Revision	ECO#	Description	Approved	Date
3		See Revision History	See ECO	04/09/2020

Pearl for J5xx FATP System Engineering Requirements Specification

Document 099-23021
Version 3
April 9, 2020

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Table of Contents

1. About This Document

This document describes the Pearl sub-assembly and related assembly process and test metrics as part of the J4XX system. The contents of this Engineering Requirements Specification, including any Apple-Vendor project-specific information, are Apple Confidential Information subject to the non-disclosure and use restrictions set forth in the Confidentiality Agreement between Vendor and Apple.

1.1. About This Document

This guide assumes you have some familiarity with Apple portable products. The people who benefit from this guide are:

- Manufacturers who are involved in assembly and test of the Pearl sub-system.
- Manufacturers who are involved in assembly and test of the J4XX product
- Engineers who are designing components and processes for the Pearl Sub-system.
- Engineers who are performing failure analysis on the Pearl sub-system at FATP.

1.2. Related Documents

Specification	Description	
Module documents	Titus system ERS	rdar://problem/41963879
	099-10370-A: Juliet-A system ERS	rdar://problem/27469342
	Rosaline System ERS	rdar://problem/27591947
	Montague	rdar://problem/20410235
Pearl Calibration/ Test ERS	099-10745: Pearl Test ERS Ver 13	rdar://problem/28279854
	099-10746: Pearl Calibration ERS Ver 17.1	rdar://problem/27002593
	099-08178; Pearl Sub-assembly ERS	rdar://problem/29803027
	Compliance Test ERS	rdar://problem/29176969
	Co-existence interface	rdar://problem/23762360
Others	Doppler-Pearl coexistence	rdar://problem/18422298
	Rel test plan	
	Wolverine ERS	
	099-13910-01: Rigel FATP Test ERS	rdar://problem/39651349

*please refer to Rosaline and Prox ERS for appropriate coverage and spec limits

1.3. Related APNs

Specification	Description
J4XX APNs	631-05065: Pearl- sub-assembly APN
	651-00141: Juliet-A module APN
	651-00156: Long Island-A module APN
	380-00055: Rosaline module APN
	673-00425: Titus-C Module APN

1.4. Abbreviations and Acronyms

Acronym	Defintion
CTS	Critical to safety
TAM	Titus Adhesive machine
PAM	Pearl Assembly Machine
TOM	Tilt of Module
MBO	Machine Buy-Off (Machine setup and validation)
IPQC	In Process Quality control
PF	Protective film
OVC	Over Current
OVV	Over Voltage
CC	Continuity checker
LSL	Lower spec limit
USL	Upper spec limit

2. Test, specs and conditions

2.1. Flow diagram

The below flow chart is an overview of the Pearl related FATP process and test steps.
The pearl metrics collected at each station is specified in the table below.

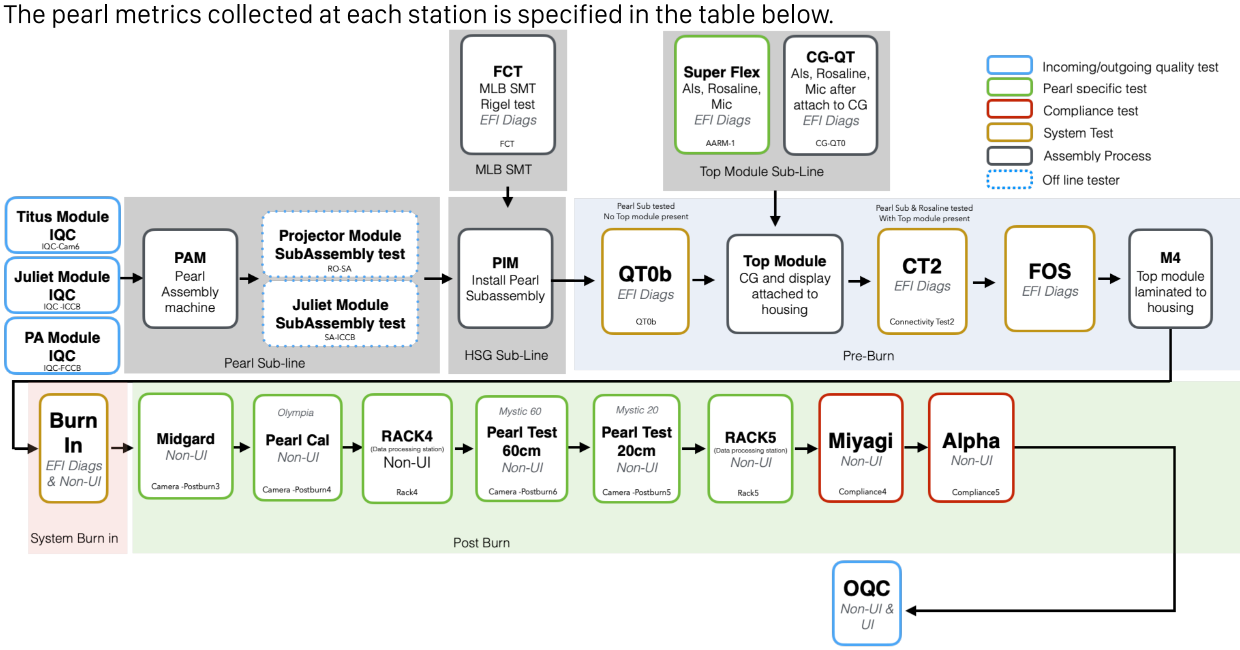

Figure 1: Pearl specific FATP process and test flow

2.2. Test Station

Station	Mode	POR	Test Item
QT0b	EFI Diags	DOE	Titus/FCAM/Juliet SN
			Mama Bear arm check
			Pearl Status
			JU & FCAM DLI
			JU Func. check using IR LED
CT2	EFI Diags	MP	Rosaline SN
			Rigel fault status
			MamaBear Arm Check

Station	Mode	POR	Test Item
			Pearl Status
			Connectivity Ju & Titus B2B Only
			NVM & Traceability
			RxCL Key Write
			Prox connectivity
CGS	N.A	MP	takes a picture of the housing Sub-assembly before closing CG.
FOS	[EFI Diags]	MP	FCAM & Juliet Preview
BurnIn	Non-UI/EFI diags	MP	Rigel fault testing (Armed only)
			Rigel OTP Checks
			MamaBear Arm Check
			Titus thermal tests (Armed only)
			Rosaline thermal tests / fuse stress test
			Pearl cap
			Juliet to Rigel strobe
			Verify Fcam to Juliet Sync Strobe
Midgard	[Non-UI]	MP	Rosaline SNR, uniformity
			JU blemish & Dark spots
Pearl Cal	[Non-UI]	MP	Image capture station for Pearl System calibration process 5 Angle Data Capturing for Pearl Calibration: Juliet images with External flood Juliet with Titus Fcam

Station	Mode	POR	Test Item
Rack1	[Non-UI]	MP	Image analysis station for Pearl System calibration process Upload to FDR Camera Posture Reference Images gen Projector Baseline Distortion (RGB/IR) EFL, Principal(RGB/IR)
Pearl Test20cm	[Non-UI]	MP	Capture station w. sanity check limits Juliet MTF testing Depth Accuracy
Pearl test 60cm	[Non-UI]	MP	Capture station w. sanity check limits Juliet MTF testing Depth Accuracy *Titus thermal tests* *(substitute for BurnIn)*
Rack2	[Non-UI]	MP	Analysis rack for all image captures Real world analysis (RWA) Registration accuracy (RA) SNR
Amai	[Non-UI]		Total power measurement, Titus, Rosaline, Prox (Audit station for Miyagi,)
Miyagi	[Non-UI]	MP	Titus/Rosaline*/Prox* Compliance AE heat map Total power
R-comp Romeo/ Rosaline	[Non-UI]		AE heat map measurements for Prox/Rosaline/Titus (Audit station for Miyagi, aka BP)

Station	Mode	POR	Test Item
Alpha	[Non-UI]	MP	Titus Compliance Rosaline Compliance* Alpha and PLR measurement

2.3. PDCA key Mapping

2.3.1. Titus IQC OTP Checks

<table>
<tr><th>Parameter</th><th>LSL</th><th>USL</th><th>Notes</th></tr>
<tr><td>OTP Version [7:0]</td><td colspan="2">0x07</td><td></td></tr>
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<tr><td>Program Variant [3:0]</td><td colspan="2">0x00</td><td></td></tr>
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<tr><td>NTC Cal Checksum</td></tr>
<tr><td>Dead Emitter Checksum</td></tr>
<tr><td>WL Cal Checksum</td></tr>
<tr><td>NTC Cal</td><td colspan="3">Must not be zeros</td></tr>
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2.3.2. Titus IQC/SA Tester

IQC is controlled by Sifter file

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
IQC								
Field of Illumination	Field of Illumination X	FOIX_H	75.3	78.7	75.3	78.7	deg	Both
	Field of Illumination Y	FOIY_H	85.2	90	85.2	90	deg	Both
Spot Size	Maximum Window Spot Diameter	SSpD_00_Max_60_H	1.51	2.14	1.51	2.14	mm	Both
	Average Window Spot Diameter	SSpD_Avg_60_00_H					mm	Both
	Maximum Window Spot Diameter	SSpD_10_Max_60_H	1.51	2.14	1.51	2.14	mm	Both
	Maximum Window Spot Diameter	SSpD_01_Max_60_H	1.51	2.14	1.51	2.14	mm	Both
	Maximum Window Spot Diameter	SSpD_11_Max_60_H	1.51	2.14	1.51	2.14	mm	Both
	Maximum Spot Diameter X	D4X_00_Max_60_H					mm	Both
	Average Spot Diameter X	D4X_00_Avg_60_H					mm	Both
	Maximum Spot Diameter Y	D4Y_00_Max_60_H					mm	Both
	Average Spot Diameter Y	D4Y_00_Avg_60_H					mm	Both
	X-to-Y Spot Diameter Ratio	D4_00_60_Ratio_H		1.19		1.19	Ratio	Both
	Spot Diameter Outlier Window Count	Window_Count_Outlier_60_00_H	0	0	0	0		Both
	Spot Diameter Outlier Window Count	Window_Count_Outlier_60_10_H	0	0	0	0		Both
	Spot Diameter Outlier Window Count	Window_Count_Outlier_60_01_H	0	0	0	0		Both
	Spot Diameter Outlier Window Count	Window_Count_Outlier_60_11_H	0	0	0	0		Both
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_60_00_H	0	0	0	0		Both
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_60_10_H	0	0	0	0		Both
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_60_01_H	0	0	0	0		Both
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_60_11_H	0	0	0	0		Both
Spot Contrast	Minimum Window Spot Contrast	SSpC_00_Min_60_H	80	100	80	100	%	Both
	Minimum Window Spot Contrast	SSpC_10_Min_60_H	80	100	80	100	%	Both
	Minimum Window Spot Contrast	SSpC_01_Min_60_H	80	100	80	100	%	Both
	Minimum Window Spot Contrast	SSpC_11_Min_60_H	80	100	80	100	%	Both
	Spot Contrast Outlier Window Count	Window_Count_Outlier_Con_60_00_H	0	0	0	0		Both
	Spot Contrast Outlier Window Count	Window_Count_Outlier_Con_60_10_H	0	0	0	0		Both
	Spot Contrast Outlier Window Count	Window_Count_Outlier_Con_60_01_H	0	0	0	0		Both
	Spot Contrast Outlier Window Count	Window_Count_Outlier_Con_60_11_H	0	0	0	0		Both
	Spot Contrast Avg OOS Window Count	Window_Count_SSpC_60_00_H	0	0	0	0		Both
	Spot Contrast Avg OOS Window Count	Window_Count_SSpC_60_10_H	0	0	0	0		Both
	Spot Contrast Avg OOS Window Count	Window_Count_SSpC_60_01_H	0	0	0	0		Both
	Spot Contrast Avg OOS Window Count	Window_Count_SSpC_60_11_H	0	0	0	0		Both
LIV	Center Wavelength	CWL_HHD	934.6	948.4	934.4	948.6	nm	IQC
	Spectral Width	SpW_HHD	1.3	4.2	1.3	4.2	nm	IQC
	Total Power	Ptot_HHD	1500	2900	1500	2900	mW	IQC
	VCSEL Voltage	V_A_HHD	1.75	2.85	1.75	2.85	V	IQC
	VCSEL Voltage	V_B_HHD	1.75	2.85	1.75	2.85	V	IQC
	VCSEL Voltage	V_D_HHD	1.75	2.85	1.75	2.85	V	IQC

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
Uniformity	VCSEL Voltage	V_S_HHD	1.75	2.85	1.75	2.85	V	IQC
	VCSEL Voltage Std	V_STD_HHD	0	0.075	0	0.075	V	IQC
	Wallplug Efficiency	WPE_HHD					%	IQC
	Tile Uniformity	Uni_T_H	6.5	65	6.5	65	%	Both
	Tile Uniformity 3 Sigma	Uni_T_3S_H					%	Both
Dead Spots	Dead Spot Count	DSC_H	0	3	0	3		Both
	Dead Spot Cluster Count	DSCC_H	0	1	0	1		Both
	Dead Spot Count in A&B	DSC_AB	10	10	10	10		Both
Alignment	Spot Separation	SpS_60_H	2.7	4.98	2.7	4.98	mRad	Both
	Z Rotation	Z_Rot_H	-2.4	2.4	-2.4	2.4	mrad	Both
	Pattern Rotation	Rot_P_H	-1.2	1.2	-1.2	1.2	deg	Both
	Pattern Tilt X	X_Tilt_H	-1.4	1.4	-1.4	1.4	deg	Both
	Pattern Tilt Y	Y_Tilt_H	-1.3	1.3	-1.3	1.3	deg	Both
	Vision Station Rotation Metric	vis_rot_1_H	-0.02	0.02	-0.02	0.02	rad	Both
	Vision Station Rotation Metric	vis_rot_2_H	-0.02	0.02	-0.02	0.02	rad	Both
	Vision Station Rotation Metric	vis_rot_3_H					rad	Both
	Vision Station Rotation Metric	vis_rot_RFXscore	0	0.15	0	0.15		Both
Thermal	NTC Delta VCSEL Off	NTC_Delta_Off_H	-5	5	-5	5	C	Both
	NTC VCSEL ON	NTC_HHD	45	59	45	59	C	Both
Cap Sense	Compliance Cap Reading	Cap_Mean	0	0	0	0	pF	Both
	Spot Power Center Tile	SpP_60_H	17	68	17	68	uW	Both
	Min Spot Power of Tile	SpP_Min_1_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_2_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_3_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_4_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_5_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_6_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_7_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_8_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_9_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_10_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_11_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_12_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_13_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_14_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_15_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_16_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_17_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_18_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_19_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_20_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_21_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_22_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_23_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_24_H	16.38		16.38		uW	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
	Min Spot Power of Tile	SpP_Min_25_H					uW	Both
	Min Spot Power of Tile	SpP_Min_26_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_27_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_28_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_29_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_30_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_31_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_32_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_33_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_34_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_35_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_36_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_37_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_38_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_39_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_40_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_41_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_42_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_43_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_44_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_45_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_46_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_47_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_48_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_49_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_50_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_51_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_52_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_53_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_54_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_55_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_56_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_57_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_58_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_59_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_60_H	12.6		12.6		uW	Both
	Min Spot Power of Tile	SpP_Min_61_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_62_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_63_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_64_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_65_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_66_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_67_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_68_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_69_H	16.38		16.38		uW	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
SpP	Min Spot Power of Tile	SpP_Min_70_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_71_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_72_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_73_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_74_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_75_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_76_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_77_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_78_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_79_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_80_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_81_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_82_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_83_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_84_H					uW	Both
	Min Spot Power of Tile	SpP_Min_85_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_86_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_87_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_88_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_89_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_90_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_91_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_92_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_93_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_94_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_95_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_96_H	16.38		16.38		uW	Both
	Min Spot Power of Tile	SpP_Min_97_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_98_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_99_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_100_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_101_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_102_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_103_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_104_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_105_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_106_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_107_H	19.98		19.98		uW	Both
	Min Spot Power of Tile	SpP_Min_108_H	19.98		19.98		uW	Both
	Max Spot Power of Tile	SpP_Max_1_H					uW	Both
	Max Spot Power of Tile	SpP_Max_2_H					uW	Both
	Max Spot Power of Tile	SpP_Max_3_H					uW	Both
	Max Spot Power of Tile	SpP_Max_4_H					uW	Both
	Max Spot Power of Tile	SpP_Max_5_H					uW	Both
	Max Spot Power of Tile	SpP_Max_6_H					uW	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
	Max Spot Power of Tile	SpP_Max_7_H					uW	Both
	Max Spot Power of Tile	SpP_Max_8_H					uW	Both
	Max Spot Power of Tile	SpP_Max_9_H					uW	Both
	Max Spot Power of Tile	SpP_Max_10_H					uW	Both
	Max Spot Power of Tile	SpP_Max_11_H					uW	Both
	Max Spot Power of Tile	SpP_Max_12_H					uW	Both
	Max Spot Power of Tile	SpP_Max_13_H					uW	Both
	Max Spot Power of Tile	SpP_Max_14_H					uW	Both
	Max Spot Power of Tile	SpP_Max_15_H					uW	Both
	Max Spot Power of Tile	SpP_Max_16_H					uW	Both
	Max Spot Power of Tile	SpP_Max_17_H					uW	Both
	Max Spot Power of Tile	SpP_Max_18_H					uW	Both
	Max Spot Power of Tile	SpP_Max_19_H					uW	Both
	Max Spot Power of Tile	SpP_Max_20_H					uW	Both
	Max Spot Power of Tile	SpP_Max_21_H					uW	Both
	Max Spot Power of Tile	SpP_Max_22_H					uW	Both
	Max Spot Power of Tile	SpP_Max_23_H					uW	Both
	Max Spot Power of Tile	SpP_Max_24_H					uW	Both
	Max Spot Power of Tile	SpP_Max_25_H					uW	Both
	Max Spot Power of Tile	SpP_Max_26_H					uW	Both
	Max Spot Power of Tile	SpP_Max_27_H					uW	Both
	Max Spot Power of Tile	SpP_Max_28_H					uW	Both
	Max Spot Power of Tile	SpP_Max_29_H					uW	Both
	Max Spot Power of Tile	SpP_Max_30_H					uW	Both
	Max Spot Power of Tile	SpP_Max_31_H					uW	Both
	Max Spot Power of Tile	SpP_Max_32_H					uW	Both
	Max Spot Power of Tile	SpP_Max_33_H					uW	Both
	Max Spot Power of Tile	SpP_Max_34_H					uW	Both
	Max Spot Power of Tile	SpP_Max_35_H					uW	Both
	Max Spot Power of Tile	SpP_Max_36_H					uW	Both
	Max Spot Power of Tile	SpP_Max_37_H					uW	Both
	Max Spot Power of Tile	SpP_Max_38_H					uW	Both
	Max Spot Power of Tile	SpP_Max_39_H					uW	Both
	Max Spot Power of Tile	SpP_Max_40_H					uW	Both
	Max Spot Power of Tile	SpP_Max_41_H					uW	Both
	Max Spot Power of Tile	SpP_Max_42_H					uW	Both
	Max Spot Power of Tile	SpP_Max_43_H					uW	Both
	Max Spot Power of Tile	SpP_Max_44_H					uW	Both
	Max Spot Power of Tile	SpP_Max_45_H					uW	Both
	Max Spot Power of Tile	SpP_Max_46_H					uW	Both
	Max Spot Power of Tile	SpP_Max_47_H					uW	Both
	Max Spot Power of Tile	SpP_Max_48_H					uW	Both
	Max Spot Power of Tile	SpP_Max_49_H					uW	Both
	Max Spot Power of Tile	SpP_Max_50_H					uW	Both
	Max Spot Power of Tile	SpP_Max_51_H					uW	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
	Max Spot Power of Tile	SpP_Max_52_H					uW	Both
	Max Spot Power of Tile	SpP_Max_53_H					uW	Both
	Max Spot Power of Tile	SpP_Max_54_H					uW	Both
	Max Spot Power of Tile	SpP_Max_55_H					uW	Both
	Max Spot Power of Tile	SpP_Max_56_H					uW	Both
	Max Spot Power of Tile	SpP_Max_57_H					uW	Both
	Max Spot Power of Tile	SpP_Max_58_H					uW	Both
	Max Spot Power of Tile	SpP_Max_59_H					uW	Both
	Max Spot Power of Tile	SpP_Max_60_H					uW	Both
	Max Spot Power of Tile	SpP_Max_61_H					uW	Both
	Max Spot Power of Tile	SpP_Max_62_H					uW	Both
	Max Spot Power of Tile	SpP_Max_63_H					uW	Both
	Max Spot Power of Tile	SpP_Max_64_H					uW	Both
	Max Spot Power of Tile	SpP_Max_65_H					uW	Both
	Max Spot Power of Tile	SpP_Max_66_H					uW	Both
	Max Spot Power of Tile	SpP_Max_67_H					uW	Both
	Max Spot Power of Tile	SpP_Max_68_H					uW	Both
	Max Spot Power of Tile	SpP_Max_69_H					uW	Both
	Max Spot Power of Tile	SpP_Max_70_H					uW	Both
	Max Spot Power of Tile	SpP_Max_71_H					uW	Both
	Max Spot Power of Tile	SpP_Max_72_H					uW	Both
	Max Spot Power of Tile	SpP_Max_73_H					uW	Both
	Max Spot Power of Tile	SpP_Max_74_H					uW	Both
	Max Spot Power of Tile	SpP_Max_75_H					uW	Both
	Max Spot Power of Tile	SpP_Max_76_H					uW	Both
	Max Spot Power of Tile	SpP_Max_77_H					uW	Both
	Max Spot Power of Tile	SpP_Max_78_H					uW	Both
	Max Spot Power of Tile	SpP_Max_79_H					uW	Both
	Max Spot Power of Tile	SpP_Max_80_H					uW	Both
	Max Spot Power of Tile	SpP_Max_81_H					uW	Both
	Max Spot Power of Tile	SpP_Max_82_H					uW	Both
	Max Spot Power of Tile	SpP_Max_83_H					uW	Both
	Max Spot Power of Tile	SpP_Max_84_H					uW	Both
	Max Spot Power of Tile	SpP_Max_85_H					uW	Both
	Max Spot Power of Tile	SpP_Max_86_H					uW	Both
	Max Spot Power of Tile	SpP_Max_87_H					uW	Both
	Max Spot Power of Tile	SpP_Max_88_H					uW	Both
	Max Spot Power of Tile	SpP_Max_89_H					uW	Both
	Max Spot Power of Tile	SpP_Max_90_H					uW	Both
	Max Spot Power of Tile	SpP_Max_91_H					uW	Both
	Max Spot Power of Tile	SpP_Max_92_H					uW	Both
	Max Spot Power of Tile	SpP_Max_93_H					uW	Both
	Max Spot Power of Tile	SpP_Max_94_H					uW	Both
	Max Spot Power of Tile	SpP_Max_95_H					uW	Both
	Max Spot Power of Tile	SpP_Max_96_H					uW	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
	Max Spot Power of Tile	SpP_Max_97_H					uW	Both
	Max Spot Power of Tile	SpP_Max_98_H					uW	Both
	Max Spot Power of Tile	SpP_Max_99_H					uW	Both
	Max Spot Power of Tile	SpP_Max_100_H					uW	Both
	Max Spot Power of Tile	SpP_Max_101_H					uW	Both
	Max Spot Power of Tile	SpP_Max_102_H					uW	Both
	Max Spot Power of Tile	SpP_Max_103_H					uW	Both
	Max Spot Power of Tile	SpP_Max_104_H					uW	Both
	Max Spot Power of Tile	SpP_Max_105_H					uW	Both
	Max Spot Power of Tile	SpP_Max_106_H					uW	Both
	Max Spot Power of Tile	SpP_Max_107_H					uW	Both
	Max Spot Power of Tile	SpP_Max_108_H					uW	Both
	PPO Center Tile	PPO_ZO_H	0.2	2	0.2	2	%	Both
	PPO of Tile	PPO_1_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_2_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_3_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_4_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_5_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_6_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_7_H	0.5175	1.7281	0.5175	1.7281	%	Both
	PPO of Tile	PPO_8_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_9_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_10_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_11_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_12_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_13_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_14_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_15_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_16_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_17_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_18_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_19_H	0.4266	1.4234	0.4266	1.4234	%	Both
	PPO of Tile	PPO_20_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_21_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_22_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_23_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_24_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_25_H					%	Both
	PPO of Tile	PPO_26_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_27_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_28_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_29_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_30_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_31_H	0.5175	1.7281	0.5175	1.7281	%	Both
	PPO of Tile	PPO_32_H	0.5535	1.7281	0.5535	1.7281	%	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
PPO	PPO of Tile	PPO_33_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_34_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_35_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_36_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_37_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_38_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_39_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_40_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_41_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_42_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_43_H	0.4086	1.364	0.4086	1.364	%	Both
	PPO of Tile	PPO_44_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_45_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_46_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_47_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_48_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_49_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_50_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_51_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_52_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_53_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_54_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_55_H	0.3078	1.221	0.3078	1.221	%	Both
	PPO of Tile	PPO_56_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_57_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_58_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_59_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_60_H	0.3303	1.221	0.3303	1.221	%	Both
	PPO of Tile	PPO_61_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_62_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_63_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_64_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_65_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_66_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_67_H	0.4086	1.364	0.4086	1.364	%	Both
	PPO of Tile	PPO_68_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_69_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_70_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_71_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_72_H	0.4365	1.364	0.4365	1.364	%	Both
	PPO of Tile	PPO_73_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_74_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_75_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_76_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_77_H	0.5535	1.7281	0.5535	1.7281	%	Both

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
	PPO of Tile	PPO_78_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_79_H	0.5175	1.7281	0.5175	1.7281	%	Both
	PPO of Tile	PPO_80_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_81_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_82_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_83_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_84_H					%	Both
	PPO of Tile	PPO_85_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_86_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_87_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_88_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_89_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_90_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_91_H	0.4266	1.4234	0.4266	1.4234	%	Both
	PPO of Tile	PPO_92_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_93_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_94_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_95_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_96_H	0.4572	1.4234	0.4572	1.4234	%	Both
	PPO of Tile	PPO_97_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_98_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_99_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_100_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_101_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_102_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_103_H	0.5175	1.7281	0.5175	1.7281	%	Both
	PPO of Tile	PPO_104_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_105_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_106_H	0.5258	1.7281	0.5258	1.7281	%	Both
	PPO of Tile	PPO_107_H	0.5535	1.7281	0.5535	1.7281	%	Both
	PPO of Tile	PPO_108_H	0.5535	1.7281	0.5535	1.7281	%	Both
	Maximum Window Spot Diameter	SSpD_00_Max_20_H			0.9	1.57	mm	SA
	Maximum Window Spot Diameter	SSpD_10_Max_20_H			0.9	1.57	mm	SA
	Maximum Window Spot Diameter	SSpD_01_Max_20_H			0.9	1.57	mm	SA
	Maximum Window Spot Diameter	SSpD_11_Max_20_H			0.9	1.57	mm	SA
	Average Spot Diameter X	D4X_00_Avg_20_H			0	1.52	mm	SA
	D4X_60/D4X_20	D4X_60_20_Ratio			1.05	1.63		SA
	Spot Diameter Outlier Window Count	Window_Count_Outlier_20_00_H			0	0		SA
Spot Size	Spot Diameter Outlier Window Count	Window_Count_Outlier_20_10_H			0	0		SA
	Spot Diameter Outlier Window Count	Window_Count_Outlier_20_01_H			0	0		SA
	Spot Diameter Outlier Window Count	Window_Count_Outlier_20_11_H			0	0		SA
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_20_00_H			0	0		SA
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_20_10_H			0	0		SA
	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_20_01_H			0	0		SA

Test Type	Description	Test Items	IQC Limit*		SA-tester Limit*		Unit	Coverage
			Min	Max	Min	Max		
Titus SA tester / IQC								
Spot Contrast	Spot Diameter Avg OOS Window Count	Window_Count_SSpD_20_11_H			0	0		SA
	Minimum Window Spot Contrast	SSpC_00_Min_20_H			77.5	100	%	SA
	Minimum Window Spot Contrast	SSpC_10_Min_20_H			77.5	100	%	SA
	Minimum Window Spot Contrast	SSpC_01_Min_20_H			77.5	100	%	SA
	Minimum Window Spot Contrast	SSpC_11_Min_20_H			77.5	100	%	SA

2.3.3.Juliet NVM Integrity Check

All values are specified in hexadecimal.

Parameter	LSL	USL	Notes
NVM Version [7:4]	0xA		Exact value
NVM Revision [3:0]	0x8		Exact value
Camera Project [7:0]	0x16		Exact value
Lens Shading Revision [7:0]	0x02		Exact value
Project Version [7:0]	0x0A		Project specific
Integrator [7:3]	0x6		Exact value
Plant [2:0]	0x0		Exact value
Lens Vendor [7:5]	0x2		Exact value
Lens Revision [4:2]	0x3		Exact value
Lens Variant [1:0]	0x0		Exact value
Filter Vendor [7:5]	0x3,0x5		Exact value
Filter Revision [4:2]	0x1	0x3	Range limit
Filter Variant [1:0]	0x0	0x2	Range limit
Substrate Vendor [7:5]	0x1, 0x2		Exact value
Substrate Revision [4:2]	0x3	0x5	Range limit
Substrate Variant [1:0]	0x0, 0x1		Exact value
Sensor Vendor [7:5]	0x5		Exact value
Sensor Revision [4:2]	0x6		Exact value
Sensor Variant [1:0]	0x2		Exact value
Flex Vendor [7:3]	0x3, 0x8		Exact value
Flex Revision [2:0]	0x4		Exact value
Stiffener Vendor [7:3]	0x2, 0x6		Exact value
Stiffener Revision [2:0]	0x6		Exact value
Camera Build [7:0]	0x10		Exact value
Config Number [7:0]	No limit		
Test Software Revision [7:0]	No limit		
Process DOE Code [7:0]	No limit		
General Info Checksum [7:0]			Must match checksum calculated from respective NVM segment

Lens Shading Checksum [7:0]			
ASP Checksum [7:0]			
X code (in SN: EEEERX)			Must match checksum calculated from serial number
Module SN			Must match scanned SN

2.3.4.Juliet SA tester/IQC

Test Items	Units	IQC Limit		SA Limit		Category	Notes
		Min	Max	Min	Max		
Juliet SA tester / IQC							
JU_20 MTF_30FP_N8_420_0	/					MTF20	
JU_20 MTF_30FP_N8_420_1	/					MTF20	
JU_20 MTF_30FP_N8_420_2	/					MTF20	
JU_20 MTF_30FP_N8_420_3	/					MTF20	
JU_20 MTF_30FP_N8_DELTA_420	/					MTF20	
JU_20 MTF_60FP_N8_420_0	/					MTF20	
JU_20 MTF_60FP_N8_420_1	/					MTF20	
JU_20 MTF_60FP_N8_420_2	/					MTF20	
JU_20 MTF_60FP_N8_420_3	/					MTF20	
JU_20 MTF_60FP_N8_DELTA_420	/					MTF20	
JU_20 MTF_85FP_N8_420_0	/					MTF20	
JU_20 MTF_85FP_N8_420_1	/					MTF20	
JU_20 MTF_85FP_N8_420_2	/					MTF20	
JU_20 MTF_85FP_N8_420_3	/					MTF20	
JU_20 MTF_85FP_N8_DELTA_420	/					MTF20	
JU_20 MTF_CENTER_N8_AVG_420	/					MTF20	
JU_20 MTF_30FP_N8_0	/	0.75	1	0.74	1	MTF20	
JU_20 MTF_30FP_N8_1	/	0.75	1	0.74	1	MTF20	
JU_20 MTF_30FP_N8_2	/	0.75	1	0.74	1	MTF20	
JU_20 MTF_30FP_N8_3	/	0.75	1	0.74	1	MTF20	
JU_20 MTF_30FP_N8_DELTA	/	0	0.15	0	0.15	MTF20	
JU_20 MTF_60FP_N8_0	/	0.71	1	0.7	1	MTF20	
JU_20 MTF_60FP_N8_1	/	0.71	1	0.7	1	MTF20	
JU_20 MTF_60FP_N8_2	/	0.71	1	0.7	1	MTF20	

Test Items	Units	IQC Limit		SA Limit		Category	Notes
		Min	Max	Min	Max		
Juliet SA tester / IQC							
JU_20 MTF_60FP_N8_3	/	0.71	1	0.7	1	MTF20	
JU_20 MTF_60FP_N8_DELTA	/	0	0.15	0	0.15	MTF20	
JU_20 MTF_85FP_N8_0	/	0.68	1	0.67	1	MTF20	
JU_20 MTF_85FP_N8_1	/	0.68	1	0.67	1	MTF20	
JU_20 MTF_85FP_N8_2	/	0.68	1	0.67	1	MTF20	
JU_20 MTF_85FP_N8_3	/	0.68	1	0.67	1	MTF20	
JU_20 MTF_85FP_N8_DELTA	/	0	0.2	0	0.2	MTF20	
JU_20 MTF_CENTER_N8_AVG	/	0.79	1	0.78	1	MTF20	
JU_60 MTF_30FP_N4_420_0	/					MTF60	
JU_60 MTF_30FP_N4_420_1	/					MTF60	
JU_60 MTF_30FP_N4_420_2	/					MTF60	
JU_60 MTF_30FP_N4_420_3	/					MTF60	
JU_60 MTF_30FP_N4_DELTA_420	/					MTF60	
JU_60 MTF_60FP_N4_420_0	/					MTF60	
JU_60 MTF_60FP_N4_420_1	/					MTF60	
JU_60 MTF_60FP_N4_420_2	/					MTF60	
JU_60 MTF_60FP_N4_420_3	/					MTF60	
JU_60 MTF_60FP_N4_DELTA_420	/					MTF60	
JU_60 MTF_85FP_N4_420_0	/					MTF60	
JU_60 MTF_85FP_N4_420_1	/					MTF60	
JU_60 MTF_85FP_N4_420_2	/					MTF60	
JU_60 MTF_85FP_N4_420_3	/					MTF60	
JU_60 MTF_85FP_N4_DELTA_420	/					MTF60	
JU_60 MTF_CENTER_N4_AVG_420	/					MTF60	
JU_60 MTF_30FP_N4_0	/	0.67	1	0.66	1	MTF60	
JU_60 MTF_30FP_N4_1	/	0.67	1	0.66	1	MTF60	
JU_60 MTF_30FP_N4_2	/	0.67	1	0.66	1	MTF60	
JU_60 MTF_30FP_N4_3	/	0.67	1	0.66	1	MTF60	
JU_60 MTF_30FP_N4_DELTA	/	0	0.12	0	0.12	MTF60	
JU_60 MTF_60FP_N4_0	/	0.6	1	0.59	1	MTF60	
JU_60 MTF_60FP_N4_1	/	0.6	1	0.59	1	MTF60	

Test Items	Units	IQC Limit		SA Limit		Category	Notes
		Min	Max	Min	Max		
Juliet SA tester / IQC							
JU_60 MTF_60FP_N4_2	/	0.6	1	0.59	1	MTF60	
JU_60 MTF_60FP_N4_3	/	0.6	1	0.59	1	MTF60	
JU_60 MTF_60FP_N4_DELTA	/	0	0.12	0	0.12	MTF60	
JU_60 MTF_85FP_N4_0	/	0.51	1	0.5	1	MTF60	
JU_60 MTF_85FP_N4_1	/	0.51	1	0.5	1	MTF60	
JU_60 MTF_85FP_N4_2	/	0.51	1	0.5	1	MTF60	
JU_60 MTF_85FP_N4_3	/	0.51	1	0.5	1	MTF60	
JU_60 MTF_85FP_N4_DELTA	/	0	0.15	0	0.15	MTF60	
JU_60 MTF_CENTER_N4_AVG	/	0.73	1	0.72	1	MTF60	
JU_60 DFOV_420	Degree					FOV	
JU_60 HFOV_420	Degree					FOV	
JU_60 VFOV_420	Degree					FOV	
JU_60 DFOV	Degree	81	83	81	83	FOV	
JU_60 HFOV	Degree	59.5	62.5	59.5	62.5	FOV	
JU_60 VFOV	Degree	68.5	71.5	68.5	71.5	FOV	
JU_60 ROT_420	Degree					Alignment60	
JU_60 TILT_TOTAL_420	Degree					Alignment60	
JU_60 TILT_X_420	Degree					Alignment60	
JU_60 TILT_Y_420	Degree					Alignment60	
JU_60 ROT	Degree	-1.1	1.1	-1.1	1.1	Alignment60	
JU_60 TILT_TOTAL	Degree	0	2	0	2	Alignment60	
JU_60 TILT_X	Degree	-1.8	1.8	-1.8	1.8	Alignment60	
JU_60 TILT_Y	Degree	-1.8	1.8	-1.8	1.8	Alignment60	
JU_20 Y_AVG_420	LSB	75	150	75	150	Brightness	consider removing
JU_60 Y_AVG_420	LSB	75	150	75	150	Brightness	consider removing
JU_20 Y_AVG	LSB	75	200	75	200	Brightness	
JU_60 Y_AVG	LSB	75	200	75	200	Brightness	
JU_60 CTF_CENTER_AVG_420	Ratio	1200		1200		Contrast	
JU_60 CTF_CENTER_AVG	Ratio	9000		9000		Contrast	
linetest_darkM_JU Sdelta_Col_Y	LSB	0.01	1.7	0.01	1.7	DarkFieldTest	
linetest_darkM_JU Sdelta_Row_Y	LSB	0.01	1.4	0.01	1.4	DarkFieldTest	

Test Items	Units	IQC Limit		SA Limit		Category	Notes
		Min	Max	Min	Max		
Juliet SA tester / IQC							
RowNoiseMC_JU pTemp	LSB	0	0.79	0	0.79	DarkFieldTest	
RowNoiseMC_JU tempRnR	Ratio	6		6		DarkFieldTest	
RowNoiseMC_JU tempRnR_total	Ratio	6		6		DarkFieldTest	
RowNoiseMC_JU total	LSB	0	0.91	0	0.91	DarkFieldTest	
RowNoiseMC_JU totalTemp	LSB	0	0.8	0	0.8	DarkFieldTest	
RowNoiseMC_JU_8x pTemp	LSB	0	3	0	3	DarkFieldTest	
RowNoiseMC_JU_8x tempRnR	Ratio	5	30	5	30	DarkFieldTest	
RowNoiseMC_JU_8x tempRnR_total	Ratio	5	30	5	30	DarkFieldTest	
RowNoiseMC_JU_8x total	LSB	0	3.6	0	3.6	DarkFieldTest	
RowNoiseMC_JU_8x totalTemp	LSB	0	3.1	0	3.1	DarkFieldTest	
blemish_JU centerCount	Count	0	0	0	0	LightFieldTest	
blemish_JU maxSize	Pixels	0	5	0	5	LightFieldTest	
blemish_JU maxSizeCenter	Pixels	0	5	0	5	LightFieldTest	
blemish_JU maxSizeOuter	Pixels	0	5	0	5	LightFieldTest	
blemish_JU outerCount	Count	0	25	0	25	LightFieldTest	
blemish_JU totalCount	Count	0	25	0	25	LightFieldTest	
blemish_JU yavg	LSB	80	200	80	200	LightFieldTest	
blemish_v3_JU centerCount	Count	0	0			LightFieldTest	
blemish_v3_JU maxSize	Pixels	0	2			LightFieldTest	
blemish_v3_JU maxSizeCenter	Pixels	0	0			LightFieldTest	
blemish_v3_JU maxSizeOuter	Pixels	0	2			LightFieldTest	
blemish_v3_JU outerCount	Count	0	2			LightFieldTest	
blemish_v3_JU totalCount	Count	0	2			LightFieldTest	
blemish_v3_JU yavg	LSB	80	200	80	200	LightFieldTest	
grayspot_JU clustercount	Count	0	0	0	0	LightFieldTest	
LDO ILDO10	mA					Electrical	system dependent, check with system EE
LDO ILDO17	mA					Electrical	system dependent, check with system EE
LDO VLDO10	mV					Electrical	system dependent, check with system EE

Test Items	Units	IQC Limit		SA Limit		Category	Notes
		Min	Max	Min	Max		
Juliet SA tester / IQC							
LDO VLDO17	mV					Electrical	system dependent, check with system EE
linetest_JU MaxRateCol_Y	Ratio	0	3.3	0	3.3	LightFieldTest	
linetest_JU MaxRateRow_Y	Ratio	0	3	0	3	LightFieldTest	
oc_JU oc_xShift	Pixels	-25	25	-25	25	LightFieldTest	
oc_JU oc_yShift	Pixels	-25	25	-25	25	LightFieldTest	
PRNU_JU PRNU_BL	%	0	3.4	0	3.4	LightFieldTest	
PRNU_JU PRNU_BR	%	0	3.45	0	3.45	LightFieldTest	
PRNU_JU PRNU_TL	%	0	3.45	0	3.45	LightFieldTest	
PRNU_JU PRNU_TR	%	0	3.4	0	3.4	LightFieldTest	
ri_JU ri_delta	Ratio	0	0.08	0	0.1	LightFieldTest	
ri_JU ri_ll	Ratio	0.29	0.5	0.28	0.5	LightFieldTest	
ri_JU ri_lr	Ratio	0.29	0.5	0.28	0.5	LightFieldTest	
ri_JU ri_ul	Ratio	0.29	0.5	0.28	0.5	LightFieldTest	
ri_JU ri_ur	Ratio	0.29	0.5	0.28	0.5	LightFieldTest	
ru_crop_JU max_ru_center	%	0	0.12	0	0.12	LightFieldTest	
ru_crop_JU max_ru_corner	%	0	0.12	0	0.12	LightFieldTest	
ru_crop_JU max_ru_edge	%	0	0.12	0	0.12	LightFieldTest	
Strobe RO	Bool	1	1	1	1	Electrical	1 indicate pass
SyncStreamSanityCheckVal Sync	Bool	0	0	0	0	Electrical	0 indicate pass

2.3.5.CT2

Test Type	Test Items	Spec Limit*		Unit	Notes
		Min	Max		
CT2					
Rigel status	read Rigel SN and fault status	0	0	N/A	
	Rigel_State	36|41|58		N/A	
Pearl Status	Pearl_Capacitance	-	-	N/A	2x readings
Mama bear arm check	MamaBear_Armed_State	1	1	N/A	
	MamaBear_Armed_State_Value	16, 17, 20, 21 or 28		N/A	Chapter 5.1.4 for explanation

2.3.6.QT1

Test Type	Test Items	Spec Limit*		Unit	Notes
		Min	Max		
QT1					
Juliet IR LED	Juliet_IR_Test_LED_ON	100		N/A	

2.3.7.Burnin

Test Type	Test Items	Spec Limit*		Unit	Notes
		Min	Max		
Burnin					
Romeo thermal	ROTherm ROActNTCDelta	6	20		Engineering build: in PT20
	ROTherm ROActNTCMax		69		Engineering build: in PT20
Pearl Status	Wildfire PearlStatus: Rigel_Fault_Status Iteration 1	0	0	N/A	
	Wildfire PearlStatus: Rigel_State Iteration 1			N/A	36 or 58
Rigel OTP	Wildfire RigelOTPVersion: Rigel_OTP_Version Iteration 1	DC	DC	N/A	
	Wildfire RigelOTPVersion: regotp26_st2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp27_st2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp37_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp38_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp39_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp40_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp43_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp48_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp49_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp50_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp51_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp52_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp53_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp54_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp55_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp56_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp57_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp58_ctm2 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp63_ctm1 Iteration 1	DC	DC	N/A	Follow Rigel DRI

Test Type	Test Items	Spec Limit* Min	Spec Limit* Max	Unit	Notes
Burnin					
	Wildfire RigelOTPVersion: regotp68_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp69_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp70_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp71_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp72_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
	Wildfire RigelOTPVersion: regotp73_ctm3 Iteration 1	DC	DC	N/A	Follow Rigel DRI
Titus Thermals	PearlTherm ROActNTC 1	N/A	N/A	ºC	Time: 0s
	PearlTherm ROActNTC 2	N/A	N/A	ºC	Time: 1s
	PearlTherm ROActNTC 3	N/A	N/A	ºC	Time: 2s
	PearlTherm ROActNTC 4	N/A	N/A	ºC	Time: 3s
	PearlTherm ROActNTC 5	N/A	N/A	ºC	Time: 4s
	PearlTherm ROActNTC 6	N/A	N/A	ºC	Time: 5s
	PearlTherm ROActNTC 7	N/A	N/A	ºC	Time: 6s
	PearlTherm ROActNTC 8	N/A	N/A	ºC	Time: 7s
	PearlTherm ROActNTC 9	N/A	N/A	ºC	Time: 8s
	PearlTherm ROActNTC 10	N/A	N/A	ºC	Time: 9s
	PearlTherm ROActNTC 11	N/A	N/A	ºC	Time: 10s
	PearlTherm ROActNTC 12	N/A	N/A	ºC	Time: 20s
	PearlTherm ROActNTC 13	N/A	N/A	ºC	Time: 30s
	PearlTherm ROActNTC 14	N/A	N/A	ºC	Time: 40s
	PearlTherm ROActNTC 15	N/A	N/A	ºC	Time: 50s
	PearlTherm ROActNTC 16	N/A	N/A	ºC	Time: 60s
	PearlTherm ROActNTC 17	N/A	N/A	ºC	Time: 70s
	PearlTherm ROActNTC 18	N/A	N/A	ºC	Time: 80s
	PearlTherm ROActNTC 19	N/A	N/A	ºC	Time: 100s
	PearlTherm ROActNTC 20	N/A	N/A	ºC	Time: 120s
	PearlTherm FrontCameraDie 1	N/A	N/A	ºC	Time: 0s
	PearlTherm FrontCameraDie 2	N/A	N/A	ºC	Time: 1s
	PearlTherm FrontCameraDie 3	N/A	N/A	ºC	Time: 2s
	PearlTherm FrontCameraDie 4	N/A	N/A	ºC	Time: 3s
	PearlTherm FrontCameraDie 5	N/A	N/A	ºC	Time: 4s
	PearlTherm FrontCameraDie 6	N/A	N/A	ºC	Time: 5s

Test Type	Test Items	Spec Limit*		Unit	Notes
		Min	Max		
Burnin					
FCAM Thermals	PearlTherm FrontCameraDie 7	N/A	N/A	ºC	Time: 6s
	PearlTherm FrontCameraDie 8	N/A	N/A	ºC	Time: 7s
	PearlTherm FrontCameraDie 9	N/A	N/A	ºC	Time: 8s
	PearlTherm FrontCameraDie 10	N/A	N/A	ºC	Time: 9s
	PearlTherm FrontCameraDie 11	N/A	N/A	ºC	Time: 10s
	PearlTherm FrontCameraDie 12	N/A	N/A	ºC	Time: 20s
	PearlTherm FrontCameraDie 13	N/A	N/A	ºC	Time: 30s
	PearlTherm FrontCameraDie 14	N/A	N/A	ºC	Time: 40s
	PearlTherm FrontCameraDie 15	N/A	N/A	ºC	Time: 50s
	PearlTherm FrontCameraDie 16	N/A	N/A	ºC	Time: 60s
	PearlTherm FrontCameraDie 17	N/A	N/A	ºC	Time: 70s
	PearlTherm FrontCameraDie 18	N/A	N/A	ºC	Time: 80s
	PearlTherm FrontCameraDie 19	N/A	N/A	ºC	Time: 100s
	PearlTherm FrontCameraDie 20	N/A	N/A	ºC	Time: 120s

