very good
    - Measure 11 fsec (0.4 degrees), spec is 27 fsec (1.0 degrees), both at 100 GHz
    - Residual phase noise is ~0.5 of the baseline Laser Synthesizer
  - Final LO phase noise is driven by individual contributors
    - CVR, LS, LLC, WCA, CCA
    - Overall improvement in final LO phase noise is ~0.7
  - Compatibility issue with LLC in Fast Frequency Switching mode
    - Re-introduction of ML after LS needs to be further evaluated
    - Requires hardware modification of existing CLO system
  - Monitor & Control
    - ALMA standard protocol is CANbus
    - MZM Laser Synthesizer utilizes Ethernet protocol
  - Physical Form Factor
    - CLO system spec calls for "flow through" air chassis design
    - MZM Laser Synthesizer utilized a commercial EMI chassis
  - Working with ALMA on an upgrade proposal for the CLO system

- APPENDIX

- Frequency Coverage

Band	1st LO Ref. Freq. (GHz)		CC	1st LO Frequency (GHz)		Sky Frequency (GHz)		IF Frequency (GHz)		# of IFs	Total IF BW
	Low	High	Multiplier	Low	High	Low	High	Low	High		(GHz)
1	27.3	33.0	1	27.3	33.0	31.3	45.0	4.0	12.0	2	16.0
2	79.0	94.0	1	79.0	94.0	67.0	90.0	4.0	12.0	2	16.0
3	92.0	108.0	1	92.0	108.0	84.0	116.0	4.0	8.0	4	16.0
4	66.5	77.5	2	133.0	155.0	125.0	163.0	4.0	8.0	4	16.0
5	28.5	34.0	6	171.0	204.0	163.0	211.0	4.0	8.0	4	16.0
6	73.7	88.3	3	221.1	264.9	211.0	275.0	6.0	10.0	4	16.0
7	94.3	121.7	3	282.9	365.1	275.0	373.0	4.0	8.0	4	16.0
8	65.5	82.0	6	393.0	492.0	385.0	500.0	4.0	8.0	4	16.0
9	67.8	79.1	9	610.2	711.9	602.0	720.0	4.0	12.0	2	16.0
10	88.3	104.7	9	794.7	942.3	787.0	950.0	4.0	12.0	2	16.0

- Power Consumption

Ref Des	Description	V (V)	I (A)	P (W)	Comments
AR1	Centellax TA2U50HA, RF amplifier	9.0	1.5	13.5	Operate from PS1
AR2	Amonics AEDFA-C-PM-17I-M, PM EDFA	5.0	1.0	5.0	Operate from PS1
SW1	Leoni, SPDT PM switch	5.0	0.1	0.5	Operate from PS1
FN1	Globe Motors D36-B10A-05W3-100	24.0	0.2	4.8	Operate from PS3
FN2	Globe Motors D36-B10A-05W3-100	24.0	0.2	4.8	Operate from PS3
A1	Advantech ADAM-5000	12.0	0.6	7.2	Operate from PS2
A2	Custom DC amplifier board	15.0	0.1	1.5	Operate from PS2
		-15.0	0.1	1.5	
	Total calculated DC of individual components			37.3	

PS1	Diatron HFS50-12, +12V @ 4.2A, 5mV ripple (85–264 VAC, 47–63 Hz)		2.6	31.2	AR1, AR2, SW1
PS2	Diatron HFD30-15, +15V @ 1.5A, -15.0V @ 0.5A, 3mV ripple (87-264 VAC, 47-63 Hz)		0.7 / 0.1	12.0	A1, A2, future AMBSI board
PS3	TDK Lambda RTW24-2R2, 24V @ 2.2A, 100mV ripple (85-265 VAC, 47-440 Hz)		0.4	9.6	FN1, FN2
	Total calculated DC including regulator losses			52.8	

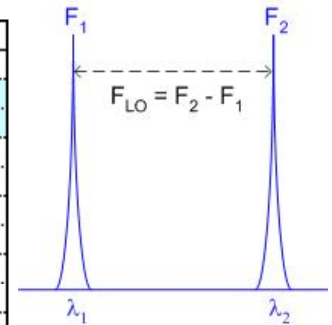
	Measured AC consumption (120 VAC)			58	MZM-LS in active mode

- Requirements Overview [reference ALMA-56.15.00.00-001-A-SPE, rev A]