2.3.8.Midgard

Test Items	Unit	Spec Limit		Category	Notes
		Min	Max		
Midgard					
RowNoiseMC_JU pTemp	LSB		0.79	Juliet Noise	
RowNoiseMC_JU tempRnR	Ratio	6		Juliet Noise	
RowNoiseMC_JU tempRnR_total	Ratio	6		Juliet Noise	
RowNoiseMC_JU total	LSB		0.91	Juliet Noise	
RowNoiseMC_JU totalTemp	LSB		0.8	Juliet Noise	
RowNoiseMC_JU_8x pTemp	LSB		3	Juliet Noise	
RowNoiseMC_JU_8x total	LSB		3.6	Juliet Noise	
RowNoiseMC_JU_8x totalTemp	LSB		3.1	Juliet Noise	
blemish_JU centerCount	NA		0	Juliet Blemish	
blemish_JU maxRatio	NA	0	0.24	Juliet Blemish	
blemish_JU maxSize	NA		0	Juliet Blemish	
blemish_JU maxSizeCenter	NA		0	Juliet Blemish	
blemish_JU maxSizeOuter	NA		0	Juliet Blemish	

Test Items	Unit	Spec Limit		Category	Notes
		Min	Max		
Midgard					
blemish_JU outerCount	NA		0	Juliet Blemish	
blemish_JU totalCount	NA		0	Juliet Blemish	
blemish_JU yavg	NA	130	200	Juliet Blemish	
blemish_v3_JU centerCount	NA		0	Juliet Blemish	
blemish_v3_JU maxSizeCenter	NA		0	Juliet Blemish	
blemish_v3_JU maxSizeOuter	NA		2	Juliet Blemish	
blemish_v3_JU outerCount	NA		2	Juliet Blemish	
blemish_v3_JU totalCount	NA		2	Juliet Blemish	
grayspot_LSC_JU clustercount	NA		0	Juliet Grayspot	
linetest_darkM_JU Sdelta_Col_Y	LSB		1.4	Juliet Linetest	
linetest_darkM_JU Sdelta_Row_Y	LSB		1.7	Juliet Linetest	
linetest_JU MaxRateCol_Y	NA		0.32	Juliet Linetest	
linetest_JU MaxRateRow_Y	NA		0.22	Juliet Linetest	
oc_JU_raw oc_xShift	Pixels	-25	25	Juliet OC	
oc_JU_raw oc_yShift	Pixels	-25	25	Juliet OC	
PRNU_JU PRNU_BL	NA		3.4	Juliet PRNU	
PRNU_JU PRNU_BR	NA		3.45	Juliet PRNU	
PRNU_JU PRNU_TL	NA		3.45	Juliet PRNU	
PRNU_JU PRNU_TR	NA		3.4	Juliet PRNU	
ri_JU ri_delta	NA	0	0.12	Juliet Image	
ri_JU ri_ll	NA	0.28		Juliet Image	
ri_JU ri_lr	NA	0.28		Juliet Image	
ri_JU ri_ul	NA	0.28		Juliet Image	
ri_JU ri_ur	NA	0.28		Juliet Image	
ru_JU max_ru_center	NA	0	0.05	Juliet Image	
ru_JU max_ru_edge	NA	0	0.05	Juliet Image	
ru_JU max_ru_corner	NA	0	0.05	Juliet Image	

2.3.9.Pearl Calibration [Sanity Check]

Test Type	Test Items	Production Limit		Unit	Notes/Nominal
		Min fail	Max fail		
Pearl Cal Sanity Check					

Cam angle	angle0-cam1-0.420_YAvg	70	240	N/A	
	angle0-cam2_YAvg	90	1023	N/A	
Cam1 Projector off	Cam1_ProjOff_-0_0.raw_YAvg_1	300	500	N/A	
	Cam1_ProjOff_-0_1.raw_YAvg_1	300	500	N/A	
	Cam1_ProjOff_-25.6_0.raw_YAvg_1	420	640	N/A	
	Cam1_ProjOff_-25.6_1.raw_YAvg_1	420	640	N/A	
	Cam1_ProjOff_-32_0.raw_YAvg_1	450	670	N/A	
	Cam1_ProjOff_-32_1.raw_YAvg_1	450	670	N/A	
	Cam1_ProjOff_25.6_0.raw_YAvg_1	310	550	N/A	
	Cam1_ProjOff_25.6_1.raw_YAvg_1	310	550	N/A	
	Cam1_ProjOff_32_0.raw_YAvg_1	270	510	N/A	
	Cam1_ProjOff_32_1.raw_YAvg_1	270	510	N/A	
Cam1 Projector on	Cam1_ProjOn_-25.6_0.raw_YAvg	190	320	N/A	
	Cam1_ProjOn_-25.6_1.raw_YAvg	190	320	N/A	
	Cam1_ProjOn_-32_0.raw_YAvg	200	400	N/A	
	Cam1_ProjOn_-32_1.raw_YAvg	200	400	N/A	
	Cam1_ProjOn_0_0.raw_YAvg	110	190	N/A	
	Cam1_ProjOn_0_1.raw_YAvg	110	190	N/A	
	Cam1_ProjOn_25.6_0.raw_YAvg	140	310	N/A	
	Cam1_ProjOn_25.6_1.raw_YAvg	140	310	N/A	
	Cam1_ProjOn_32_0.raw_YAvg	140	320	N/A	
	Cam1_ProjOn_32_1.raw_YAvg	140	320	N/A	
Reference	Reference0-cam2_YAvg	60	65	N/A	
	Reference100-cam2_YAvg	110	155	N/A	
	Reference100LP-cam2_YAvg	82	115	N/A	
	Reference40-cam2_ActNTC	25	47	N/A	
	Reference40-cam2_YAvg	82	110	N/A	
	Reference40LP-cam2_YAvg	79	100	N/A	
	Reference40LPProbe-cam2_YAvg	81	105	N/A	
	Reference40LPRFC-cam2_YAvg	71	90	N/A	
	Reference40Probe-cam2_YAvg	86	110	N/A	
	Reference60-cam2_YAvg	87	115	N/A	
	Reference60LP-cam2_YAvg	73	92	N/A	

2.3.10.Rack 4

Test Type	Test Items	Spec Limit Min	Spec Limit Max	Unit	Notes/Nominal
Rack1					
Module to module angular measurements	CamAng_0	-1.8	1.8	deg	FCAM's tilt compared to JU in X-tilt
	CamAng_1	-1.5	1.5	deg	FCAM's tilt compared to JU in Y-tilt
	CamAng_2	88.3	91.7	deg	FCAM's tilt compared to JU in Z-tilt
Baselines - distance between modules	CamBaseLine_0	-13.7	-13.3	mm	FCAM distance compared to JU in X-Axis
	CamBaseLine_1	-0.348	0.052	mm	FCAM distance compared to JU in X-Axis
	CamBaseLine_2	-0.2	0.2	mm	FCAM distance compared to JU in X-Axis
Dead VCSEL emitters	deadEmitters_1	0	3	NA	number of VCSEL emitters that aren't emiting light in FP sparse
	deadEmitters_2	0	3	NA	number of VCSEL emitters that aren't emiting light in FP dense
	deadEmitters_3	0	3	NA	number of VCSEL emitters that aren't emiting light in LP sparse
Thermal	mpc_capture_temp_delta	0.05	0.75	ºC	the difference in temperatures from the beginning of the image grabbing
Field of View	FoVcoverage_1	0	85000	NA	number of pixels in the extended FOV in FP sparse
	FoVcoverage_2	0	85000	NA	number of pixels in the extended FOV in FP Dense
	FoVcoverage_3	0	85000	NA	number of pixels in the extended FOV in LP sparse
Juliet Distortion	IRdist_0	0	1.1	%	JU distortion in 30% of the total FOV radius
	IRdist_1	0	1.1	%	JU distortion in 50% of the total FOV radius
	IRdist_2	0	1.1	%	JU distortion in 80% of the total FOV radius
Juliet EFL	IRefl	2.595	2.65	mm	JU effective focal length
Number of checkerboard	IRfeatureNum_2	1200	2000	NA	the number of checkerboard features seen by JUin 0 angle (between the target and the DUT).
Juliet principal points	IRpp_0	1.504	1.588	mm	JU Principal point for x axis
	IRpp_1	1.795	1.883	mm	JU Principal point for y axis
Juliet geometric error	IRreprojectionError	0.05	0.5	Pixel	the JU geometric error corresponding to the image distance between a projected point and a measured one

Probing	numProbingEmittersA	5	5	NA	The number of active probing emitters in probing pattern A
	numProbingEmittersB	5	5	NA	The number of active probing emitters in probing pattern A
Sanity check	outOffTaregetPix	0	200	NA	sanity check for the number of pixels that are not on the target
	plainAng_2	-5	5	deg	Sanity check for the DUT to target plane angle
t signal to noise. Combi effect of Titus-C and Juliet	ref_3_SignalPerWindow_1	96.8	1000	NA	SNR per window in window #1
	ref_3_SignalPerWindow_2	91.2	1000	NA	SNR per window in window #2
	ref_3_SignalPerWindow_3	86	1000	NA	SNR per window in window #3
	ref_3_SignalPerWindow_4	74.4	1000	NA	SNR per window in window #4
	ref_3_SignalPerWindow_5	60.6	1000	NA	SNR per window in window #5
	ref_3_SignalPerWindow_6	43.3	1000	NA	SNR per window in window #6
	ref_3_SignalPerWindow_7	29.8	1000	NA	SNR per window in window #7
	ref_3_SignalPerWindow_8	19.4	1000	NA	SNR per window in window #8
Reference distance	ReferenceDist	390	410	mm	the distance between the target plane and JU
Projector spot counting	RFCspots_1	9000	20000	NA	Numbers of spots found in LP sparse (40%)
	RFCspots_2	9000	20000	NA	Numbers of spots found in FP sparse (40%) Probe A/B
	RFCspots_3	9000	20000	NA	Numbers of spots found in FP sparse (60%)
	RFCspots_4	9000	20000	NA	Numbers of spots found in LP sparse (60%)
Spot matching	RFXfinalScore	0	.000000	NA	The optimization algorithm score for the spot matching
module angular meas	RFXRa_1	-34.5	34.5	mrad	RO's tilt compared to JU in X-tilt
	RFXRa_2	-46	46	mrad	RO's tilt compared to JU in Y-tilt
	RFXRa_3	-27	27	mrad	RO's tilt compared to JU in Z-tilt
Fcam distortion	RGBdist_0	0	10	%	FCAM distortion in 30% of the total FOV radius
	RGBdist_1	0	20	%	FCAM distortion in 50% of the total FOV radius
	RGBdist_2	0	50	%	FCAM distortion in 80% of the total FOV radius
Fcam geometric error	RGBreprojectionError	0.05	1.5	Pixel	FCAM geometric error corresponding to the image distance between a projected point and a measured one

Thermal	RO_initial_temp	5	50	ºC	the RO NTC's initial working temperature |(Idle)
	RObaseLine_0	-27.34	-26.74	mm	RO distance compared to JU in X-Axis
ce between Romeo anc	RObaseLine_1	-0.7	0.7	mm	RO distance compared to JU in Y-Axis
	RObaseLine_2	-0.9	0.7	mm	RO distance compared to JU in Z-Axis
Romeo Geometric error	ROreprojection	0.05	0.25	Pixel	the RO geometric error corresponding to the image distance between a projected point and a measured one
Probing	validProbingCodeA	1	1	NA	validating the probing code for probing pattern A
	validProbingCodeB	1	1	NA	validating the probing code for probing pattern B
Thermal	warmup_temp	20	52	ºC	the temperature span after warm-up
	warmup_temp_delta	0	7	ºC	NTC temperature difference after wu
Midas to VCSEL tilt	HomRot_3	-0.0035	0.0035	mrad	
	Daratio	0.69	N/A		How good simulated reference matches with actual reference

2.3.11. Pearl Test 20/60

Test Type	Test Items	Production Limit		Unit	Notes
		Min	Max		
Pearl test 20/60					
PT60	J60_Y_AVG_RAW	2500	N/A	DN	
	J60_TILT_X_RAW	-2.2	2.2	deg	
	J60_TILT_Y_RAW	-2.2	2.2	deg	
	J60_TILT_TOTAL_RAW	0	2.5	deg	
	J60_ROT_RAW	-1.8	1.8	deg	
	J60_DFOV_RAW	81.0	83.0	°	
	J60_VFOV_RAW	68.5	71.5	°	
	J60_HFOV_RAW	59.5	62.5	°	
	J60_MTF_CENTER_N4_AVG_RAW	0.72*	1	N/A	
	J60_MTF_30FP_N4_RAW_(0-1-2-3)	0.63*	1	N/A	
	J60_MTF_60FP_N4_RAW_(0-1-2-3)	0.59*	1	N/A	
	J60_MTF_85FP_N4_RAW_(0-1-2-3)	0.50*	1	N/A	
	J60_MTF_30FP_N4_DELTA_RAW	0	0.14	N/A	
	J60_MTF_60FP_N4_DELTA_RAW	0	0.14	N/A	
	J60_MTF_85FP_N4_DELTA_RAW	0	0.17	N/A	
	J60_CTF_CENTER_AVG_RAW	20000	-	N/A	
PT20	J20_Y_AVG_RAW	2500	N/A	DN	
	J20_MTF_CENTER_N8_AVG_RAW	0.78*	1	N/A	
	J20_MTF_30FP_N8_RAW_(0-1-2-3)	0.73*	1	N/A	
	J20_MTF_60FP_N8_RAW_(0-1-2-3)	0.69*	1	N/A	
	J20_MTF_85FP_N8_RAW_(0-1-2-3)	0.63*	1	N/A	
	J20_MTF_30FP_N8_DELTA_RAW	0	0.17*	N/A	
	J20_MTF_60FP_N8_DELTA_RAW	0	0.17*	N/A	
	J20_MTF_85FP_N8_DELTA_RAW	0	0.22*	N/A	

2.3.12. Rack 2

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
Depth Quality (DQ)	FP_200_DQSparse_holesHolesAreaInPixel	0	200	pixels	Number of pixels that don't have depth reading in FP Sparse mode
	FP_200_DQSparse_z_planeFit_perc95	0	1.3	mm	distance error in Z axis between the target plane and the DUT in FP Sparse mode
	FP_200_DQSparse_z_wideRefRight	-1.5	1.25	mm	the size of the gap between the actual depth created by the reference and the syntetic reference
	FP_200_DQSparse_zStdPrecentaile95_0	0	0.2123	Pixel shift	the 95% worse error of depth precision in R0 in FP Sparse mode in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_1	0	0.1925	Pixel shift	the 95% worse error of depth precision in R1 in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_2	0	0.1975	Pixel shift	the 95% worse error of depth precision in R2 in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_3	0	0.2024	Pixel shift	the 95% worse error of depth precision in R3 in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_4	0	0.2123	Pixel shift	the 95% worse error of depth precision in R4 in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_5	0	0.2222	Pixel shift	the 95% worse error of depth precision in R5 in FP Sparse mode
	FP_200_DQSparse_zStdPrecentaile95_6	0	0.2419	Pixel shift	the 95% worse error of depth precision in R6 in FP Sparse mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
	FP_200_DQSparse_z StdPrecentaile95_7	0	0.2864	Pixel shift	the 95% worse error of depth precision in R7 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_err	0	0	NA	Number of probing mismatches found in the Probing A pattern (entire image) in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q1_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 1 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q2_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 2 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q3_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 3 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q4_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 4 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q5_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 5 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q6_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 6 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q7_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 7 in FP Sparse mode
	FP_200_Probe_SPA RSE_A_Q8_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 8 in FP Sparse mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
Probing	FP_200_Probe_SPARSE_A_Q9_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 9 in FP Sparse mode
	FP_200_Probe_SPARSE_B_err	0	0	NA	Number of probing mismatches found in the Probing B pattern (entire image) in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q1_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 1 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q2_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 2 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q3_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 3 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q4_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 4 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q5_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 5 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q6_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 6 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q7_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 7 in FP Sparse mode
	FP_200_Probe_SPARSE_B_Q8_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 8 in FP Sparse mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
	FP_200_Probe_SPARSE_B_Q9_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 9 in FP Sparse mode
Registration (RA)	FP_200_RASparse_dist_r_percMax95_err	0	5	RGB pixels	registration error in FCAM compared to JU between the target plane and the DUT in FP Sparse mode
	FP_200_RASparse_RGB_op_rotAng_0	-5	5	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU Y-Axis in FP Sparse mode
	FP_200_RASparse_RGB_op_rotAng_1	-5	5	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU X-Axis in FP Sparse mode
	FP_200_RASparse_RGB_op_rotAng_2	-3	3	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU Z-Axis in FP Sparse mode
Accuracy (RWA)	FP_200_RWASparse_percMax95_error	0	1.2	%	registration error in RO compared to JU between the target plane and the DUT in FP Sparse mode
	FP_200_RWASparse_proj_op_rotAng_0	-5	5	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU X-Axis in FP Sparse mode
	FP_200_RWASparse_proj_op_rotAng_1	-5	5	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU Y-Axis in FP Sparse mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
SNR	FP_200_RWASparse_proj_op_rotAng_2	-3	3	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU Z-Axis in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_0	52.861	10000	NA	the 95% worse SNR count in R0 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_1	49.328	10000	NA	the 95% prectile of the SNR in R1 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_2	46.159	10000	NA	the 95% prectile of the SNR in R2 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_3	39.863	10000	NA	the 95% prectile of the SNR in R3 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_4	32.046	10000	NA	the 95% prectile of the SNR in R4 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_5	25.669	10000	NA	the 95% prectile of the SNR in R5 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_6	19.051	10000	NA	the 95% prectile of the SNR in R6 in FP Sparse mode
	FP_200_SNRSparse_WorstCaseSnr_7	12.976	10000	NA	the 95% prectile of the SNR in R7 in FP Sparse mode
Thermal	FP_200_temperature_range_sparse	0	1	°C	the temperature range between the initial image and the last image of RO's NTC in FP Sparse mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2					
Thermal	FP_200_tMax_sparse	0	50	°C	the maximal temperature read during the image grab from RO's NTC in FP Sparse mode

2.3.13.Rack 2 (Pearl test 60)

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2 (Pearl Test 60)					
Depth Quality (DQ)	FP_600_DQDense_holesHolesAreaInPixel	0	100	pixels	Number of pixels that don't have depth reading in FP Dense mode
	FP_600_DQDense_z_planeFit_perc95	0	7.8	mm	distance error in Z axis between the target plane and the DUT in FP Dense mode
	FP_600_DQDense_z_wideRefLeft	**-10.5**	**6.5**	mm	the size of the gap between the actual depth created by the reference and the syntetic reference
	FP_600_DQDense_zStdPrecentaile95_0	0	0.1941	Pixel shift	the 95% worse error of depth precision in R0 in FP Dense mode in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_1	0	0.1838	Pixel shift	the 95% worse error of depth precision in R1 in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_2	0	0.1735	Pixel shift	the 95% worse error of depth precision in R2 in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_3	0	0.1632	Pixel shift	the 95% worse error of depth precision in R3 in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_4	0	0.1632	Pixel shift	the 95% worse error of depth precision in R4 in FP Dense mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2 (Pearl Test 60)					
	FP_600_DQDense_zStdPrecentaile95_5	0	0.203	Pixel shift	the 95% worse error of depth precision in R5 in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_6	0	0.2578	Pixel shift	the 95% worse error of depth precision in R6 in FP Dense mode
	FP_600_DQDense_zStdPrecentaile95_7	0	0.3497	Pixel shift	the 95% worse error of depth precision in R7 in FP Dense mode
	FP_600_Probe_DENSE_A_err	0	0	NA	Number of probing mismatches found in the Probing A pattern (entire image) in FP Dense mode
	FP_600_Probe_DENSE_A_Q1_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 1 in FP Dense
	FP_600_Probe_DENSE_A_Q2_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 2 in FP Dense
	FP_600_Probe_DENSE_A_Q3_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 3 in FP Dense
	FP_600_Probe_DENSE_A_Q4_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 4 in FP Dense
	FP_600_Probe_DENSE_A_Q5_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 5 in FP Dense
	FP_600_Probe_DENSE_A_Q6_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 6 in FP Dense
	FP_600_Probe_DENSE_A_Q7_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 7 in FP Dense
	FP_600_Probe_DENSE_A_Q8_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 8 in FP Dense

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2 (Pearl Test 60)					
Probing	FP_600_Probe_DENSE_A_Q9_err	0	0	NA	Number of probing mismatches found in the Probing A pattern in partition 9 in FP Dense
	FP_600_Probe_DENSE_B_err	0	0	NA	Number of probing mismatches found in the Probing B pattern (entire image) in FP Dense mode
	FP_600_Probe_DENSE_B_Q1_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 1 in FP Dense
	FP_600_Probe_DENSE_B_Q2_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 2 in FP Dense
	FP_600_Probe_DENSE_B_Q3_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 3 in FP Dense
	FP_600_Probe_DENSE_B_Q4_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 4 in FP Dense
	FP_600_Probe_DENSE_B_Q5_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 5 in FP Dense
	FP_600_Probe_DENSE_B_Q6_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 6 in FP Dense
	FP_600_Probe_DENSE_B_Q7_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 7 in FP Dense
	FP_600_Probe_DENSE_B_Q8_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 8 in FP Dense
	FP_600_Probe_DENSE_B_Q9_err	0	0	NA	Number of probing mismatches found in the Probing B pattern in partition 9 in FP Dense
	FP_600_RADense_dist_r_percMax95_err	0	5	RGB pixels	registration error in FCAM compared to JU between the target plane and the DUT in FP Dense mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2 (Pearl Test 60)					
Registration (RA)	FP_600_RADense_RGB_op_rotAng_0	-5	5	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU
	FP_600_RADense_RGB_op_rotAng_1	-5	5	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU
	FP_600_RADense_RGB_op_rotAng_2	-3	3	mrad	operation rotation error in FCAM's tilt compared to JU between the calibration and the current test in JU
	FP_600_RWADense_percMax95_error	0	1.6	%	registration error in RO compared to JU between the target plane and the DUT in FP Dense mode
	FP_600_RWADense_proj_op_rotAng_0	-5	5	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU X-
	FP_600_RWADense_proj_op_rotAng_1	-5	5	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU Y-Axis
	FP_600_RWADense_proj_op_rotAng_2	-3	3	mrad	operation rotation error in RO's tilt compared to JU between the calibration and the current test in JU Z-
SNR properties	FP_600_SNRDense_SNRVertUnif05Deg	NA	NA	NA	The 95% worse SNR value between between the upper 5deg of the FOV region and the lower
	FP_600_SNRDense_SnrPerForSplineWC	NA	NA	NA	The 95% worse SNR value within the upper 5deg of the FOV region
	FP_600_SNRDense_WorstCaseSnr_0	89.3201	10000	NA	the 95% worse SNR count in R0 in FP Dense mode
	FP_600_SNRDense_WorstCaseSnr_1	80.9523	10000	NA	the 95% prectile of the SNR in R1 in FP Dense mode
	FP_600_SNRDense_WorstCaseSnr_2	71.5578	10000	NA	the 95% prectile of the SNR in R2 in FP Dense mode

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Rack 2 (Pearl Test 60)					
SNR properties	FP_600_SNRDense_ WorstCaseSnr_3	61.7696	10000	NA	the 95% prectile of the SNR in R3 in FP Dense mode
	FP_600_SNRDense_ WorstCaseSnr_4	47.8660	10000	NA	the 95% prectile of the SNR in R4 in FP Dense mode
	FP_600_SNRDense_ WorstCaseSnr_5	34.7957	10000	NA	the 95% prectile of the SNR in R5 in FP Dense mode
	FP_600_SNRDense_ WorstCaseSnr_6	24.5448	10000	NA	the 95% prectile of the SNR in R6 in FP Dense mode
	FP_600_SNRDense_ WorstCaseSnr_7	16.1310	10000	NA	the 95% prectile of the SNR in R7 in FP Dense mode
Thermal	FP_600_temperature_ range_dense	0	1	℃	the temperature range between the initial image and the last image of RO's NTC in FP Dense mode
	FP_600_tMax_dense	0	50	℃	the maximal temperature read during the image grab from RO's NTC in FP Dense mode

2.3.14.Amai

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Amai					
Titus	function Romeo OnTime	17.2	18		
	function Romeo mean	15	40.21		
	function RomeoFaultStatus	0	0.5		

2.3.15.Miyagi

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Miyagi					
Fixture Alignment	fixture ActiveAlignment Romeo_PatternScore	50			

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Miyagi					
Titus function	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 saturationScore		1		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 CameraSensorDeltaTemperature	-10	27	ºC	
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 HotSpotRatio	0	0.95		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 MaxPowerTheta(deg)	0	39	°	
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 TotalPower(mW)	15	38.96	mW	
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 PowerFraction_65	0.97	1		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 Power_LeftvsRight	0.8	1.2		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 Power_UpleftvsLowerright	0.8	1.2		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 Power_UprightvsLowerleft	0.8	1.2		
	function Romeo_X0.0_Y0.0_Z0.0_Ex20.0 Power_UpvsLow	0.8	1.2		
Titus LSH	function Romeo AE_Eye(mW)	2	8.455	mW	
	function Romeo AE_Skin(mW)	15	37.012	mW	

2.3.16.Alpha

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Alpha					
Romeo_X [-6.0,-2.0,2.0,6.0]_Y[-4.0,-2.0,0.0,2.0,4.0, 6.0]	Romeo_CenterX	350	650		
	Romeo_CenterY	350	650		
	Romeo_Max-MeanPix_n6_p6	2	8		
	Romeo_MaxPix_n6_p6	10	255		

Test Type	Test Items	Spec Limit*		Unit	Notes/Nominal
		Min	Max		
Alpha					
Romeo	Romeo_qcond3TOTP01_Max	0.7	0.98		
	min_alpha	6	21.6	mRad	
	max_q	0.7	0.95		
Rosaline_X0.0_Y0.0	Rosaline_CenterX	350	650		
	Rosaline_CenterY	350	650		
	Rosaline_Max-MeanPix_p0_p0	14.5	43.5		
	Rosaline_alphacond3TOTPmrad_p0_p0	4.4	6.1	mRad	
	Rosaline_qcond3TOTP01_p0_p0	0.7	0.98		
Rosaline	PLR_ed2_max	0.01	0.15		
	PLR_ed3_max	0.01	0.09		
	max_q	0.7	0.98		
Alpha	Rosalineqae	0.2	0.9	mW	
	Romeoplr_simple		0		

Items	Minimum Wire Bond Count for 1mil wire bonds	Minimum Wire Bond Count for 1.1mil wire bonds
Dense	6	5
Sparse	5	4
A	2	2
B	2	2
Cathode	9	9

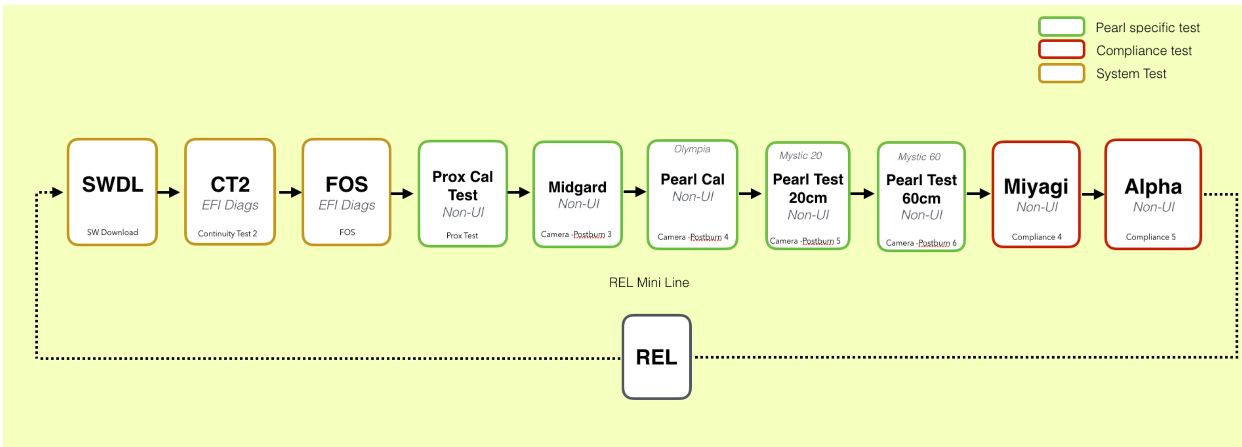
2.3.17.Prox Cal / Test

Test Type	Test Items	Spec Limit*		Unit	Notes
		Min	Max		
R-comp Romeo/Rosaline					
Romeo Ratio	sequencer matlab RomeoRatio	1	1.08	N/A	

3. FATP Reliability Test coverage

3.1. Reliability Test flow

The test flow used in reliability has differences to the main FATP test flow. The main difference are to Pearl test stations. The pearl test 20 and 60cm test stations calculate the complete set of metrics.



3.2. Pearl Calibration station

This section defines the Pearl cal drift specifications to be applied post reliability stress.

Test Type	Test Item	REL Limit		Drift Limit*		Unit	Notes
		LSL	USL	Min	Max		
Pearl Cal							
Alignment / Calibraito	CamAng_0	-1.8	1.8	-0.75	0.75	deg	drift compare to T0 event in FCAM distance compared to JU in X-Axis
	CamAng_1	1.5	4.5	-0.75	0.75	deg	drift compare to T0 event in FCAM distance compared to JU in Y-Axis
	CamAng_2	88.3	91.7	-0.5	0.5	deg	drift compare to T0 event in FCAM distance compared to JU in Z-Axis
	IRpp_0	1.504	1.588	-0.008	0.008	mm	drift compare to T0 event in JU Principal point for x axis
	IRpp_1	1.795	1.883	-0.008	0.008	mm	drift compare to T0 event in JU Principal point for y axis
	RFXRa_1	-34.5	34.5	-10.5	10.5	mrad	drift compare to T0 event in RO distance compared to JU in X-Axis
	RFXRa_2	-46	46	-14.5	14.5	mrad	drift compare to T0 event in RO distance compared to JU in Y-Axis
	RFXRa_3	-27	27	-14.5	14.5	mrad	drift compare to T0 event in RO distance compared to JU in Z-Axis

n	RGBpp_0			-0.015	0.015	mm	drift compare to T0 event in FCAM Principal point for x axis
	RGBpp_1			-0.015	0.015	mm	drift compare to T0 event in FCAM Principal point for y axis
	RObaseLine_0	-27.34	-26.74	-0.074	0.074	mm	drift compare to T0 event in RO distance compared to JU in X-Axis
	RObaseLine_1	-0.7	0.7	-0.48	0.48	mm	drift compare to T0 event in RO distance compared to JU in Y-Axis
	RObaseLine_2	-0.9	0.7	-0.54	0.54	mm	drift compare to T0 event in RO distance compared to JU in Z-Axis
	mpc_capture_temp_delta	0.05	0.75			ºC	MPC Capture Temp Delta
	warmup_temp_delta	0	7			ºC	MPC Calibration warmup Temp Delta
	DeadEmitters_2	0	3			#	Dead Emitters

3.3. Pearl Test 20cm Test Station

Test Type	Test Item	REL Limit		Drift Limit*		Unit	Notes
		LSL	USL	Min	Max		
	Pearl Test 20cm						
	FP_200_RASparse_dist_r_percMax95_err	0	14.5	NA	NA	RGB-Pixels	Registration Accuracy r
	FP_200_RASparse_RGB_op_rotAng_0	-13.1	13.1			mrd	RASparse_RGB_op_rotAng_0
	FP_200_RASparse_RGB_op_rotAng_1	-13.1	13.1			mrd	RASparse_RGB_op_rotAng_1
	FP_200_RASparse_RGB_op_rotAng_2	-8.7	8.7			mrd	RASparse_RGB_op_rotAng_2
	FP_200_RWASparse_percMax95_error	0	4			%	RWASparse_percMax95_error
	FP_200_RWASparse_proj_op_rotAng_0	-17	17			N/A	RWASparse_proj_op_rotAng_0
	FP_200_RWASparse_proj_op_rotAng_1	-28	28			N/A	RWASparse_proj_op_rotAng_1
	FP_200_RWASparse_proj_op_rotAng_2	-28	28			N/A	RWASparse_proj_op_rotAng_2
	FP_200_SNRSparse_WorstCaseSnr_0	52.8606	10000	-16.2	16.2	%	SNRSparse_WorstCaseSnr_0
	FP_200_SNRSparse_WorstCaseSnr_2	46.1588	10000	-17.7	17.7	%	SNRSparse_WorstCaseSnr_2
	FP_200_SNRSparse_WorstCaseSnr_4	32.0456	10000	-19.2	19.2	%	SNRSparse_WorstCaseSnr_4

	FP_200_SNRSparse_WorstCaseSnr_6	19.0514	10000	-22.1	22.1	%	SNRSparse_WorstCaseSnr_6
	FP_200_temperature_range_sparse	0	1			N/A	temperature_range_sparse
	FP_200_tMax_sparse	0	50			N/A	tMax_sparse
	J20_MTF_30FP_N8_RAW_0	0.73	1	-12	12	%	
	J20_MTF_30FP_N8_RAW_1	0.73	1	-12	12	%	
	J20_MTF_30FP_N8_RAW_2	0.73	1	-12	12	%	
	J20_MTF_30FP_N8_RAW_3	0.73	1	-12	12	%	
	J20_MTF_60FP_N8_RAW_0	0.69	1	-15	15	%	
	J20_MTF_60FP_N8_RAW_1	0.69	1	-15	15	%	
	J20_MTF_60FP_N8_RAW_2	0.69	1	-15	15	%	
	J20_MTF_60FP_N8_RAW_3	0.69	1	-15	15	%	
	J20_MTF_85FP_N8_RAW_0	0.63	1	-20	20	%	
	J20_MTF_85FP_N8_RAW_1	0.63	1	-20	20	%	
	J20_MTF_85FP_N8_RAW_2	0.63	1	-20	20	%	
	J20_MTF_85FP_N8_RAW_3	0.63	1	-20	20	%	
	J20_MTF_85FP_N8_DELTA_RAW	0	0.22				
	J20_MTF_CENTER_N8_AVG_RAW	0.78	1	NA	NA	%	
	MamaBearCapacitance	NA	NA	100000	-100000	N/A	MamaBearCapacitance
	MamaBearCapacitance-2	NA	NA	100000	-100000	N/A	MamaBearCapacitance
	RO_THERMAL_NTC_tMax	-	69			ºC	
	RO-THERMAL_NTC_tRange	10	32			ºC	
	FP_200_DQSparse_zStdPrecentaile95_0	0.0000	0.2123	-0.0509	0.0558	Pixel shift	Drift limits are a sanity check: units failing should be FA'ed, but if they are passing absolute specifications, this is not a concern.
	FP_200_DQSparse_zStdPrecentaile95_1	0.0000	0.1925	-0.0390	0.0410	Pixel shift	
	FP_200_DQSparse_zStdPrecentaile95_2	0.0000	0.1975	-0.0370	0.0360	Pixel shift	
	FP_200_DQSparse_zStdPrecentaile95_3	0.0000	0.2024	-0.0370	0.0339	Pixel shift	
	FP_200_DQSparse_zStdPrecentaile95_4	0.0000	0.2123	-0.0350	0.0339	Pixel shift	
	FP_200_DQSparse_zStdPrecentaile95_5	0.0000	0.2222	-0.0370	0.0320	Pixel shift	

	Test Item	LSL	USL	Min	Max	Unit	Notes
	FP_200_DQSparse_zStdPrecentaile95_6	0.0000	0.2419	-0.0360	0.0389	Pixel shift	
	FP_200_DQSparse_zStdPrecentaile95_7	0.0000	0.2864	-0.0460	0.0507	Pixel shift	

3.4. Pearl Test 60cm Test Station

	Test Item	REL Limit		Drift Limit*		Unit	Notes
		LSL	USL	Min	Max		
Pearl Test 60cm							
	FP_600_RADense_dist_r_percMax95_err	0	14.5			RGB-Pixels	Registration Accuracy r
	FP_600_RADense_RGB_op_rotAng_0	-13.1	13.1			mrd	RADense_RGB_op_rotAng_0
	FP_600_RADense_RGB_op_rotAng_1	-13.1	13.1			mrd	RADense_RGB_op_rotAng_1
	FP_600_RADense_RGB_op_rotAng_2	-8.7	8.7			mrd	RADense_RGB_op_rotAng_2
	FP_600_RWADense_percMax95_error	0	8	-3	3	%	RWASparse_percMax95_error
	FP_600_RWADense_proj_op_rotAng_0	-17	17			mrd	RWASparse_proj_op_rotAng_0
	FP_600_RWADense_proj_op_rotAng_1	-28	28			mrd	RWASparse_proj_op_rotAng_1
	FP_600_RWADense_proj_op_rotAng_2	-28	28			mrd	RWASparse_proj_op_rotAng_2
	FP_600_SNRDense_WorstCaseSnr_0	74.8617	10000	-16.2	16.2	%	SNRDense_WorstCaseSnr_0
	FP_600_SNRDense_WorstCaseSnr_2	58.911	10000	-17.7	17.7	%	SNRDense_WorstCaseSnr_2
	FP_600_SNRDense_WorstCaseSnr_4	38.6987	10000	-19.2	19.2	%	SNRDense_WorstCaseSnr_4
	FP_600_SNRDense_WorstCaseSnr_6	19.112	10000	-22.1	22.1	%	SNRDense_WorstCaseSnr_6
	FP_600_SNRDense_SNRVertUnif05Deg	NA	NA			N/A	
	FP_600_SNRDense_SnrPerForSplineWC	NA	NA			N/A	
	FP_600_temperature_range_dense	0	1			N/A	Temperature range
	FP_600_tMax_dense	0	50			N/A	Max temperature
	J60_CTF_CENTER_AVG_RAW	10000	NA	NA	NA	N/A	

	J60_DFOV_RAW	81	83	NA	NA	N/A	
	J60_HFOV_RAW	59.5	62.5	NA	NA	N/A	
	J60_MTF_30FP_N4_RAW_0	0.63	1	-12	12	%	
	J60_MTF_30FP_N4_RAW_1	0.63	1	-12	12	%	
	J60_MTF_30FP_N4_RAW_2	0.63	1	-12	12	%	
	J60_MTF_30FP_N4_RAW_3	0.63	1	-12	12	%	
	J60_MTF_60FP_N4_RAW_0	0.59	1	15	15	%	
	J60_MTF_60FP_N4_RAW_1	0.59	1	15	15	%	
	J60_MTF_60FP_N4_RAW_2	0.59	1	15	15	%	
	J60_MTF_60FP_N4_RAW_3	0.59	1	15	15	%	
	J60_MTF_85FP_N4_RAW_0	0.5	1	-20	20	%	
	J60_MTF_85FP_N4_RAW_1	0.5	1	-20	20	%	
	J60_MTF_85FP_N4_RAW_2	0.5	1	-20	20	%	
	J60_MTF_85FP_N4_RAW_3	0.5	1	-20	20	%	
	J60_MTF_CENTER_N4_AVG_RAW	0.72	1	NA	NA	N/A	
	J60_ROT_RAW	-1.8	1.8	NA	NA	N/A	
	J60_TILT_TOTAL_RAW	0	2.5	-2.5	2.5	N/A	
	J60_TILT_X_RAW	-2.2	2.2	-2.2	2.2	N/A	
	J60_TILT_Y_RAW	-2.2	2.2	-2.2	2.2	N/A	
	J60_VFOV_RAW	68.5	71.5	NA	NA	N/A	
	MamaBearCapacitance	NA	NA	100000	-100000	N/A	MamaBearCapacitance
	MamaBearCapacitance-2	NA	NA	100000	-100000	N/A	MamaBearCapacitance-2
	FP_600_DQDense_zStdPrecentaile95_0	0	0.1941	-0.0730	0.0749	Pixel shift	Drift limits are a sanity check: units failing should be FA'ed, but if they are passing absolute specifications, this is not a concern.
	FP_600_DQDense_zStdPrecentaile95_1	0	**0.1834**	-0.0680	0.0690	Pixel shift	
	FP_600_DQDense_zStdPrecentaile95_2	0	**0.1723**	-0.0600	0.0570	Pixel shift	
	FP_600_DQDense_zStdPrecentaile95_3	0	**0.1610**	-0.0530	0.0520	Pixel shift	
	FP_600_DQDense_zStdPrecentaile95_4	0	**0.1792**	-0.0440	0.0490	Pixel shift	
	FP_600_DQDense_zStdPrecentaile95_5	0	**0.2348**	-0.0400	0.0440	Pixel shift	
	FP_600_DQDense_zStdPrecentaile95_6	0	**0.3033**	-0.0390	0.0528	Pixel shift	

	FP_600_DQDense_zStdPrecentaile95_7	0	**0.4409**	-0.0430	0.0679	Pixel shift	

4. Electrical Requirements

4.1. Titus Module Electrical Requirements

Electrical connection between subcomponents in the Titus module shown below:

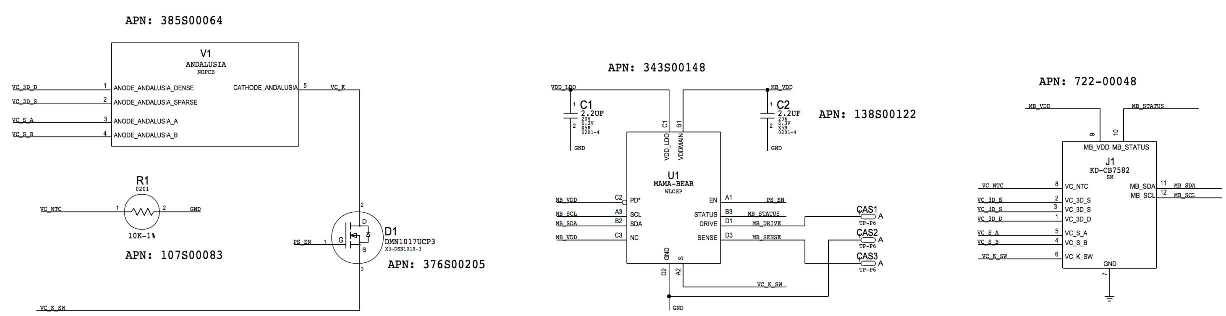


Table below describes electrical specification for the module

Parameter	Symbol	Min	Nom	Max	Unit	Frequency
MB SCL	MB_SCL	Pull up 1kΩ to 1.8V			V	400 kHz
MB SDA	MB_SDA	Pull up 1kΩ to 1.8V			V	400 kHz
Jewel VDD	Gem_VDD	2.97	3.0	3.5	V	
NTC Voltage	VC_NTC	0.8	1.0	5	V	

4.1.1. Module DC Resistance Budget

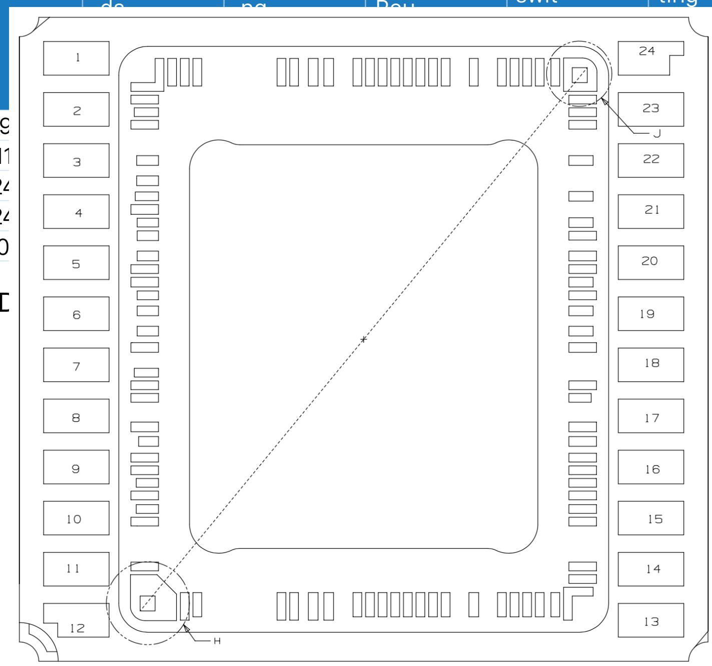
Table below describes breakdown of DCR on each trace starting from B2B connector all the way to the VCSEL. All units in this section are mΩ.

Items	B2B Connector	Flex trace	Substrate Vias	Wire Bonds	AIN Plating	Substrate Surface Routing (VC_K)	Power switch	Sub Surface Routing (VC_K_SW)
Dense	15.0	20.0	7.0	10.0				
Sparse	15.0	32.0	9.0	10.0				
A	25.0	93.0	19.0	25.0				
B	25.0	93.0	19.0	25.0				
Cathode	2.5	8.0	0.0	5.0	4.9	18.0	22.0	7.0

Table: Typical DCR Budget: Nominal Copper Thickness at 25C

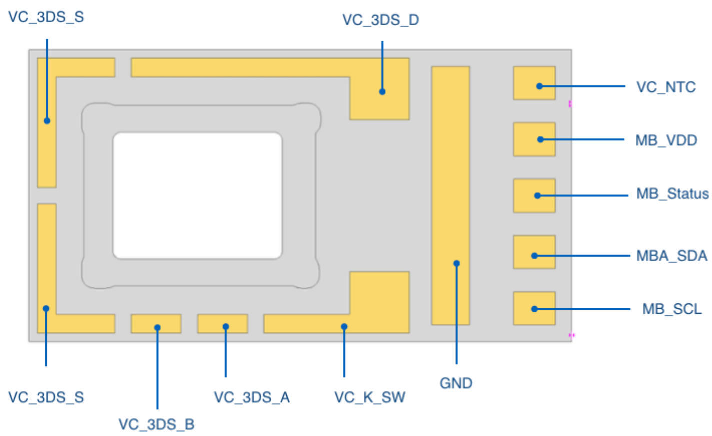
Items	B2B Connector	Flex trace	Substrate Vias	Wire Bon	AlN Plati	Substrate Surface Rou	Power swit	Sub Surface Routing
Dense	20.0	26.0	9					
Sparse	20.0	27.3	11					
A	35.0	120.9	24					
B	35.0	120.0	24					
Cathode	3.8	12.0	0					.1

Table: Worst Case D



4.1.2. Substrate Bottom

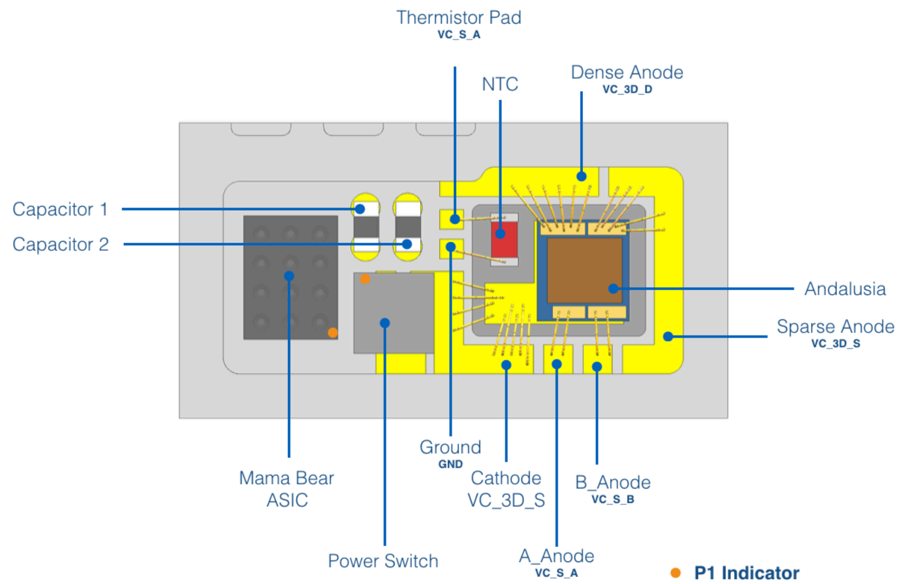
Electrical Pin-Out and orientation of components is described in this section. The figure below is bottom side as seen from the bottom side of the substrate.



Pin	Signal Name
12	SDA
11	SCL
10	Status
9	Jewel VDD
8	NTC
7	NC
6	GND
5	VC_K_SW
4	B_Anode
3	A_Anode
2	Dense_Anode
1	Sparse_Anode

4.1.3.Substrate Top

Figure: Jewel Substrate Wire Bond Pin Out and Component Overview (Top View)



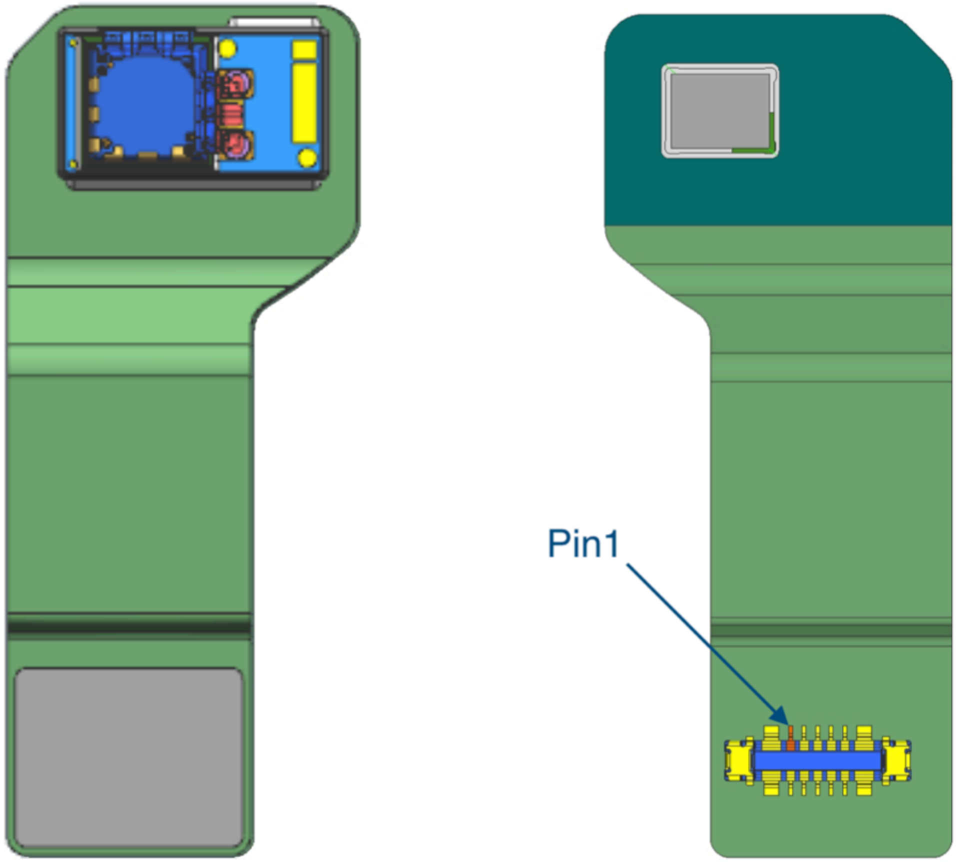
Based on DCR budget, the recommended minimum number of wire bonds is captured in table below:

4.1.4. Flex Board to Board (B2B) connector

Table: Jewel Flex Pin Out

Pin	Signal Name		Pin
17	Dense Anode	Dense Anode	18
13	Cathode	Cathode	14
9	B2B Detect	VC NTC	10
7	GND	MB SCL	8
5	GND	MB SDA	6
3	A Anode	MB Status	4
1	B Anode	MB VDD	2
11	Cathode	Cathode	12
15	Sparse Anode	Sparse Anode	16

The Titus Module 'Jewel' Flex and Pin 1 Location are shown in the figure below:



4.1.5.EOS/ ESD Protection

Below table captures requirements for providing ESD/EOS protection to all pins in testers as SA tester and IQC.

Pin	ESD/EOS protection requirement
VC_3D_D	Back to Back TVS to GND
VC_3D_S	Back to Back TVS to GND
VC_S_A	Back to Back TVS to GND
VC_S_B	Back to Back TVS to GND
VC_K_SW	Back to Back TVS to GND
RSV	N/A
GND	N/A
VC_NTC	Back to Back TVS to GND
Jewel_VDD	Back to Back TVS to GND 2.2uF MLCC capacitor to GND 0.1uF MLCC capacitor to GND
Jewel_STATUS	Back to Back TVS to GND
Jewel_SCL	Back to Back TVS to GND
Jewel_SDA	Back to Back TVS to GND

Back to back TVS requirement

0402 package;

Compliant to IEC-61000-4-2 standard level 4;

Bi-directional TVS diodes structure for dual way protection;

<=15pF IO capacitance;

Min ±6V breakdown voltage;

Example component: TI TPD1E10b06

http://www.ti.com/lit/ds/symlink/tpd1e10b06.pdf

2.2uF and 0.1uF MLCC requirement

0402 package;

Rated voltage >=10V;

X5R with capacitance tolerance <=10%

http://www.yageo.com/documents/recent/UPY-GPHC_X5R_4V-to-50V_22.pd

Same protection approach applies after flex attach and need to be implemented with pogo pins.

4.1.6.Power Up/ Down Sequence

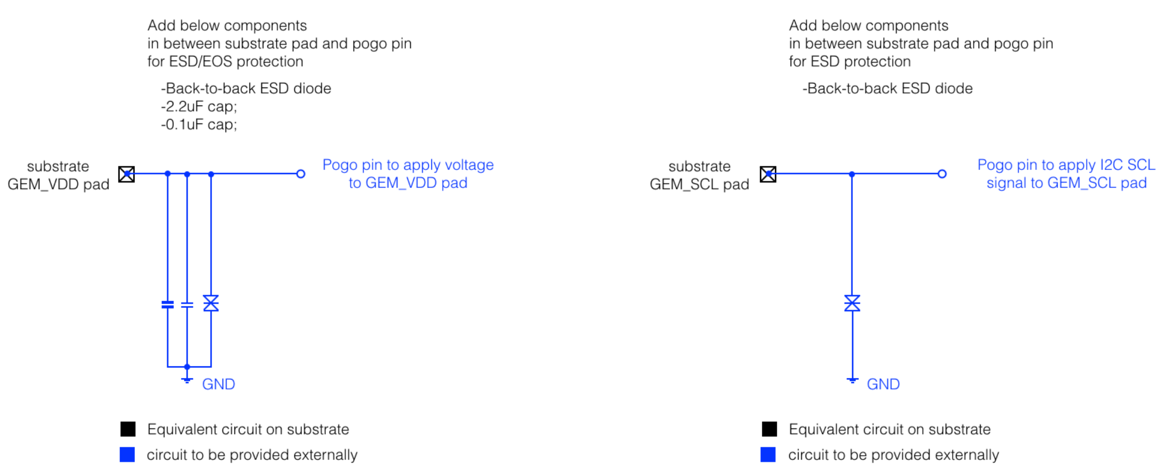
Closing the power switch is needed to run current through Andalusia. When Mama Bear (MB) is in test Mode (Pre Armed) the toggle EN pin sequence should be communicated through I2C. When Mama Bear is armed the switch can be closed after successful scan. To enable scanning Cap Sense, ensure MB_VDD and Status pins are pulled high.

4.1.7.Test Mode Sequence

The following sequence can be used in test mode:

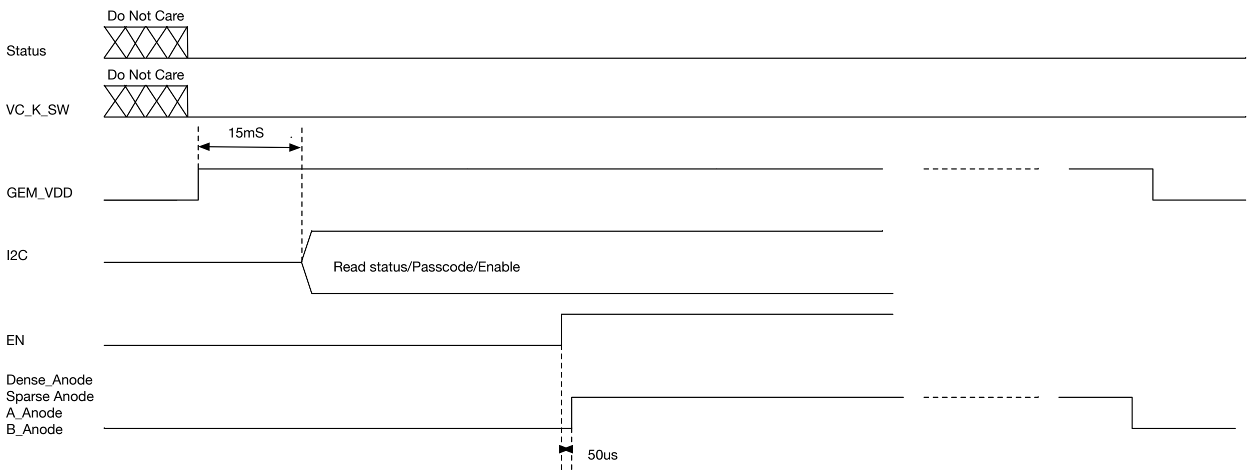
1. VC_K_SW is pulled to GND before turning on MB_VDD to 3.3V.

Figure 8: Below schematic describes protection items described above:



2. Status is pulled to GND.
3. Wait for 15mS MB initialize time.
4. Use I2C to Enable the Power switch.
5. Wait for at least 50 us to turn on the VCSEL power after power switch is enabled.
6. Turn off the VCSEL power before pulling MB_VDD back low.

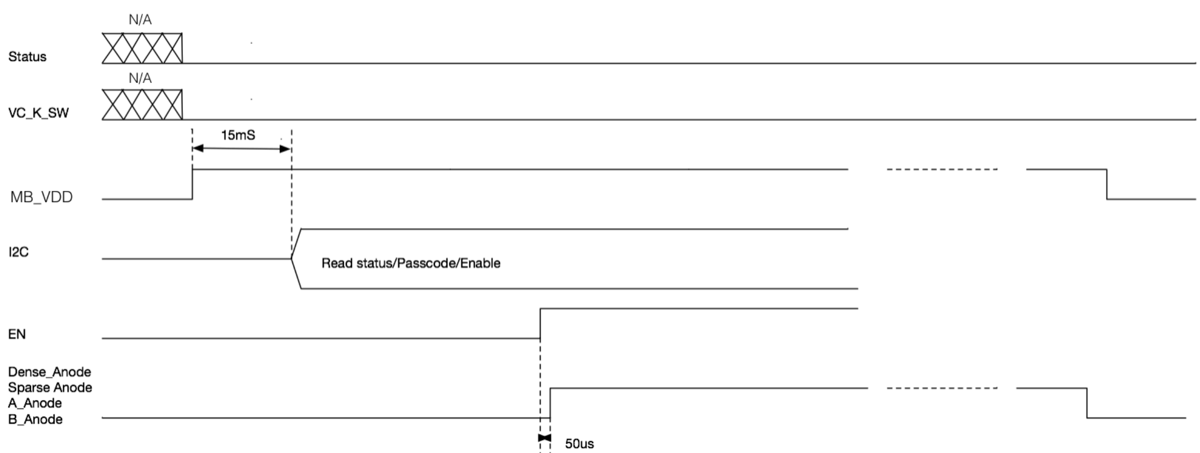
Figure 9: Test mode sequence



4.1.8.Armed Mode Sequence

The following sequence can be used in armed mode:

1. VC_K_SW is pulled to GND before turning on MB_VDD to 3.3V.
2. Status needs to be pulled high through external 1KΩ resistor to 1.8V before scanning
3. Wait for 15mS MB initialize time.
4. Scan takes about 8.33ms before turning on power switch.
5. Wait for at least 50 us and check Status to be high to turn on the VCSEL power.
6. Turn off the VCSEL power before pulling MB_VDD back low.



4.2. Juliet Module Electrical Specifications

The table below describes the electrical specifications for this image sensor module. Electrical test specifications are indicated in section 2.3.

Parameter	Symbol	Min	Nom	Max	Unit	Frequency	Note
Analog Voltage	AVDD	2.77	2.85	3.0	V		
Digital Voltage	DOVDD	1.75	1.80	1.98	V		
Core Voltage	DVDD	1.15	1.19	1.26	V		
Analog Operating Current	I_AVDD	-	10.7	14.9	mA	100%	
Analog PowerDown Current	Ipd_AVDD	-	0.0256	525.62	uA	100%	MCLK Off
Analog Standby Current	Is_AVDD	-	127.3	450	uA	100%	MCLK On
Digital Operating Current	I_DOVDD	-	7	11	mA	100%	
Digital PowerDown Current	Ipd_DOVDD	-	5.2	12	uA	100%	MCLK Off
Digital Standby Current	Is_DOVDD	-	15.5	97	uA	100%	MCLK On
Core Operating Current	I_DVDD	-	86.8	127.3	mA	100%	
Core PowerDown Current	Ipd_DVDD	-	0.580	4.55	mA	100%	MCLK Off
Core Standby Current	Is_DVDD	-	3.7	8	mA	100%	MCLK On
Analog Ripple (AVDD)		-	-	±5	mV		
Digital Ripple (DOVDD)		-	-	±15	mV		
Core Ripple (DVDD)		-	-	±10	mV		

4.2.1. Clocks

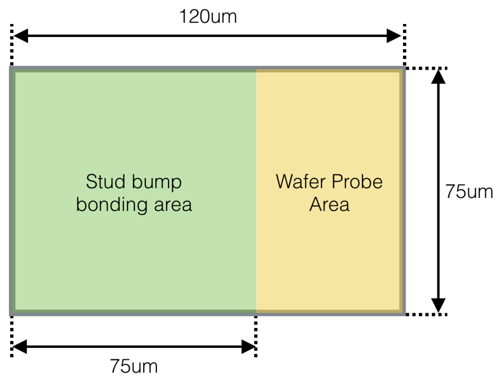
The table below describes the clock frequencies to be used for this image sensor module. All testing should be done using the clock frequencies listed. These clock frequencies are matched to the sensor register settings included in the Appendix. The MIPI CRC/ECC must be checked and validated after each capture to ensure the data is valid from the sensor.

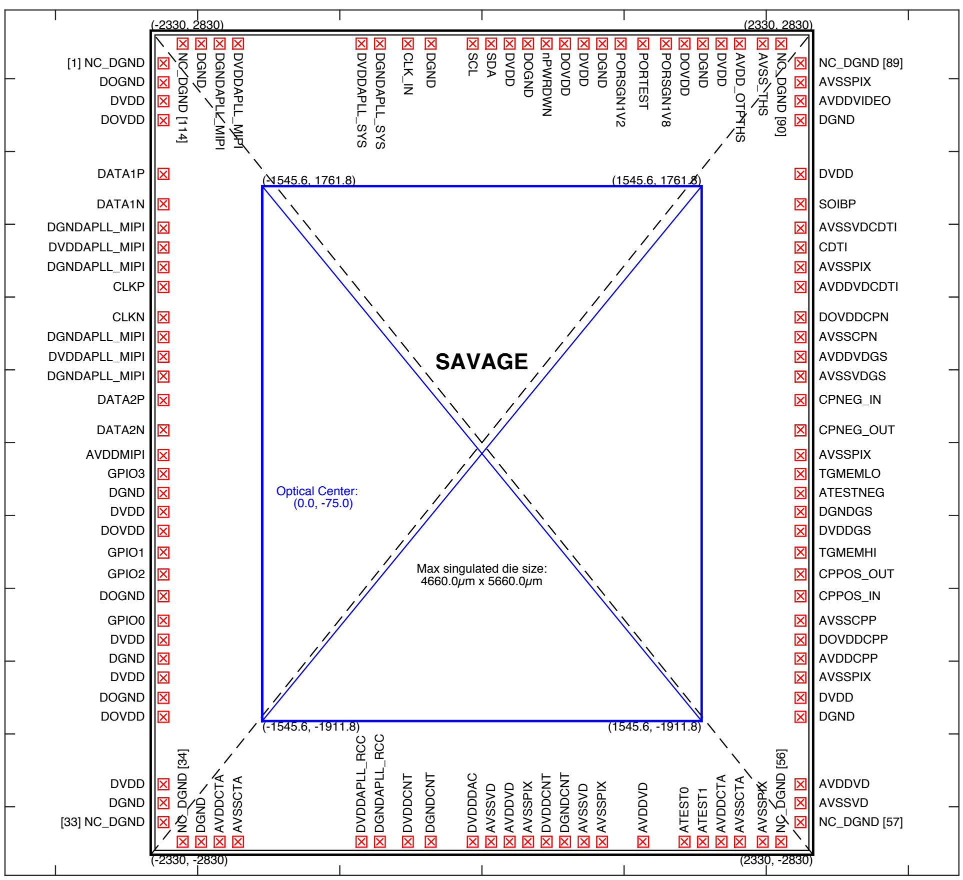
Clock	Primary
Sensor Input	12.00MHz
I2C	400KHz or 1MHz
MIPI CLK	Adjusted per settings (Max 800Mbps)

4.2.2. Sensor Die Pads Definition and Dimensions

The sensor pixel array area has total 1104x1312 pixels. All pixels are sensor output. The sensor has 114 pads. Bond pad area on each pad is 75x75µm (pad size is actually 120x75um, but a 45x75um area is reserve for wafer probe at sensor vendor). Refer to VD56G0 data sheet for pad definition and locations.

The sensor pad dimensions are called out in the diagram below.





4.2.3. Camera Cube Pinout

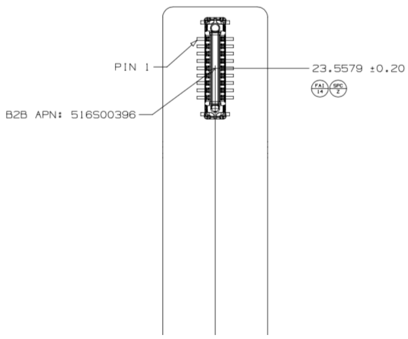
The cube is using an ACF interface to connect to the flex with pinout and pin 1 location identified below. NOTE: Diagram shown from top looking through.

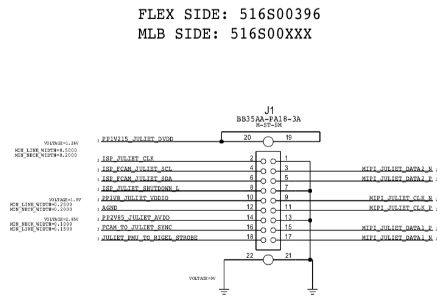
Pin	Net
1	DGN D
2	DVD D
3	DGN D
4	DATA 1P
5	DATA 1N
6	DGN D
7	CLKP
8	CLK N
9	DGN D
10	DATA 2P
11	DATA 2N
12	DGN D
13	DGN D
14	STR OBE
15	SYN C
16	AGN D
17	AVD D
18	DGN D
19	DOV DD
20	SHU TDO WN
21	SDA
22	SCL
23	CLKI N
24	DGN D

4.2.4. Camera Module Assembly Pinout

The module is using a B2B connector with pinout and pin 1 location identified below. NOTE: The flex tail is showing a top view looking downward through the stiffener and flex.

Location	APN	Description	MFG	MPN
Plug (Juliet	516	CONN,B2B,PLUG,	DDK	BB35A
Receptical	516	CONN,B2B,RCPT,1	DDK	BB35A

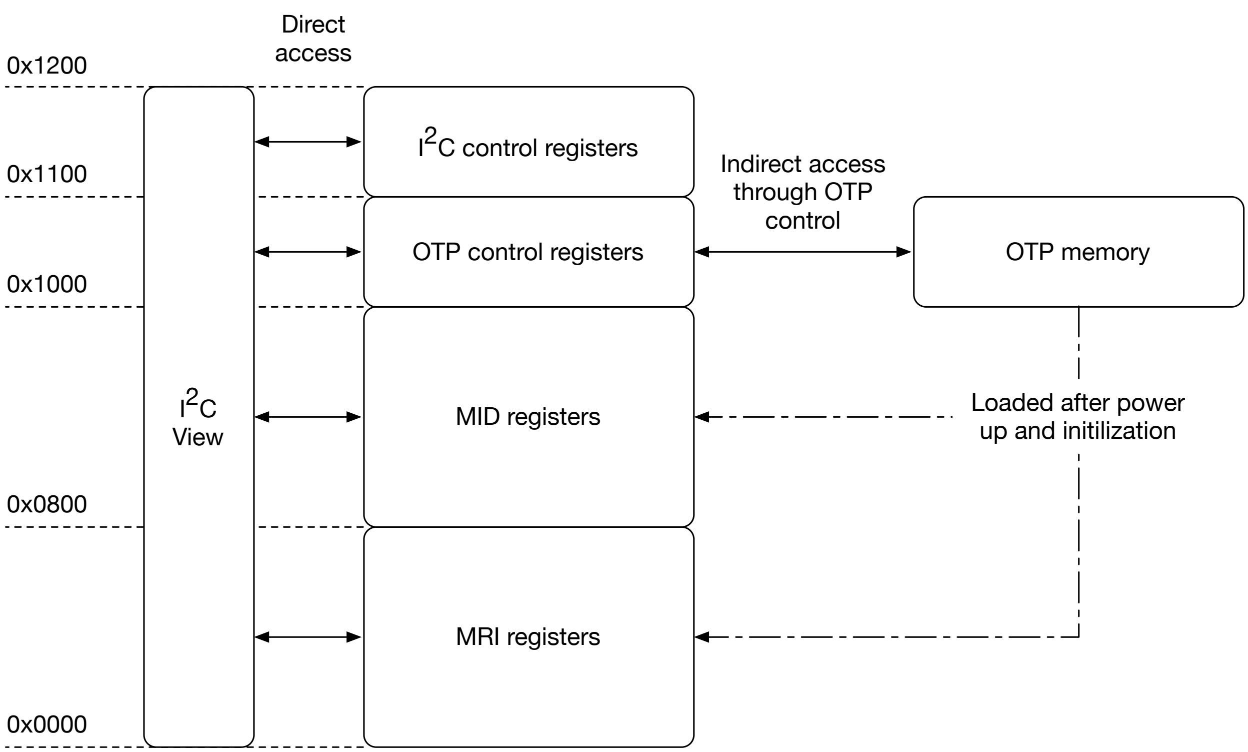




5. Titus OTP and Juliet NVM

5.1. Mama Bear & OTP

The Titus module contains OTP on Mama Bear Chip. The Mama Bear OTP must be programmed on every module. The memory must withstand a minimum of 10,000 reads. Every write to Mama Bear OTP should be read back for verification.



The tables in this section describe the Mama Bear OTP registers that should be programmed. See the Appendix for details on how to program and read back the Mama Bear. The I2C communication allows access to the register space and programming the on-chip OTP memory. Several examples are given to illustrate the different use cases.

5.1.1.Register Space and OTP Memory Mapping

Mama Bear register and OTP memory space is explained in Figure 1. The register space spans from address 0x0000 to address 0x1200. The width of each register is 32 bits. The I^2C communication bus has direct access to all the register space as shown in the figure.

The OTP memory can't be accessed through the I^2C communication bus. Instead, reads and writes to the OTP memory are done indirectly through the OTP control register and is controlled by the ASIC FSM. The OTP memory space spans from row 0x000 to row 0x0A0. Each group of rows are grouped into several sections. The OTP memory sections are as follows:

1. Lock region rows (rows 0x006 – 0x007): Required to prevent further modifications to the OTP memory sections.

2. Internal registers rows (rows 0x008 – 0x012): Holds internal data. Once Mama Bear is armed, the internal registers rows might be indirectly accessible through the OTP control registers communication bus. That includes the unique secure passkey and Arm data. The data in this section is triple redundant.

3. MID section (rows 0x013 - 0x076): Module ID data. The data stored in this section will be loaded into the MID register space. The data in this section is double redundant.

4. MRI section (rows 0x80 – 0x0A0): Scan parameters data. This data defines all the capacitance scan related parameters including the capacitance thresholds. This data is populated during the module integration and before arming Mama Bear. The data stored in this section will be loaded in the MRI register space. The data in this section is triple redundant.

5.1.2.OTP Parameters

OTP Version:	OTP version. Assigned by Apple. This value is incremented every time the OTP format changes. See VSR (Vendor Specific Requirements) for details
Project:	Project Identifier. Assigned by Apple. See VSR document for details.
Integrator:	Integrator ID. Assigned by Apple. See VSR document for details.
Plant:	Factory ID. Assigned by Apple. See VSR document for details.
Benvolio:	Lens vendor and type ID. Assigned by Apple. See VSR document for details.
Midas:	Diffractive Optical Element vendor and type ID. Assigned by Apple. See VSR document for details.
Substrate:	Substrate vendor and type ID. Assigned by Apple. See VSR document for details.
Rock:	Rock vendor and type ID. Assigned by Apple. See VSR document for details.
Andalusia:	VCSEL vendor and type ID. Assigned by Apple. See VSR document for details.
Flex:	Flex vendor and type ID. Assigned by Apple. See VSR document for details.
Beetle:	Beetle vendor and type ID. Assigned by Apple. See VSR document for details.
Test Station:	Test station ID. Assigned by Apple, See VSR document for details.

Projector Build: Module build phase. Assigned by Apple. The four MSBs describe the major build stage (e.g. ‘4’ of C4) and the four LSBs describe the minor build stage (e.g. ‘1’ of C4.1). Some examples shown below:

Projector Build [7:0]	Value (binary)	Value (hex)
C5.0	0101 0000	0x50
C4.0	0100 0000	0x40
C4.1	0100 0001	0x41
C3.0	0011 0000	0x30
C3.1	0011 0001	0x31
C3.2	0011 0010	0x32
C2.0	0010 0000	0x20
C2.1 (TB&MP)	0010 0001	0x21

Config Number: Module build config code. The two digits config number shall be converted to hex number and saved in Mama Bear. e.g. for C4231, the config number is 31, and the value in OTP of config number shall be 0x1F.

Year: Last digit of calendar year (2 for 2012, 3 for 2013 …)

Work Week: Integer value of 1 through 53.

Day: Day of week as integer value of 1 through 7 with 1 being Monday, 7 being Sunday.

Sequence Number: This is a sequence number. Each day the number will start at 0 and increment by 1 digital count for each module. At the exact time the day field changes the ID will reset to 0. So a combination of day, week, year, and ID results in a uniquely identifiable module. The ID is synchronized with the serial number in the barcode by the method of translation from 4 digit base 34 number to a 3 byte number based on the example in Appendix C. Base 34 consists of the digits 0 through 9 and the letters “A” through “Z,” excluding the letters ”I” and “O” because of their similarity to the digits 1 and 0.

Test Software: Test software and algorithm revision. Assigned by Apple, See VSR document for details.

DOE: DOE lookup table. Assigned by Apple, See VSR document for details.

WL/ Temp/ Spectrum: Details and instructions covered in section 7

OTP Checksum†: Checksum to verify OTP contents.

Group Name	Calculation	Color Coded NVM Map
Traceability	(256 - (sum(0x0800~0x080D) & 0x0FF))&0x0FF	
FOL ID	(256 - (sum(0x0814~0x081E) & 0x0FF))&0x0FF	
Andalusia Wafer	(256 - (sum(0x0820~0x0822) & 0x0FF))&0x0FF	
SN	(256 - (sum(0x0828~0x0838) & 0x0FF))&0x0FF	
DVC/ NTC	(256 - (sum(0x0840~0x084D) & 0x0FF))&0x0FF	

Group Name	Calculation	Color Coded NVM Map
LIV Cal	(256 - (sum(0x0850~0x086F) & 0x0FF))&0x0FF	
AA	(256 - (sum(0x0878~0x0887) & 0x0FF))&0x0FF	
EOL	(256 - (sum(0x088C~0x088E) & 0x0FF))&0x0FF	
Compliance	(256 - (sum(0x0890~0x0892) & 0x0FF))&0x0FF	

Waiver: Engineering build waiver ID. Assigned by Apple, See VSR document for details.
Serial Number: Module serial number in base34 format.

Waiver: Engineering build waiver ID. Assigned by Apple, See VSR document for details.
Serial Number: Module serial number in base34 format.

5.1.3. OTP Map Version 7 (MID Section)

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
13	14	800	OTP Version [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Project [7:4]				Program Variant [3:0]				
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Integrator [7:3]					Plant [2:0]			
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Andalusia Vendor [7:5]			Andalusia Version [4:2]			Andalusia Variant [1:0]		
15	16	804	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Benvolio Vendor [7:5]			Benvolio Version [4:2]			Benvolio Variant [1:0]		
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Midas Vendor [7:5]			Midas Version [4:2]			Midas Variant [1:0]		
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Substrate Vendor [7:5]			Substrate Version [4:2]			Substrate Variant [1:0]		
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Rock Vendor [7:5]			Rock Version [4:2]			Rock Variant [1:0]		
17	18	808	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Flex Vendor [7:5]			Flex Version [4:2]			Flex Variant [1:0]		
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Beetle Vendor [7:5]			Beetle Version [4:2]			Beetle Variant [1:0]		EOL
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Tick Vendor [7:5]			Tick Version [4:2]			Tick Variant [1:0]		
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Projector Build [7:0]								
19	1A	80C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Config Number [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			DOE Byte [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Traceability Checksum [7:0]								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								
1B	1C	810	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
1D	1E	814	FOL_ID_PPPYWW [31:24]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			FOL_ID_PPPYWW [23:16]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			FOL_ID_PPPYWW [15:8]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			FOL_ID_PPPYWW [7:0]								
1F	20	818	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			FOL_ID_DSSSS [23:16]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			FOL_ID_DSSSS [15:8]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			FOL_ID_DSSSS [0:7]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			FOL_ID_EEEERX [31:24]								
21	22	81C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			FOL_ID_EEEERX [23:16]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			FOL_ID_EEEERX [15:8]								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
21	22	81C	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	FOL
			FOL_ID_EEEERX [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SN Checksum [7:0]								
23	24	820	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Andalusia Wafer ID 1 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Andalusia Wafer ID 2 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Andalusia Wafer ID 3 [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Andalusia Wafer ID Checksum [7:0]								
25	26	824	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
27	28	828	Year [3:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Work Week [5:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Day [2:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Sequence Number [7:0]								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
29	2A	82C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	AA
			Sequence Number [15:8]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Sequence Number [23:16]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SN_PPPYWW [31:24]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SN_PPPYWW [23:16]								
2B	2C	830	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			SN_PPPYWW [15:8]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			SN_PPPYWW [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SN_DSSSS [23:16]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SN_DSSSS [15:8]								
2D	2E	834	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			SN_DSSSS [0:7]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			SN_EEEERX [31:24]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SN_EEEERX [23:16]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SN_EEEERX [15:8]								
2F	30	838	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			SN_EEEERX [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			SN Checksum [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

Group Name	Calculation	Color Coded NVM Map
Integrator NVM [7:0]	(256 - (sum(0x019C~0x01CB) & 0x0FF))&0x0FF	
Lens Shading [7:0]	(256-(sum(0x01E5 ~ 0x0235) & 0x0FF)) & 0x0FF	
ASP Gain Cal [7:0]	(256-(sum(0x0237 ~ 0x03FE) & 0x0FF)) & 0x0FF	

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
			FOL Test Software Algorithm Revision [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			FOL Test Station ID [7:0]								
31	32	83C	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			FOL Test Station Head/Para [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			FOL Tester Checksum [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			NTC Calibration a1 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
33	34	840	NTC Calibration a2 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			NTC Calibration b1 [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			NTC Calibration b2 [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			NTC Calibration c1 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
35	36	844	NTC Calibration c2 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	FOL
			NTC Calibration a3 [7:4]				NTC Calibration b3 [3:0]				
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			NTC Calibration C3 [7:4]				RESERVED				
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Dead Emitter Sparse 1 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
37	38	848	Dead Emitter Sparse 2 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Dead Emitter Sparse 3 [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Dead Emitter Dense 1 [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
39	3A	84C	Dead Emitter Dense 2 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Dead Emitter Dense 3 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			NTC/ Dead Emitter Checksum [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
3B	3C	850	WL1 LHD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			WL2 LHD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SP1 LHD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SP2 LHD [7:0]								
3D	3E	854	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Temp1 LHD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Temp 2 LHD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Power1 LHD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Power2 LHD [7:0]								
3F	40	858	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			WL1 LCD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			WL2 LCD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	FOL

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
			SP1 LCD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SP2 LCD [7:0]								
41	42	85C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Temp1 LCD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Temp 2 LCD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Power1 LCD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Power2 LCD [7:0]								
43	44	860	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			WL1 HHD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			WL2 HHD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SP1 HHD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SP2 HHD [7:0]								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
45	46	864	Temp1 HHD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Temp 2 HHD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Power1 HHD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Power2 HHD [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			WL1 HCD [7:0]								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
47	48	868	Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	FOL
			WL2 HCD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			SP1 HCD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			SP2 HCD [7:0]								
49	4A	86C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Temp1 HCD [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Temp 2 HCD [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Power1 HCD [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Power2 HCD [7:0]								
4B	4C	870	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			LIV Cal Checksum [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								
4D	4E	874	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
4F	50	878	Midas Attach ID [7:0]								AA
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			AA Station ID [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			AA Station ID Head/Para [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
51	52	87C	Benvolio WWD1 [11:4]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Benvolio WWD2 [3:0]				Benvolio SSSS 1 [23:19]				
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Benvolio SSSS 2 [18:11]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Benvolio SSSS 3 [10:4]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
53	54	880	Benvolio SSSS 4 [3:0]				Benvolio RRCC 1 [11:8]				
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Benvolio RRCC 2 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Midas Row [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Midas Column [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
55	56	884	Midas Wafer 1 [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Midas Wafer 2 [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Midas Wafer 3 [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Midas Wafer 4 [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			AA Offset [7:0]								
			Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
57	58	888	AA Checksum [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
59	5A	88C	EOL Test Software Algorithm Revision [7:0]								EOL
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			EOL Test Station ID [7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			EOL Test Station Head/Para [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			EOL Checksum [7:0]								
5B	5C	890	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			Compliance Test Software Algorithm Revision [7:0]								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			Compliance Test Station ID[7:0]								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			Compliance Test Station Head/Para [7:0]								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			Compliance Checksum [7:0]								
5D	5E	894	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Co

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
			RESERVED								Co mpl ian ce
5F	60	898	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								
61	62	89C	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
6D	6E	8B4	RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								
6F	70	8B8	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Co mpl ian
			RESERVED								

OTP Row		Addr (hex)	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	Station
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	ce
			RESERVED								
71	72	8BC	Bit 31	Bit 30	Bit 29	Bit 28	Bit 27	Bit 26	Bit 25	Bit 24	
			RESERVED								
			Bit 23	Bit 22	Bit 21	Bit 20	Bit 19	Bit 18	Bit 17	Bit 16	
			RESERVED								
			Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	
			RESERVED								
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
			RESERVED								
...	...	...	RESERVED								
77	78	8C8	RESERVED								

* when applicable, otherwise write 0x00

5.1.4.OTP Integrity

Parameter	LSL	USL	Notes
OTP Version [7:0]	0x07		
Project [7:4]	0x03		
Program Variant [3:0]	0x03		
Integrator/ Plant [7:0]	0x08		
Andalusia Vendor [7:5]	0x02		
Andalusia Version [4:2]	0x02		
Andalusia Variant [1:0]	0x00		
Benvolio Vendor [7:5]	0x01		
Benvolio Version [4:2]	0x03		
Benvolio Variant [1:0]	0x01	0x03	
Midas Vendor [7:5]	0x02		
Midas Version [4:2]	0x02		
Midas Variant [1:0]	0x00		
Substrate Vendor [7:5]	0x01		

Substrate Version [4:2]	0x01		
Substrate Variant [1:0]	0x01		
Rock Vendor [7:5]	0x01		
Rock Version [4:2]	0x02		
Rock Variant [1:0]	0x00		
Flex Vendor [7:5]	0x01	0x04	
Flex Version [4:2]	0x02		
Flex Variant [1:0]	0x00		
Beetle Vendor [7:5]	0x02		
Beetle Version [4:2]	0x02		
Beetle Variant [1:0]	0x00		
Tick Vendor [7:5]	0x02		
Tick Version [4:2]	0x01	0x02	
Tick Variant [1:0]	0x01		
Projector Build [7:0]	21	20	
General Info Checksum	Must match checksum calculated from respective segment		
NTC/WL Cal Checksum			
Dead Emitter Checksum			
FOL Checksum			
NTC Cal	Must not be zeros		

DOE [7:0]	Value (binary)	Value (hex)
No DOE Byte - Cxxxx	0000 0000	0x00
No MiniLizard - CxxxxA	0000 0001	0x01
Burn In - CxxxxB	0000 0010	0x02
CxxxxC	0000 0011	0x03
CxxxxD	0000 0100	0x04
CxxxxE	0000 0101	0x05
CxxxxF	0000 0110	0x06

DOE [7:0]	Value (binary)	Value (hex)
CxxxxG	0000 0111	0x07
Hot Lot - CxxxxH	0000 1000	0x08
CxxxxJ	0000 1001	0x09
CxxxxK	0000 1010	0x0A
CxxxxL	0000 1011	0x0B
CxxxxM	0000 1100	0x0C
CxxxxN	0000 1101	0x0D
CxxxxP	0000 1110	0x0E
CxxxxQ	0000 1111	0x0F
Rel Config - CxxxxR	0001 0000	0x10
CxxxxS	0001 0001	0x11
CxxxxT	0001 0010	0x12
CxxxxU	0001 0011	0x13
CxxxxV	0001 0100	0x14
Weak Bond - CxxxxW	0001 0101	0x15
CxxxxX	0001 0110	0x16
CxxxxY	0001 0111	0x17
CxxxxZ	0001 1000	0x18

5.1.5.Arming Status

Arming Status Summary

Description	Arm state	Cap limits	Comment
Armed	0x14,0x15	MP/functional Capacitance values	Standard MP modules
Unarmed	0x10,0x11	MP/functional Capacitance values	Has not been armed to allow Cap values to be read & be optically functional. Requires LHZ by default
Brick-able	0x10,0x11	LSL and USL = 0xFFFFF	Has not been armed, requires LHZ by default, programmed with limits that would cause the module brick upon arming & Power cycling
Bricked	0x1C	MP/functional Capacitance values or 0xFFFF	Module optically non-functional
Soft Bricked	0x14	MP/functional Capacitance values	Module temporarily optically non-functional

5.2. Juliet Module Non Volatile Memory

The image sensor module contains Non Volatile Memory (NVM) that must be programmed. This memory may be any form of non volatile memory including one time programmable memory. The NVM must be programmed on every module. The memory must withstand a minimum of 10,000 reads. Every write to NVM should be read back for verification.

The tables in this section describe the NVM registers that should be programmed. See the Appendix for details on how to program and read back the NVM.

The procedure for generating the lens shading data is provided in the Quarry testing ERS.

5.2.1. NVM Parameters

NVM Version: NVM version. Assigned by Apple. This value is incremented every time the NVM format changes. See VSR (Vendor Specific Requirements) for details

Camera Project: Project Identifier. Assigned by Apple. See VSR document for details.

Project Version: Project Version. Assigned by Apple. See VSR document for details.

Integrator: Integrator ID. Assigned by Apple. See VSR document for details.

Plant: Factory ID. Assigned by Apple. See VSR document for details.

Camera Build: Module build phase. Assigned by Apple. The four MSBs describe the major build stage (e.g. '4' of C4) and the four LSBs describe the minor build stage (e.g. '1' of C4.1). Some examples shown below:

Camera Build [7:0]	Value (binary)	Value (hex)
C6.0	0110 0000	0x60
C5.0	0101 0000	0x50
C5.1	0101 0001	0x51
C4.0	0100 0000	0x40
C4.1	0100 0001	0x41
C4.2	0100 0010	0x42
C3.0	0011 0000	0x30
C3.1	0011 0001	0x31
C2.0	0010 0000	0x20
C1.0	0001 0000	0x10

Config Number: Config Identifier. Assigned by Apple. See VSR document for details.

Filter: Filter vendor and type ID. Assigned by Apple. See VSR document for details.

Substrate: Substrate vendor and type ID. Assigned by Apple. See VSR document for details.

Sensor: Sensor vendor and type ID. Assigned by Apple. See VSR document for details.

Sensor DOE Lot #: Sensor DOE Lot #. Assigned by Apple. See VSR document for details.

Lens: Lens vendor and type ID. Assigned by Apple. See VSR document for details.

Flex: Flex vendor and type ID. Assigned by Apple. See VSR document for details.

Stiffener:	Stiffener vendor and type ID. Assigned by Apple. See VSR document for details.
Module SN:	Module Serial Number in base 34. See detailed description in section 2.5.4 & 3.3.6
Process Control Plan:	PCP Revision. Assigned by Apple, See VSR document for details.
Process DOE Code:	Code for Process DOEs. Assigned by Apple, See VSR document for details.
Test Software:	Test software and algorithm revision. Assigned by Apple, See VSR document for details.
Waiver:	Engineering build waiver ID. Assigned by Apple, See VSR document for details.
Machine ID:	Machine ID byte. Assigned by Apple, See VSR document for details.
Lens shading revision:	Lens shading revision. Assigned by Apple. See VSR document for details. This value is incremented every time the Color Shading Calibration format changes.
Lens SN:	Lens SN. See detailed description in section 2.5.5
NVM Checksum:	Three bytes checksum to verify NVM contents: for general information, lens shading calibration and ASP gain calibration separately. The NVM address for each group and the calculation method are listed below: †the checksum of each category shall be calculated and programmed into NVM at the same time as the information collected
Optical Center (X, Y):	Optical center measurement (OC X and OC Y). NVM_Value = round(ActualOCShift / 0.015) and converted to Hex with negatives programmed as two's complement. This supports OC values from -30.72 to +30.705 in 0.015 steps, stored as a signed 12-bit number. The narrow band (NB) image must be used for the OC value stored in NVM.
EFL:	Effective Focal Length as measured using the specified SFR Chart. NVM_Value = round([ActualEFLmm - 2.55] / 0.0002) and convert to Hex. This supports EFL in the range of 2.55mm to 2.7546mm in 0.0002mm steps, stored as an unsigned 10-bit number.
Sensor Cal Temp:	Temperature of the image sensor during the EFL measurement. NVM_Value = round([ActualTemperature - 20] / 0.25) and convert to Hex, supports temperature range of 20C to 51.75C in 0.25C steps, stored as an unsigned 7-bit number.
Lens Cal Temp:	Temperature of the Module lens at the time of calibration, stored the same as module temp.
Lens Shading Cal:	Lens shading calibration stored in an 9 x 9 array. Each entry is an 8-bit number representing the average absolute pixel value of the ROI in each grid position in the image as defined by Apple EOL flat field test software. Online RGB cameras with multi-channel shading, Juliet used single channel monochrome shading calibration, stored in (N,M) fashion, N being the short axis of the image sensor, M being the long axis)
ASP Delta:	Delta value used to finely adjust the coarse gain value to get region specific accurate ASP gain map. Values exist in an 8 x 8 grid for each ASP type (H1, H2, V1, V2). ASP Delta is calculated by Apple Matlab code and stored as a 12-bit signed number using two's complement (range -2048…+2047).
Neighbor Delta:	Delta value used to finely adjust the coarse gain value to get region specific accurate Neighbor gain map. Values exist in a 4 x 4 grid for each of 8 neighbors (1 through 8). Neighbor Delta is calculated by Apple Matlab code and stored as a 4-bit signed number using two's complement (range -8…+7).
ASP Coarse Gain:	Coarse gain value for compensating the Asymmetric pixel response, there is a unique value for each ASP type (H1, H2, V1, V2). This is a global gain value used for all pixels of it's type and when combined with the respective delta value, creates a precise region based gain map for ASP response correction. Stored as an 8-bit value with 6-bit fractional component, calculated by Apple Matlab code.

Neighbor Coarse Gain: Coarse gain value for compensating the ASP Neighboring pixel response, there is a unique value for 8 different neighbors (#1~8). This is a global gain value used for all neighbors of it's type and when combined with the respective delta value, creates a precise region based gain map for ASP response correction. Stored as a 4-bit value (range 0…15), calculated by Apple Matlab code.

ASP Gain map(X,Y) = ASP Coarse Gain + ASP Delta(X,Y) / 6400
Neighbor gain map(X,Y) = 1 + Neighbor Coarse Gain / 200 + Neighbor Delta(X,Y) / 400

NOTE: The narrow band (NB) image must be used for the ASP values stored in NVM.