Para. #	Parameter	Specification	Capability	Comments
	AC INPUT POWER			
4.1	Input power voltage/frequency	120 VAC, 60 Hz / 230 VAC, 60 Hz	Comply	By design, auto switching
4.1	Power consumption	< 200 W	< 50 W	
	MASTER LASER INPUT SOURCE			
2.1.1	Optical input wavelength	1556.21 +/- 0.01 nm	Comply	Defined for tests
2.1.3	Optical input power	20 +/- 10 mW	20 mW	Settable with variable attenuator
2.1.5	Optical input polarization	Linear	Comply	Slow axis keyed
2.1.6	Optical input PER	>/= 25 dB	21 dB	TeraXion master laser, can improve with external polarizer
	CENTRAL VARIABLE REFERENCE			
2.2.1	RF input frequency	8.182 - 16.525 GHz	13.630 - 30.428 GHz	MZM-LS does not have an internal frequency doubler (can be added upon request)
2.2.3	RF input power	+21 +/- 3 dBm	+8 +/- 1 dBm	13 - 31 GHz
2.2.5	RF input RMS phase delay noise	< 50 fsec, 1 Hz to 1 kHz	TBD	Spec is equivalent to 0.425 degrees at 25 GHz
2.2.5	RF input RMS phase delay noise	< 27 fsec, 1 kHz to 1 MHz	29 fsec, 3 kHz to 3 MHz (@ 25 GHz)	Spec is equivalent to 0.243 degrees at 25 GHz

- Requirements Overview (continued)

Para. #	Parameter	Specification	Capability	Comments
	OPTICAL OUTPUT (J2)			Single fiber output will carry 2 optical wavelengths
3.3.1	Band 1 LO coverage (difference frequency between optical tones)	27.260 - 33.050 GHz	26.0 - 34.0 GHz	Null bias mode
3.3.1	Bands 2 - 10 LO coverage	65.460 - 121.712 GHz	64.0 - 124.0 GHz	
3.4.7	Fast frequency switching	</= 500 msec (goal < 100 msec)	200 msec	
3.4.4 / 3.4.7	Fast frequency switching duty cycle	10 seconds min.	Comply	10 sec frequency A, 10 sec frequency B, …
2.3.5	Optical output wavelength range, approximate	1555.7 - 1556.7 nm	1555.709 - 1556.711 nm	For 124.0 GHz LO frequency
3.5.1	Optical output power per lightwave	>/= 2 mW (>/= +3 dBm)	+4.0 dBm	Output power tunable via EDFA, can achieve +7 dBm per tone
3.5.4	Optical output power stability, RMS over 300 sec interval, samples averaged over 10 sec	</= 0.4 dB	0.04 dB	Worstcase over a measurement interval of 12 hours
3.5.3	Optical output lightwave tone imbalance	</= 3 dB	< 0.6 dB	Can easily meet this requirement
3.5.2	Optical output desired tone to undesired tone + noise power	>/= 10 dB	18 dB	Degrades with higher LO frequency, 18 dB was measured at 124 GHz



- Requirements Overview (continued)

Para. #	Parameter	Specification	Capability	Comments
3.9	Optical output polarization	Slow axis keyed	Comply	By design
3.9	Polarization extinction ratio (PER)	>/= 20 dB	23 dB	
3.9	Misalignment of 2 lightwaves	</= 1.15 degrees	TBD	Measurement of NAOJ system was < 0.9 degrees
3.9	State of polarization change, measured over 300 seconds	</= +/-0.01 radians	+/-0.0095 radians	RMS value, worst case over a measurement interval of 12 hours
	PHOTOMIXER OUTPUT			
3.6.3 / 3.6.4	Residual phase noise: 1 Hz to 1 kHz, coherent noise over differential fiber distances of 0.2 km to 15 km	</= 50 fsec (</= 1.800 deg. at 100 GHz)	TBD	"Residual" refers to phase noise contribution of the ALS alone & excludes the CVR contribution
3.6.1	Residual phase noise: 1 kHz to 1 MHz, non-coherent noise over differential fiber distances of 0.2 km to 15 km	</= 27 fsec (</= 0.972 deg. at 100 GHz)	12 fsec, 3 kHz to 3 MHz (@ 100 GHz)	
3.7	Optical output phase drift WRTo temperature	< 200 fsec/K (<7.2 deg./K at 100 GHz)	TBD	