5.2.2. NVM Map

Block	Byte Index	Addr (hex)	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	0	0	Vendor RSVD							
…	…	…	…							
102	411	19B	Vendor RSVD							
103	412	19C	NVM Version [7:4]				NVM Revision [3:0]			
103	413	19D	Camera Project [7:0]							
103	414	19E	Project Version [7:0]							
103	415	19F	Integrator [7:3]					Plant [2:0]		
104	416	1A0	Camera Build [7:0]							
104	417	1A1	Config Number [7:0]							
104	418	1A2	Filter Vendor [7:5]			Revision [4:2]			Variant [1:0]	
104	419	1A3	Substrate Vendor [7:5]			Revision [4:2]			Variant [1:0]	
105	420	1A4	Sensor Vendor [7:5]			Sensor/Pixel Rev [4:2]			Logic [1:0]	
105	421	1A5	Sensor DOE Lot Number [7:0]							
105	422	1A6	Lens Vendor [7:5]			Revision [4:2]			Variant [1:0]	
105	423	1A7	RSVD							
106	424	1A8	RSVD							
106	425	1A9	RSVD							
106	426	1AA	Flex Vendor [7:3]					Revision [2:0]		
106	427	1AB	Stiffener Vendor [7:3]					Revision [2:0]		
107	428	1AC	RSVD							
107	429	1AD	RSVD							
107	430	1AE	RSVD							
107	431	1AF	SN_PPPYWW [31:24]							
108	432	1B0	SN_PPPYWW [23:16]							
108	433	1B1	SN_PPPYWW [15:8]							
108	434	1B2	SN_PPPYWW [7:0]							
108	435	1B3	SN_DSSSS [23:16]							
109	436	1B4	SN_DSSSS [15:8]							
109	437	1B5	SN_DSSSS [0:7]							
109	438	1B6	SN_EEEERX [31:24]							
109	439	1B7	SN_EEEERX [23:16]							
110	440	1B8	SN_EEEERX [15:8]							
110	441	1B9	SN_EEEERX [7:0]							
110	442	1BA	Process Control Plan Revision [7:0]							
110	443	1BB	Process DOE code [7:0]							
111	444	1BC	Test Software Revision [7:0]							
111	445	1BD	Waiver Field [7:0]							
111	446	1BE	Machine ID 1 [7:0]							
111	447	1BF	Machine ID 2 [7:0]							
112	448	1C0	Machine ID 3 [7:0]							
112	449	1C1	Machine ID 4 [7:0]							
112	450	1C2	Machine ID 5 [7:0]							
112	451	1C3	Lens Shading Revision [7:0]							
113	452	1C4	Lens_SN_P [7:0]							
113	453	1C5	Lens_SN_S [7:0]							

Block	Byte Index	Addr (hex)	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
113	454	1C6	Lens_SN_M [7:0]							
113	455	1C7	Lens_SN_EEEE [7:0]							
114	456	1C8	Lens_SN_EEEE [7:0]							
114	457	1C9	Lens_SN_EEEE [7:0]							
114	458	1CA	Lens_SN_EEEE [7:0]							
114	459	1CB	Lens_SN_H [7:0]							
115	460	1CC	Integrator NVM Checksum [7:0]							
115	461	1CD	OC Offset X 11..4 [7:0]							
115	462	1CE	OC Offset X 3..0 [7:4]				OC Offset Y 11..8 [3:0]			
115	463	1CF	OC Offset Y 7..0 [7:0]							
116	464	1D0	EFL 9..2 [7:0]							
116	465	1D1	EFL b1 [7]	Sensor Cal Temp [6:0]						
116	466	1D2	EFL b0 [7]	Lens Cal Temp [6:0]						
116	467	1D3	0x00 (write zero here)							
117	468	1D4	RSVD - For FATP Use (16bytes) - DO NOT WRITE ANYTHING HERE							
…	…	…	…							
120	483	1E3	RSVD - For FATP Use (16bytes) - DO NOT WRITE ANYTHING HERE							
121	484	1E4	0x00 (write zero here)							
121	485	1E5	Lens Shading MonoChrome byte (0,0) [7:0]							
121	486	1E6	Lens Shading MonoChrome byte (1,0) [7:0]							
…	…	…	…							
141	565	235	Lens Shading MonoChrome byte (8,8) [7:0]							
141	566	236	Lens Shading Checksum [7:0]							
141	567	237	ASP Delta H1 (0,0) 11..4 [7:0]							
142	568	238	ASP Delta H1 (0,0) 3..0 [7:4]				ASP Delta H1 (0,1) 11..8 [3:0]			
142	569	239	ASP Delta H1 (0,1) 7..0 [7:0]							
142	570	23A	ASP Delta H1 (0,2) 11..4 [7:0]							
142	571	23B	ASP Delta H1 (0,2) 3..0 [7:4]				ASP Delta H1 (0,3) 11..8 [3:0]			
143	572	23C	ASP Delta H1 (0,3) 7..0 [7:0]							
…	…	…	…							
165	662	296	ASP Delta H1 (7,7) 7..0 [7:0]							
165	663	297	ASP Delta H2 (0,0) 11..4 [7:0]							
166	664	298	ASP Delta H2 (0,0) 3..0 [7:4]				ASP Delta H2 (0,1) 11..8 [3:0]			
…	…	…	…							
189	758	2F6	ASP Delta H2 (7,7) 7..0 [7:0]							
189	759	2F7	ASP Delta V1 (0,0) 11..4 [7:0]							
190	760	2F8	ASP Delta V1 (0,0) 3..0 [7:4]				ASP Delta V1 (0,1) 11..8 [3:0]			
…	…	…	…							
213	854	356	ASP Delta V1 (7,7) 7..0 [7:0]							
213	855	357	ASP Delta V2 (0,0) 11..4 [7:0]							
214	858	35A	ASP Delta V2 (0,0) 3..0 [7:4]				ASP Delta V2 (0,1) 11..8 [3:0]			
…	…	…	…							
237	950	3B6	ASP Delta V2 (7,7) 7..0 [7:0]							
237	951	3B7	Neighbor #1 Delta (0,0) [7:4]				Neighbor #1 Delta (0,1) [3:0]			
…	…	…	…							
239	958	3BE	Neighbor #1 Delta (3,2) [7:4]				Neighbor #1 Delta (3,3) [3:0]			
239	959	3BF	Neighbor #2 Delta (0,0) [7:4]				Neighbor #2 Delta (0,1) [3:0]			
…	…	…	…							
241	966	3C6	Neighbor #2 Delta (3,2) [7:4]				Neighbor #2 Delta (3,3) [3:0]			
241	967	3C7	Neighbor #3 Delta (0,0) [7:4]				Neighbor #3 Delta (0,1) [3:0]			
…	…	…	…							
243	974	3CE	Neighbor #3 Delta (3,2) [7:4]				Neighbor #3 Delta (3,3) [3:0]			
243	975	3CF	Neighbor #4 Delta (0,0) [7:4]				Neighbor #4 Delta (0,1) [3:0]			
…	…	…	…							
245	982	3D8	Neighbor #4 Delta (3,2) [7:4]				Neighbor #4 Delta (3,3) [3:0]			
245	983	3D8	Neighbor #5 Delta (0,0) [7:4]				Neighbor #5 Delta (0,1) [3:0]			
…	…	…	…							
247	990	3DE	Neighbor #5 Delta (3,2) [7:4]				Neighbor #5 Delta (3,3) [3:0]			
247	991	3DF	Neighbor #6 Delta (0,0) [7:4]				Neighbor #6 Delta (0,1) [3:0]			

Block	Byte Index	Addr (hex)	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
…	…	…	…							
249	998	3E6	Neighbor #6 Delta (3,2) [7:4]				Neighbor #6 Delta (3,3) [3:0]			
249	999	3E7	Neighbor #7 Delta (0,0) [7:4]				Neighbor #7 Delta (0,1) [3:0]			
…	…	…	…							
251	1006	3EE	Neighbor #7 Delta (3,2) [7:4]				Neighbor #7 Delta (3,3) [3:0]			
251	1007	3EF	Neighbor #8 Delta (0,0) [7:4]				Neighbor #8 Delta (0,1) [3:0]			
…	…	…	…							
253	1014	3F6	Neighbor #8 Delta (3,2) [7:4]				Neighbor #8 Delta (3,3) [3:0]			
253	1015	3F7	ASP Coarse Gain Value H1 [7:0]							
254	1016	3F8	ASP Coarse Gain Value H2 [7:0]							
254	1017	3F9	ASP Coarse Gain Value V1 [7:0]							
254	1018	3FA	ASP Coarse Gain Value V2 [7:0]							
254	1019	3FB	Neighbor #1 Coarse Gain Value [7:4]				Neighbor #2 Coarse Gain Value [3:0]			
255	1020	3FC	Neighbor #3 Coarse Gain Value [7:4]				Neighbor #4 Coarse Gain Value [3:0]			
255	1021	3FD	Neighbor #5 Coarse Gain Value [7:4]				Neighbor #6 Coarse Gain Value [3:0]			
255	1022	3FE	Neighbor #7 Coarse Gain Value [7:4]				Neighbor #8 Coarse Gain Value [3:0]			
255	1023	3FF	ASP Gain Cal Checksum [7:0]							

5.2.3.Serial Number in NVM

The Image Sensor Module serial number shall be stored in NVM in three base-34 hex numbers. The conversion shall follow the steps below (the encoding/decoding code in Matlab is provided in the Appendix):

a) The 17 digits SN shall be divided into three parts: PPPYWW, DSSSS and EEEERX.

b) Each part of SN shall be converted to a base-34 decimal number, with the left-most digit as the most significant digit (e.g. 'D' is the most significant digit of 'DSSSS').

c) Each of three decimal base-34 numbers shall be converted to a hex number. PPPYWW shall be converted into a 8-digit hex value. DSSSS shall be converted into a 6-digit hex value and EEEERX shall be converted into a 8-digit hex value.

d) Each of three base-34 hex numbers shall be save in the designated NVM locations as in table 6.

6. Mechanical Specifications

6.1. Projector Module Test Fixture Requirements

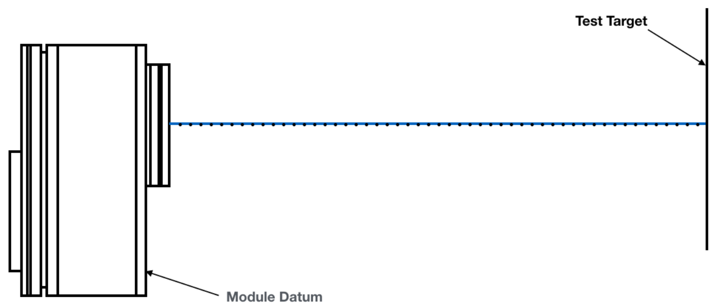
A summary report of the method and techniques used to measure alignment errors of the test fixture shall be provided to Apple Engineering for approval. This report will include details of the construction of the fixture as well as any alignment jigs used in production line. An analysis of alignment accuracy must be included for both the Projector Module as well as the test fixture. This analysis must include all error sources and magnitudes.

6.2. Projector Module Pointing Tilt and Rotation

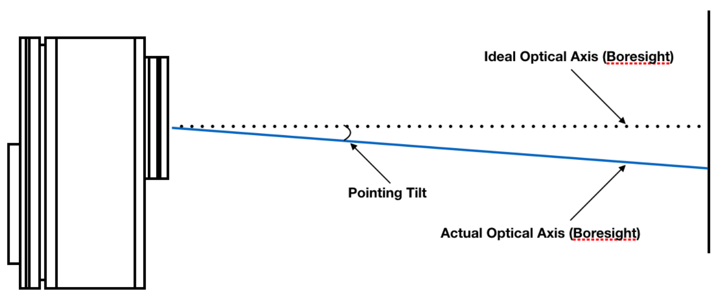
Alignment definitions are given by the figures below. Reference surfaces for alignment and rotation should be those defined in the Mechanical Control Outline (MCO).

Tests must be performed in appropriate fixtures that are calibrated (e.g. with a laser) to remove errors in alignment, tilt and rotation of the Projector module with respect to the target. Use of "golden modules" is unacceptable as these modules are built with unknown alignment errors. Process capability (Cpk) must be calculated for these items and controlled to Cpk > 1.3.

Ideal Test Condition



Tilted Test Condition



6.3. Mechanical Dimensions and Tolerances

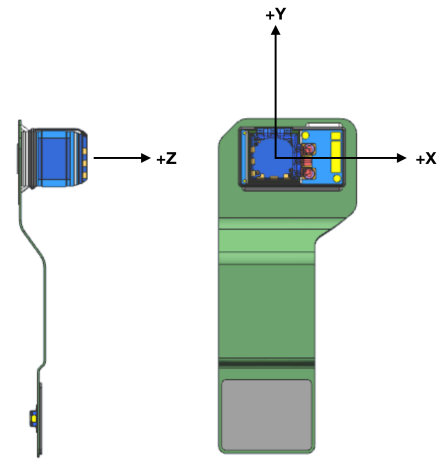
The Projector Module shall conform to the mechanical dimensions and tolerances of the engineering drawing package supplied by Apple Engineering. Please refer to module MCO 613-11311 and module cube 613-10640 for dimensions.

6.4. Module Mechanical Datums

The reference planes for the module must be used when holding the Projector module in any optical test fixtures. The reference planes to be used is illustrated below.

6.5. Juliet Test Fixture Requirements

A summary report of the method and techniques used to measure alignment shall be provided to Apple Engineering for approval. This report will include details of the

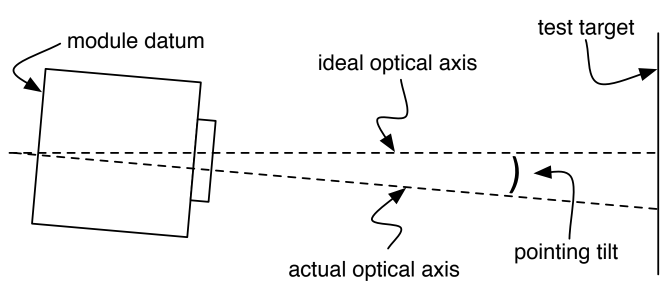


construction of the fixture as well as any alignment jigs. An analysis of alignment accuracy must be included for both the Image Sensor Module as well as the test fixture. This analysis must include all error sources and magnitudes.

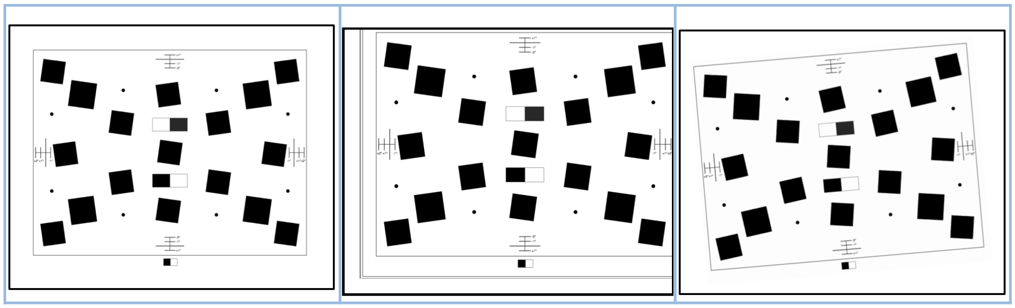
6.6. Juliet Pointing Tilt and Rotation

Alignment definitions are given by the figures below. Reference surfaces for alignment and rotation should be those defined in the MCO.

Tests must be performed in appropriate fixtures that are calibrated absolutely (e.g. with a laser) to remove alignment, tilt and rotation of the camera module with respect to the target. Use of "golden modules" is unacceptable as these modules are built with unknown alignment errors. Process capability (Cpk) must be calculated for these items and controlled to Cpk > 1.3.



Ideal Alignment	Positive X & Y Pointing Tilt	Positive Rotation

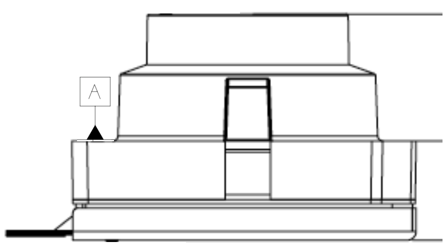


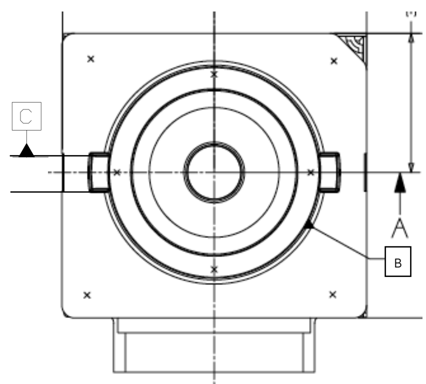
6.7. Mechanical Dimensions and Tolerances

The Image Sensor Module shall conform to the mechanical dimensions and tolerances of the engineering drawing package supplied by Apple Engineering. Please refer to module MCO for dimensions.

6.8. Module Mechanical Datums

The reference planes for the module must be used when holding the camera module in any optical testing fixtures. The reference planes to be used is illustrated below.

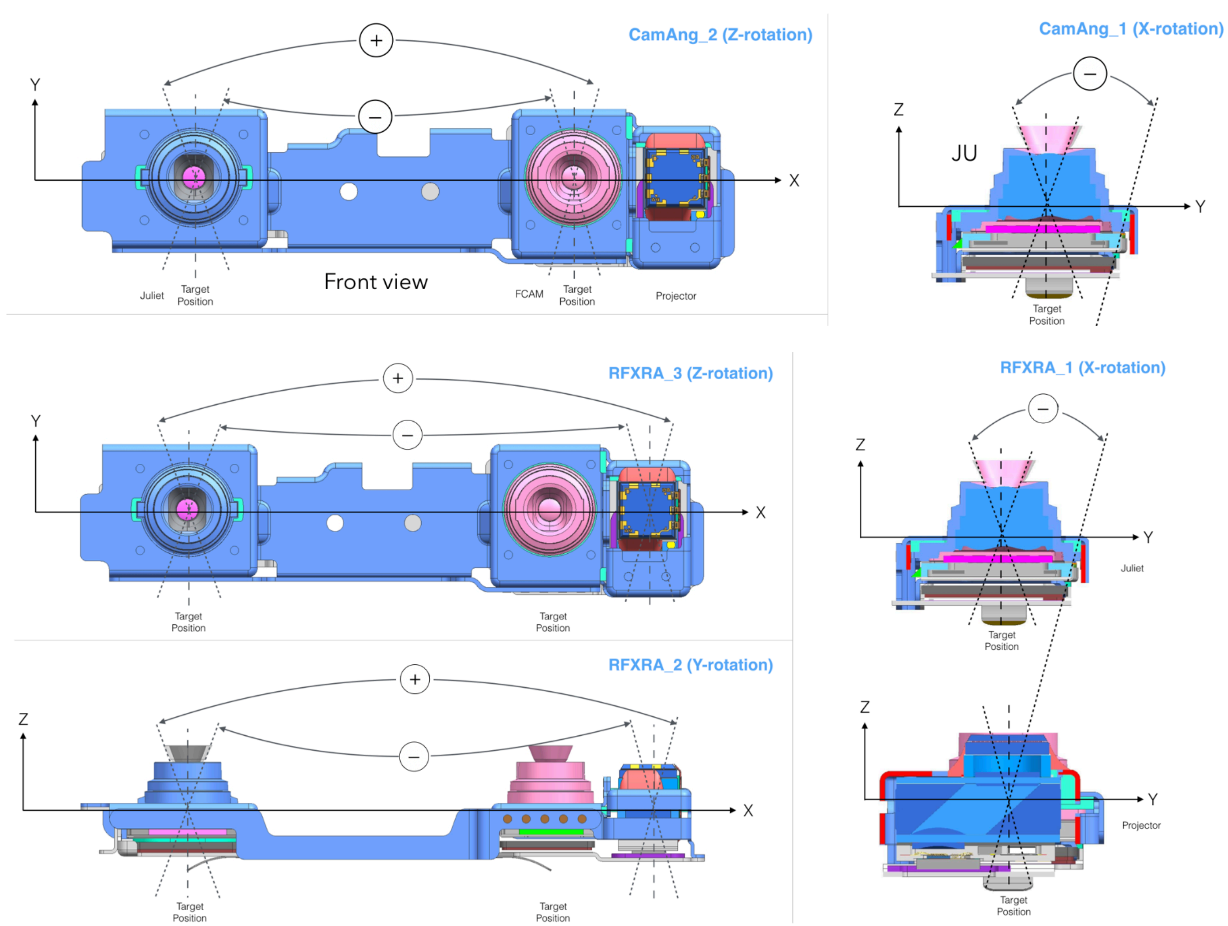




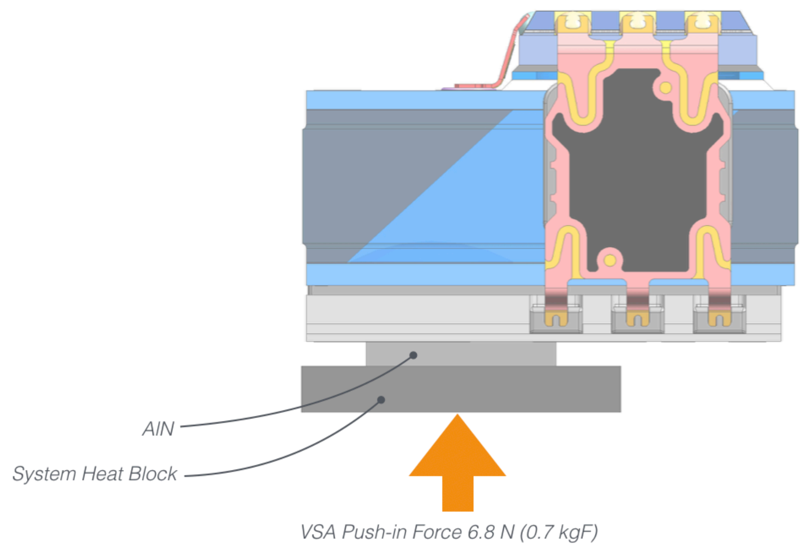
6.9. Module to module alignment metrics at Rack1

Test Type	Test Items	Abbreviation	Production Limit*		Unit	Notes
			Min	Max		
Tilt	Juliet to Fcam Y-tilt	CamAng_0	-1.8	1.8	deg	
	Juliet to Fcam X-tilt	CamAng_1	-1.5	1.5	deg	

Rotation	Juliet to Fcam Z-rotation	CamAng_2	88.3	91.7	deg	CamAng_2 has an offset of 90˚, Juliet to Maryland-R rotation is 90˚ - CamAng_2
Alignment	Juliet to Fcam X-distance	CamBaseline_0	-21.58	-21.18	mm	
	Juliet to Fcam Y-distance	CamBaseline_1	-0.20	0.20	mm	
	Juliet to Fcam Z-distance	CamBaseline_2	-0.20	0.20	mm	
Tilt	Juliet to Dot Projector X-tilt	RFXRa_1	-34.50	34.50	mrad	
	Juliet to Dot Projector Y-tilt	RFXRa_2	-46.00	46.00	mrad	
Rotation	Juliet to Dot Projector Z-rotation	RFXRa_3	-27	27	mrad	
Alignment	Juliet to Dot Projector X-distance	RObaseline_0	-27.34	-26.74	mm	
	Juliet to Dot Projector Y-distance	RObaseline_1	-0.7	0.7	mm	
	Juliet to Dot Projector Z-distance	RObaseline_2	-0.9	0.7	mm	



6.10.Projector loading conditions



Recommended VSA Push-in Force Spec: 6.8 N (0.7 kgF)

6.11.SN Decoding

6.11.1.Titus

- Each Romeo Module shall have a unique serial number that is 17 characters long.
- Each serial number character is restricted to the set of base-34 characters. Valid characters are digits “0” through “9” and letters “A” through “Z” except for letters “O” and “I” which are invalid due to similarity to numbers “0” and “1”.
- The serial number must be generated using the format detailed in the table below.
- The Projector Module serial number shall be applied to the stiffener on the flex of Projector module in a human readable format using laser marking, scannable by the barcode readers listed in the Appendix.

INFO TYPE	Plant Code	Date Code of Manufacturer	Sequence Number	Config Code	Checksum
Format	PPP	YWWD	SSSS	EEEER	X
#Characters	3	4	4	5	1
Explanation	**PPP = Vendor and lant/Factory Locatio** The code indicating the projector module vendor and where it is manufactured. Assigned by Apple.	**Y = Year:** 0 = 2010 1 = 2011 2 = 2012 … etc.	**SSSS = 4 char Sequence Number** (base-34)	**EEEE = Engineering Config Codes** **R=revision** The code indicating the Projector Module Lens, VCSEL, and other configuration details. This code will be assigned to the Vendor by Apple.	X = Checksum See Appendix
		WW = Week of Manufacture: 01 to 53 weeks	Each module must have a unique sequence number for each plant and day per product		
		D = Day Days 1 to 7 with 1 = Monday	This allows for 34^4 = 1,336,336 units per day per plant		
Example	XSW341200Z3A2341Q				
Example	XSW	3412	00Z3	A2341	Q
	Built at Vendor XYZ Inc. Singapore Plant	Manufactured on Tuesday of the 41st week of 2013	Sequence# 00Z3	Apple provided	See ex of checksum

6.11.2. Serial number in OTP

The Projector Module serial number shall be stored in OTP in three base-34 hex numbers. The conversion shall follow the steps below (the encoding/decoding code in MATLAB is provided in the Appendix):

a) The 17 digits SN shall be divided into three parts: PPPYWW, DSSSS and EEEERX.

b) Each part of SN shall be converted to a base-34 decimal number, with the left-most digit as the most significant digit (e.g. 'D' is the most significant digit of 'DSSSS').

c) Each of three decimal base-34 numbers shall be converted to a hex number. PPPYWW shall be converted into a 8-digit hex value. DSSSS shall be converted into a 6-digit hex value and EEEERX shall be converted into a 8-digit hex value.

d) Each of three base-34 hex numbers shall be saved in the designated OTP locations as in table 6.

6.11.3.Component Traceability Rules

6.11.3.1.Andalusia Traceability

Andalusia Wafer ID will be encoded in the OTP. Three bytes are allocated to it. To properly encode wafer ID follow the following steps:

- Record the last 6 digits of wafer ID
  - Example: 164009-10-55
  - Use 09-10-55
- Convert each 2 digits to a hex number
- Store the first number in first byte and second in the second byte
  - Example:
    - 09 = 0x09 will be stored inAndalusia Wafer ID 1
    - 10 = 0x10 will be stored in Andalusia Wafer ID 2
    - 55 = 0x55 will be stored in Andalusia Wafer ID 3

6.11.3.2.Benvolio Traceability

Benvolio Barcode information including sequence number, date of production and Row/ Column will be encoded in the OTP. Six bytes are allocated to it. To properly encode information follow the following steps:

Date code (WWD) has 12 bits allocated to it. Maximum value for WWD = 527 which can be stored as decimal in WWD [11:0]

Sequence number is base 34 sequence and can be stored in allocated 24 bits. Maximum value for SSSS sequence number = ZZZZ = 1336335 decimal = 0x14640F which will be stored in locations SSSS [23:0]

Row and Column information have 2 bits allocated to them. There are no more than 37 rows and 21 columns on a wafer. Maximum value for that = 3721 = 0xE89 which can be stored on RRCC [11:0]

- Example:
  - Barcode: BVHA7527ZZZZ3721
  - 52 = 0x52 will be stored in WWD 1
  - 7=0x07 will be stored in WWD 2
  - ZZZZ = 0x14640F

- 0x1 will be stored in SSSS1
- 0x46 will be stored in SSSS2
- 0x40 will be stored in SSSS3
- 0xF will be stored in SSSS4
- 3721= 0xE89
- 0xE will be stored in RRCC1
- 0x89 will be stored in RRCC2

6.11.3.3.Midas Traceability

Midas Wafer ID, Week, and Row/ Column will be encoded in the OTP. Six bytes are allocated to it. To properly encode information follow the following steps:

- Record the last 4 digits of wafer/ Lot ID
  - Example: 16Z1141-2
  - Use 1412
- Convert each 2 digits to a hex number
- Store the first number in first byte and second in the second byte
  - Example:
    - 14 = 0x14 will be stored in Wafer ID 1
    - 12 = 0x12 will be stored in Wafer ID 2
  - Locate Row/ Column ID can be decoded from key for patterns on Midas MCO
  - Convert Row/ Column numbers (X,x,Y,y) to hex
  - Example:
    - Row/ Column 3FA2
    - 3F = 0x3F (X,x) will be stored in Row/ Column 1
    - A2 = 0xA2 (Y,y) will be stored in Row/ Column 2

6.11.1.Juliet

- Each Juliet Image Sensor Module shall have a unique serial number that is 17 characters long.
- Each serial number character is restricted to the set of base-34 characters. Valid characters are digits “0” through “9” and letters “A” through “Z” except for letters “O” and “I” which are invalid due to similarity to numbers “0” and “1”.
- The serial number must be generated using the format detailed in the table below.

- The Image Sensor Module serial number shall be applied to the camera module in a human readable format using laser marking, scannable by the barcode readers listed in the Appendix.
- See the module MCO for serial number placement

Info Type	Plant Code	Date Code of Manufacture	Sequence Number	Config Code	Checksum
Format	PPP	YWWD	SSSS	EEEER	X
# of Characters	3	4	4	5	1
Explanation	**PPP = Vendor and Plant/Factory Location:** The code indicating the Image Sensor Module vendor and where it is manufactured. This code will be assigned to the Image Module vendor by Apple.	**Y = Year:** 0 = 2010 1 = 2011 2 = 2012 … etc. **WW = Week of Manufacture:** 01 to 53 weeks where week 01 includes January 1st **D = Day** **s 1 to 7 with 1 = Mon**	**SSSS = 4 char Sequence #** (base-34) Each module must have a unique sequence number for each plant and day This allows for 34^4 = 1,336,336 units per day per plant	**EEEE = Engineering Config Codes** **R=revision** The code indicating the Image Sensor Module Lens, r, and other configu details. This code will be assigned to the Vendor by Apple.	X = Checksum See Appendix
Example	**XSW341200Z3A2341Q**				
xample Meanin	XSW Built at Vendor XYZ Singapore Plant	3412 Manufactured on Tuesday of the 41st week of 2013	00Z3 Sequence# 00Z3	A2341 Apple provided	Q See example of checksum

6.11.2. Serial Number in NVM

The Image Sensor Module serial number shall be stored in NVM in three base-34 hex numbers. The conversion shall follow the steps below (the encoding/decoding code in Matlab is provided in the Appendix):

a) The 17 digits SN shall be divided into three parts: PPPYWW, DSSSS and EEEERX.

b) Each part of SN shall be converted to a base-34 decimal number, with the left-most digit as the most significant digit (e.g. ‘D’ is the most significant digit of ‘DSSSS’).

c) Each of three decimal base-34 numbers shall be converted to a hex number. PPPYWW shall be converted into a 8-digit hex value. DSSSS shall be converted into a 6-digit hex value and EEEERX shall be converted into a 8-digit hex value.

d) Each of three base-34 hex numbers shall be save in the designated NVM locations as in table 6.

6.11.3. Lens Serial Number (2D Barcode and NVM encoding)

Each manufactured lens shall have an associated unique 2D barcode (serial number) laser etched in the barrel plastic as a Matrix format. It must also be read and programmed in the Module NVM. The serial number is a sequence of 16 characters which are hex values that are directly mappable to the 8bytes allocated in NVM for storage.

The lens serial number must be included in the EOL data log as part of OK2SEND data.

Example 2D Matrix Barcode

This example barcode would scan as Lens SN = 0x12400158620b2d01.

Lens Serial Number Format

The table below describes the serial number format and method for assigning the 16 character Lens SN into the 8bytes in NVM (using Example Lens SN = 12400158620b2d01).

Byte	Code	Description	Byte	Example NVM
1	P	Program (assigned 1-255, with table lookup)	1	0x12
2	S	Site (assigned 1-255, with table lookup)	2	0x40
3	M	Machine ID	3	0x01
4	EEEE	Sequence ID	4	0x58
5			5	0x62
6			6	0x0b
7			7	0x2d
8	H	Hash value	8	0x01

The table below outlines expected values for the first 2 NVM bytes of the Lens SN.

Byte	Code	Description	Value
1	P	Juliet	0x12
2	S	Lens Vendor Site: Genius	0x40
		Lens Vendor Site: Largan	0x10

7. Assembly Process

The Pearl sub-assembly is comprised of three optical modules. The RGB camera (Fcam), the infra-red camera (Juliet) and the Infra-red Dot projector (Titus).

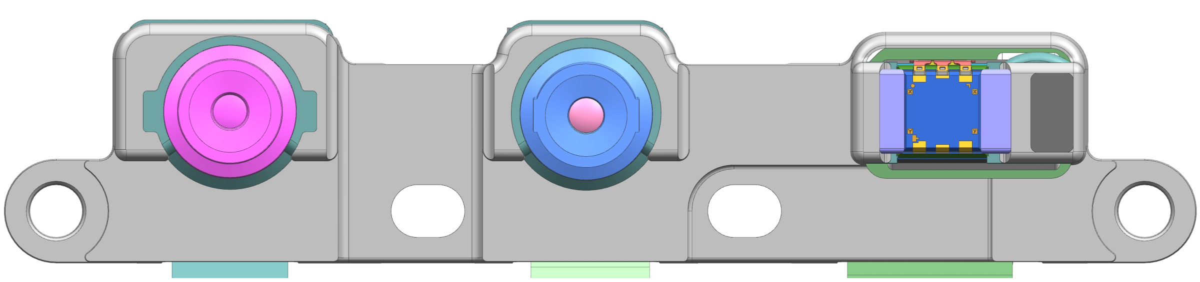


Figure : Pearl sub-assembly (Pearl SA)

Each of the modules has an associated Design DRI from the camera HW team. There is a DRI for pearl sub-assembly performance and system integration. The DRIs and contact details are listed below.

Table: Pearl DRI list

Component	DRI Name	DRI Email
Pearl sub-assembly	David Manca	dmanca@apple,com
Juliet-A	Aaron Cong	acong@apple.com
Titus-C	Patrick Lu	plu2@apple.com
Long Island-A	Te Hu	te_hu@apple.com
Compliance	Arun Nallani Chakravartula	ncarun@apple.com
Rosaline	Ehsan Hamidi	ehsanhamidi@apple.com

Figure : Pearl sub-assembly showing all 3 flexes(Pearl SA)

7.1. Pearl Electrical Sub-system

A simplified view of the Pearl electrical sub-system is shown below. Rigel is a key component of the pearl sub-system located on the system MLB.
Rigel status is a common starting point for all Pearl FA. The error codes will often point to an electrical open/short and status of signals between modules.

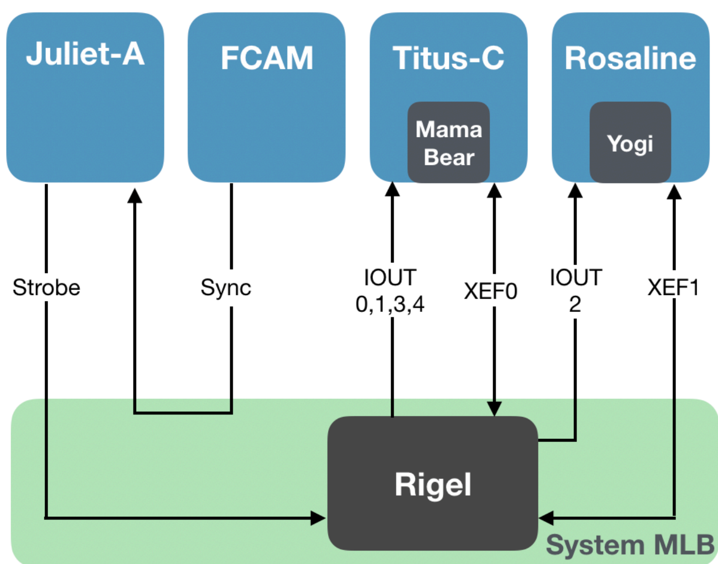


Figure : Pearl electrical sub-system

7.2. Pearl Assembly Machine (PAM)

The pearl bracket assembly flow is shown below. Inspections stations on the PAM line ensure the X,Y and Z-rotation specs are in spec according to the Pearl sub-assembly MCO

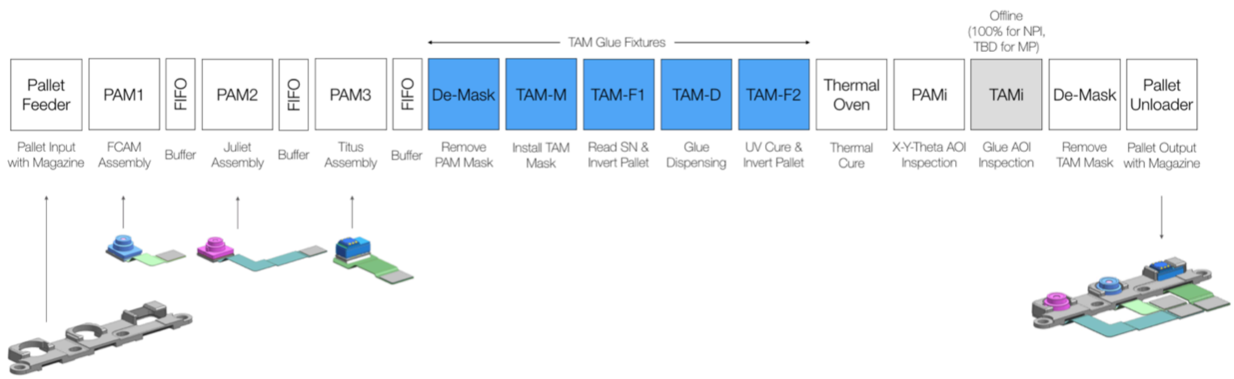


Figure : PAM Flow

7.3. Tilt of Module (TOM)

Tilt of Module (TOM)

The tilt of module is a data collection station used to bring up a PAM line. The tool is Keyence confocal microscope that measures the XY tilt of key items on the Pearl sub-assembly.

#	Variable	LSL	Target	USL	Comment
1	R_braX	-2.2°	0°	2.2°	Titus module to bracket tilt in X
2	R_braY	-2.2°	0°	2.2°	Titus module to bracket tilt in Y
3	FcamB_RoBX	-2.2°	0°	2.2°	FCAM bracket section to Titus bracket tilt in X
4	FcamB_RoBY	-2.2°	0°	2.2°	FCAM bracket section to Titus bracket tilt in Y
5	JulietB_ROBX	-2.2°	0°	2.2°	Juliet bracket section to Titus bracket tilt in X
6	JulietB_ROBY	-2.2°	0°	2.2°	Juliet bracket section to Titus bracket tilt in Y
7	FCAM_ROX	-2.2°	0°	2.2°	FCAM module to Titus module tilt in X
8	FCAM_ROY	-2.2°	0°	2.2°	FCAM module to Titus module tilt in Y
9	JU-RO X	-1.98	0°	1.98	Juliet to Titus module tilt in X
10	JU-RO Y	-2.65	0°	2.65	Juliet to Titus module tilt in Y

11	Fcam_JU X	0.8	3°	5.22	Fcam module to Juliet module tilt in X
12	Fcam_JU Y	-1.45	0°	1.45	Fcam module to Juliet module tilt in Y
13	J-J BraX	-2.2°	0°	2.2°	Juliet module to Juliet bracket tilt in X
14	J-J BraY	-2.2°	0°	2.2°	Juliet module to Juliet bracket tilt in Y
15	F-F BraX	-2.2°	0°	2.2°	Fcam module to Fcam bracket tilt in X
16	F-F BraY	-2.2°	0°	2.2°	Fcam module to Fcam bracket tilt in Y

Table : TOM specifications (For reference)

8. Laser Compliance

8.1. Class 1 IEC Compliance Testing.

Romeo is designed to operate as Class 1 devices per IEC 60825-1 2007: edition 2 and IEC 60825-1 2014: edition 3 specifications.
In order to guarantee a laser to be Class 1 laser compliant (eye), the projector's AE(eye) to AEL(eye) ratio (PLR) needs to be within a target limit. AE(eye) is a measure of the total energy entering the eye's pupil (modeled as a circular 7 mm aperture). AEL(eye) is a function of apparent source size (alpha), wavelength and emission duration.
Similarly for skin compliance, the projector's AE(skin) to AEL(skin) ratio (PLR) needs to be within a target limit. AE is a measure of the total energy incident on the skin. AEL(skin) is a function of the wavelength and emission duration.

8.1.1.Laser Compliance (Eye) Test

The laser compliance (eye) test is composed of four different steps:

A. Accessible emission (eye) / heatmap measurement - measures power output across the full laser FOI.
B. Apparent source size (alpha) Measurement - measures the apparent source size across the full laser FOI.
C. Laser Wavelength measurement - measured left ankle wavelength at a point in the FOI. One point in FOI is deemed sufficient as wavelength does not change in the FOI.
D. Combining data from steps A, B and C to determine worst case AE(eye), worst case AEL(eye) and worst case PLR.

The laser drive conditions and laser temperature impact above measurements and so need to be controlled. Tester limits need to be set to ensure laser remains compliant during all possible use case drive, temperature exposure and reasonable single point defect conditions.

8.1.1.1.Ideal AE (Eye)/Heatmap Measurement

In the heatmap measurement, energy through a 7 mm aperture is measured across the full FOI at a spherical distance of 100 mm in 3.5mm tangential steps. This is achieved by sampling the FOI on a 2° x 2° Projection Angle Space (PAS) grid. Figure 5.1.1.1.a and figure 5.1.1.1.b describe the PAS space and the heatmap sampling grid overlaid on the projected laser pattern respectively. The 2° x 2° stepping angle is not a parameter that is specified in the IEC laser spec. It is picked arbitrarily to ensure optimal overlap between successive measurement locations in the laser FOI.

Location	Parameter	Units	Tester	Nominal Value
FATP	Compliance mode	NA	Alpha-BP-A & AE(Skin)-Amai AE(Eye)-Miyagi	Complicane Mode A
	Compliance mode A: Drive Current (Dense)	A		1.824
	Compliance mode A: Drive Current (Sparse)	A		1.528
	Compliance mode A: Drive Current (Probe A)	mA		57.82
	Compliance mode A: Drive Current (Probe B)	mA		57.82
	Compliance mode A: Pulse Width	Ms		2.93
	Compliance mode A: Pulse Freq	HZ		5
	# of pulses per measurement	#	Alpha- BP- A	1
			AE(Skin)-Amai	6
			AE(Eye)-Miyagi	3

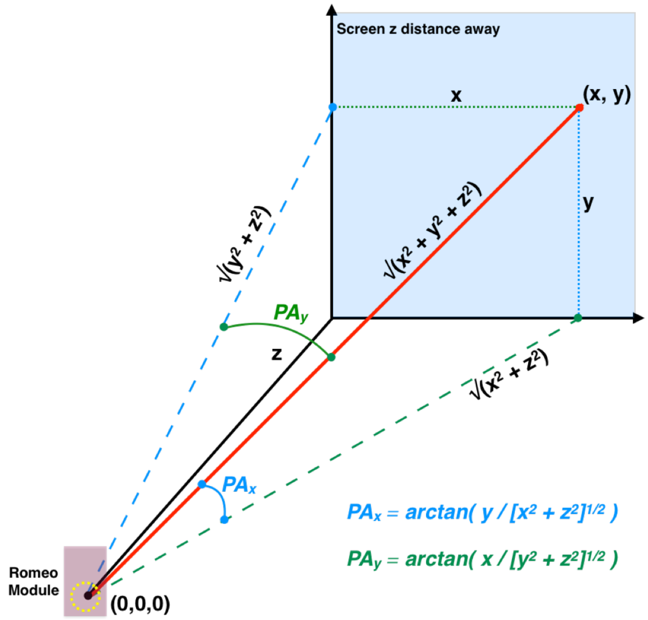


Figure 5.1.1.1.a: PAS coordinates (PAx/PAy) as defined for a point (x,y) on a screen at a normal distance of z

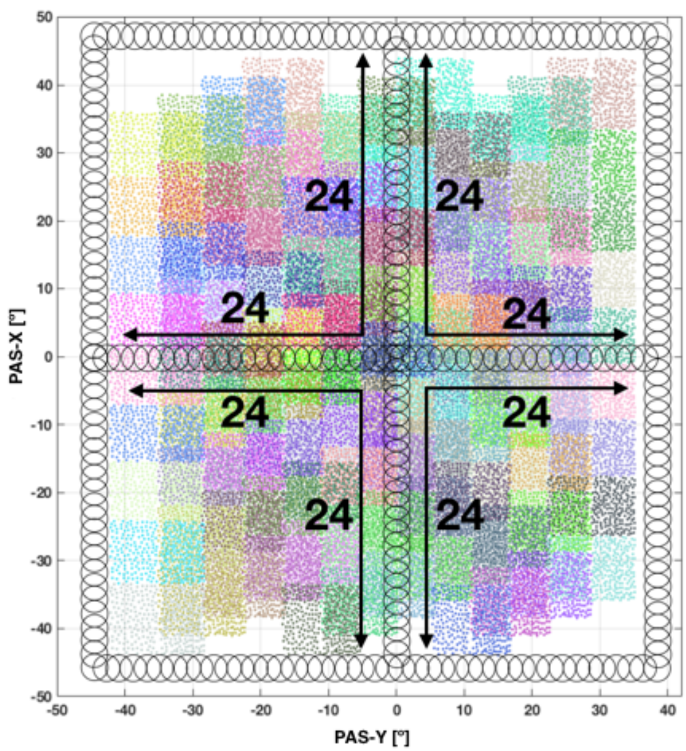


Figure 5.1.1.1.b: Laser (Romeo shown here as example) heatmap sampling in PAS space with a 49x49 array of 4° diameter apertures (corresponding to a 7 mm diameter aperture on a 100 mm radius spherical surface)

Once the energy is sampled at the required locations, a heatmap of the full FOV can be generated. The location of maximum energy found across all sampled locations on the heatmap is denoted the *hotspot* and the energy measured at this location is denoted ***AE_P***. Additionally, the energy at the on-axis position (PAx = 0, PAy = 0) is denoted ***AE_P_00.***

AE_P is the worst case accessible emission for the laser-under-test. ***AE_P_00*** is the accessible emission in the 0-order tile for the module-under-test.

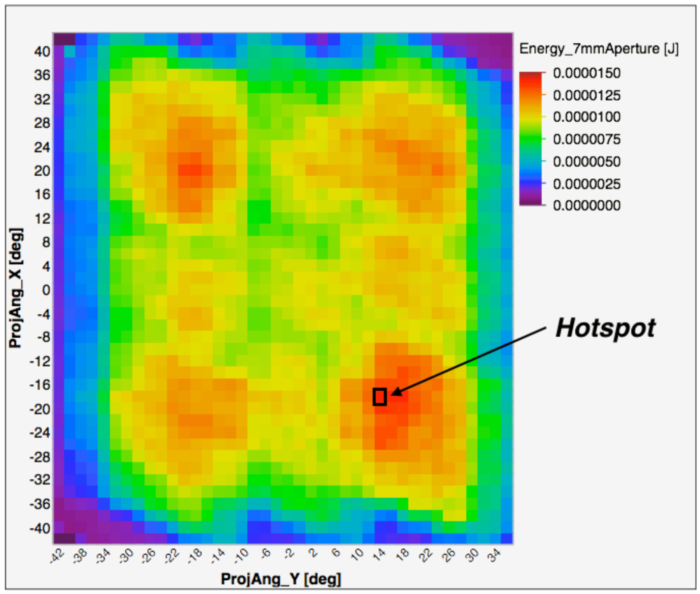


Figure 5.1.1.1.c: PAS coordinates (PAx/PAy) as defined for a point (x,y) on a screen at a normal distance of z

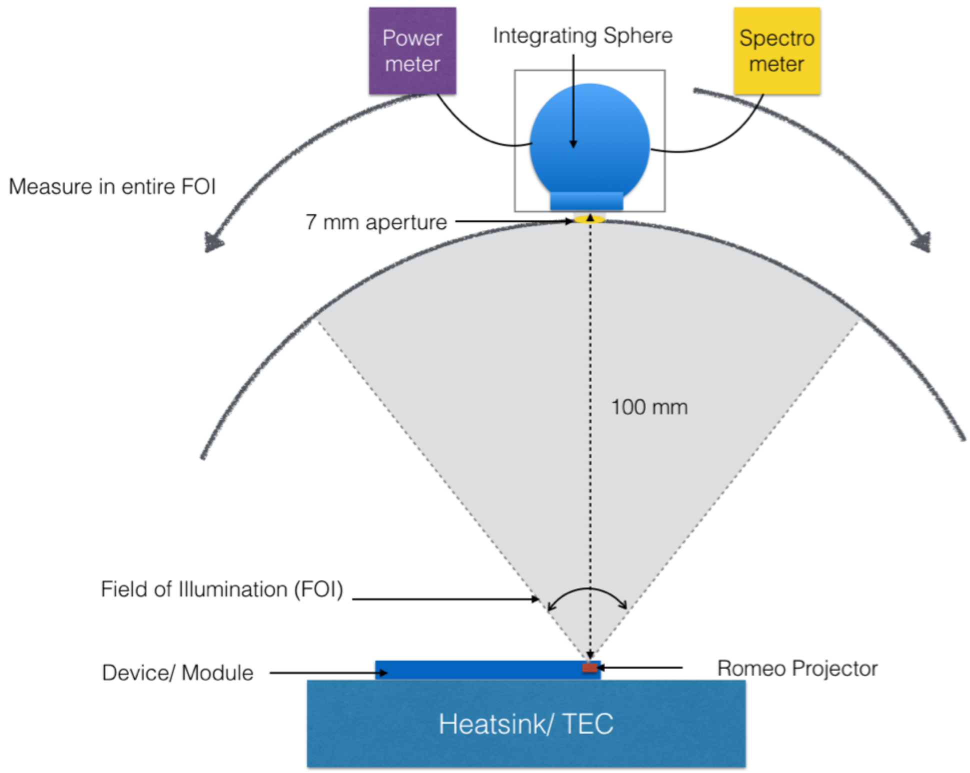


Figure 5.1.1.1.d : “Ideal” IEC Accessible Emission (Eye) testing setup

An ideal setup for measuring ***AE (eye)*** (Figure 5.1.1.1d) requires an integrating sphere sensor with a 7 mm entrance aperture mounted at a 100 mm measurement distance from the projector exit pupil. The integrating sphere is connected to a suitable power meter. The setup allows measurement of optical power at all points in the projector FOI.

The measurement setup is to be properly enclosed to avoid the impact from ambient light.

As laser characteristics vary with temperature, sufficient period should be allowed between measurements to reach thermal steady state (<~2^{o}C). An TEC active cooling system can be used to decrease the wait period between measurements.

Table5.1.1.1.a: Ideal Accessible Emission (Eye) measurement parameters summary

Component	Parameter	Value	Units
AE Tester	Romeo exit pupil to aperture distance	100+/-0.25	mm
Integrating sphere	Sphere entrance pupil	7+/-0.1mm	mm
Integrating sphere	Sphere diameter	>2”	inches
Power-meter	Power measurement range	10e-6 to 1	Watts
	Power measurement resolution	10e-6	Watts
Spectro-meter	Wavelength measurement range	800-1000	nanometer
	Wavelength measurement resolution	2	nanometer

8.1.1.2.Simplified , MP Scalable Accessible Emission (Eye) Heatmap Measurement

For MP test, a large-FOV imaging method is allowed to achieve the required UPH, provided that a power calibration using a NIST-traceable power meter is necessary. Conversion from the field images to a heatmap can be done by integrating pixel intensity within a 7 mm aperture mask in 3.5mm steps across the field images in ***PAS*** space.

Two examples of the large-FOV imaging method are:

1) Use a screen and collect the scattering intensity from a camera system that images the screen to the camera sensor surface. See Figure below.

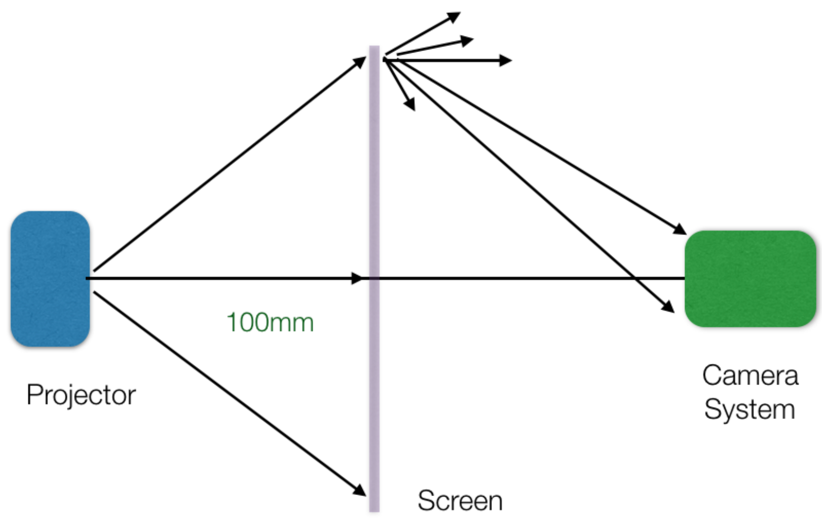


Figure5.1.1.2.a: Screen based setup illustration

2) Use relay optics to directly image the output emission from Romeo to the camera sensor surface. See Figure below.

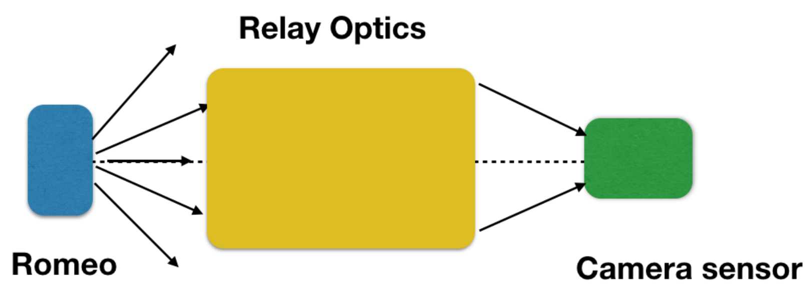


Figure 5.1.1.2.b. Direct-imaging based setup illustration

The correlation between the large-FOV imaging method and the aforementioned “ideal” test setup needs to be established.

8.1.1.3.Ideal Apparent Source Size Measurement

The ideal source size measurement setup (Figure 5.1.1.3.a) is similar to that of the accessible emission setup; however, the integrating sphere is replaced with a 7 mm aperture stop coupled to a relay lens such that the laser exit pupil can be imaged onto a CCD camera. The optical path should include neutral density filters to ensure there is no image saturation. The distance between the CCD sensor and the lens (image distance) is precisely adjusted to achieve this accommodation of the laser exit pupil at a 100 mm measurement distance (object distance).

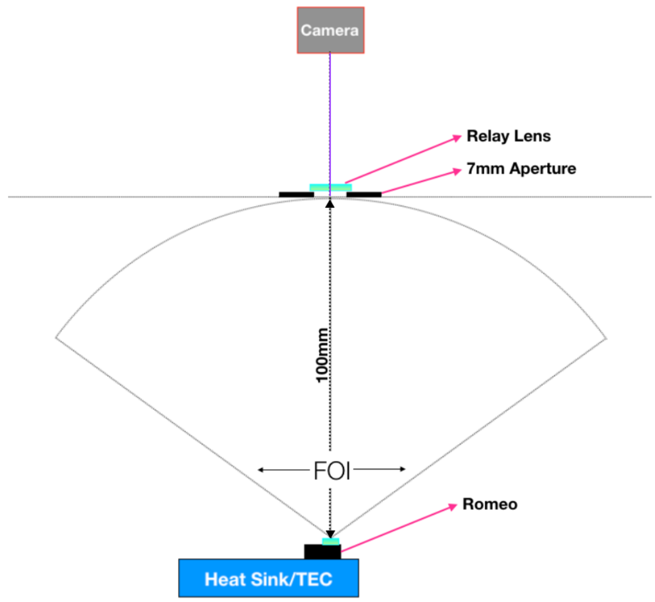


Figure 5.1.1.3.a. Ideal apparent source size measurement setup

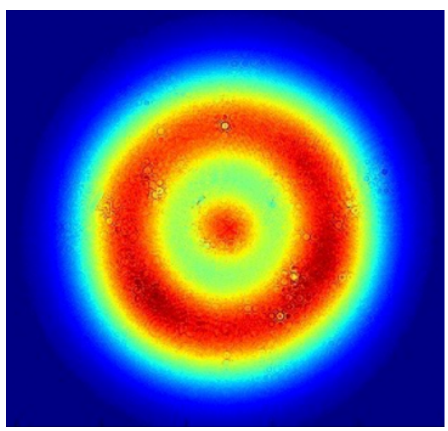


Figure 5.1.1.3.b. Sample “apparent source” image captured by a CCD focused onto the Romeo module exit pupil

In order to prevent external light from adding to measurement noise, the setup should is enclosed in a blackbox.

Apparent source size measurements are required to be measured across the full FOV at a spherical distance of 100 mm in 3.5mm tangential steps, similar to accessible emission.

Each source image obtained needs to be processed through an algorithm specified in the IEC spec to determine the worst case apparent source size (alpha box, alpha and q).

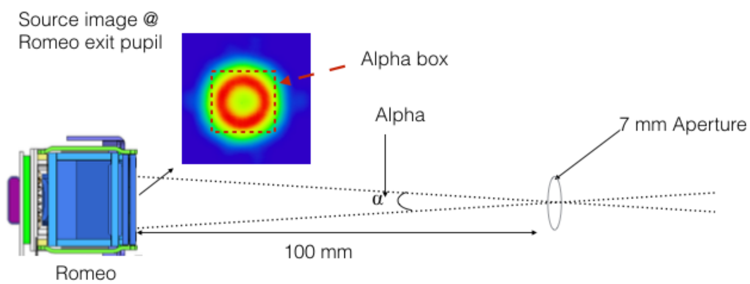


Figure 5.1.1.3.c. Schematic illustrating apparent source size: “Alpha”

Alpha box is the worst case region in the source image for eye retinal hazard. An example of such a box is shown as a dotted red box in figure 5.1.1.3.c. Uniform energy distribution in the source image yields larger alpha boxes while non uniform energy distribution with local high energy areas generate smaller alpha boxes centered around the high energy areas.

Alpha is the angle subtended by the alpha box at the point of observation, which is at the center of the 7 mm aperture at 100 mm distance.

q is the % energy in alpha box as compared to total energy in the source image.

For reference, a high-level description of the algorithm is presented below.

1. On an image collected at aperture focus, start with rectangular window of size: $\alpha_x = \alpha_{min}$ and $\alpha_y = \alpha_{min}$;
2. Calculate percentage of energy within window relative to energy in full image (q)
3. Determine: Local Accessible Energy (LAE) = q * E, where E is the total theoretical energy the source would deliver over emission duration t (value of t depends on which PLR analysis method, of the three, is used).
4. Determine: PLR = LAE / AEL, where AEL is Accessible Energy Limit allowed over emission duration t (value of t depends on which PLR analysis method, of the three, is used).
5. Repeat 1-4 for all window positions in image
6. Repeat 1-5 for all possible sizes of α_x and α_y between α_{min} and α_{max}
7. Pick the α (window) and apparent source size for the largest PLR.

Table: Ideal apparent source size measurement setup parameters summary.

Compone nt	Parameter	Valu e	Units
Accessible emission tester	Romeo exit pupil to aperture distance	100+/-0.25	mm
Accessible emission tester	Aperture size	7+/-0.1	mm
Beam Profiler	Intensity resolution per pixel	10	bits
Beam Profiler	Source image X-Y resolution: 2mmX2mm window @100 mm	100x100	pixels

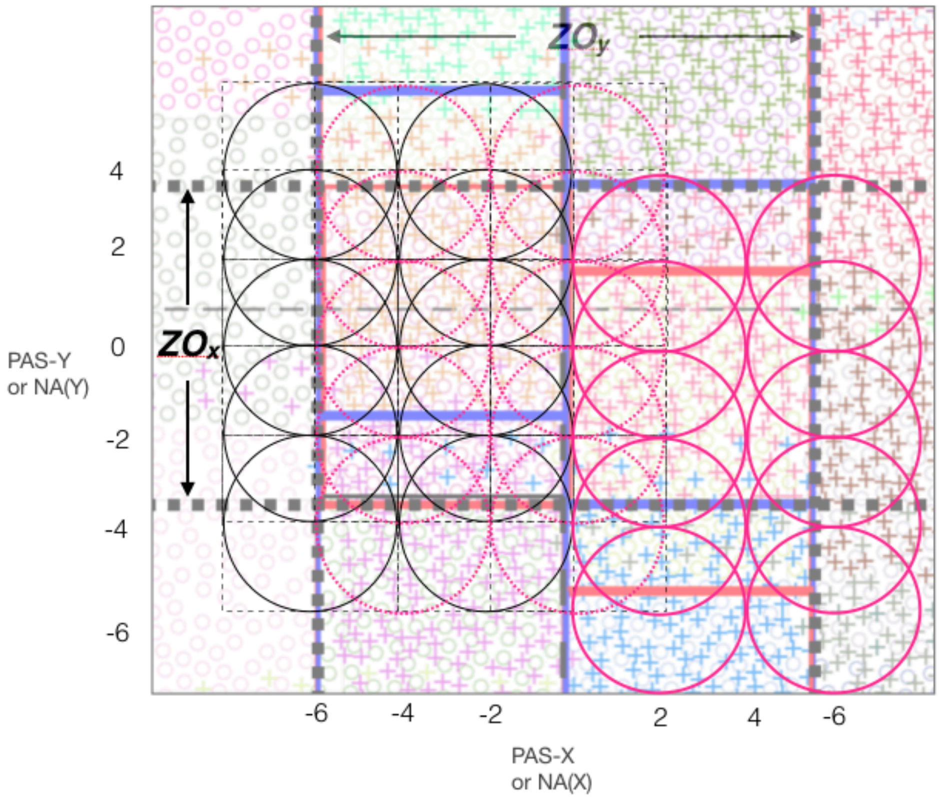
8.1.1.4.Simplified MP Scalable Apparent Source Size Measurement

Apparent source size at a location in the FOI typically follows a cosine relation to the on-axis apparent source size. If this is validated to be true for a laser, the source size at any location in the field of view can be estimated by equation below.

$$Source\ size\ (PAx, PAy) = \frac{\left(Source\ size\ x\ (PA0)\cdot \mathrm{Cosine}(PAx) + Source\ size\ (y)\cdot \mathrm{Cosine}(PAy)\right)}{2}$$

This has been validated to be true for Romeo projectors (<rdar://problem/32701262> Compliance Tester Simplification Data). So source size measurement at the on-axis position is deemed to be sufficient to estimate source size in the entire FOI.

For Romeo, however, since the emitter combination captured in each 7 mm location is unique across a DOE tile, 20 unique measurements (Figure 5.1.1.4.a) covering the zero order (on-axis) tile are required to predict source sizes across the entire FOI.



$$\{(\boldsymbol{PAx_1}, \boldsymbol{PAy_1}), (\boldsymbol{PAx_2}, \boldsymbol{PAy_2}), \ldots, (\boldsymbol{PAx_N}, \boldsymbol{PAy_N})\} =$$

{(-4, -6), (-4, -2), (-4, 2), (-4, 6),

(-2, -6), (-2, -2), (-2, 2), (-2, 6),

(0, -6), (0, -2), (0, 2), (0, 6),

(2, -6), (2, -2), (2, 2), (2, 6),

(4, -6), (4,-2), (-6,2), (-6, 6)}

Figure 5.1.1.4.a: Romeo source size sampling locations in PAS co-ordinates

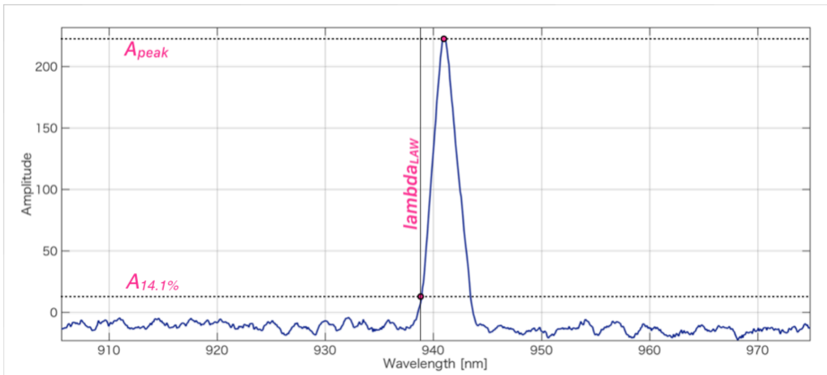
PLR at a particular location in the FOI is computed using measured AE(eye) and predicted alpha (on-axis alpha * cosine correction) at that location.

PLR_simple, a further simplified PLR, at particular location in the FOI is computed using measured AE(eye) at that location and predicted worst case alpha at FOI edge (on-axis alpha * max cosine correction). This assumption eliminates spatial matching requirement of AE(eye) measurements and source size measurements. The impact on PLR budget due to this assumption is not severe as the AE hotspots for both Vader and Romeo are off-axis, closer to FOI edge. If the AE hotspot of a laser is on-axis, this simplification method will impact PLR budget severely.

8.1.1.5.Wavelength Measurement

A spectrometer is used to determine the left ankle wavelength (LAW). LAW is defined as the wavelength at 14.1% amplitude to the left of the spectral peak, in units of nanometers.

This measurement can be integrated into any compliance or upstream tester.



Left Ankle Wavelength in a Romeo emission spectra

Since laser wavelength is held within a tight wavelength range (~+/-10nm) and PLR is not very sensitive to such small wavelength changes, worst case (lower spec limit) wavelength is assumed in PLR generation, regardless of the actual wavelength measurement.

So the primary requirement of this test is to guarantee all lasers have wavelength > lower spec limit assumed in the PLR generation math.

Wavelength testing details are provided in table below.

Table: Wavelength measurement setup parameters summary

Component	Parameter	Value	Units
Spectro-meter	Wavelength measurement range	800-1000	nanometer
	Wavelength measurement resolution	2	nanometer

8.1.2.Laser Compliance (Skin) Test

8.1.2.1.Accessible Emission (skin) Measurement

Per the IEC standard, the laser compliance (skin) is validated by ensuring that the AE /AEL ratio (PLR) is lower than a target limit, similar to laser compliance (eye). AE is energy captured over 0.18s emission duration through a 3.5mm aperture positioned at the closest accessible point, in this case the Romeo exit surface. Laser compliance (eye) Class 3B limit is used as laser compliance (skin) AEL.

An ideal Accessible Emission (skin) measurement setup contains an integrating sphere that collects output power from the full Romeo FOV at the closest accessible point

For a module, the closest accessible point is the Romeo exit aperture. Given the wide FOI of the Romeo and Vader projector, special accommodations need to be made to ensure that all of the light energy being emitted is captured by the integrating sphere. A custom wide aperture, thin wall, integrating sphere is recommended to get accurate and repeatable measurements. The ideal measurement setup is illustrated in the figure below.

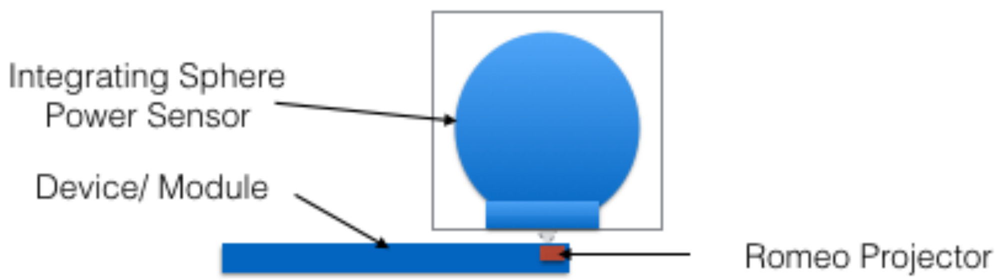


Figure 5.1.2.1.a. Laser compliance (skin) measurement setup. Integrating sphere is placed such that all of the energy coming out of the projector is captured

8.1.3.Romeo/Titus Compliance Tester Drive Conditions and Spec Limits.

Compliance drive conditions and tester spec limits at FATP for each build are stored at <rdar://problem/29176969> and are derived from the L-comp calculator at <rdar://problem/26640683>. Drive requirements and test parameters specifications are captured below in tables 5.1.3 a/b and 5.1.3c respectively.

Generally AE(eye) and alpha are gauged against respective USL and LSL. The AE(eye) USL is based on an assumption that alpha is at its LSL and similarly alpha LSL is set on an assumption that AE(eye) is at USL. However if either AE(eye) or alpha do not meet respective specs, “PLR_simple” metric is used for yield recovery. PLR_simple metric allows comparison of actual measured AE(eye) value to actual measured ZO alpha on that unit and passes the unit if PLR_simple is below assumed budget max. Test flow for PLR_simple is shown in Figure 5.1.3.a.

Table 5.1.3.a: Module drive conditions for Romeo compliance testing

Location	Parameter	Units	Tester	Nominal Value	Tolerance
Module Integrator	Drive Current (Dense)	A	Alpha & AE(Eye) & AE(Skin)	1.824	± 2
	Drive Current (Sparse)	A		1.528	± 2
	Drive Current (Probe A)	mA		57.82	± 1
	Drive Current (Probe B)	mA		57.82	± 1
	Pulse Width	ms		2.93	± 0.1
	Pulse Rise time	us		3	± 1
	Power source noise ripple (Pk-Pk)	mA		0	± 0.1
	Pulsing Freq	Hz		30	± 0.1
	Module temperature before pulse	oC	Alpha & AE(Eye)	15	± 0.5
	Module temperature before pulse	oC	AE (Skin)	50	± 0.5
	# of pulses per measurement	#	AE (Skin)	6	0
	# of pulses per measurement	#	Alpha	3, 2 or 1	0
	# of pulses per measurement	#	AE(Eye)	1	0

Table 5.1.3.b: System drive conditions for Romeo compliance testing

Table 5.1.3.c: Romeo compliance testing specifications (27.1% AE metrology Error).

	Parameter	AE (Eye)_max (mW)		AE_eye_ Max sat pix		ZO Alpha_min (mRad)		q_max (%)		Alpha Max to Avg Ratio		Alpha Max sat pix		AE (Skin) (mW)		LAW (nm)		Δ Tot_power (15-50ºC)/ Tot_power (15ºC) @ FOL
	Comment	Peak Power in a 7mm aperture MI-15oC, FATP-40oC		Max # of saturated pixels		Source angle		Power in alpha/ total power				Max # of saturated pixels		Total Avg power MI- 30Hz; FATP-5 Hz MI-50oC, FATP-40oC		Left ankle wavelength		
	Unit->	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL	USL
MI (15oC)	MI Tester limit	2	9.7	0		See slide 5	21.6	70	94	2	8	0		100	216.32	930	950	0.15
FATP (40oC)	FATP Tester limit	2	8.9	0			21.6	70	95	2	8	0		15	38.96	N/A		NA
Rel	Rel Drift Spec	+/-5% of T=0 value		0		+/-5% of T=0 value		MI: +3%, -2% of T=0 value FATP: +/-2% of T=0 value		2	8	0		+/-5% of T=0 value		N/A		0.15

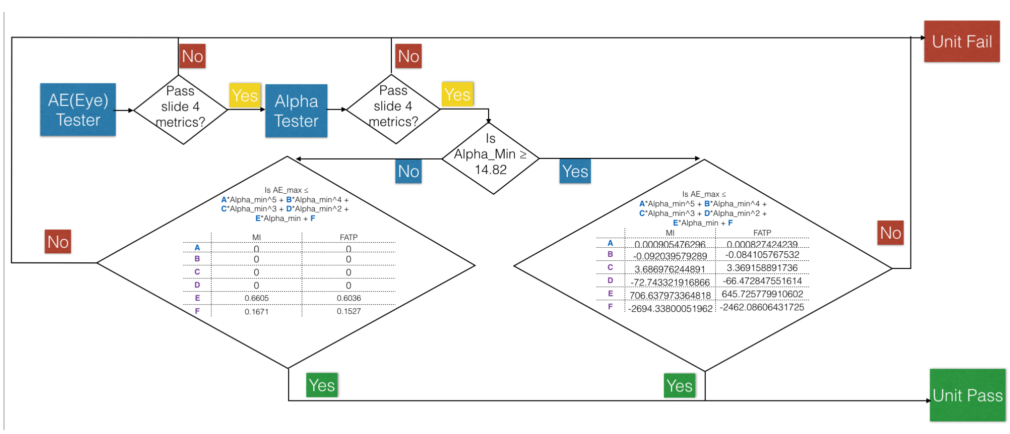


Figure 5.1.3.a: PLR_simple yield recovery computation math (27.1% AE Metrology Error)

9. Pearl Calibration

9.1. Station Operation

9.1.1.MPC calibration concept

The MPC station, as its name implies, is based on capturing images of a plane at multiple angles. The idea is to have a specific, known, high quality, fixed target as the plane being captured and to have the DUT mounted on a rotating stage. The stage is then rotated to multiple angles, capturing images of the target with both the RGB and the IR camera and with and without the projector pattern.

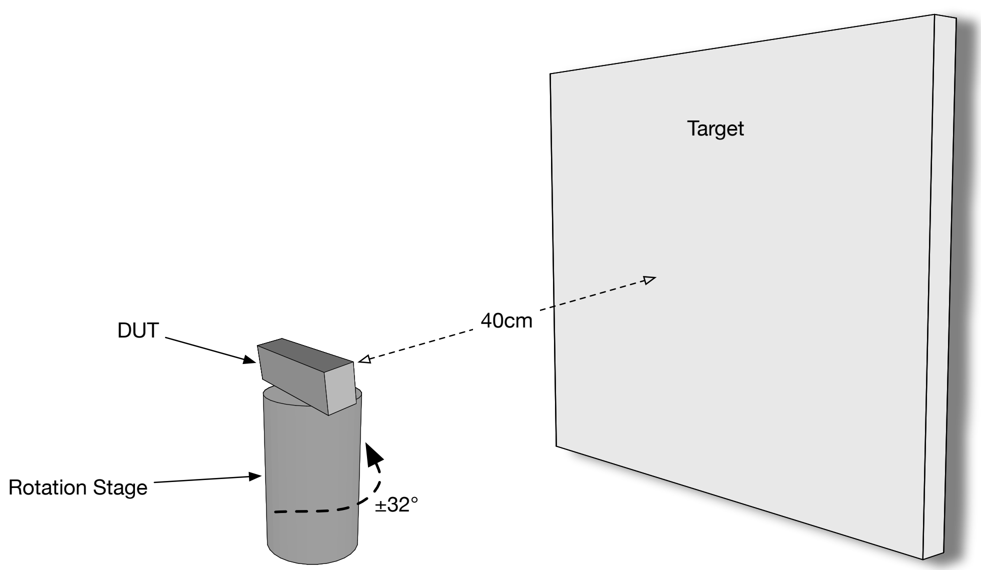


Figure 1 - MPC station layout

The target is based on a checkerboard like pattern with several distinct features to disambiguate the locations. Using feature extraction, each frame (IR or RGB) captured of the target gives an additional set of point correspondents, which is fed into the calibration algorithm. This data is used to calibrate the cameras intrinsic parameters and the extrinsic parameters between them.

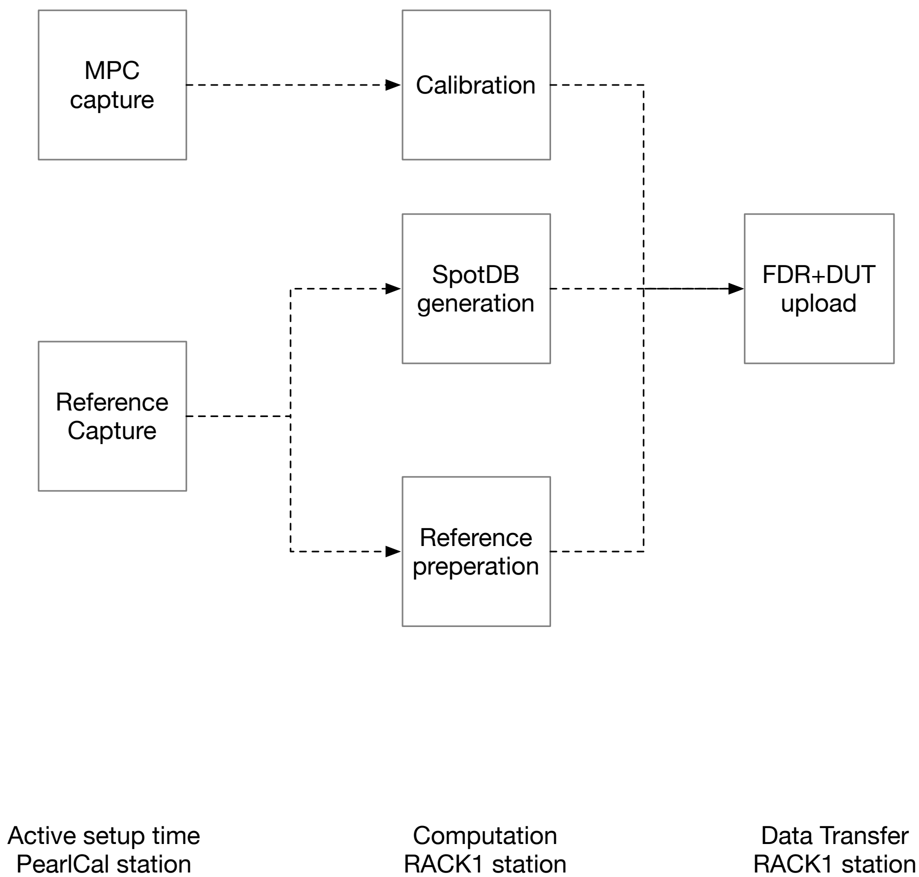
The frames containing the projector's pattern (IR only) are processed separately; for these frames, we detect the position of each spot in the pattern and then track it between the frames. The position of the spots is also fed to the calibration algorithm and used to calibrate the extrinsic parameters (the baseline) of the projector and IR module.

For the final stage of the calibration we return to the 0° position where the DUT is directly facing the target and capture what is known as the reference images. These images are a core part of the algorithm which the system uses in real time to generate the depth image.

9.1.2.Calibration Flow Overview

For MPC station high-level flow is described in the following diagram:

Figure 2 - MPC station flow



As described in the diagram above, the MPC station flow can be broken down into several sub-stages:

- **<u>Multi-Plane image capture</u>**: This stage captures the raw images required to perform the calibration. At each angle three types of images are captured - RGB image from Maine, an IR image of the Romeo pattern on the target and an IR image of the target without the Romeo pattern (with ambient IR light).
- **<u>Reference image capture:</u>** Next the stage is set to it's 0° angle (directly facing the target), and we start capturing the reference images. We capture a reference image for each of the operational modes the system is expected to use. In addition we capture a couple of reference which are only used for the SpotDB generation.
- **<u>Calibration:</u>** This is the key algorithm stage where we analyze the different frames captured in the "Multi-Plane image capture" stage and estimate the optical parameters of the system. Once we have the different parameters

we then “translate” them into configuration that can be loaded back to the system.

- **<u>RFC reference generation:</u>** using the captured reference images we identify each spot location and source, combined with calibration information from the Ro vendor we can now estimate how the spots will move due to temperature changes, using the estimates we resample the original reference to produce a “corrected” reference for each temperature the device is meant to work in. **In addition** to RFC,the RFC block is also detecting the probing pattern and creates the probing data-base later used to detect it in real time. Also the RFC algorithm was modified to extend the reference images to create wider image recovering system FOV when working very close or far.
- **<u>FDR+DUT upload:</u>** once the different configuration data is ready, it’s need to be pushed back into the device and uploaded to the FDR in order to be available for future sensor use.

REL station exception : in REL the MPC station is **not** broken into 2 separate stations like it is in FATP main line - it only consists on one station combining capturing and computation flow together. Prerequisite
RFC calibration assume availability of Romeo vendor calibration data. This data is used in order to tailor the temperature model used for reference correction to the specific Romeo manufacturing tolerances.

9.1.3.Prerequisite

RFC calibration assume availability of Romeo vendor calibration data. This data is used in order to tailor the temperature model used for reference correction to the specific Romeo manufacturing tolerances.

9.1.4.Pre-Heat Stage

The Pre-Heat stage is where all the initialization of the system is done. The DUT is set to the required operation mode and then we need to wait for it’s temperature to get stable.
We are mainly interested in the Romeo temperature, which we can sample using it’s internal thermistor (connected to the Rigel). The Romeo pattern will shift ~0.06pixels for every degree change. Assuming we don’t want more than 0.1pixel change during “Multi-Plane Capture Sequence” we must wait until the temperature is stable within ±0.75°C.
In practice the amount of time we have to wait will depend on the thermal characteristics of the system and the length of time it takes to perform - “Multi-Plane Capture Sequence”.

9.1.5.Multi-Plane Capture Sequence

This is the main part of the station operation and the key for calibrating the intrinsic and extrinsic parameters of the Pearl modules. The stage start immediately after the pre-heat stage and assumes that the system is already

configured and operating at the correct mode for performing the calibration. **It's very important that nothing will interrupt the system during this stage so that the system will remain thermally stable**.
During this stage the station rotates the DUT through several position/angles and captures at each position/angle three type of images - RGB image of the target, IR image of the target (illuminated by ambient light) and and IR image of the Romeo pattern illuminating the target.
The following table summarize all the requirements form this stage:

Table 3: Requirements from Multi-Plane capture sequence

Parameter	Requirement	Remarks
Calibration operating mode	15FPS interleaved: 40% density, "ambient"	See "40% full power operating mode"
Romeo exposure - *Rx*	2.5ms≤*Rx*≤3.5ms and no more than 100 pixels in saturation	Actual exposure will depend on exact values of target reflectivity and lighting condition. Saturation is defined as any value above and including 1000 gray-levels.
"Ambient" exposure - *Ax*	*Ax*=15ms	Should verify that no 20x20 pixel block average gray level will be below 200 or above 850 gray level.
Nominal Angles	-32˚, -25.6˚, 25.6˚, 32˚, 0˚	The sequence should always end at the 0° so that there won't be any movement between this sequence and the reference capture sequence
RGB mode	1080P	Recommended to fix exposure when sequence start.
Images captured per angle	#1 IR image of ambient, #1 IR image of Ro pattern, #1 RGB image (Maine)	

9.1.6.Reference Capture Sequence

The reference capture starts as soon as the calibration sequence is done. Unlike calibration sequence here the system keeps switching modes, and care must be taken to verify and capture the meta data indicating the state of the system at each reference. the following table describes the required reference image that need to be captured.

Table 13 - MPC Target Requirements

Parameter	Units	Requirement	Remarks
Distance to target - refDistance	cm	40±1	
Min target size	cm	55x60	For a single DUT. In addition need account for DUT x,y position tolerances.
Surface flatness max peak to peak	mm	<0.3	“low” frequency noise
Surface flatness local amplitude	mm	<0.1	“high” frequency noise
Pattern absolute scale error	%	<0.1	X and Y scale together
Aspect ratio	%	<0.02	Might need to calibrate the target
Max pattern skew	°	0.1	How much can the squares digress from 90°
Feature position accuracy	mm	<0.2	Assume random independent distribution (no bias!)
White reflectivity (@940nm)	%	39.5±1	To help prevent saturation. Assumes Lambertian surface. Based on current JOT Beijing updated spec
Black reflectivity (@940nm)	%	20±1	Too low reflectivity degrades the reference, too high hurts the feature extraction accuracy. Based on current JOT Beijing updated spec
Black intensity/White intensity (@visible)	%	<70	

Table 4: Required References-1

Name	Operation Mode						# image	Remarks
	FPS	S	D	R	A	B		
100% Full Power	15	1529	1824	0	0	0	5	FPS is related to IR frames with Ro Pattern
40% Full Power	15	1529	0	0	0	0	5	
40% Low Power	15	1242	0	0	0	0	5	
40% Full Power Probe A/B	15	1529	0	0	58	58	2	For RFC Probing DB algorithm (not saved).

60% Full Power RFC	15	0	1824	0	0	0	2	Used for RFC spot registration (not saved).

Operation Mode key:
S - sparse array, D - dense array, R - Vader, A/B probing patterns.

In cases where multiple images are captured an average image of the references is used. If averaging is done externally to the existing block (like on device) need also to average the projector temperature associated with each image. **The following order** is suggested as to minimize thermal changes in the device during the sequence: 40% full power, 40% full power Probe A/B, 60% full power, 100% full power.

9.2. Calibration Algorithm

9.2.1.Calibration parameters

The following diagram depicts the optical and mechanical parameters involved in converting the shifts found by the PCE (Pearl Correspondence Engine) into actual depth.

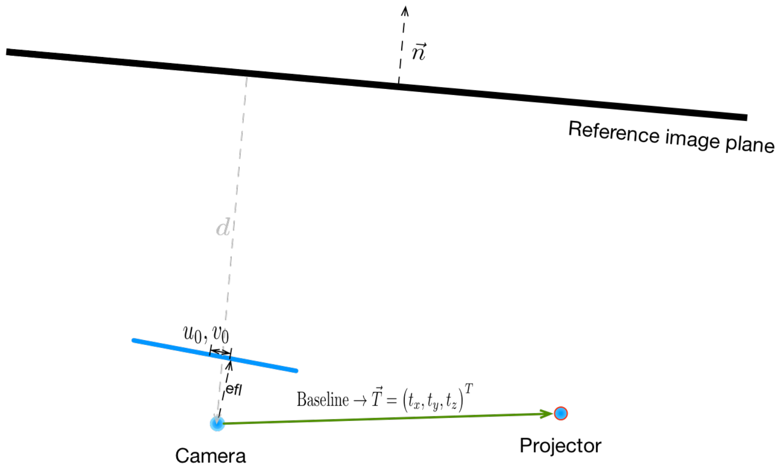


Figure 3 - System Calibration Parameters

In addition we need to calibrate the camera distortion so that we can use the simple pinhole camera model depicted in the above diagram.
The following table summarizes all the parameters that need to be calibrated for Pearl:

Table 5 - Calibration Parmeters

Parameter	Units	Assembly Range	Remarks
Camera Principle Point (u_0,v_0)	µm	42	Represent the optical center of the CMOS and is used in order to get the proper angles/vectors of the pixels.
Lens EFL	µm	25.2	Represents the optical magnification of the lens (average) and is used in order to get the proper angles/vectors of the pixels.
Distortion	µm		The distortion is defined as a deviation from rectilinear projection. We use the distortion model in order to correct the pixel angles.

Baseline (x,y,z)	µm	200	The baseline is the vector connecting the camera's entrance pupil and the projector's exit pupil (see Figure 3), the assembly range represents the error from nominal placement.
Reference wall distance	mm	5	All the depth measurements performed by the system are relative to the reference wall or reference plane. Therefore even though it's exactly an internal parameter of the system, it;s still a key parameter to estimate in the station.
Reference wall normal (Θ_x,Θ_y)	mrad	100	

9.2.2.Calibration algorithm principles

The following diagram gives a high level overview of the operation of the calibration algorithm.

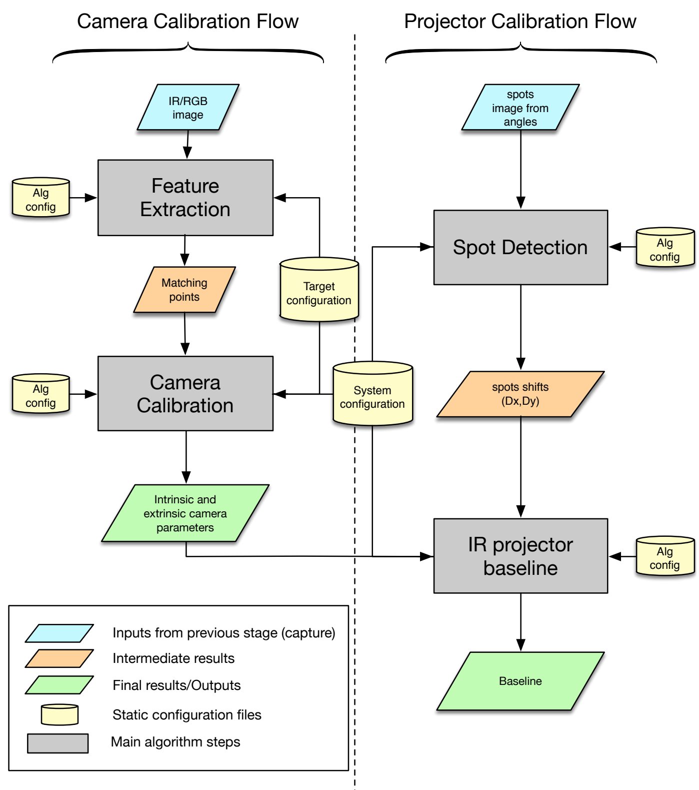


Figure 4 - Calibration Algorithm Overview

The algorithm has two flows: A camera calibration flow for the IR and RGB (without the Ro pattern) images and a projector calibration flow based on the Ro pattern images.

The goal of the camera calibration flow is to find and calibrate the intrinsic parameters of the cameras and to estimate parameters such as the baseline between the two cameras (used for depth to RGB registration) and the position and angle of the different planes used for the calibration (and most importantly the reference plane).
The calibration is based on us knowing the target very accurately. We start by using feature extraction to find all the crosses on the target (a “cross” is the joint corner of two black squares and two white squares). Once we have all the crosses we associate them with the known ideal pattern, now we try to “project” the known crosses through a model of the station and camera and how well they fit the observed data. By running a non linear optimization that try to minimize the re-projection error we find the parameters which “best” fit the observation.
The calibration flow is focused on finding the extrinsic parameters describing the relative position of the Projector (Romeo) and the IR camera (Juliet) (in other words the system baseline). This flow begins with finding all the spots in the projector pattern images captured in the previous stage. Using the information from the camera calibration (mainly the knowledge of the distortion and the position of the planes) we can now associate the spots from the different image with one another and trace the exact movement between the planes. Using non linear optimization again, we can find the baseline which best fit the results.

9.2.3.Generating configuration

Once we have the calibration parameters, the final stage is to use them in order to generate a configuration that can be uploaded and used by the system. This is done by a operate block which generate the proper register mapping and prepares the data to be uploaded to the DUT and the FDR.
The following tables list the raw data structures (plist) outputted by the calibration stage (before being converted to binary format).

Table 6 - Cameras.plist

Key	Type	Description	Units
irCamera	Dictionary		
irCamera.resX	Integer	Width of the camera sensor	pixels
irCamera.resY	Integer	Height of the camera sensor	pixels
irCamera.pixelSize	Real	Pixel size	mm
irCamera.efl	Real	Effective focal length	pixels
irCamera.principalPoint	Array 2xReal	x, y coordinates of the optical center. 0,0 is the center of the top left pixel.	pixels
irCamera.distortionLUT	Array 256x2xReal	First 256 entries describe the undistorted radii, the last 256 entries describe the corresponding distorted radii	pixels

irCamera.distortion RadialCVCoeffs	Array 3xReal	The 3 radial distortion coefficients as used by OpenCV	
rgbCamera	Dictionary		
rgbCamera.resX	Integer	Width of the camera sensor	pixels
rgbCamera.resY	Integer	Height of the camera sensor	pixels
rgbCamera.pixelSize	Real	Pixel size	mm
rgbCamera.efl	Real	Effective focal length	pixels
rgbCamera.principalPoint	Array 2xReal	x, y coordinates of the optical center. 0,0 is the center of the top left pixel.	pixels
rgbCamera.distortionLUT	Array 256x2xReal	First 256 entries describe the undistorted radii, the last 256 entries describe the corresponding distorted radii	pixels
rgbCamera.distortionRadialCVCoeffs	Array 3xReal	The 3 radial distortion coefficients as used by OpenCV	
rgbCamera.T	Array 3xReal	X,Y,Z location of the RGB camera relative to IR camera. Right handed coordinate system. Z axis pointing outwards the camera	mm
rgbCamera.R	Array 3x3xReal	Rotation matrix relative to IR camera stored in row major. The projection formula for point X is $R^T(X-T)$	

Table 7 - Projector.plist

Key	Type	Description	Units
baseline	Array 3xReal	X,Y,Z location of the projector relative to IR camera. Right handed coordinate system. Z axis pointing outwards the camera	mm

Table 8 - RefWall.plist

Key	Type	Description	Units
distance	Real	The distance to the reference plane from IR camera	mm
normal	Array 3xReal	The normal of the reference plane relative to IR camera	

Table 9 - ShiftParams-XXXXX.plist

Key	Type	Description	Units
minDx	Integer	Min DX of search range	pixels
maxDx	Integer	Max DX of search range	pixels

minDy	Integer	Min DY of search range	pixels
maxDy	Integer	Max DY of search range	pixels
refOffsetX	Integer	X Offset added by RG block to the resulting shifts	pixels
refOffsetY	Integer	Y Offset added by RG block to the resulting shifts	pixels
dxcShift	Integer	Offset added by DXC block to the resulting shifts	pixels

Registers-XXXX.bin
Set of registers in address (32bit), value (32bit) format.

9.2.4.RFC reference generation

RFC is the algorithm correcting the temperature effect on the projected Romeo pattern. The temperature causes the wave-length of the individual emitters inside the Romeo to change and that in turn cause the spots in the pattern to shift in direct relation with the temperature change. The exact way the wave-length change in each projector depends on the tolerance of the manufacturing and assembly of the Romeo and is calibrated by the module integrator.
The following diagram shows how the RFC algorithm in the station work in order to produce the corrected references.

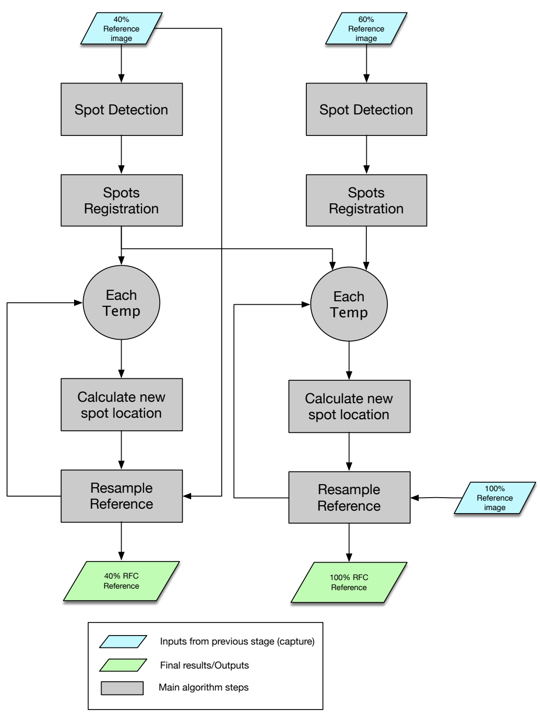


Figure 5 -RFC Reference Generation Overview

Note that the above diagram has to be duplicated for the low power mode of the references also.

In order to work properly the RFC algorithm must start with identifying each spot in the projected pattern and associate it with it's original emitter and DOE order. Unfortunately we can't do that directly on the 100% density pattern as some of the spots are too close to each other or even overlapping, so the algorithm must use both the 40% pattern and the 60% pattern in order to locate the spots correctly in the 100% pattern.
For each of the references the algorithm starts by detecting the spots. It then tries to find the origin of the spots using correspondence to a known simulator pattern. Once the origin of each spot in the pattern is down we can use the Romeo calibration data and the RFC model to predict how the spots will shift in each temperature (we are basically invested in temperature delta from the reference temperature). Knowing where the spots should be and where they are in the original reference we can resample the original reference and produce the new corrected reference. This process has to be repeated for each temperature delta required.

Table 10: RFC Reference Generation Requirements

Parameter	Requirement	Remarks
Reference ΔT	$\Delta T=6°C$	The temperature delta between reference was chosen to keep the operational error at 0.1pixel
Min temperature	$T_{min}=-12°C$	Minimum temperature the reference is compensated for
Max temperature	$T_{max}=72°C$	maximum temperature the references are compensated for.

In order to minimize the errors the original reference is always kept as is and it's temperature is the nominal temperature the rest of the reference are related to. The operational temperature range of the system is set to T_{min}-T_{max} and we create a reference for every ΔT degree change, giving us 14 reference for each required original reference.

The output references of the RFC will be stored as:

Reference-XXXX-tttt.bin
Reference image after data reduction 8-bits per pixel padded for DMA for each temperature. 'tttt' will be replaced by the temperature.

9.2.5.Probing DB creation

As part of the RFC spot detection algorithm, a special routine will be used to detect the probing spots. Once detected the algorithm will store the specific configuration found on the DUT, and will in addition create a generic probing data base consisting of the theoretic location of all the possible probing spots under all temperatures and references.

9.2.6.Reference extension (AKA Wide Reference)

Without farther correction the Romeo FOV captured by the Juliet at the reference will only be complete for the specific reference distance. At any other distance new parts of Romeo's FOV will appear (marked in red in the figure below). If these "new" areas are not captured in the reference image no depth can be created for them resulting in lost FOV.

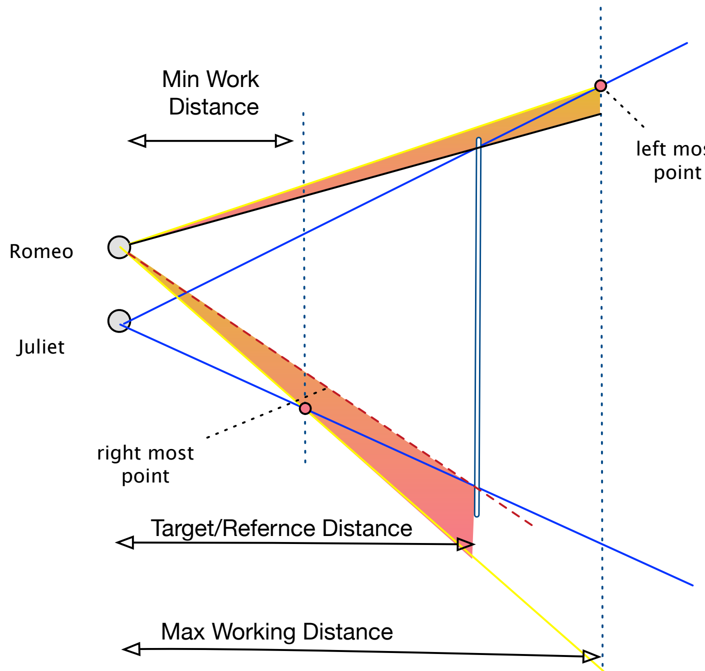


Figure 6 - Reference FOV explained

The solution is to synthetically extend the reference to include these areas. This is accomplished by special algorithm known as RFX which calculate the projector intrinsics, and extrapolate the captured pattern synthetically to the unseen areas. The results is a reference of size 1216x1312 (instead of 1104X1312) where we added 45 columns on one side and 67 on the other. This extended references are produces at the same stage the RFC temperature correction is performed and are produced for all temperatures and operating modes of the system (to clarify all references used by the system are extended - no regular reference is saved).

9.2.7.Parameters for PDCA

The following list of parameters represents the complete list of parameters produced by different versions of the station for different devices. A specific build or system might only use a sub-set of these parameters.

Table 11 - Parameters PDCA

Key	Type	Description/Remark	Units
IRpp	2xDouble	JU Principle Point (u_0,v_0)	mm
RGBpp	2xDouble	Maine Principle Point (u_0,v_0)	mm

IRefl	1xDouble	JU efl	mm
RGBefl	1xDouble	Maine efl	mm
ReferenceDist	1xDouble	Reference plane distance	mm
ReferenceAngle	3xDouble	Reference plane angle - normal	Radi an
RObaseLine	3xDouble	JU to RO Baseline (x,y,z)	mm
CamBaseLine	3xDouble	JU to Maine Baseline (x,y,z)	mm
CamAng	3xDouble	Maine to JU rotation convert rotation matrix into Euler angles	°
plainAng	5xDouble	Calibration planes angles	°
IRdist	3xDouble	JU Distortion values at 30%,50% and 80% of FOV	%
RGBdist	3xDouble	Maine Distortion values at 30%,50% and 80% of FOV	%
RefPlainOffset	3xDouble	Reference Plane offset (tvecs) indicates the offset to the left most corner of the target.	mm
IRreprojectionError	1xDouble	JU re-projection error	pixe l
RGBreprojectionErr or	1xDouble	Maine re-projection error	pixe l
ROreprojection	1xDouble	RO baseline re-projection error	pixe l
IRfeatureNum	5xUint16	# of features found at JU image of each plane used for calibration	cou nt
RGBfeatureNum	5xUint16	# of features found at ME image of each plane used for calibration	cou nt
RFCspots	5xUint16	# of spots found for each plane used for RO calibration	cou nt
Calibration RO temp	5xDouble	tempIdleNTC for each image used in RO calibration	°C
Calibration JU temp	5xDouble	sensorTemperature for each image used in JU calibration	°C
RFCspots	5xUint16	Numbers of spots found for each 40% and 60% reference used for RFC	
Mean of center spots	5x9xDouble	Mean gray level of spot center pixel, calculated for 9 different ROI of FOV.	GL
STD of center spots	5x9xDouble	STD gray level of spot center pixel, calculated for 9 different ROI of FOV.	GL
(IR/ RGB)ang(x)MeanLo w	5x9xDouble	Mean of the lower part of the histogram (black squares) of the (x)° (JU/ME) image, calculated at 9 different ROI in the FOV.	GL
(IR/ RGB)ang(x)StdLow	5x9xDouble	STD of the lower part of the histogram (black squares) of the (x)° (JU/ME) image, calculated at 9 different ROI in the FOV.	GL

(IR/ RGB)ang(x)MeanHigh	5x9xDouble	Mean of the higher part of the histogram (white squares) of the (x)° (JU/ME) image, calculated at 9 different ROI in the FOV.	GL
(IR/ RGB)ang(x)StdHIgh	5x9xDouble	STD of the higher part of the histogram (white squares) of the (x)° (JU/ME) image, calculated at 9 different ROI in the FOV.	GL
RFCmeanMatchDst	5xUint16	Spot matching mean distance for each 40% and 60% reference used for RFC	Radian
RFCstdMatchDst	5xUint16	Spot matching distance STD for each 40% and 60% reference used for RFC	Radian
minDAL	1xDouble	Minimum/Maximum shift (in Alpha) space between the nominal (synthetic) reference and the actual reference.	Shift (α)
maxDAL	1xDouble		
minDBE	1xDouble	Minimum/Maximum shift (in Beta) space between the nominal (synthetic) reference and the actual reference.	Shift (β)
maxDBE	1xDouble		
meanDAL	1xDouble	mean alpha of shift map	Shift (α)
meanDBE	1xDouble	mean beta of shift map	Shift (β)
stdDAL	1xDouble	std of alpha shift map	Shift (α)
stdDBE	1xDouble	std of beta shift map	Shift (β)
DAratio	1xDouble	Ration of valid alpha to total Alpha FOV	Shift (α)
totalNearestNeighbourDist	1xDouble	The “winning” homography nearest neighbor distance	Shift (α)
RFXgradientDescentVal	1xDouble	RFX optimization initial stage score.	
RFXgradientDescentIter	1xDouble	# of iteration in the initial optimization stage	
RFXfinalScore	1xDouble	RFX final optimization score	mrad
RFXfminIter	1xDouble	RFX number of iterations second stage.	
RFXRa	3xDouble	RO rotation (α,β,ɣ)	mrad
RFXinDOERot	1xDouble	Rotation between DOEs	mrad
RFXdxA	1xDouble	Midas grating parameter	
RFXdxB	1xDouble	Midas grating parameter	
RFXdyA	1xDouble	Midas grating parameter	
RFXdyB	1xDouble	Midas grating parameter	
refStateZeroCount	4xDouble	Number of peaks in the input references where we expect them	#count

outOffTaregetPix	1xDouble	Number of pixels in JU FOV which are outside of the target area	#count
FoVcoverage	4xDouble	Counts the number of pixels in the extended FoV that the current reference pattern doesn't cover.	#pixels
deadEmitters	4xUint16	Counts emitters that where detected less then 3 times in total in all of the tiles	#emitters
numProbingEmittersA	1xUint16	Number of emitters detected on in probing pattern A	#emitters
numProbingEmittersB	1xUint16	Number of emitters detected on in probing pattern B	#emitters
validProbingCodeA	1XUint16	Does the recognized probing code exist in the code book	true / false
validProbingCodeB	1XUint16	Does the recognized probing code exist in the code book	true / false
ref_(x)_SignalPerWindow_(r)	4x8xDouble	For each output reference type x gives a metric of the signal per window quality at radial ROI r. This is indication of how good the projected pattern is looking.	GL
HomRot	3xDouble	Relative rotation between Midas and Andalusia. Measured around each axis.	Radian
IRcalibrationParamVar	31xDouble	Internal metric of the variance of each calibration parameter being optimized. Can indicate the confidence level in the calibration.	
IRcalibrationParamIdx	31xDouble	Associate each variance with an internal index of parameter being calibrated.	
RObaselineCalibrationVar	3xDouble	Internal metrics from the baseline optimization algorithm on the optimization certainty of the baseline results.	mm^2
irRgbOverlapRatio	5xDouble	FOV overlap between the RGB and IR cameras for each of the calibration planes	
minProbeDist	20xDouble	For each emitter in the probe pattern lists the minimum distance over all the orders to it's nearest non probing spot.	#pixels
P5ProbeDist	20xDouble	For each emitter in the probe pattern lists the 5th percentile of the distance over all the orders to it's nearest non probing spot.	#pixels

P50ProbeDist	20xDouble	For each emitter in the probe pattern lists the median distance over all the orders to it's nearest non probing spot.	#pix els

9.2.8.PDCA temperature monitoring

There are 3 temperature points that the system is providing which are of interest for the calibration:

* tempIdleNTC - The temperature recorded right before the RO pulse.
* tempActNTC - The temperature recorded right after the RO pulse.
* sensorTemperature - The internal temperature reading from the JU.

For each image with projector pattern on, a matching temperature record should be saved to PDCA including these 3 temperatures.
In addition we want the following temperatures recorded and monitored by PDCA:

Table 12 - Temperatures for PDCA

Key	Type	Description/Remark	Unit s
Initial Temperature	3xDouble	The initial temperature when the DUT was first initialized	˚C
Setting Temperature	3xDouble	The temperature after waiting for the system temperature to stabilize.	˚C
Heat-Up	3xDouble	Setting Temperature - Initial Temperature	˚C
Calibration Mean Temperature	3xDouble	The mean temperature of the 5 angles captured during the calibration sequence	˚C
Calibration Max Temperature offset	3xDouble	The maximal temperature offset between each angle temperature and the mean temperature.	˚C

9.2.9.PDCA binary process log

The following data should be stored to the process log in order to enable easy debug and to enable offline execution of the RFC and the calibration algorithm.

* All images specified in table 3 with their metadata.
* All references specified at table 4 and their metadata - preferably after the averaging.

9.2.10.PDCA flattening convention

Since in principle we prefer PDCA values to be scalar we need to define an excepted way to “flatten” the vector and matrix outputted by the station code.
The only “matrix” values related to table 11 are those that has to do with the angles of the calibration plains. Those matrix will be “flatten” into vectors **by the station** code where each vector name will have a suffix angX specifying the number of plain they refer to.

The remaining vector data described by table 11 will be flatten by the FATP code appending _x according to the location of the variable inside the vector.

9.2.11.PDCA Limits

PDCA limits had been transferred to the appendix and are listed on a per project/device basis in order to facilitate easier version control and tracking.

Note that latest mechanical tolerances should be available under radar <rdar://problem/29803027> Pearl Sub-Assembly ERS

9.2.12.Sensor upload and FDR upload

See latest info at - T287 FDR

9.3. Station Requirements

9.3.1.MPC station components

The MPC station can be broken down into the following key elements:

- Target
- Rotation Stage and Jig
- Ambient Lights
- External Camera

The following section will specify the detailed requirements from each element. Not that in addition to the above elements the station should probably include elements such as chamber, computer, controller etc… these are left outside the scope of this document as they don't effect the operation of the station in a direct way.

9.3.2.Target Specification

The target pattern should match the file: 'PearlCalibrationTargetV2.0.pdf' can be found in: <rdar://problem/17605738> Pearl Calibration

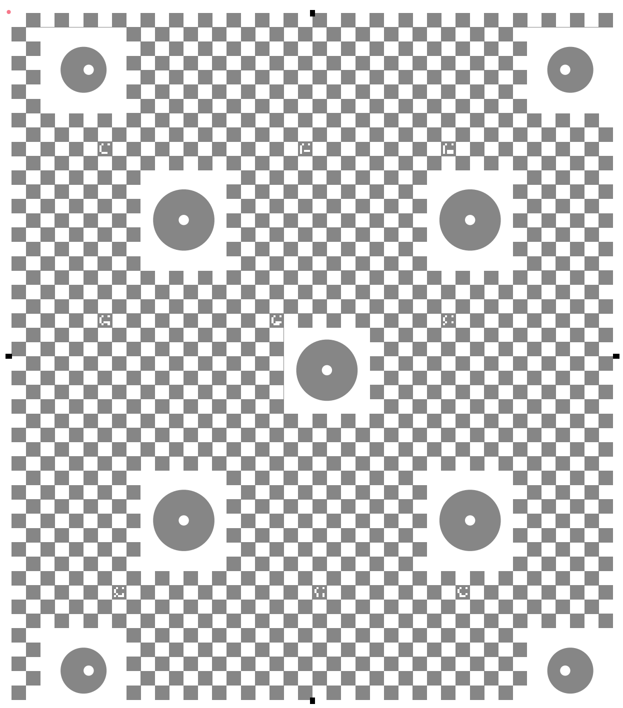


Figure 7 - MPC target pattern

The following table summarizes the requirements from the target in terms of mechanical properties and pattern accuracies.

The target image available in the radar is for 1x1m target. For smaller targets it can be cropped equally around the center.

9.3.3.Rotation Stage Requirements

The following table summarizes the requirements from the rotating stage and the jig holding the DUT

Table 14 - Rotation stage and JIG requirements

Parameter	Units	Requirement	Remarks
Number of rotation axes		1	Still studying if adding 2nd axis can improve performance.
Relative angle to target (Θ_x,Θ_y)	°	<3	Applies only to the 0° position where the reference is taken. Need to be taken into account for target size tolerances.
Lateral offset of IR camera entrance pupil from target center (x,y)	cm	<10	Need to make sure that DUT FOV is within the target.
Rotation range	°	±32	
Nominal offset distance of IR camera from rotation axis (x,z[1])	cm	<10	For optimal performance the IR camera should be placed on the rotation axis, but the sensitivity to offset is small.
Rotation angle error	°	<0.5	Still want the angle delta to be roughly correct.

[1] z-offset is only relative to rotation axis! the target is still with nominal offset of ±1cm to DUT.

9.3.4.Lighting Requirements

The MPC station needs to use external light source in order for the target to be visible for both RGB and IR.

Table 15 - Lighting requirements

Parameter	Units	Requirement	Remarks
IR Bandwidth	nm	$931 \le \lambda \le 961$	That the wavelength we care about, but actual light can be wider or narrower as long as it has enough power within the bandwidth
IR Irradiance	W/m^2	$2 \le E_e \le 3$	Assumes exposure of 15ms[2]. the power should be integrated over the bandwidth specified (use Capulet)
RGB image min brightness for black squares	GL	≥50	The visible light can be more flexible, as long the image is well lit as defined by having enough dynamic range between the white and black.
RGB image max brightness for white squares	GL	≤230	

[2] Numbers should scale linearly with exposure -> higher exposure less power

10. Pearl Test

10.1. System Overview and Limits

The purpose of the Pearl FATP tool is to determine that the assembly, integration and calibration of the Pearl modules has succeeded. There are three key metrics that define the success or failure of the integration and calibration.

5. System signal to noise ratio (SNR) Limits defined in section 2.3.13 and 2.3.14
6. Real world accuracy (RWA) Limits defined in section 2.3.13 and 2.3.14
7. Pearl to RGB registration (REG) Limits defined in section 2.3.13 and 2.3.14

10.1.1.Overview

The Pearl FATP tool is essentially an enclosure in which a unit under test (UUT) may be mounted opposite a verification target. The FATP tool is operated by the UUT in that it requires no other power source in other to perform its task all other components are passive.

A UUT is placed into a precise holder that positions the UUT in such a way so as to define an exact orientation and distance between the UUT and the verification target of the tool. Then the UUT acquires a series of images using the Pearl module as well as the RGB front camera. Following this step the captured images are analyzed and the metrics and the above metrics are calculated.

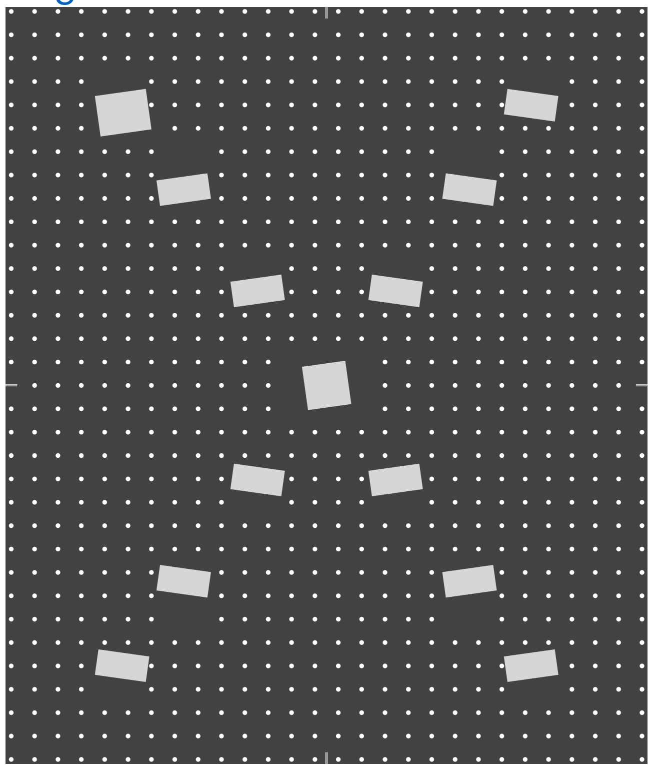
10.1.2.Tool Enclosure

The enclosure is required to hold a UUT in an unobstructed manner in front of the verification target. There will be two different enclosures designed for the FATP tool. One will have a nominal distance between the UUT and the target of 200mm and another that will have 600mm as the nominal distance. Inside the enclosure the verification target will be positioned parallel to the UUT.

Table 4 :Target definitions

Parameter	Symbol	Units	Nominal	Tolerance	Note
Distance To Target	DTT200	mm	200	±0.1	
	DTT600	mm	600	±0.1	
Target Decenter	TD	mm	0	±2	Separately in X\Y
Target Parallelism	TP	º	0.1	±2	Separately in X\Y
Target Rotation	TR	º	0.1	±1	
Target obstruction	TO	%	0	0	Complete target visible

10.1.3. Verification Target



The verification target (see related documents for target drawing) consists of an evenly spaced repeating dot pattern. The pattern shall have a defined contrast ratio and hence will comprise of white markers on a grey background. On top of the even grid there will be an additional set of larger circles that will create a sort of cross shape as depicted in the image. The target shall be used to measure SNR, RWA, and its features allow registration between the Pearl module and the front facing RGB camera.
In order to achieve this the target must be accurate and precise as defined in the following tables. The target origin will be defined as the top left of the target.

Table 5 :600 [mm] target pattern

Parameter	Symbol	Units	Nominal	Tolerance	Note
Target horizontal size	Hz600	mm	825	-0	
Target vertical size	Vt600	mm	980	-0	
Accumulated pattern error	APE600	mm	0	±0.2	
BG pattern Vert. spacing	BGV600	mm	30	±0.2	Small dot grid
BG pattern Horiz. spacing	BGH600	mm	30	±0.2	
Dot diffusive reflectivity	DR	%	60	-1.5, +2	at 940nm
BG diffusive reflectivity	BGR	%	34	±1	at 940nm

Parameter	Symbol	Units	Nominal	Tolerance	Note
Dot specular reflectivity	DR	%	0	+0.1	at 940nm
BG specular reflectivity	BGR	%	0	+0.1	at 940nm
Dot diameter	DD600	mm	6	±0.2	
Rectangle dimensions	CD600	mm			See target drawing
Rectangle tilt	CDD600	°			See target drawing
Rectangle number	Cn	-			See target drawing
Target flatness	TF600	mm	0	0.6	P-V

Table 6 :200 [mm] target pattern

Parameter	Symbol	Units	Nominal	Tolerance	Note
Target horizontal size	Hz200	mm	280	-0	Target can be larger, not smaller
Target Vertical size	Vt200	mm	330	-0	Target can be larger, not smaller
Accumulated pattern error	APE200	mm	0	±0.2	
BG pattern Vert. spacing	BGV200	mm	10	±0.2	Small dot grid
BG pattern Horiz. spacing	BGH200	mm	10	±0.2	
Dot diffusive reflectivity	DR	%	50	±2	at 940nm
BG diffusive reflectivity	BGR	%	20	±1	at 940nm
Dot specular reflectivity	DR	%	0	+0.1	at 940nm
BG specular reflectivity	BGR	%	0	+0.1	at 940nm
Dot diameter	DD200	mm	2	±0.2	
Rectangle dimensions	CD600	mm	??x??	±0.2	See target drawing
Rectangle tilt	CDD600	°	?	±0.2	See target drawing
Rectangle number	Cn	-	12	-	See target drawing
Target flatness	TF200	mm	0	0.2	P-V

10.1.4.System Operation

In order to achieve a proper set of measurements the UUT needs to be thermally stable during its data collection sequence. In order to achieve this the UUT needs to be operated For a predefined warmup time. After this warmup time the UUT is considered stable. The stable temperature needs to be recorded. Once the UUT reaches the designated temperature the FATP tool measurements can be collected.

Table 7 :Thermal Stability parameters

Parameter	Symbol	Units	Nominal	Tolerance	Note
Thermal stability	DT	ºC	0	±1	Temperature variation between first and last frame

Once the UUT is thermally stable The following sequence is performed:

3. 10 images of the target IR and depth are captured using sparse/dense mode
4. 10 images of the target are captured under flood illumination
5. 10 RGB images of the target are captured

During the capture sequence the four temperature sensors are recorded (Idle_NTC, Active_NTC, DIE and NTC)

A detailed set of sequences is described in the following section.

10.1.5.Image Capturing Conditions

In all of the measurements described in this document the image acquisition parameters will be as defined in the following table.

All images must be taken in the following mode

Table 7 :Image Capturing Conditions

Name	Operation Mode				
	S	D	R	A	B
100% Full Power	1529	1824	0	0	0
40% Full Power	1529	0	0	0	0
100% Low Power	828	986	0	0	0
40% Low Power	1242	0	0	0	0
40% Full Power Probe A/B	1529	0	0	58	58
40% Low Power Probe A/B	1242	0	0	58	58
40% Low Power RFC	828	0	0	0	0
0% Noise Image	0	0	0	0	0

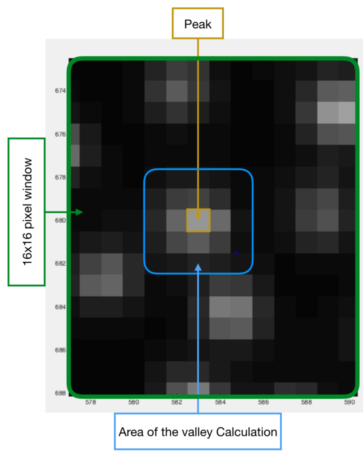
10.2. Measurements description

This section describes measurements done by the FATP tool. All of the measurements described in this section start with a data capture procedure. This procedure is done only once per UUT and all of the measurements will share the data collected in this step. This procedure is reiterated in this chapter for each measurement for the purpose of allowing the measurement to be run as a standalone instance.

Note : Data processing runs in station : Rack2

10.2.1. System SNR

System SNR is one of the key metrics measured by the FATP tool. The value for system SNR is constructed by calculating spot SNR and integrating over an ROI of 16x16 pixels.



10.2.1.1. Spot SNR

Spot SNR is defined as the peak to valley over the noise for each spot.

The peak of the spot is defined as the maximal signal of a spot when it is convolved with a match filter of 5x5 pixels as defined in the Pearl Depth Engine chip (PDE).

The valley value is defined as the average of the pixels below the median of a 5x5 pixel region having the peak pixel at its center.

SNR is measured with no ambient light. The only noises measured are CMOS noises and signal shot noise.

SNR changes as the distance from the center of FOV increases and so the thresholds are set accordingly. SNR will be measured at 20cm with the Pearl module operating in sparse pattern mode and at 60cm operating with dense pattern mode.

10.2.1.2. Spot SNR calculation method

In order to calculate the spot SNR the following steps must be executed.

1. Operate the Pearl module according to the desired testing distance (20cm or 60cm).

2. Capture N raw images from the Pearl module.
3. All spots are detected by convolving the image with a match filter as described in the previous section stored in the PDE. The Match filter is a 5x5 pixel matrix.
4. After The convolution step the maximum valued pixel for each detected spot is taken as the peak value. This results in M peaks.
5. In order to define the valley value a 5x5 region of pixels is defined around every peak found in step 4. The valley value is defined as the average of the pixels below the median of a that 5x5 pixel region having the peak pixel at its center.
6. The spot SNR is defined as the peak of step 4. minus the valley of step 5. divided by the standard deviation of the M peaks for the N images collected. This is performed for the M spots detected.

$$SNR_{Spot} \stackrel{def}{=} \frac{Peak - Valley}{STD_{images}(Peak)}$$

10.2.1.3.System SNR calculation method

In order to calculate the system SNR a 16x16 pixel window is selected in the image. Spot SNR as defined in the previous section is then calculated for the spots in that window. System SNR is defined as the RSS of the spot SNR results in the window of interest.

$$SNR_{System} \stackrel{def}{=} \sqrt{\sum_{i=1}^{n} (SNR_{Spot})_i^2}$$

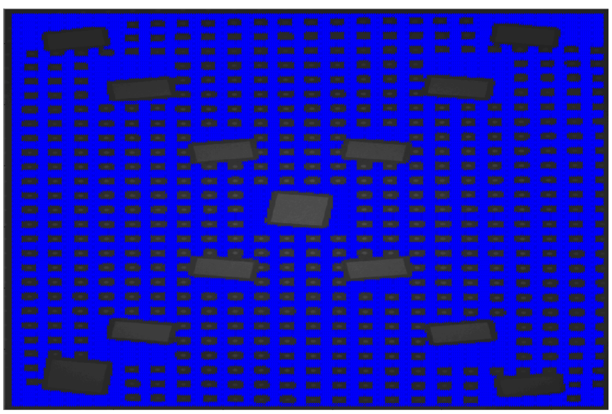
Several 16x16 pixel windows are defined throughout the system FOV and system SNR is calculated for each of them. A map of SNR throughout the FOV is obtained.

10.2.1.4.Test procedure (Per distance, Per density)

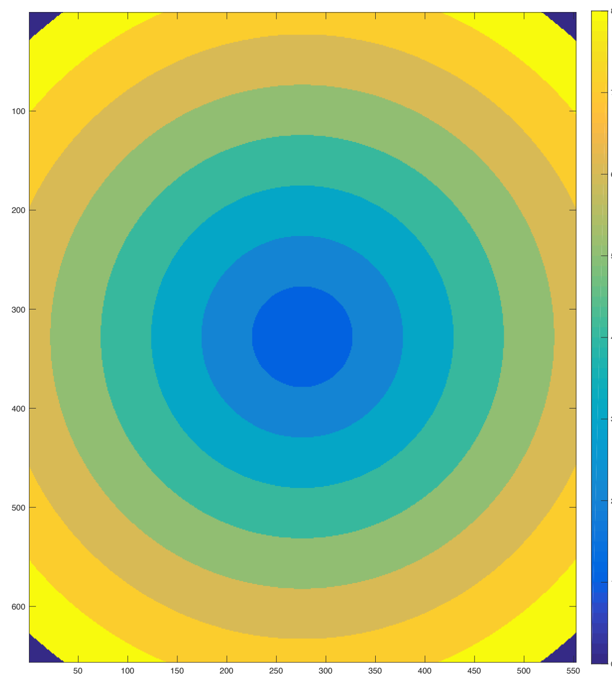
1. Select operating mode based on the measurement distance (20cm or 60cm).
2. Make sure that Ambient light is OFF.
3. Capture 10 images of the target in “Sparse mode” (for 20cm) or “Dense mode” (for 60cm) as defined in “Image Capturing Conditions” section above.
4. Capture 10 images of the target in “Flood illumination” mode as defined in “Image Capturing Conditions” section above.
5. Average the images taken in step 3 temporally.
6. Find all spots in the pattern averaged image by convolving the match filter defined in the PDE see appendix A.
7. For each spot captured in the averaged image calculate the spot SNR see appendix A.
    I. Signal is calculated as the peak to valley difference in a 5x5 pixels window after applying match filter on averaged image (see “Spot SNR Calculation” section).

   II. Noise is calculated as the temporal standard deviation of the signal after applying the match filter over all captured images in step 3. (see “Spot SNR Calculation”section)
8. Divide the images into 16x16 pixels regions see appendix A.
   I. An allowed region must not have any target region in it like a circle or a dot. and must be of a uniform color of the BGR as defined above.
   II. Adjacent regions will be spaced by 4 pixels in X and 4 pixels in Y.
9. RSS the SNR of all spots in the same region (weighted by the relative part of the spot in the region).
10. For each region defined in 8.I. calculate the distance from the region center to the image center in pixels.
11. Distribute the region population into 8 bins as a function of the distance from the center of the image. [0÷100, 100÷200, 200÷300, 300÷400, 400÷500 ...] pixels.
12. The reported system SNR for each bin is the system SNR of the lower 5% results. Ignoring regions that are out side the system FOV.

An example of the SNR bins and a typical result.



System SNR regions (blue) out of the verification target.



Pixel info: (X, Y) Intensity

10.2.2.Z-Precision Over Time

Another critical metric for the Pearl module is its the precision over time of pixel Z values. The precision over time is measured by taking all the Z values of pixel (i , j) over N frames of a static scene and calculate the standard deviation (STD) of the population for that pixel.

10.2.3.Z-Precision Calculation Method

The captured depth measurement must be calculated using all of the compensating algorithms (Polar, RFC, GMC). This means that RFC and GMC must be enabled in the PCE. Z-Precision is to be measured at a distance of 20cm illuminated by a pattern designated as “Sparse” and at a distance of 60cm illuminated by a pattern designated as “Dense”.

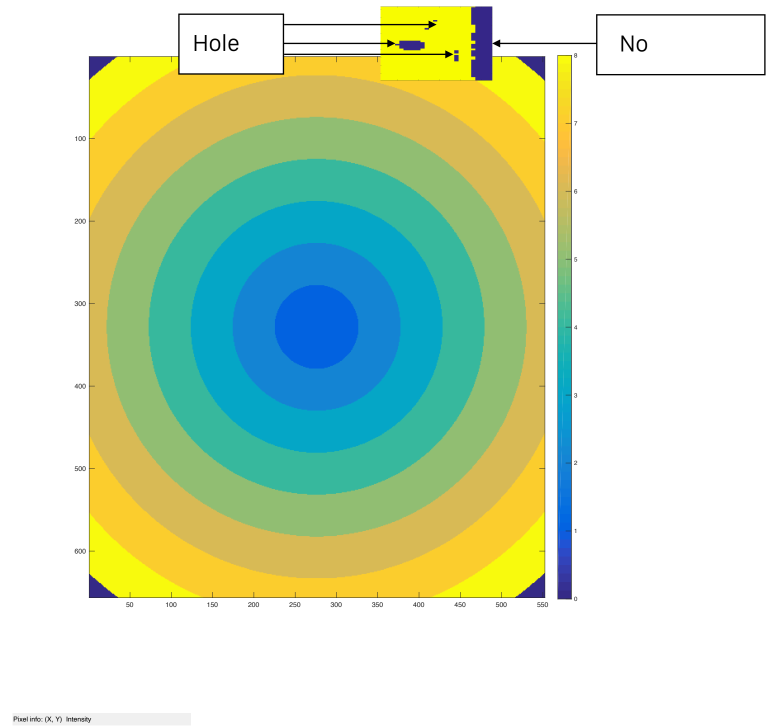
10.2.4.Test procedure (Per distance, per density)

1. Select operating mode based on the measurement distance (20cm or 60cm).
2. Make sure that Ambient light is OFF.
3. Capture 10 images of the target in “Sparse mode” and “Dense mode” as defined in “Image Capturing Conditions” section above.
4. Generate a reference image based on the RO temperature using the RFC algorithm from the PDE.
   I. Read spotDB and reference IR images
   II. Read projector thermal parameters
   III. Produce RFC reference according to RO temperature using the RFC algorithm
5. Run the PDE (onboard from P2 onward) region growing (‘Skye’) to produce DX and DY shift map
6. Run GMC on same data of 9 (onboard from P2 onward).
   I. Record GMC output. Projector Rotation Change (tx,ty,tz)
   II. Record GMC output. Juliet EFL
7. Run depth engine post processing (DSC, DXC RFV, RGS, S2D)
8. Run depth image enhancement to filter out depth holes
9. Multiply all image with mask
10. Calculate “No Depth %”
11. Remove“No Depth” Samples
12. Calculate STD per pixel and create 2D Map
13. Divide the map to rings:

14. For each ring
    I. Find the 95% percentile STD
    II. Calculate the percentage of the valid samples

10.3.Holes Calculation In Depth Map

Another metric for the Pearl module is the number of depth holes in N Frames
In each frame we mark “no depth” values as 0 , and depth as 1
Holes Definition - Island of no depth values(NaN’s or zeros)



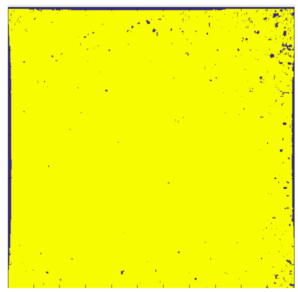
The verification target have area with high reflectivity that can cause saturation in the image. To neglect possible saturation effects all the location of the high reflectivity in the target are filled with 1 values to start with.

10.3.1.Test procedure (Per distance, per density)

1. Select operating mode based on the measurement distance (20cm or 60cm).
2. Make sure that Ambient light is OFF.
3. Capture 10 images of the target in “Sparse mode” and “Dense mode” as defined in “Image Capturing Conditions” section above.
4. Generate a reference image based on the RO temperature using the RFC algorithm from the PDE.
   I. Read spotDB and reference IR images
   II. Read projector thermal parameters
   III. Produce RFC reference according to RO temperature using the RFC algorithm
5. Run the PDE region growing (‘Skye’) to produce DX and DY shift map
6. Run GMC on same data of 9.
   I. Record GMC output. Projector Rotation Change (tx,ty,tz)

   II. Record GMC output. Juliet EFL
7. Run depth engine post processing (DSC, DXC RFV, RGS, S2D)
8. Run depth image enhancement to filter out depth holes and false regions.
9. For each depth frame mark pixel with “No Depth” as 0, and “Depth” as 1
10. Calculate the aggregated frame
   I. aggregated frame = $\prod$frames (see image below)
11. Calculate on the aggregated image the following metric:
   I. Find the number of holes
   II. Calculate the area of all the holes in pixels
   III. Calculate the biggest hole size in pixels

Aggregated Holes Images



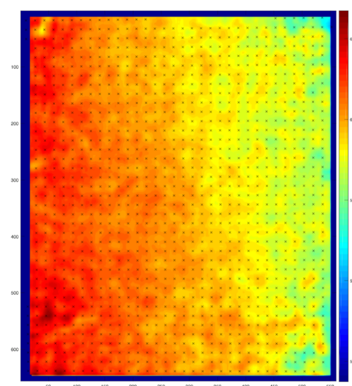
10.3.2.Real World Accuracy (RWA)

Another critical metric for the Pearl module is its Real World Accuracy (RWA). What RWA means is the error between a measured object or distance (not necessarily depth) in 3D space by the Pearl module and its actual real world dimensions.
RWA is measured by taking the raw self illuminated image of the verification target identifying predefined objects on the verification target and registering their coordinates in pixels (p_{xi}, p_{yi}). Following this step by knowing the exact distance to the target a calculation is applied that transforms the object pixel coordinates into real world locations (X(p), Y(p) Z(p)) with respect to an origin point which is defined to be the camera entrance pupil. When a subsequent depth image is captured the X(p), Y(p) and Z(p) are compared and the difference is calculated.

10.3.3.RWA Calculation Method

The real world accuracy can be defined as the measured depth point cloud absolute depth error of the validation target divided by the target true position point cloud. In order to achieve this the two point clouds must be registered to each other.
The absolute depth error is defined as the difference between the measured depth data and the ground truth data of the same target (X(p), Y(p) Z(p)) when the two data sets are registered to each other.
The captured depth measurement must be calculated using all of the compensating algorithms (Polar, RFC, GMC). This means that RFC and GMC must be enabled in the PDE.
Real world accuracy is to be measured at a distance of 20cm illuminated by a pattern designated as “Sparse” and at a distance of 60cm illuminated by a pattern designated as “Dense”.
When measuring the real world accuracy, the temporal noise of the images needs to be suppressed. This is achieved by capturing a train of N images and averaging them.

$$RWA(x,y)=\frac{|Z_{Depth}(x,y)-Z_{GT}(x,y)|}{Z_{GT}(x,y)}$$



Example of RWA output

10.3.4.Test procedure (Per distance, per density)

1. Select operating mode based on the measurement distance (20cm or 60cm).
2. Make sure that Ambient light is OFF.
3. Capture 10 images of the target in “Sparse mode” or “Dense mode” as defined in “Image Capturing Conditions” section above.
4. Make sure that ambient light is ON.
5. Capture 10 images of the target in “Flood illumination” mode as defined in “Image Capturing Conditions” section above.
6. Average all images taken in step 3 temporally.
7. Average all images taken in step 5 temporally.

8. Generate a reference image based on the RO temperature using the RFC algorithm from the PDE.
   I. Read spotDB and reference IR images
   II. Read projector thermal parameters
   III. Produce RFC reference according to RO temperature using the RFC algorithm
9. Run the PDE region growing ('Skye') to produce DX and DY shift map
10. Run GMC on same data of 9.
    I. Record GMC output. Projector Rotation Change (tx,ty,tz)
    II. Record GMC output. Juliet EFL
11. Run depth engine post processing (DSC, DXC RFV, RGS, S2D)
12. Run depth image enhancement to filter out depth holes and false regions.
13. Find markers location in the ambient averaged image
14. For each marker find the ground truth location $Z_{GT}(x,y)$
15. For each marker find the depth from the depth image $Z_{Depth}(x,y)$
16. Using the marker location in the image and the depth value (X, Y, Z) calculate the real world location in space (X, Y, Z)
17. For each point, the real world error is the distance between the real world location and the ground truth
18. Real world accuracy is the worst case 95 percentile of the errors divided by the Z distance of the target

10.4.Depth to RGB Registration accuracy

The registration accuracy is taken between two sets of data one being the RGB image and the other being the depth calculated image. The registration error is defined as the top 5 percentile of the difference between the two images the worst case 95 percentile of the pixel distance between the predefined matching points. No translation, rotation or scaling is applied.

Registration accuracy is measured at 20cm using the sparse pattern and at 60cm using the dense pattern.

10.5.Test procedure (Per distance, per density)

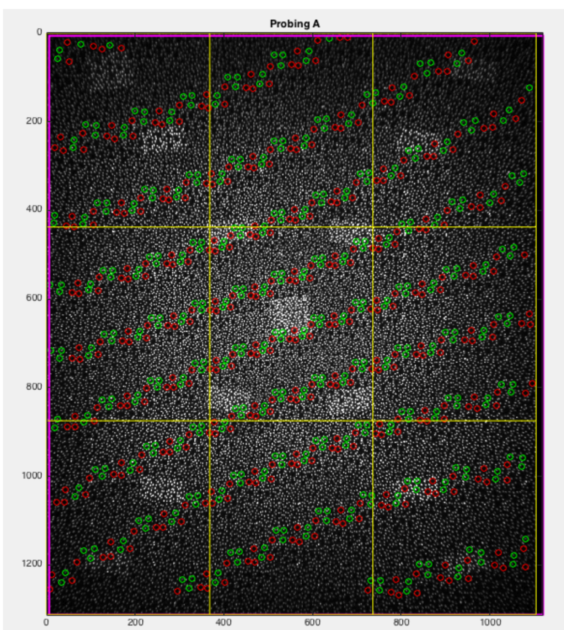
1. Capture 10 images of the target in “Sparse mode” or “Dense mode” as defined in “Image Capturing Conditions” section above.
2. Capture 10 images of the target in “Flood illumination” mode as defined in “Image Capturing Conditions” section above.
3. In case of external light source requirement is TBD
4. Capture one RGB image of the target with ambient light
5. Record RO temperature (ROIdleNTC)
6. Generate an average JU pattern image by temporally averaging all acquired images
7. Generate an average JU ambient image by temporally averaging all acquired images
8. Generate a reference image based on the RO temperature using the RFC algorithm from the PDE.
   I. Read spotDB and reference IR images
   II. Read projector thermal parameters
   III. Produce RFC reference according to RO temperature using RFC algorithm
9. Run the PDE region growing (‘Skye’) to produce DX and DY shift map
10. Run GMC on the same shift map
11. Run depth engine post processing (DSC, DXC RFV, RGS, S2D)
12. Find markers location in the JU ambient averaged image
13. For each marker find the depth from the depth image
14. Using the marker location in the image and the depth value (i, j, Z) calculate location of the marker in the RGB image (l, k)
15. Find markers location in the RGB ambient averaged image
16. For each marker calculate the distance between the registered marker location and the matching marker location in the RGB image. Error units are RGB pixels.
17. Registration accuracy is the worst case 95 percentile of the errors

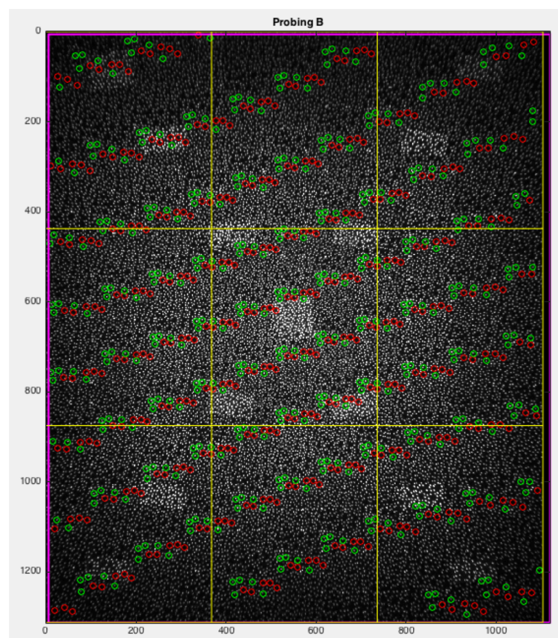
10.6. SNR vertical uniformity [Cover Glass Performance Impact (Spline)]

1. Select operating mode based on the measurement distance (60cm).
2. Make sure that Ambient light is OFF.
3. Capture 10 images of the target in "Dense mode" as defined in "Image Capturing Conditions" section above.
4. Capture 10 images of the target in "Flood illumination" mode as defined in "Image Capturing Conditions" section above.
5. Average the images taken in step 3 temporally.
6. Find all spots in the pattern averaged image by convolving the match filter defined in the PDE see appendix A.
7. For each spot captured in the averaged image calculate the spot SNR see appendix Signal is calculated as the peak to valley difference in a 5x5 pixels window after applying match filter on averaged image (see "Spot SNR Calculation" section).
8. The averaged image is divided into two equal portions (top and bottom) around the center of the vertical axis.
9. Set two regions : Top 5deg and bottom 5deg
10. For each region the average spot signal over the average window grey level signal is calculated
11. Average spot quality calculation: dividing the average spot signal by average pixels intensity per region
12. The uniformity metric is defined as the quotient of the top window divided by its corresponding bottom window

10.7.Probe Pattern Detection

1. For 20cm target - two images are captured with the Sparse regular pattern: one with probing pattern "A" and one with probing pattern B.
   1.1. Per each image PCE runs in Ref2Pic mode to produce the region-growing shifts map: DX, DY.
   1.2. Read and decrypt the device's spotDB, read PCECalib and extract RFC index from each image metadata.
   1.3. Run PPD on 10 ROI-s for each image above (total 40=2x2x10 runs):
      - Full plane ROI (roi0)
      - 9 ROI-s defining 3x3 even partition of the target FoV.
2. For 60cm target - two images are captured with the Dense regular pattern: one with probing pattern "A" and one with probing pattern B.
   2.1. Per each image PCE runs in Ref2Pic mode to produce the region-growing shifts map: DX, DY.
   2.2. Read and decrypt the device's spotDB, read PCECalib and extract RFC index from each image metadata.
   2.3. Run PPD on 10 ROI-s for each image above (total 40=2x2x10 runs):
      - Full plane ROI (roi0)
      - 9 ROI-s defining 3x3 even partition of the target FoV.
3. For each of the running outputs above - we look at number of hard errors.





11. Critical to safety

The table below lists the CTS (Critical to safety) test and process items at the FATP site.
It is required that the following data is captured 100% for all material built and intended to be shipped out of the factory for any reason. By design the Pearl system is Class 1 laser safety complaint, however this data should always be captured and readily available. The data in this table should be saved for a minimum of 5 years so it's available for internal or external audit.
There are three categories of data

1. Metric - this relates to a measured metric in a test station with associated LSL (lower Spec limits) and/or USL (Upper spec limit)
2. Pass/Fail - this relates to a binary check of a parameter such as a status register or confirmation of the presence of a glue bond
3. Image - this relates a matrix of data or an image that is captured by a specialist imaging device.

Table: Pearl CTS table

FATP Test station	CTS Type	Descripton	ERS Reference	Critical Parameter Storage	Location	5 YEAR Storage	LSL	USL	Rel Drift spec
R-Comp Alpha	Metric	Romeoplr_simple	Titus-C system ERS	Romeoplr_simple	PDCA	Yes	—	0	
	Metric	Alpha (min_alpha)		Alpha_min	PDCA	Yes	6	21.6	+/- 5% of T=0 Value
	Metric	q-percentage of 7mm aperture power within alpha		q_max	PDCA	Yes	0.7	0.95	+/- 2% of T=0 Value
	Image	ZO Image, zero order image save		ZO Image	PDCA	Yes	NA	NA	
	Image	Required for Alpha calculation		LHS/Romeo/*tiff	Blob	Yes	NA	NA	
	Metric	Alpha_00	Rosaline Flood System ERS	alphacond3TOTPmrad_p0_p0	PDCA	Yes	*	*	
	Metric	Q_00		qcond3TOTP01_p0_p0	PDCA	Yes	*	*	
	Metric	PLR_ED2		PLR_ED2_MAX	PDCA	Yes	*	*	
	Metric	PLR_ED3		PLR_ED3_MAX	PDCA	Yes	*	*	
R-Comp Miyagi	Metric	AE_Eye(mW). Function of alpha	Titus-C system ERS	Romeo_X0.0_Y0.0_Z0.0_Ex20.0 MaxPowerValue (mW)	PDCA	Yes	2	8.9	+/- 5% of T= 0 value
	Metric	AE_Skin(mW)		TotalPower(mW)	PDCA	Yes	15	38.96	+/- 5% of T=0 Value
	Metric	AE heat Map		LHS/Romeo/ *COnoPXPY.cvs	Blob	Yes	NA	NA	
	Metric	Prox_compliance_AE70		Prox MaxPowerValue70mm(mW)	PDCA	Yes	*	*	

	Metric	Prox_compliance_AE100	Rosaline Flood System ERS	Prox MaxPower Value100mm(mW)	PDCA	Yes	*	*	
	Metric	Prox_compliance_Total_Power		Prox Total Power20deg(mW)	PDCA	Yes	*	*	
	Metric	Rosaline AE_Eye(mW)		Rosaline AE_Eye(mW)	PDCA	Yes	*	*	
	Metric	Rosaline heat Map		ConoPxPy.csv file	Blob	Yes	NA	NA	

*please refer to Rosaline and Prox ERS for appropriate coverage and spec limits

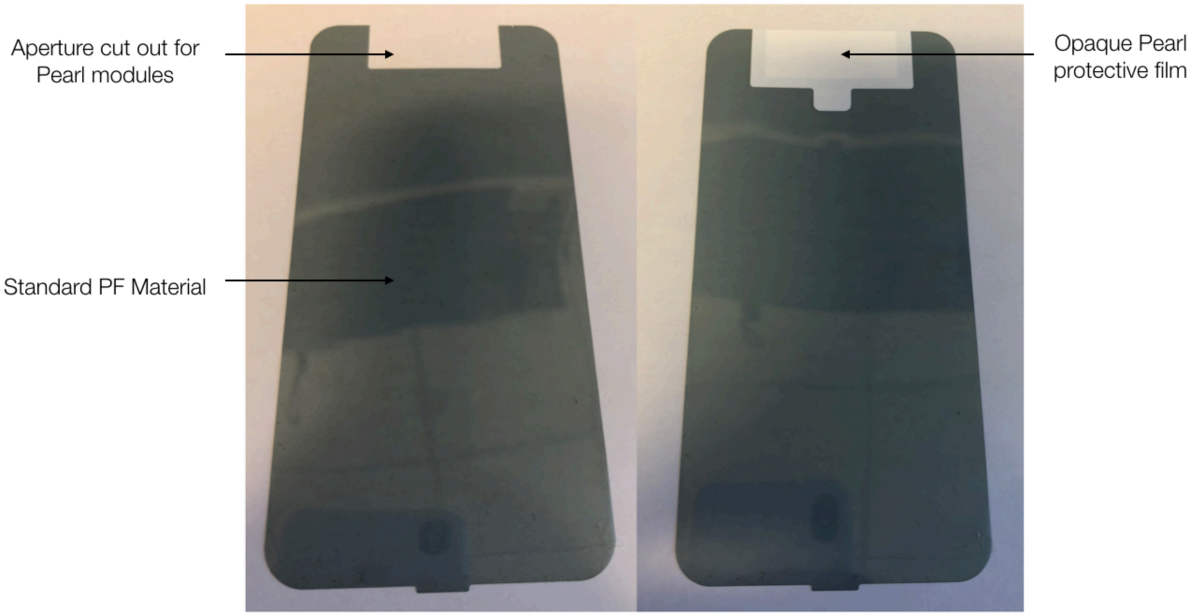
FATP Test station	CTS Type	Descripton	ERS Reference	Critical Parameter Storage	Location	5 YEAR STORAGE	LSL	USL
System Burn-in	Pass/Fail	Rigel OTP Check script	Rigel System ERS 1.2		PDCA	No	NA	NA
	Pass/Fail	Rigel Illegal drive	Rigel System ERS 1.3		PDCA	No	NA	NA
	Pass/Fail	Mama bear and switch toggle check	Rigel System ERS 1.4		PDCA	No	NA	NA
	Pass/Fail	Arm check	Titus-C system ERS		PDCA	No	NA	NA
	Pass/Fail	Yogi Illegal Drive	Rosaline Flood System ERS		PDCA	No	NA	NA

11.1. Protective Films

A standard transparent/ translucent protective film (PF) covering the projector apertures is a compliance risk and is not permitted. A standard PF may corrupt the optical power measurements at the compliance tester. The PF would attenuate the light and result in the optical power being underestimated. Optical power is a critical laser safety compliance metric.

Figure: Example transparent protective film without cutout and white opaque pearl PF

In the instance where an operator forgets to remove the CG PF, the compliance tests may pass because the optical power is attenuated resulting in a fault positive result.
To protect against this risk, all PFs covering the projector aperture should be IR-opaque.
This ensures that if the external CG PF or internal aperture PF, are left on the test will fail forcing the operator to correct the mistake and retest.



11.2. Rigel Laser Control

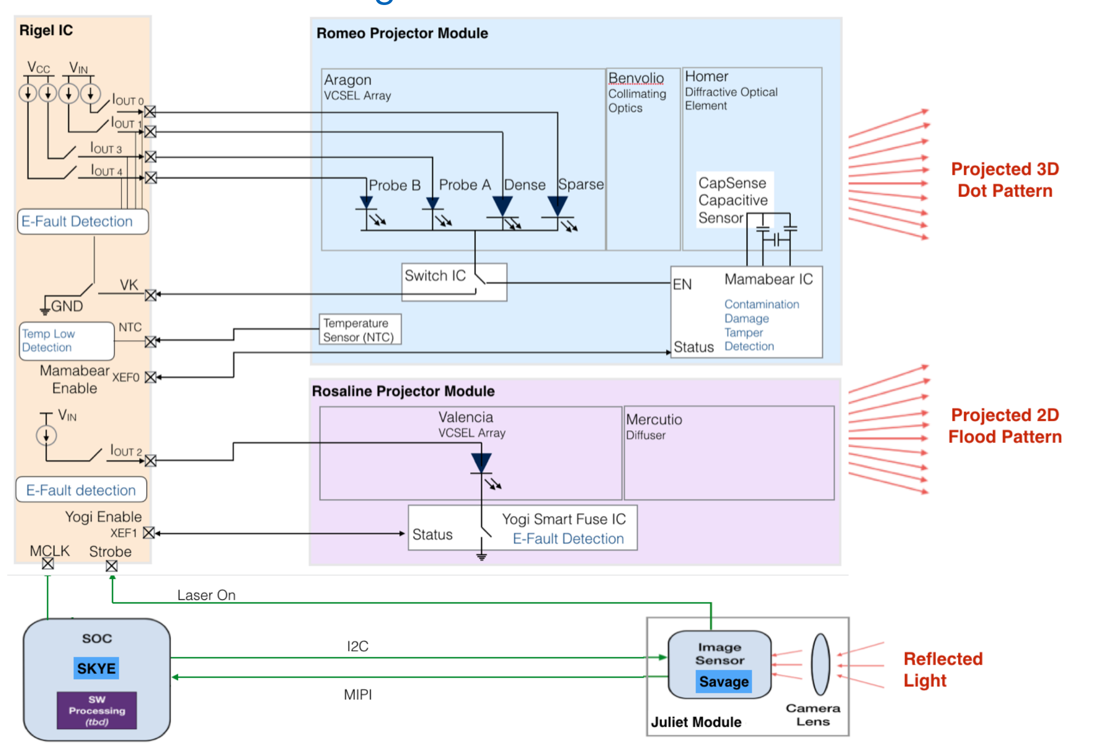


Figure 3.b: Pearl projectors and fail-safe architecture.R

Rigel is a 5-channel current source supporting pulsed operation. Rigel has several built-in mechanisms to limit pulse amplitude, pulse width, pulse power, duty cycle and burst pulse count to preset max values. Rigel also detects circuit and module faults and prohibits operation of the projectors.

4 channels (IOUT0, IOUT1, IOUT3, IOUT4) are connected to Dense, Sparse, Probe A and Probe B VCSEL sub-arrays respectively in Romeo projector and the fifth channel (IOUT2) is connected to Vader projector’s VCSEL array.

IOUT0, IOUT1, IOUT2 (IOUTx) are the main channels and can supply up to 2.5A of current while IOUT3 and IOUT4 (IOUTy) are sub-channels and can supply a max of 143 mA.

Allowed combinations of channels is shown in Table 3.1.a.

Table 3.1.a: Allowed combinations of channels

<table>
<tr><th rowspan="2">Allowed combination #</th><th>Romeo Dense</th><th>Romeo Sparse</th><th>Vader</th><th>Romeo Probe A</th><th>Romeo Probe B</th></tr>
<tr><th>IOUT0</th><th>IOUT1</th><th>IOUT2</th><th>IOUT3</th><th>IOUT4</th></tr>
<tr><td>0</td><td>off</td><td>off</td><td>off</td><td>off</td><td>off</td></tr>
<tr><td>1</td><td>ON</td><td>off</td><td>off</td><td rowspan="3" colspan="2">Any combination

(IOUT 3/4 only allowed with IOUT 0/1)</td></tr>
<tr><td>2</td><td>off</td><td>ON</td><td>off</td></tr>
<tr><td>3</td><td>ON</td><td>ON</td><td>off</td></tr>
<tr><td>4</td><td>off</td><td>off</td><td>ON</td><td>off</td><td>off</td></tr>
</table>

Rigel has 4 power modes. A simplified no fault steady state description of the power modes is given in Table 3.1.b below . The transitions between states has more constraints and documented in detail in the Rigel data sheet.

Table 3.1.b: Rigel operation states

Rigel Power Mode	Rigel Enable Signal	External Enable (XEFx)	Rigel Internal Driver/Regulators	Strobe (laser on/off request)	Output current
1. Powerdown	OFF	OFF	Not Ready	ON/OFF	OFF
2. Standby	ON	OFF	Not Ready	ON/OFF	OFF
3. Idle	ON	ON	Ready	OFF	OFF
4. Active	ON	ON	Ready	ON	ON

11.2.1.Drive Current Control (Max Output Amplitude- MOA)

The target drive current to each of the three main channels (IOUTx) is controlled via a 8-bit register value, IOUT_Bx, with a linear mapping of digital value to current. This register can be written by an I2C firmware write. The equation for digital value to current is:

$$IOUTx = IOUT\_Bx \times 9.86\ mA$$

The maximum drive current is limited by a locked-down 8-bit OTP NVM setting IOUT_MAXVAL_Bx. The maximum current possible for each driver is then IOUT_MAXVALx * 1.058 to account for the +5.8% accuracy of the output. For sub channels it is IOUT_MAXVALx * 1.119 to account for the 11.9% accuracy of the output.

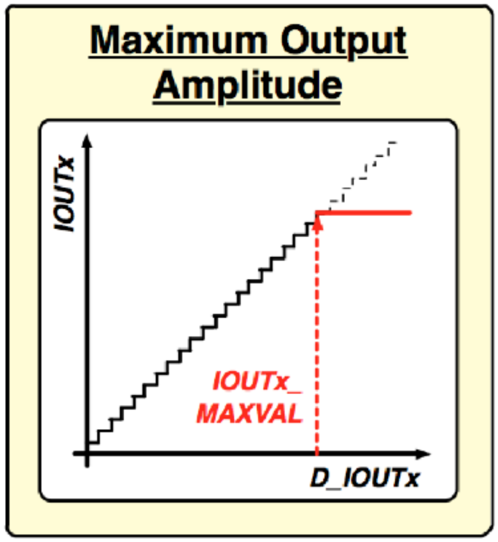


Figure 3.1.1.a: Max Output Amplitude: correlation between digital value and channel current.

The target drive current to each of the two sub channels (IOUTy) is controlled via a 5-bit register value, IOUT_By. As with the main channel, this register can be written by an I2C firmware write.

IOUTy = IOUT_By * 5.256mA

The maximum driver current is limited by a locked-down 5-bit OTP NVM setting IOUT_MAXVAL_By. The maximum current possible for each sub channel is IOUT_MAXVAL_Bx * 1.058 to account for the +5.8% accuracy of the output.

Table 3.1.1.a: Max current allowed per channel

		Romeo Dense	Romeo Sparse	Rosaline	Romeo Probe A	Romeo Probe B
Parameter	Units	IOUT0	IOUT1	IOUT2	IOUT3	IOUT4
Use Case IOUTx/y	A	1.824	1.528	0.749	0.058	0.058
OTP: IOUT_MAXVAL_Bx/y	#	185	155	76	11	11
Allowed Tolerance	%	5.8	5.8	5.8	11.9	11.9
IOUT_MAXVAL x/y	A	1.930	1.617	0.793	0.065	0.065

11.2.2.Maximum Pulse Power (MPW)

Rigel enforces a maximum (TONx) X (IOUTx) product to limit the maximum pulse energy. Pulse energy is the product of (TONx) X (IOUTx) X VCSEL slope efficiency (W/A)x. Maximum (TONx) X (IOUTx) value is set such that the pulse energy (@maximum slop efficiency as specified in VCSEL ERS) is below target laser compliance limit.

The maximum (TONx) X (IOUTx) product for main channels (IOUTx) is set through an 8-bit OTP parameter, C1_MAXPWx. This is channel specific value allowing different max pulse power on each of the main channel. The pulse width maximum limit is calculated by Rigel as a function of a parameter IOUTx_VAL_EFF and C1_MAXPWx. IOUTx_VAL_EFF is the lower of the current output value IOUT_Bx_d or the maximum current value IOUT_MAXVALx. The max pulse width on sub-channels (IOUTy) follows the same limit derived for the IOUT1 main channel.

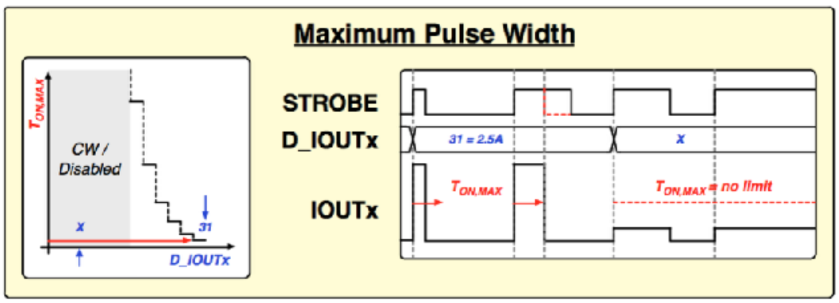


Figure 3.1.2.a: Max pulse power description

Maximum allowed pulse width (C1_TONMAX) for a pulse current IOUTx_VAL_EFF is derived from C1_MAXPW as per

$$C1\_TONMAX\_Bx = (C1\_MAXPW\_Bx / IOUTx\_VAL\_EFF) \times 2^{11}$$

where C1_TONMAX_Bx is a digital value that translates to absolute time through the equation

$$C1\_TONMAX\_Bx\_abs = C1\_TONMAX\_Bx * (1/clk\_safety)$$

where clk_safety is a dedicated 1MHz internal clock on Rigel for compliance. The frequency tolerance on clk_safety is +/- 6% so the worst-cast frequency is 940kHz where the clock period is the longest. An additional 1% clock error from Savage SOC is taken into account to define absolute maximum pulse width.

It should be noted the clk_safety has a self checker and if for some reason does not oscillate, Rigel would shut down the current sources for the main channels.

Beyond that there is another back up low power, low freq clock (clock_lp- clock low power) that would trigger Rigel states in case of a defect. For the purpose of laser compliance analysis, only the clk_safety will be used.

Beyond the maximum pulse power, Rigel also enforces an absolute maximum pulse width, ABSMAXPW. This is common to all channels and not dependent on the channel current values IOUTx and IOUTy. This is set by an 8 bit OTP register C3_MAXPW.

$$ABSMAXPW = C3\_MAXPW \times 2^7$$

Allowed maximum pulse width for any channel at a given drive current, IOUTx_VAL_EFF, is the minimum value of C1_TONMAX_Bx_abs and ABSMAXPW.

Table 3.1.2.a: Max Pulse width allowed per channel

		Romeo Dense	Romeo Sparse	Rosaline	Romeo Probe A	Romeo Probe B
Parameter	Units	IOUT0	IOUT1	IOUT2	IOUT3	IOUT4
Use case pulse width TONx/y	ms	2.93	2.93	9	2.93	2.93
OTP: C1_MaxPW_x/y	8 bit #	36	30	127	N/A	N/A
Xx/y at max current/ 940 kHz clk	ms	3.41	3.44	11.14*	3.44	3.44
Xx/y at low currents/ 940 kHz clk	ms	11.85				

* Yogi enforces a tighter limit, please see section 3.3.3

11.2.3.Maximum Duty Cycle (MAXDC)

An output maximum current duty cycle (MAXDCx/y) limitation limits the average power delivered by the system. This is channel specific value allowing different maximum duty cycles for each of the main channels. OTP parameters C1_MAXDCx (6 BITS) AND C2_MAXDCx (2 bits) are used to set the maximum duty cycle (MAXDCx). The sub channels (MAXDCy) follow the limit set for IOUT1 channel.

This feature blocks current generation until a minimum TOFF time (TOFFx_min) is reached since previous pulse. In case a request to turn on laser drive current occurs before TOFFx_min is reached, no current is produced and channel remains in Idle mode. TOFFx_min is set based on the max pulse width and max current to guarantee that the DC power for that scenario is lower than a maximum average power, PAVG.

MaxDCx for a given TONx_max and IOUTx is derived by

$$MAXDCx = (TONx\_max)/ (TONx\_max + TOFFx\_min)$$

Where TOFFx_min is

$$TOFFx\_min =$$

$$MAX\ [1ms,\ (N_{on}/f_{ocs})*(MAX(1,(((IOUTx*C1\_MAXDCx)\ /\ (2^{(6+C2\_MAXDCx)}))-1)]$$

N_{on} = Pulse width in # of OSC clock periods

f_{osc} = Oscillator based clock freq in Hz (1MHz)

The above constraint limits the minimum TOFF to 1ms, which allows Rigel to perform needed fault checks before firing the next pulse.

Max-allowed frequency can be determined by:

Max Allowed Freq = TONx / MAXDCx

Clock errors impact TON and TOFF similarly. Since duty cycle is a ratio of TON and TOFF durations, the TON and TOFF clock errors cancel out and so are not considered.

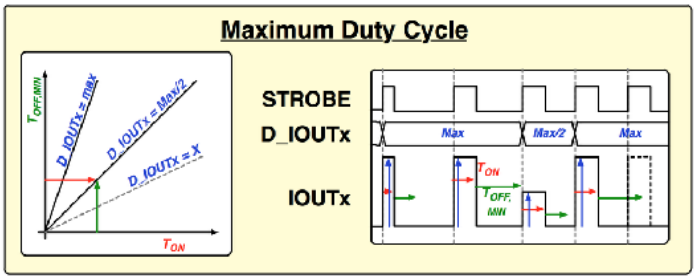


Figure 3.1.3.a: Max allowed duty cycle description

Table 3.1.3.a: Max allowed frequency per channel

		Romeo Dense	Romeo Sparse	Rosaline	Romeo Probe A	Romeo Probe B
Parameter	Units	IOUT0	IOUT1	IOUT2	IOUT3	IOUT4
Use case freq (max)	Hz	60	60	60	60	60
OTP: C1_MAXDCx/y	6 bit #	30	36	45	36	36
OTP: C2_MAXDCx/y	2 bit #	1	1	2	1	1
Max OTP allow freq	Hz	61.6	62	60.5 *	62	62

* Yogi enforces a tighter limit, please see section 3.3.3

11.2.4.Max Pulse Count (MAXPC)

Several Pearl use cases (Eg T287), require Pearl projectors to pulse at high freq (60Hz) for short burst (~3 pulses) durations, with wait time between bursts. To enable such use cases, maximum duty cycle OTP setting is configured to allow 60Hz frequency pulses. Without any “burst duration” limiting control feature, the average power from a 60Hz pulse sequence would need to be used for assessing OTP limited PLR even for long exposure laser compliance elements (refer to Table 2.3.a).

A maximum pulse count control feature (MaxPC) limits the number of pulses over a configurable time interval using a moving sum of number of pulses as a means to lower the average power over longer exposure times while allowing burst mode MaxDC limited pulses over shorter exposure times.

Each main channel IOUTx can be configured to have its own maximum pulse count control, while sub-channels IOUTy maximum pulse count is determined by IOUT1 max pulse count.

Each main channel has its CNTx counters to determine the number of TON pulses during a common period CNT_DURx.

A second counter (PCNT) performs a running sum of CNTx counter over a number of CNT_DUR periods defined by PCNT_INTV1 (1, 2, 3 or 4 are available choices). As shown on Figure 3.3.4.a, PCNT counters are updated each end of CNT_DUR period**.**

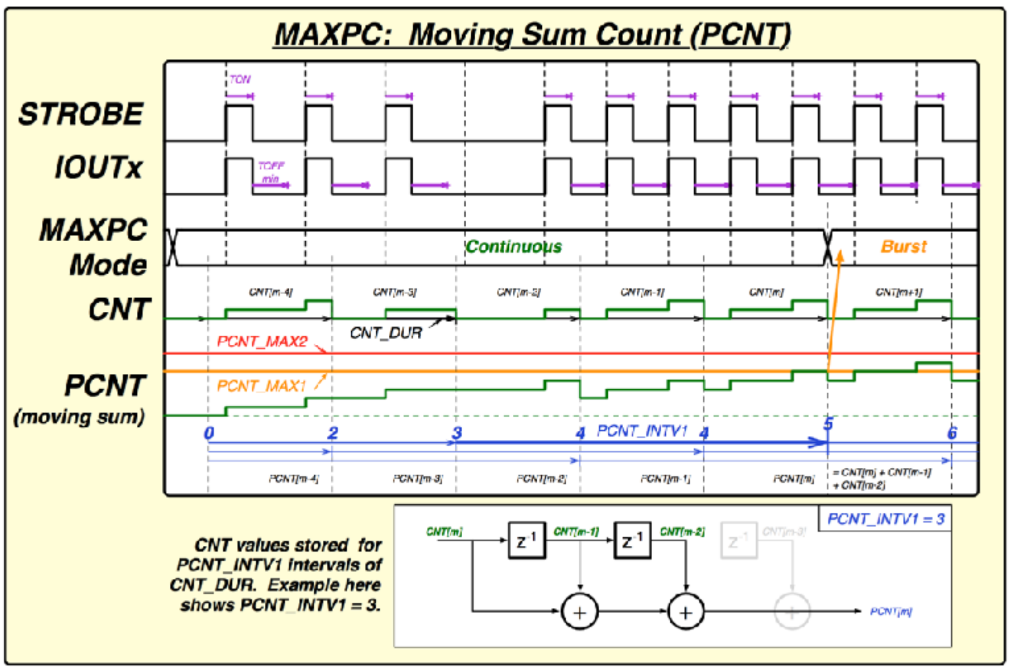


Figure 3.1.4.a: Max pulse count feature description.

MAXPC function has 3 different running modes (Continuous / Burst / Throttle) to limit the number of current pulses. At each CNT_DUR period, PCNTx counters are compared to PCNT_MAX1 and PCNT_MAX2 thresholds and Rigel enters in one of MAXPC modes or goes in Standby as described in Table 3.1.4.a and Figure 3.1.4.b:

In any case if PCNT_MAX2 is reached, device goes in standby and ceases driving pulses on IOUTx.

Table 3.1.4.a: MaxPC running modes

Max PC Mode	Strobe Pulse	Max CNT_DUR periods	Next Max PC Mode		
			Max CNT_DUR periods is reach	PCNTx is over	
				Max PC1	Max PC2
Continous	Applied	Unlimited	na	Burst	Standby
Burst	Applied	4	Throttle	na	Standby
Throttle	Applied	4	Contain	na	na

Max CNT_DUR periods for Burst and Throttle modes are respectively defined for all IOUTx by PCNT_INTV2 and PCNT_INTV3.

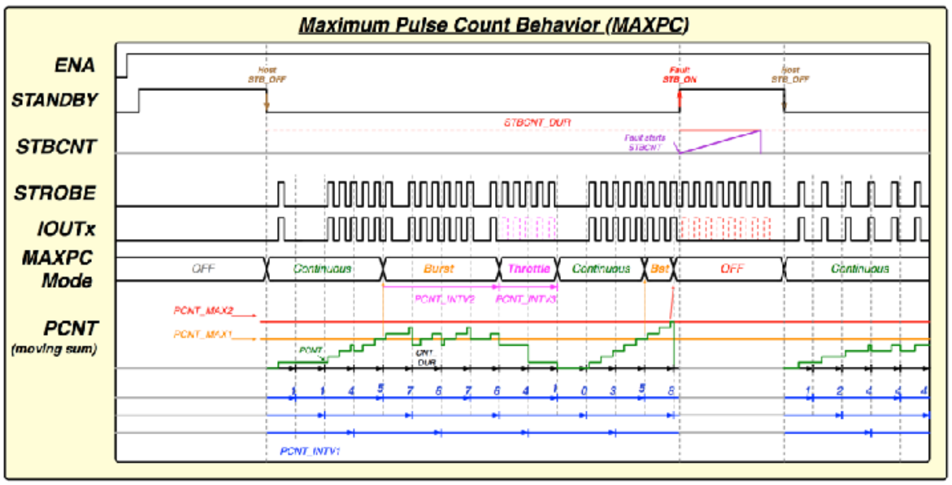


Figure 3.1.4.b: MAXPC modes transitions

Table 3.1.4.b: Summary of MAXPC parameters

Parameter	Units	Romeo Dense IOUT0	Romeo Sparse IOUT1	Rosaline IOUT2	Romeo Probe A IOUT3	Romeo Probe B IOUT4
Counter Duration CNT_DURx	OTP #/ equivalent msec	2 / 50				
PCNT_INTV1 (Rolling window size)	OTP #/ equivalent msec	3 / 200				
PCNT_INTV2 (Burst)	OTP #/ equivalent msec	0/ Disabled				
PCNT_INTV3 (Throttle)	OTP #/ equivalent msec	1 / 50				
PCNT_MAX1	#	8	8	12	8	8
PCNT_MAX2	#	8	8	12	8	8
Use case max # of pulses in any 200ms window	#	6	6	6	6	6
MaxPC limited # of pulses in any 200ms window	#	7	7	11*	7	7
Use case continuous Freq	Hz	30	30	30	30	30
Long exposure (>1 sec) Avg freq	Hz	37	37	55 *	37	37

* Yogi enforces a tighter limit, please see section 3.3.3

11.2.5.Use Case and OTP-Limited Current Parameter Summary

Summary of current characteristics per channel for normal use case as well as for an OTP limited scenarios is listed in Table 3.1.5.a (For Rigel B0-V4, D3x EVT). The OTP limited values are used to determine worst case laser compliance PLRs.

Table 3.1.5.a: Use case and OTP limited parameter summary

Current Parameter	Units	Relevant Control Parameter	Scenario	Romeo Dense IOUT0	Romeo Sparse IOUT1	Rosaline IOUT2	Romeo Probe A IOUT3	Romeo Probe B IOUT4
Current Amplitude	A	IOUT_MAXVAL	Use Case	1.824	1.528	0.749	0.058	0.058
			OTP Limited	1.930	1.617	0.793	0.065	0.065
Pulse Width	ms	TON_MAX	Use Case	2.93	2.93	9	2.93	2.93
			OTP Limited	3.41	3.44	11.14*	3.44	3.44
Burst Freq	Hz	MAXDC	Use Case	60	60	60	60	60

	Hz	MAXDC	OTP Limited	61.6	62	60.5*	62	62
Max # of pulses In 200ms	#	MAXPC	Use Case	6	6	6	6	6
			OTP Limited	7	7	11*	7	7
Continuous Mode Freq	Hz	MAXPC	Use Case	30	30	30	30	30
			OTP Limited	37	37	55 *	37	37

* Yogi enforces a tighter limits, please see section 3.3.3

11.3. Rigel2-3 OTP validation

The first goal of this test is to ensure that the correct Rigel version is being used (chip revision and OTP version. The second goal is to ensure that the safety (CTS parameters) are programmed correctly.

Component	Register name	# of bytes	Address	Bits	Expected Value	Comment
STB601A0, STB601A0N	regstatus_id1, regstatus_id2, regstatus_id3	3	0x00	All	0x01 0xB6 0x00	0x00 for A0
STB601A0N	regotp47_ctm1	1	0xEF	[5:0]	0x02	OTP version 2

Safety Parameters						
Component	Register name	# of bytes	Address	Bits	Expected Value	Comment
STB600B0 and STB601A0, STB601A0N	regotp68_ctm3, regotp69_ctm3, regotp70_ctm3	3	0xB4	[7:5], All, All	[011], 0x2D, 0x55	IOUT_MAXVAL_B3, IOUT_MAXVAL_B4, SAFETY_CC_CONF2
STB600B0 and STB601A0, STB601A0N	regotp71_ctm3, regotp72_ctm3, regotp73_ctm3 bit 0	3	0xB7	All, All, [0]	0x05, 0x50, [0]	SAFETY_CC_CONF2, SAFETY_CC_CONF3
STB601A0N	regotp26_st2, regotp27_st2	2	0xDA	All	0x01, 0x16	PCNT_MAX2_IOUT1, PCNT_MAX1_IOUT2, PCNT_INVT3
STB601A0N	regotp37_ctm1, regotp38_ctm1, regotp39_ctm1, regotp40_ctm1	4	0xE5	All	0x95, 0xBB, 0xE9, 0xDD	SAFETY_CC_CONF1, SAFETY_CC_STEP_DUR, IOUT_MAXVAL_B0, IOUT_MAXVAL_B1, IOUT_MAXVAL_B2
STB600B0 and STB601A0, STB601A0N	regotp43_ctm1	1	0xEB	All	0x38	PCNT_INVT1, PCNT_INVT2
STB601A0N	regotp48_ctm2, regotp49_ctm2, regotp50_ctm2	3	0xF0	All	0x24, 0xCF, 0x2B	C1_MAXPWx_B0, C1_MAXPWx_B1, C1_MAXPWx_B2

STB601A0N	regotp51_ctm2, regotp52_ctm2, regotp53_ctm2, regotp54_ctm2	4	0xF3	All	0xF7, 0x48, 0xAB, 0x**BA**	C1_MAXDCx_B0, C1_MAXDCx_B1,C1_MAXDCx_B2,C2_MAXDCx_B0, C2_MAXDCx_B1, C2_MAXDCx_B2
STB601A0N	regotp55_ctm2, regotp56_ctm2, regotp57_ctm2, regotp58_ctm2	4	0xF7	All	0x22, 0x**00**, 0x11, 0x6A	C3_MAXPW, PCNT_MAX1_IOUT0, PCNT_MAX2_IOUT0, PCNT_MAX2_IOUT2, PCNT_MAX1_IOUT1

To perform this test: Write 0x01 to register 0x24 in Rigel(I2C address 0x55) to switch to page 1 and access OTP. Write 0x00 to register 0x24 in Rigel(I2C address 0x55) to switch back to normal register access when done.

11.4. Rigel3 Illegal Drive parameters and limits

The goal of this test is to confirm that after burn in, Rigel is safe to operate. To perform this test Rigel is driven above the limits and the expected result is a Rigel fault.

Component	Vendor	Test Parameter	LSL	LTL	UTL	Notes	APN	FATP Test condition
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	IOUT_MAXVAL_B0		1.824	1.913	A		UTL not explicitly set/tested DAC code=186
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	IOUT_MAXVAL_B1		1.528	1.603	A		UTL not explicitly set/tested DAC code=156
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	IOUT_MAXVAL_B2		1.759	1.845	A		UTL not explicitly set/tested DAC code=223
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	TON_MAX_0		2.93	3.41	ms		pulse width=3.6ms FPS=30Hz IOUT0=1.824A
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	TON_MAX_1		2.93	3.44	ms		pulse width=3.6ms FPS=30Hz IOUT0=1.528A
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	MAX_BURST_FREQ_0		60	62.3	Hz	099-03882 Pearl Laser Compliance	pulse width=2.93ms FPS=65Hz IOUT0=1.824A
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	MAX_BURST_FREQ_1		60	62.8	Hz		pulse width=2.93ms FPS=65Hz IOUT0=1.528A
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	MAX_PULSES_IN_200ms		6	7	Count		IOUT0=1.824A IOUT1=1.528A pulse width=2.93ms fps=40Hz frames#: 12
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	MAX_CONT_FREQ_0		30	37.2	Hz		
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	MAX_CONT_FREQ_1		30	37.2	Hz		
STB601A0 (Rigel 2A0, OTP V1) STB601A0N (Rigel 3, OTP V2)	ST	LOW_TEMP_SHUTDOWN	-10	-14	-20	ºC		

11.5.Test 3: Rigel3 MamaBear fault coverage

The fist goal of this test is to make sure that if MamaBear faults and opens the switch, Rigel sees it and generates a fault.

The second goal of this test is to make sire that if there's a fault on XEF0 Rigel reacts accordingly.

1- Drop Romeo supply and expect CC fault

To perform this test:

spmiwrite 0 0x09 0x1203 2 1 0x0 (turn-off PMU Adam)
Fault registers addresses in Rigel(0x55): 0x7C, 0x7E, 0x80, 82, 0x84
Continuity check address in Rigel(0x55): 0x1C and 1xF0

Should return:
Fault: 0x00 **0x08** 0x00 0x00 0x00
CC: **0A 04**

For a correct behavior.

2- Drop GPIO pullup on XEF0 and expect XEF fault on Rigel

Fault registers addresses in Rigel(0x55): 0x7C, 0x7E, 0x80, 82, 0x84
Continuity check address in Rigel(0x55): 0x1C and 1xF0

Should return:
Fault: 0x00 **0x40** 0x00 0x00 0x00
CC: 00 00

In normal conditions, the value of mama bear status status is:

Address in MB(0x66): 0x8860
Data: 00000000-00000000-00000000-00010101 = 0x15 (armed mamabear)
Data: 00000000-00000000-00000000-00010001 = 0x11 (un-armed mamabear)

When XEF0 error is forced by the PMU GPIO mamabear should see a fault and open the switch.

Address in MB(0x66): 0x8860
Data: 00000000-00000000-00000000-00010100 = 0x14 (armed mamabear)
Data: 00000000-00000000-00000000-00010000 = 0x10 (un-armed mamabear)

D.4.4 I2CS_R_MB_STATUS_MEMADDR

This register holds general chip status and error information.

- Offset (byte space) = 32'h110c
- Physical Address (byte space) = 32'h110c
- Verilog Macro Address = `I2CS_REG_START + `I2CS_R_MB_STATUS_MEMADDR Reset Value = 32'bxxxxxxxx_xxxxxxxx_xxxxxx00_00000000
- Access = RO (32-bit only)

Table 156: I2CS_R_MB_STATUS_MEMADDR

Bit Field	Flags	Field Name	Description	Properties
31:10	–	Reserved	Reserved bits must be written with 0. A read returns an unknown value.	–
09	–	MRI_ECC_ERR_FATAL	An OTP mem ECC read-out error one or more MBREG row(s) and all its redundant rows. This bit is sticky. Reset value is *0* decimal.	MRI_ECC_ERR _FATAL Attributes: attr0: SRO4
08	–	MRI_ECC_ERR	An OTP mem ECC read-out error is detected in the MRI section. This bit is sticky Reset value is *0* decimal.	MRI_ECC_ERR Attributes: attr0: SRO4

Table 156: I2CS_R_MB_STATUS_MEMADDR (Cont.)

Bit Field	Flags	Field Name	Description	Properties
07	–	PASSKEY_ECC_ERR_FATAL	An OTP mem ECC read-out error on one or more PASSKEY rows and all its redundant rows. This bit is sticky. Reset value is *0* decimal.	PASSKEY_ECC _ERR_FATAL Attributes: attr0: SRO4
06	–	PASSKEY_ECC_ERR	An OTP mem ECC read-out errors detected in the Read_pass_key section. This bit is sticky. Reset value is *0* decimal.	PASSKEY_ECC _ERR Attributes: attr0: SRO4
05	–	MODID_ECC_ERR	An OTP mem ECC read-out error is detected in the AID section. This bit is sticky. Reset value is *0* decimal.	MODID_ECC_ERR Attributes: attr0: SRO4
04	–	NON_ZERO_PASS_KEY	Non-zero Pass Key has been programmed to OTP memory. Reset value is *0* decimal.	NON_ZERO_PASS _KEY Attributes: attr0: SRO4
03	–	EN_force_low	EN force low state of the OTP Fout EN_force_low fields. Reset value is 0 decimal.	EN_force_low Attribute: attr0: SRO4
02	–	ARM_MB_NOREAD	ARM MB No-read State of the OTP Fout ARM_MP fields. Reset value is *0* decimal.	ARM_MB _NOREAD Attributes: attr0: SRO4
01	–	ARM_MB_STATE	ARM MB State of the OTP Fout AM_MP_NOREAD fields Reset value is *0* decimal.	ARM_MB_STATE Attributes: attr0: SRO4
00	–	EN_PIN_STATE	EN Pin State Reset value is *0* decimal.	EN_PIN_STATE Attributes: attr0: SRO4

11.6.Test 4: Rigel1/2/3 XEF1 fault coverage

The goal of this test is to make sure when XEF1 is pulled down , whether Rigel could see it and generate a fault.

To perform this test: (i.e. D3x, other program Rigel I2C device address could be different from 0x55)

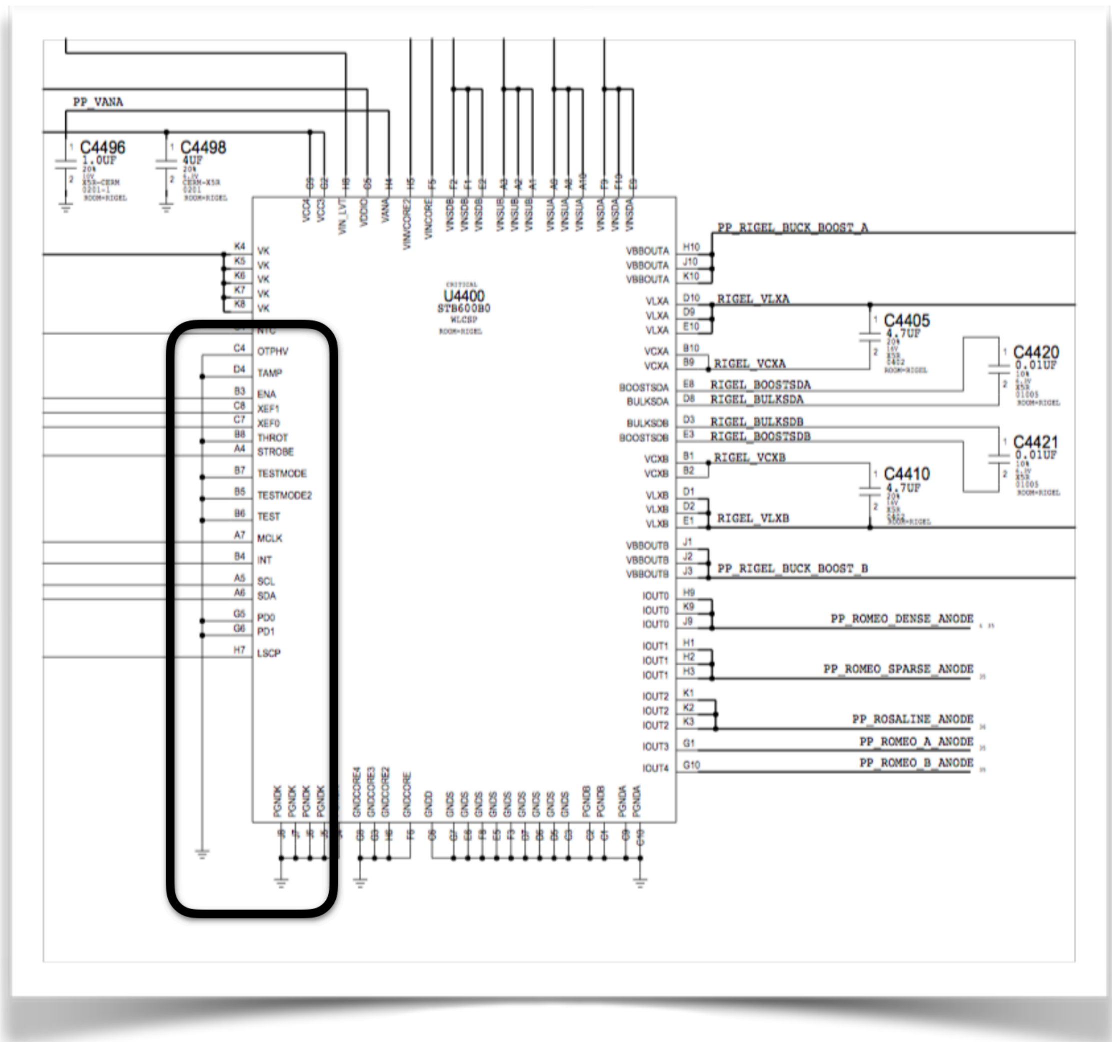
Fault registers addresses in Rigel(0x55): 0x7C, 0x7E, 0x80, 82, 0x84

Pull down XEF1 PIN only , Rigel Should return:
Fault: 0x00 **0x80** 0x00 0x00 0x00

Note: in D3x/D4x this test is covered in Yogi test

11.7.Test 4: Rigel3 TestMode Pin Test

The goal of this test is to make sure that Rigel (0x55) cannot enter in Debug mode on the field and that test mode pins are properly grounded.



Write 0x31 into register 0xBC in Rigel (at I2C address 0x55)

reg_mn_debug

7	6	5	4	3	2	1	0
mn_debug							
R/W							

Address: b600_regBaseAddress + 0xBC

Type: R/W

Reset: 0x0

Description:

[7:0]	**mn_debug**: parameter 8bit if MN_DEBUG=00110001 and TESTMODE pin=1 then DEBUG mode is enable

Read from address 0x20:

regstatus_otp1 **status register**

7	6	5	4	3	2	1	0
status_int_shortanode[4:0]					mux_otp_i2cid	mux_otp_ctm	mux_otp_st
R					R	R	R

Address: 0x20

Type: R

Reset: 0x0

Description: OTP mux and short anode status

[7:3]	**status_int_shortanode[4:0]**: latched source for INT_SHORTANODE value reset at each STDBY2IDLE transition 0x01: (bit0) shortanode IOUT0 0x02: (bit1) shortanode IOUT1 0x04: (bit2) shortanode IOUT2 0x08: (bit3) shortanode IOUT3 0x10: (bit4) shortanode IOUT4
[2]	**mux_otp_i2cid**: mux status of otp_I2CID 0x00: Functional mode OTP value 0x01: Non-functional in Emulation mode
[1]	**mux_otp_ctm**: mux status of otp_CTM 0x00: Functional mode OTP value 0x01: Non-functional in Emulation mode
[0]	**mux_otp_st**: mux status of otp_ST 0x00: Functional mode OTP value 0x01: Non-functional in Emulation mode

Expect bit 0, 1 and 2 to be set to 0 (was not able to enter debug mode)

Appendix

A. Capacitance calculation

B. Pearl Calibration

B.1. - REL overlay

As part of the reliability test of the system, the MPC is used for the purpose of analyzing how and how much different optical parameters changed due to the stress on the system and accelerated aging applied in the reliability tests.

The general idea is to measure the device before and after each reliability test. However since we are also running Pearl-Test after each reliability event, we don't really want to change the calibration stored on the device, but rather only update the PDCA logs.

Since for reliability testing we are interested in the behavior of individual parameters and want to minimize the effect of different compensations between the parameters the following changes are suggested in order to maximize the measurement accuracy.

- Multiple runs of the calibration sequence - ~5 consecutive runs will allow us to understand better the measurement noise associated with each parameter.
- Assign each DUT to a specific test station - testing at the same station repeatedly will minimize the noise due to differences between stations.
- Special RFC config - since we are not actually interested in producing the full set of references, but are still interested in some of the parametric data produced by RFC, we can save some major processing time by generating a special configuration disabling most of the un-necessary computations.

B.2.Station Validation

The following is a suggested method for performing station validation based on the experience gained bringing up the prototype MPC station.

The validation is based on performing accuracy test to a collection of sensors that passed through the station under test. The accuracy test is performed over several distance ranging from 20cm up to 70cm covering the entire operational range of the sensor. For each DUT we suggest the following procedure:

- The DUT is calibrated multiple times in the MPC - suggested ~10 times over several days including dismounting between calibration and optional different operators.
- The same DUT is tested multiple times in the accuracy setup. We only capture raw IR data in different distances. Since we inly capture raw data this stage doesn't depend directly on the calibration and can be done before hand.
- We now use the system simulation to analyze a "matrix" combining the different calibrations and the different accuracy tests producing a distribution of the sensitivity of the accuracy test to the calibration results.

The following figure shows a sample of the how the results are expected to look like:

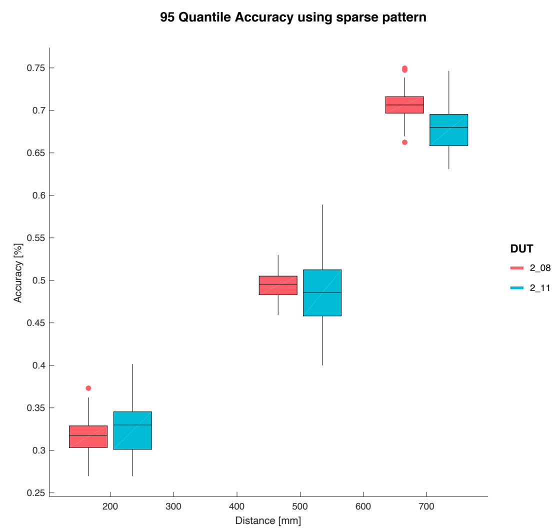


Figure 7 - Sample validation results

B.3. Multi Sensor Operation

The station is assumed to be a serial single sensor only station. However future versions of the station will likely improve UPH by letting multiple sensors to be calibrated together.

The issue with having multiple sensors operating simultaneously is that their projected pattern might interfere with each other. If two sensors will project their pattern in overlapping time periods, the two pattern will be mixed and prevent proper calibration of the baseline of both sensors.

The key then for multi-sensor operation is to detect interference and prevent it by -syncing the sensors to each other during the calibration and reference sequences.

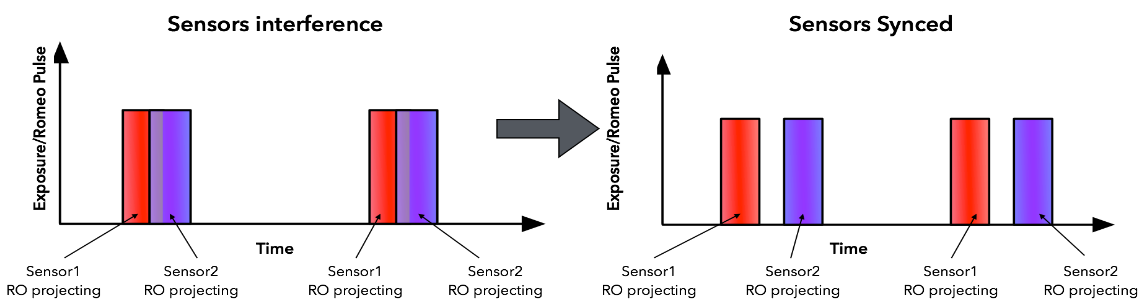


Figure 8 - Sensor interference

The synchronization concept presented here is still in proof of concept but nevertheless shown in order to facilitate easier integration in future stages.

The synchronization concept is based on two key elements:

- The use of a photo-diode to detect and time the RO pulses, enabling visualization and tracking of the different sensors pulses in real time with direct feed-back about any changes to their timing.

- The use of slightly different pulse width for each sensor operating concurrently. This enable the association of each detected pulse with the specific sensor generating it.

The following diagram depicts the suggested algorithm for verifying and syncing the multiple sensors:

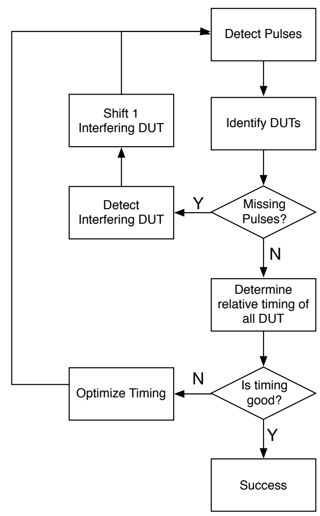


Figure 9 - Suggested Algorithm for syncing multiple DUT

Detecting the pulses is a relative simple task using the photo-diode, we next attempt to identify all the DUT according to their expected pulse-width. If for some reason we didn't manage to identify all the DUTs the assumption is that the missing DUTs are interfering either with each other, or with one of the detected DUTs. We then try to change missing DUT timing until they are detected correctly.
Once we detected all the DUTs we try to set their timing so that they would be properly spread in a way that will allow us to maintain the proper sensor FPS with no interference see the following diagram for example of 4 sensors synchronization:

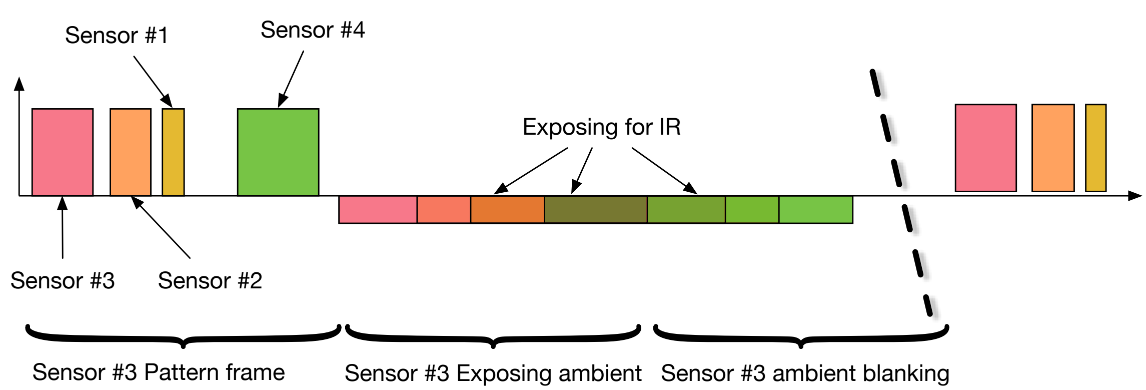


Figure 10 - Sample "Optimized" multiple DUT timing

Note the diagram above exaggerate the difference in pulse timing for better clarity.

it's important to note that the RO pulse can interfere also with the "regular" IR exposure when working in interleaved mode.
The sensor synchronization need to happen before we start the station operation, and it can happen either as part of the station or on a separate stage.

C. Pearl test Algorithm description

The FATP tool comprises of a library of Matlab functions that execute the various measurements. This appendix describes the functions and their callouts.

```
function outputs = BT_FATP(sensorName, folderName, MPCDir, testConfig)
outputs = BT_FATP(sensorName, folderName, MPCDir, testConfig)
Pearl test main function
Loads input files, runs tests and prepare outputs
Input    sensorName  - string with sensor name or serial number to be included in the outputs
folderName  - Location off raw data from Pearl test, in the agreed structure
MPCDir      - Location of calibration data from Pearl Cal
testConfig  - Include tests configuration in the following fields
isRWASparse - Run Real-World-Accuracy on Sparse pattern2x
isRWADense - Run Real-World-Accuracy on Sparse pattern
isSNRSparse - Run SNR on Sparse pattern
isSNRDense - Run SNR on Sparse pattern
isREGSparse - Run Registration on Sparse pattern
isREGDense - Run Registration on Sparse pattern
plotFlag - Plot figures for debug
SNRplotFlag - Plot SNR additional figures for debug
saveFlag - Save figures and images
isDotsChart - Uses P2 dots charts instead of P1 checkerboard
centerFlag - Incase of checkerboard target, use checkerboard centers and
not corners for RWA
gmcFlag - Run GMC for RWA
TargetdMarkerSpacing_mm - Checkerboard or Target (dots) scale
detectionUpscale - Use upsclae (downscale) before checkerboard pattern
recognition
RWA_IR_GT_flag - Use ground truth for RWA from IR image
Output    outputs    - All tests outputs in the agreed format
```

```
function [dataRecordIRSparse, dataRecordIRDense, dataRecordIRFlood, dataRecordDXSparse,
dataRecordDYSparse, dataRecordDXDense,dataRecordDYDense,rfc_Sparse_name,rfc_Dense_name,
sparse_index, dense_index, tMax] = ReadGenesisData(dataFolder, MPCFolder)
[dataRecordIRSparse, dataRecordIRDense, dataRecordIRFlood, dataRecordDXSparse, dataRecordDYSparse,
dataRecordDXDense,dataRecordDYDense,rfc_Sparse_name,rfc_Dense_name, sparse_index, dense_index, tMax]
= ReadGenesisData(dataFolder, MPCFolder)
This funation read the input raw data and calibration data into Matlab structures.
Input     dataFolder - Pearl Test raw data folder
MPCFolder  - Pearl Cal data folder
Output    dataRecordIRSparse  - IR sparse images
```

dataRecordIRDense - IR dense images
dataRecordIRFlood - IR flood (ambient) images
dataRecordDXSparse - Sparse DX stream (If DX has been recorded)
dataRecordDYSparse - Sparse DY stream (If DY has been recorded)
dataRecordDXDense - Dense DX stream (If DX has been recorded)
dataRecordDYDense - Dense DY stream (If DY has been recorded)
rfc_Sparse_name - Sparse Reference file name of the right temperature
rfc_Dense_name - Dense Reference file name of the right temperature
sparse_index - Number of Sparse images
dense_index - Number of Dense images
tMax - Units maximum temperature of RO NTC

function [accuracyOutput,ptsBoardGT, ptsBoardMeasured,ptsIm,ptsBoard] = FATP_accuracyTest(imProjOff, imProjOn, refIm, RWADX, RWADY, calib, config, testConfig)

[accuracyOutput,ptsBoardGT, ptsBoardMeasured,ptsIm,ptsBoard] = FATP_accuracyTest(imProjOff, imProjOn, refIm, RWADX, RWADY, calib, config, testConfig)
This function calculates Real-World-Accuaracy metric, the function can
use IR images and rub simulateChip to produce DX/DY images or get the
DX/DY iamges as an input
Inputs imProjOff - Image of the target with ambient light and no Pattern (use for recognizing the target pattern)
imProjOn - Image of the RO pattern (not needed incase of use DX/DY streams)
refIm - Reference image (not needed incase of use DX/DY streams)
RWADX - DX images (If not available use RWADX = [])
RWADY - DY images (If not available use RWADY = [])
Calib - Units calibration data
config - Target information
testConfig - Test configuration
plotFlag - Plot figures for debug
sparseFlag = Indicates that the RO pattern is sparse, other wise dense
centerFlag - Incase of checkerboard target, use checkerboard centers and not corners for RWA
gmcFlag - Run GMC for RWA
Outputs accuracyOutput - Test outputs in the agreed format
ptsBoardGT - Pattern XYZ location from ground truth [mm]
ptsBoardMeasured - Pattern XYZ location from depth image [mm]
ptsIm - Pattern location on the IR image [Pixels]
ptsBoard - Pattern location on the target plane (Z=0mm) [mm]

function [registrationOutput, RGB_ptsIm, irCornersOnRgbX, pixel_dist_r, pointsDistFromCenter] = FATP_RegistrationTest(ptsBoardMeasured, ptsIm, ptsBoard, imProjOff, imProjOn, refIm, RWADX, RWADY, rgbImage, calib, config, testConfig)

[registrationOutput, RGB_ptsIm, irCornersOnRgbX, pixel_dist_r, pointsDistFromCenter] = FATP_RegistrationTest(ptsBoardMeasured, ptsIm, ptsBoard, imProjOff, imProjOn, refIm, RWADX, RWADY, rgbImage, calib, config, testConfig)
This function calculates Registration metric, the function can
use IR images, DX/DY or Real-World pattern location in XYZ

Inputs ptsBoardMeasured - Pattern XYZ location from depth image [mm]
ptsIm - Pattern location on the IR image [Pixels]
ptsBoard - Pattern location on the target plane (Z=0mm) [mm]
imProjOff - Image of the target with ambient light and no Pattern (use for recognizing the target pattern)
imProjOn - Image of the RO pattern (not needed incase of use DX/DY streams)
refIm - Reference image (not needed incase of use DX/DY streams)
RWADX - DX images (If not available use RWADX = [])
RWADY - DY images (If not available use RWADY = [])
rgbImage - RGB images of the same target
Calib - Units calibration data
config - Target information
testConfig - Test configuration
plotFlag - Plot figures for debug
sparseFlag = Indicates that the RO pattern is sparse, other wise dense
centerFlag - Incase of checkerboard target, use checkerboard centers and not corners for RWA
gmcFlag - Run GMC for RWA
Outputs registrationOutput - Test outputs in the agreed format
RGB_ptsIm - Pattern location on the RGB image [RGB Pixels]
irCornersOnRgbX - Pattern location on the IR image [IR Pixels]
pixel_dist_r - Distance between matching point between RGB image and IR image [RGB pixels]
pointsDistFromCenter - Distance of the RGB pattern from RGB image center [RGB Pixels]

D. Operational Rating

E. Pearl Diagnostics tools

The latest version of Pearl Diags tools internal repo is on <rdar://problem/29282343>,

forget
fwlog on ## FW verbose
v on
on

Setup
writeraw on
writemeta on
writebin off

writejpeg on
jpegQuality 0.8

POOLBUFCOUNT 16
FWPOOLPRIMECOUNT 16

setverboseflags 0x40
propertywrite 3 0x5a2 0xD0

Get info
getnvm 3 ## Dump from Juliet (allows to see if NVM is empty or corrupted)
MSECDELAY 100
getdevicenvm 3 10 ## Dump from Romeo (through Juliet channel)
MSECDELAY 100
i ## Info command for every connected cameras - resolution and configuration (parsed information)
MSECDELAY 300
PROJECTORCALIBRATEDVALUES 3 ## Rigel limits (OTP & NVM - current & pulse width for strobe)
MSECDELAY 100

Proj Cap
GETPROJECTORCAP 3 ## Get Mamabear capacitance parsed (0 if MB is armed)
MSECDELAY 200

Proj Faults (Before)
GETPROJECTORFAULTSTATUS 3 ## Mamabear fault status
GETPROJECTORFAULTSTATUS 3 1 ## Yogi fault status (Vader driver)
MSECDELAY 200

Check PDE Calib
GETPDECALIBDATA 3 ## Get Pearl Depth Engine calibration data (valid flag and version)
MSECDELAY 200

Check Mama Bear Capacitance Values (if possible) -- not required anymore (replaced by GETPROJECTORCAP)
i2cwrite ZMBCHAN 0x66 0x8820 2 4 TERMTERM001
msecdelay 10
i2cwrite ZMBCHAN 0x66 0x8840 2 4 TERMTERM002
msecdelay 10
i2cread ZMBCHAN 0x66 0x80 2 4
msecdelay 10
i2cread ZMBCHAN 0x66 0xA0 2 4
msecdelay 10
i2cread ZMBCHAN 0x66 0xC0 2 4
msecdelay 10
i2cread ZMBCHAN 0x66 0x1800 2 4
MB_REG_R_AFE_RX_GAIN_CAL_MEMADDR
msecdelay 10
i2cread ZMBCHAN 0x66 0x880 2 4

capture sparse
setprojectortype 3 sparse ## Set the projector mode (sparse/dense) -- here dense is sparse array + dense array
projectoron 3 ## Enables the projector

start 3 127 0 ## Starts streaming the camera (refer to i command output: 127 is output size, 0 is colorspace)

Savage Status Dump (stuff for sensor DRI)
FWOBJECTSPECIALFUNC FrontIRSensor 1 2 0 0
MSECDELAY 100

NAMEBASE pearldiagscapture-sparse 1 ## Define frame name (1 is the number of digits for indexing)
MSECDELAY 750
p 1 3 ## Grabs a frame based on all previous settings (count and channel number)
Strobe Count Before
i2cread ZRIGELCHAN 0x55 0x08 1 1
MSECDELAY 400
Strobe Count After
i2cread ZRIGELCHAN 0x55 0x08 1 1
Validate
validateconfig 3
MSECDELAY 200
GETPROJECTORFAULTSTATUS 3
GETPROJECTORFAULTSTATUS 3 1
GETPROJECTORTEMP 3
MSECDELAY 200
fwobjectspecialfunc FrontIRStrobe 4 0 0 0
MSECDELAY 200

capture dense
NAMEBASE pearldiagscapture-dense 1
setprojectortype 3 dense
MSECDELAY 750
p 1 3
MSECDELAY 400
Validate
validateconfig 3
MSECDELAY 200
GETPROJECTORFAULTSTATUS 3
GETPROJECTORFAULTSTATUS 3 1
GETPROJECTORTEMP 3
MSECDELAY 200
fwobjectspecialfunc FrontIRStrobe 4 0 0 0
MSECDELAY 200

capture dense+probeAB (test only, no raw capture...)
NAMEBASE pearldiagscapture-denseprobeAB 1
setprojectortype 3 dense probeAB
MSECDELAY 750
p 1 3
MSECDELAY 400
Validate

```
validateconfig 3
MSECDELAY 200
GETPROJECTORFAULTSTATUS 3
GETPROJECTORFAULTSTATUS 3 1
GETPROJECTORTEMP 3
MSECDELAY 200
fwobjectspecialfunc FrontIRStrobe 4 0 0 0
MSECDELAY 200

### capture flood
NAMEBASE pearldiagscapture-flood 1
setprojectortype 3 flood
MSECDELAY 750
p 1 3
MSECDELAY 400
## Validate
validateconfig 3
MSECDELAY 200
GETPROJECTORFAULTSTATUS 3
GETPROJECTORFAULTSTATUS 3 1
GETPROJECTORTEMP 3
MSECDELAY 200
fwobjectspecialfunc FrontIRStrobe 4 0 0 0
MSECDELAY 200

stop 3

### front RGB
writeraw off
writemeta on
NAMEBASE pearldiagscapture-frontrgb 1
start 2 255 0
MSECDELAY 1000
p 1 2
MSECDELAY 400

stop 2

### Depth Setup
writeraw on
writebin on
writemeta on
writejpeg off
FWOBJECTDEBUGLEVEL PDE 255
yuvoff 3
USEALTRAWDMA 3 1

### Depth Sparse
NAMEBASE pearldiagscapture-depth-sparse 1
```

```
setprojectortype 3 sparse
enablepdestreaming 3 0x27
start 3 127 0
projectoron 3
MSECDELAY 750
p 1 3
MSECDELAY 400
stop 3

### Depth Dense
NAMEBASE pearldiagscapture-depth-dense 1
setprojectortype 3 dense
enablepdestreaming 3 0x27
start 3 127 0
projectoron 3
MSECDELAY 750
p 1 3
MSECDELAY 400


### RGB SYNC
stop 3
ENABLEMULTICAM 2 1
ENABLEMULTICAM 3 1
propertywrite 0 2 0x11
setmasterslavesync 2 1
minframerate 3 30.25
maxframerate 3 30.25
aeoff 3
manualae 3 2940 0x100 0x100 0x100 0x1e1e ## Integration time - 2.94 ms, analog gain, digital
gain, framerate - 30.11 Hz
minframerate 2 30
maxframerate 2 30
aeoff 2

start 2 5 0 ## Start RGB - see i command settings
msecdelay 10

start 3 127 0 ## Start Juliet
MSECDELAY 400

## Stop streaming cameras
stop 3
stop 2


### Recheck Mama Bear Capacitance (if possible)
i2cread ZMBCHAN 0x66 0x1800 2 4
msecdelay 10
```

F. Rigel error codes list

A complete list of Rigel error codes and their corresponding descriptions is shown below. The Rigel error code should always be checked during FA.

Table : Complete list of Rigel Error codes and description

#	Rigel Error code	Error String	Description
1	0x0000000000	No error	No errors detected
2	0x0100000000	bba_ovc	OVC fault on IOUT0: DC/DC overload protection (current through SW1)
3	0x0200000000	bbb_ovc	OVC fault on IOUT1 or IOUT2
4	0x0400000000	bba_ovv	OVV fault on IOUT0
5	0x0800000000	bbb_ovv	OVV fault on IOUT1 or IOUT2
6	0x1000000000	bba_udc	UDC fault on IOUT0
7	0x2000000000	bbb_udc	UDC fault on IOUT1 or IOUT2
8	0x4000000000	adc_ready	Non-fault: ADC data is ready to be read.
9	0x8000000000	tamp	TAMP pin is open.
10	0x0001000000	vinuvlo	VIN UVLO fault
11	0x0002000000	vin_ovv	VIN OVV fault
12	0x0004000000	throt	Non-fault: Rigel throttled using THROT pin.
13	0x0008000000	cc	CC fault detected.
14	0x0010000000	otp	OTP fault detected.
15	0x0020000000	maxpc	MAXPC fault detected.
16	0x0040000000	xef0	XEF0 fault detected.
17	0x0080000000	xef1	Yogi status line pulled low when Rigel was in Idle / Active (will not flag during Standby).
18	0x0000010000	mode1	Strobe mode1 active.
19	0x0000020000	tsd_warn	NTC low temperature fault or Rigel die temperature fault (via ADC, sampled per pulse)
20	0x0000040000	thsd	Rigel die temperature fault (continuous).
21	0x0000080000	stdbydly	Standby Delay fault.
22	0x0000100000	maxdc_clksaf_bba	IOUT0 pulse rate is too high (clk_safety domain). Spacing between adjacent pulses is too short.
23	0x0000200000	maxpw_clksaf_bba	IOUT0 pulse width is too high (clk_safety domain).
24	0x0000400000	maxdc_clklp_bba	IOUT0 pulse rate is too high (clk_lp domain). Spacing between adjacent pulses is too short.
25	0x0000800000	maxpw_clklp_bba	IOUT0 pulse width is too high (clk_lp domain).
26	0x0000000100	maxdc_clklp_bbb	IOUT1/2 pulse rate is too high (clk_lp domain). Spacing between adjacent pulses is too short.
27	0x0000000200	maxpw_clklp_bbb	IOUT1/2 pulse width is too high (clk_lp domain).

28	0x0000000400	maxdc_clksaf_bbb	IOUT1/2 pulse rate is too high (clk_safety domain). Spacing between adjacent pulses is too short.
29	0x0000000800	maxpw_clksaf_bbb	IOUT1/2 pulse width is too high (clk_safety domain).
30	0x0000001000	lvt	Non-fault: Rigel throttled due to low VDDMAIN, default threshold < 2.7V.
31	0x0000002000	bba_ovp	IOUT0 regulator overload fault.
32	0x0000004000	bbb_ovp	IOUT1/2 regulator overload fault.
33	0x0000008000	strobe_short	Pulse width too short (< 220μs)
34	0x0000000001	bba_wdg_sfst	IOUT0 regulator soft start did not finish in time.
35	0x0000000002	bbb_wdg_sfst	IOUT1/2 regulator soft start did not finish in time.
36	0x0000000004	ls_ovc	Current through low side switch is too high (3.4A for 1 channel selected, 6.7A for 2 channels selected)
37	0x0000000008	shortanode	IOUTx shorted to positive supply
38	0x0000000010	shortanode_act	VBBOUT monitoring feature has detected a large change in forward voltage.
39	0x0000000020	i2cwdg	I2C watchdog timeout fault. Current OTP requires an I2C transaction to Rigel every two seconds.
40	0x0000000040	bbsat	Regulator saturation detection fault.
41	0x0000000080	supply	Supply fault - VCC is too low.
42	Other	Unknown	Uknown

G. FA SOP (Pearl Diags)

G.1. Assembly related failures

Reported failures:
RFXRA_x,
OUTOFFTAREGETPIX
CAMANG_X
FOVCOVERAGE_x
Failure meaning: Assembly tolerances affect system performance.
SOP:

For RFXRA_x failures:
Retest the unit 3 times in pearlCal

1. Pull:
    1. PAM line data
    2. TOM data
    3. SA-Juliet data
    4. Pearl test60cm
    5. Juliet data

2. Grab OGP Measurements for 3 modules (RO, JU, MA) – measure Tilt relative to the CG.

   For RFXRa_1/2 failures:
   1. remove and replace with current (original) CG and retest on Pearl Cal/Rack1, Pearl Test 20/60/Rack2
   2. Swap with the good CG (golden unit) and retest.
   3. Swap back to original CG and retest.
   4. If failure is indepent of CG, swap out the pearl sub and do CT scan on pearl sub and upload data to Radar – update PD

   For RFXRa_3 failure:
   1. Get PAM1, PAM2 and PAM3 pictures upload to radar. If confirmed by PD big relative rotation happens in PAM line, then COF
   2. If noticed a rotation in PAM , do step 1 to step 5 in RFXRa_1/2 failure

For CAMANG_X failure:

Retest the unit 3 times.

1. Pull :
   1. PAM line data
   2. TOM data
   3. SA-Juliet data
   4. Pearl test60cm
   5. Juliet data
   6. FMust data
2. Grab OGP Measurements for 3 modules (Tilt relative to the CG)

   For CamAng_0/1 failures:

   1. remove and replace with current (original) CG and retest on Pearl Cal/Rack1, Pearl Test 20/60/Rack2
   2. Swap with the good CG (golden unit) and retest.
   3. Swap back to original CG and retest.
   4. If failure is independent of CG, swap out the pearl sub and do CT scan on pearl sub- open radar and inform PD

   For CamAng_2 failure:

   1. Get PAM1, PAM2 and PAM3 pictures upload to radar. If confirmed relative rotation
   2. If a rotation in PAM, do step 1 to step 4 in CamAng_0/1 failure
   3. Consult PD with the results
      1. If approved – return to line

For FOVCOVERAGE_x failure:

Retest the unit 3 times in pearlCal

1. Pull:
    1. PAM line data
    2. TOM data
    3. SA-Juliet data
    4. Pearl test60cm
    5. Juliet data
2. Grab OGP Measurements for 3 modules (RO, JU, MA) - measure Tilt relative to the CG.
    1. remove and replace with current (original) CG and retest on Pearl Cal/Rack1, Pearl Test 20/60/Rack2
    2. Problem detection :
        1. Look for the root cause of the assembly issue:
        2. Co-work with PD to open up the unit
        3. Look for issues:
            1. Sensor flex interference
            2. Check for Housing problem
            3. Check for Pearl bracket that is causing the modules to flex in an unexpected way
            4. Re-assemble the unit more carefully to see if that fixes the issue.
3. If failure is indepent of CG, swap out the pearl sub and do CT scan on pearl sub
4. Contact PD if CT shows abnormal marks \rotation\tilt
5. If CT is with no error - return to line

G.2. Calibration parameter out of spec

Reported failures:

IREFL
IRPP_x
IRDIST_x
RGBEFL
ROBASELINE_x
RGBpp_x
ReferenceDistance
IRdist-x
RGBdist_x
CamBaseLine_x

Failure meaning: Outlier component and\or calibration process failed to converge properly.

SOP:

Verify that the calibration process converged correctly:

<u>**Eliminating station issues:**</u>

Run unit in a different tester:
If passes- contact HWTE for station FA

If fails:

If there is **more than one** failure from the above list:

1. Create a unique radar for the unit in question, run Pearl Diags, post all data there
2. Look at the values for RREPROJECTIONERROR, RGBREPROJECTIONERROR, RFXFinalScore
3. Visual inspection to look for Optical Obstruction damage, take and save images
   * Optical Obstruction : Tape/Smudge/Plastic Clear cover/Other abnormal marks on the cover glass top
4. If the damage is noticeable / obvious, then clean the unit, remove tape or clear cover and re-run pearl cal three times, if passes - return the unit to the line. if fails - go to step 3.
5. Check for Spline - run pearlTest and check spline parameters - if <15 - return to line. if not - go to step 6
6. Work with FX-PD to replace Cover Glass:
7. Look for the root cause of the assembly issue:
   1. Sensor flex interference
   2. Check for Housing problem
   3. Check for Pearl bracket that is causing the modules to flex in an unexpected way
   4. Re-assembling the unit more carefully to see if that fixes the issue.
   5. Replace CG and run pearlCal 3 times
8. If the damage is not noticeable or nit obvious , them preform the following:
   1. Review the unit with FX PD and re-capture PAMi5 image
   2. Work with AE / PAM team to pull all PAM images (PAMi3, PAMi5, PAM3 pickup images)
   3. Swap in a new Pearl sub and keep the old one, return the unit to the line
9. Hold the Pearl subs until further instructions from Apple team.

If there is **only one** failure from the above list:

1. Need to check the module level:
   1. Check each Module IQC and Vendor tests for failures\deviation in these parameters :
      1. Juliet EFL
      2. Juliet MTF
      3. ME EFL
      4. ME MTF
      5. Romeo power per order
      6. Abnormal Marks
      7. Does this failure happened in the past ? Does it correlate with specific vendor \Batch?

2. Run Pearl Cal three times
    1. If passes within 5% spec limit return the unit to the line
    2. If Fails :
        1. Look for the root cause of the issue:
            1. Sensor flex interference
            2. Check for Housing problem
            3. Check for Pearl bracket that is causing the modules to flex in an unexpected way
            4. Re-assembling the unit more carefully to see if that fixes the issue.
            5. Replace CG and run pearlCal 3 times
        2. If the damage is not noticeable or not obvious , them preform the following:
            1. Review the unit with FX PD and re-capture PAMi5 image
            2. Work with AE / PAM team to pull all PAM images (PAMi3, PAMi5, PAM3 pickup images)
            3. Swap in a new Pearl sub and keep the old one, return the unit to the line
        3. Hold the Pearl subs until further instructions from Apple team.

G.3. Calibration Algorithm/Process failure

Reported failures:
REFSTATEZEROCOUNT_2
IRFEATURENUM_2
IRREPROJECTIONERROR
RFXFINALSCORE
RGBFEATURENUM_2
RGBREPROJECTIONERROR
RFCSPOT_ANGx_MEAN_y
RFCSPOT_ANGx_STD_y
PlainAng_2 , DAratio

Failure meaning: All of these parameters are indications of issues during the calibration or reference capture sequence. A failure here indicates that there was an issue with the raw data used as input for the calibration algorithm.

SOP:

<u>Eliminating station issues</u>:
Run unit in a different tester:
If passes- contact HWTE for station FA
If fails:

2. Pull spline data from PearlTest:
    1. If high :
        1. Co-work with PD to open up the unit
        2. Re-assembling the unit more carefully to see if that fixes the issue
        3. Re-run PearlCal
3. Check for Optical Obstruction :
    1. Tape
    2. Smudge
    3. Plastic clear cover
    4. Other abnormal marks on the cover glass top
4. Check for MTF
    1. If low - retest 3 times
        1. if fails - Replace Pearl Module
5. Run PearlDiag and verify RO is operating correctly at all modes.

G.4. RO pattern related failures

Reported failures:
DEADEMITTERS_x
numProbingEmittersA/B

Failure meaning: These are indications of issues with the projected pattern.
SOP:

Create a unique radar for the unit in question, run Pearl Diags, capture images and post them on radar.

Retest the unit 3 times
Pull:
PAM line data
TOM data
SA-Juliet data
Pearl test60cm

1. Run PearlDiag and verify RO is operating correctly at all modes:
    1. Perform EE checks on Romeo (diode voltage, DCR, pin-to-pin short check
        1. If confirmed EE check abnormal, swap Pearl Sub and return the unit to the line
        2. If EE checks normal, contact Apple team for review and discussion
    2. Perform visual inspection on RO :
        1. Abnormal marks, Beetle connections
        2. If confirmed abnormal - swap pearl sub and return the unit to the line.
    3. Check Romeo IQC data for any issues:
        1. Abnormal Marks
        2. SpotSize deviation
        3. Look for Dead Emitters
        4. Other IQC items

G.5. Thermal related failures

Reported failures: MPC_CAPTURE_TEMP_DELTA, WARMUP_TEMP_DELTA
Failure meaning: These are indications of thermal issues within the DUT.
SOP:

1. Reset unit (need to verify no process is running in parallel)
2. Wait 10 minutes (Cool down)
3. Retest unit in PearlCal
4. Run PearlDiag
    1. go to file : pearldiagscapture-sparse-0.meta.txt
    2. Read thermistor values under: check Shared Projector values :
        1. look for tempActNTC values
            1. values should be between 30-45
5. If problem is within lower limit (WARMUP_TEMP_DELTA) - retest unit 3 times and re-read this value.
    1. if value doesn't change - replace pearl module and return to line
6. If problem is within higher limit - retest the unit 3 times and re-read the values
    1. if value is consistent :
        1. Co-Work with PD to examine thermal pad:
            1. If pad is missing or loose - replace thermal pad and re-test
            2. If unit passes - re-test 2 more times
            3. if all three times passes - assembly issue confirmed
                1. Return unit to the line
            4. If fails
                1. Swap pearl module
                2. return unit to the line

G.6. Station flow related failures

Reported failures:

ROMEO_SELF_TEST_FAIL
MISSING_PDCA_MAT_FILE
FDR_BLOB_GENERATION_PCIC
FDR_BLOB_GENERATION_PBAS
FDR_BLOB_GENERATION_PCII
ANGLE0-CAM2_YAVG
PEARL_TOKEN_GENERATION
READ_UCID
INSTANTPUDDING ADDED FAIL
ANGLE0-CAM1-0.420_YAVG
FIXTURE_ERROR_ENABLE_AXIS
FDR_BLOB_GENERATION_PCVC
TELNETBASEDDUT

Next Steps :
Re-test on a different station - if failure doesn't repeat - Call HWTE for Station FA

G.7. Proj_rotation failure and RGB_rotation failure SOP

Common root cause for failure in following metric: housing/CG deformation (BG/CG crack), module loose in bracket, bracket deforms during REL, and etc.

1. Cometic check on BG/CG/Housing to check whether there is BG/CG crack or deformation on housing. Take pictures for the front and back side of the unit
2. If no abnormality found, please send the unit to CT and focus on the whole pearl sub-assembly area
3. Use OGP measuring Romeo to CG tilt, Juliet to CG tilt, Romeo to Juliet tilt, and FCAM to Juliet tilt.
4. Do FaceID/Animoji/Portrait mode OQC test
5. Request for approval for open the unit.
6. Without touching pearl sub (keep pearl sub in housing), use OGP measuring Romeo to Juliet tilt and FCAM to Juliet Tilt.
7. Cosmetic check and save cosmetic check images for Pearl sub and CG alignment ring area for any abnormality
8. Send CG sub for PFRi measurement.
9. Test Pearl sub on TOM and PAMi5
10. For RGB_rotAng_x failure, take high resolution images for Juliet and FCAM from Top down view, side isometric view and front isometric view.
11. For Proj_rotAng_x failure, take high resolution images for Juliet and Romeo from Top down view, side isometric view and front isometric view.

G.8.RObaseline_x failure SOP

Common root cause for failure in following metric: housing/CG deformation (BG/CG crack), module loose in bracket, bracket deforms during REL, and etc.

1. Cometic check on BG/CG/Housing to check whether there is BG/CG crack or deformation on housing.
2. Take pictures for the front and back side of the unit
3. If no abnormality found, please send the unit to CT and focus on the whole pearl sub-assembly area
4. Use OGP measuring Romeo to Juliet distance and Romeo to Juliet relative tilt
5. Do FaceID/Animoji/Portrait mode OQC test
6. Request for approval for open the unit.
7. Without touching pearl sub (keep pearl sub in housing), use OGP measuring Romeo to Juliet distance and Romeo to Juliet relative tilt
8. Cosmetic check Pearl sub and CG alignment ring area for any abnormality
9. Send CG sub for PFRi measurement.
10. Test Pearl sub on TOM and PAMi5
11. Take high resolution images for Juliet and Romeo from Top down view, side isometric view and front isometric view

G.9.Pearl Test 20 or Pearl Test 60 Station

G.9.A.Failure Mode: No image, cannot communicate with camera Error

This occurs when the camera cannot capture an image correctly at the test station.

Failure Analysis:

1. Retest on several Pearl Test stations to see if it is station specific or follows FF
2. Retest the QT0 and QT1 stations, if they fail, follow the related FA SOP (do no proceed here)
3. Test the Midgard, Pearl Cal, Pearl Test 20 and Pearl Test 60 stations, any problem capturing images on these stations?
   - If no, then need to check with HWTE, could be a Midgard station issue
   - If yes, proceed to next step
4. Reproduce the failure with manual non-UI H10ISP commands sent to the FF
   - Run h10isp, send the “on” and “start 3 127 0” commands
   - Hold IR light source (like dino-scope) in front of Juliet camera and observe the display, if you can see the light, camera is working, if all black, this is a failing observation
   - Compare to a good passing unit, any difference observed in behavior?
5. Run PearlDiags script and compare to a known good unit, any difference that can help indicate the problem?

6. If nothing is found from the above FA steps, contact Apple DRI, this is a unique failure.

G.9.B.Failure Mode: MTF Parametric Failure (any ROI or MTF delta)

If the sharpness of the image is degraded in some way, then the MTF testing will fail at one of (or both) 20cm & 60cm distances.

NOTE: See system ERS for example chart image, and ROI naming compared to PDCA data names.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
    - Any big concentricity shift? If so, it could shift Juliet more into the spline and cause MTF degradation
    - Any lens or CG aperture damage/contamination? This could cause MTF to degrade
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
    - Look for blemishes or dots in the image, dark areas or shadows in the image (un-even lighting)
    - Is there any noticeable blurriness in the image (compared to good unit)? Is the blurriness uniform across the whole image or only part of the image?
    - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
    - Any failing Tilt or rotation? If yes, take OGP measurements as described in FA toolbox section to help confirm, if tilt is failing, follow tilt FA SOP
    - Any other strange problem with the image that doesn't align with normal passing unit?
8. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)

9. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any possible lens / module damage / contamination
    - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
10. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - NOTE: When swapping, swap the entire Pearl sub to new FF
    - If the failure follows the CG, perform more careful inspection of the CG, keep the CG in the FA lab and return the rest of the unit to the line (need to work with PD to perform CG FA)
    - If the failure follows the Juliet module, proceed to next step
11. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
12. If the failure still exists, but original Juliet-SA test is pass, there could be some camera performance degradation due to assembly process
    - Compare all 20cm and 60cm MTF values at the following stations:
        - Original IQC record
        - Original Juliet-SA record
        - Pearl Test 20/60 record
        - Juliet-SA re-test record
    - Did 20cm and 60cm both get worse? Did one get better?
        - If both got worse, then its either a de-focus towards infinity (lens barrel got closer to image sensor) or some kind of damage or contamination in the optical path
        - If 20cm got better and 60cm got worse, then its a defocus towards macro (lens got further away from image sensor)
13. If no clear root cause, remove the Juliet module and return to vendor for FA.

<u>Possible root causes for this failure mode include:</u>
- Fully or partially blocked Juliet aperture (protective films, foams, etc…)
- Dirt or contamination on the outside or inside of the CG (in Juliet aperture)
- Dirt or contamination on the Juliet lens surface
- Dirt or contamination inside the Juliet module (inside the lenses, on the IR filter, on the image sensor surface)
- Juliet concentricity to aperture is very bad (causing spline interference or blocking view of camera)
- High Juliet tilt relative to the CG causing ROIs to be outside of the image
- External/internal module damage/contamination causing change in performance
- ISP FW issue applying incorrect image processing, degrading performance
- Mechanical deformation of the barrel, causing change in focus (could be caused by mechanical applied pressure, or environmental conditions like REL, PAM thermal curing ovens, etc…)

G.9.C.Failure Mode: xTilt, yTilt or Rotation Parametric Failures

If any of the alignment items are failing, this means that relative to the outer dimensions of the FF (device edges and CG) that there is some mis-alignment of the Juliet module causing these items to fail.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
   - Any big concentricity shift?
   - Any lens or CG aperture damage/contamination?
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
   - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
   - Is tilt or rotation failure obvious from image review?
   - Any other strange problem with the image that doesn't align with normal passing unit?
8. Take OGP measurements on FF level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
9. If this is a new failure more for the build, or a noticeable outlier, add to the CT scan list and look for all relevant measurements as called out in FA toolbox
10. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
11. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any Juliet rotation or tilt issues relative to the bracket, any difference compared to a good unit?
    - Look at the alignment ring on the CG side, is it placed properly? Any difference compared to a good unit?
    - Any dented flexes, foams or other components that look like they were causing interference?
12. Take OGP measurements on Pearl Sub level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)

13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - If the failure follows the FF (CG or housing), perform more careful inspection of the alignment ring and housing, review this unit with the PD team to help identify the root cause
    - If the failure follows the Juliet module, proceed to next step
14. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
    - If evidence points to PAM assembly issue, review the Pearl sub with PD and AE team to identify how to improve tilt / rotation performance
    - NOTE: If PAM issue, it may be useful to perform Pearl Sub level CT scan for better detailed result, and lastly try performing cross section of failures to see how the mis-alignment in the bracket really looks
15. If no clear root cause but still follows Juliet module, request support from Apple team

<u>Possible root causes for this failure mode include:</u>
- Juliet module tilted or rotated in PAM assembly
- Pearl bracket tilted or rotated in Housing (FF assembly)
- CG alignment ring not installed properly
- Sensor flex stuck between CG alignment ring and shoulder of Juliet module causing assembly issue induced tilt

G.9.D.Failure Mode: CTF (contrast) Parametric Failure

If the contrast in the Juliet captured image is reduced for some reason, the CTF metric will fail.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
    - Any lens or CG aperture damage/contamination? This could cause contrast to degrade

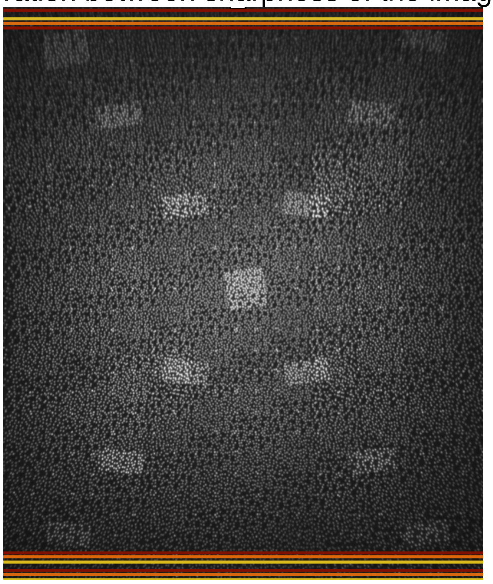
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
    - Look for haze in the image (like a cloudy image), is it visible?
    - Is there any noticeable blurriness in the image (compared to good unit)? Is MTF also failing? If yes, follow MTF fail SOP.
    - Any other strange problem with the image that doesn't align with normal passing unit?
8. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
9. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any possible lens / module damage / contamination
    - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
10. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - If the failure follows the CG, perform more careful inspection of the CG, keep the CG in the FA lab and return the rest of the unit to the line (need to work with PD to perform CG FA)
    - If the failure follows the Juliet module, proceed to next step
11. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
12. If no clear root cause, remove the Juliet module and return to vendor for FA.

<u>Possible root causes for this failure mode include:</u>

- Dirt or contamination on the outside or inside of the CG (in Juliet aperture)
- Dirt or contamination on the Juliet lens surface
- Dirt or contamination inside the Juliet module (inside the lenses, on the IR filter, on the image sensor surface)
- Scratches on the coverglass in front of Juliet aperture
- Smudge or skin oil on the coverglass in front of Juliet aperture
- External/internal module damage/contamination causing change in performance
- ISP FW issue applying incorrect image processing, degrading performance

G.9.E.Failure Mode: Cover Glass Performance Impact- Spline

The spline testing is only data collection for J4xx program and it defined as ration between sharpness of the image on the top and bottom of the FOV.



Failure Analysis:

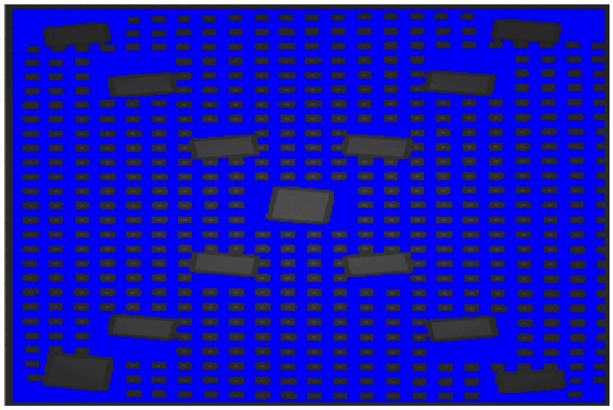
1. Make sure that there is nothing covering the Pearl module aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the Pearl test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet and Romeo IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
   - Any big concentricity shift?
   - Any lens or CG aperture damage/contamination?
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
   - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
   - Is tilt or rotation failure obvious from image review?
   - Any other strange problem with the image that doesn't align with normal passing unit?

8. Take OGP measurements on FF level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
9. If this is a new failure more for the build, or a noticeable outlier, add to the CT scan list and look for all relevant measurements as called out in FA toolbox
10. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
11. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any Juliet rotation or tilt issues relative to the bracket, any difference compared to a good unit?
    - Look at the alignment ring on the CG side, is it placed properly? Any difference compared to a good unit?
    - Any dented flexes, foams or other components that look like they were causing interference?
12. Take OGP measurements on Pearl Sub level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - If the failure follows the FF (CG or housing), perform more careful inspection of the alignment ring and housing, review this unit with the PD team to help identify the root cause
    - If the failure follows the Juliet module, proceed to next step
14. Re-calibrate at pearlCal and retest at pearlTest to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
    - If evidence points to PAM assembly issue, review the Pearl sub with PD and AE team to identify how to improve tilt / rotation performance
    - NOTE: If PAM issue, it may be useful to perform Pearl Sub level CT scan for better detailed result, and lastly try performing cross section of failures to see how the mis-alignment in the bracket really looks
15. If no clear root cause but still follows pearl module, request support from Apple team

<u>Possible root causes for this failure mode include:</u>
- Juliet module tilted or rotated in PAM assembly
- Pearl bracket tilted or rotated in Housing (FF assembly)
- CG alignment ring not installed properly
- CG change between builds
- Fully or partially blocked Pearl aperture (protective films, foams, etc…)
- Light source illuminating the scene un-intentionally (should not happen, could be test station or ISP FW issue)

G.9.F.Failure Mode: SNR

System SNR is one of the key metrics measured by the FATP tool



SNR changes as the distance from the center of FOV increases and so the thresholds are set accordingly. SNR will be measured at 20cm with the Pearl module operating in sparse pattern mode and at 60cm operating with dense pattern mode

System SNR regions (blue) out of the verification target.

Failure Analysis:

1. Make sure that there is nothing covering the Pearl module aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the Pearl test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet and Romeo IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
    - Any big concentricity shift?
    - Any lens or CG aperture damage/contamination?
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
    - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
    - Is tilt or rotation failure obvious from image review?

- Any other strange problem with the image that doesn't align with normal passing unit?

8. Take OGP measurements on FF level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
9. If this is a new failure more for the build, or a noticeable outlier, add to the CT scan list and look for all relevant measurements as called out in FA toolbox
10. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
11. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any Juliet rotation or tilt issues relative to the bracket, any difference compared to a good unit?
    - Look at the alignment ring on the CG side, is it placed properly? Any difference compared to a good unit?
    - Any dented flexes, foams or other components that look like they were causing interference?
12. Take OGP measurements on Pearl Sub level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - If the failure follows the FF (CG or housing), perform more careful inspection of the alignment ring and housing, review this unit with the PD team to help identify the root cause
    - If the failure follows the Juliet module, proceed to next step
14. Re-calibrate at pearlCal and retest at pearlTest to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
    - If evidence points to PAM assembly issue, review the Pearl sub with PD and AE team to identify how to improve tilt / rotation performance
    - NOTE: If PAM issue, it may be useful to perform Pearl Sub level CT scan for better detailed result, and lastly try performing cross section of failures to see how the mis-alignment in the bracket really looks
15. If no clear root cause but still follows pearl module, request support from Apple team

<u>Possible root causes for this failure mode include:</u>

- Juliet module tilted or rotated in PAM assembly
- Pearl bracket tilted or rotated in Housing (FF assembly)
- CG alignment ring not installed properly
- Low MTF on Juliet (See applicable FA)
- Light source illuminating the scene un-intentionally (should not happen, could be test station or ISP FW issue)
- ISP FW issue applying incorrect image processing, degrading performance
- Fully or partially blocked Pearl aperture (protective films, foams, etc…)

G.9.G.Failure Mode: Precision (FP_600_DQDense_zStdPrecentaile95_X, FP_200_DQSparse_zStdPrecentaile95_X)

Precision (or Z-Precision) is one of the key metrics measured by the FATP tool
Precision will be measured at 20cm with the Pearl module operating in sparse pattern mode and at 60cm operating with dense pattern mode

Failure Analysis:

1. Make sure that there is nothing covering the Pearl module aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the Pearl test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet and Romeo IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
    - Any big concentricity shift?
    - Any lens or CG aperture damage/contamination?
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
    - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
    - Is tilt or rotation failure obvious from image review?
    - Any other strange problem with the image that doesn't align with normal passing unit?
8. Take OGP measurements on FF level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
9. If this is a new failure more for the build, or a noticeable outlier, add to the CT scan list and look for all relevant measurements as called out in FA toolbox
10. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
11. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any Juliet rotation or tilt issues relative to the bracket, any difference compared to a good unit?
    - Look at the alignment ring on the CG side, is it placed properly? Any difference compared to a good unit?
    - Any dented flexes, foams or other components that look like they were causing interference?

12. Take OGP measurements on Pearl Sub level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - If the failure follows the FF (CG or housing), perform more careful inspection of the alignment ring and housing, review this unit with the PD team to help identify the root cause
    - If the failure follows the Juliet module, proceed to next step
14. Re-calibrate at pearlCal and retest at pearlTest to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
    - If evidence points to PAM assembly issue, review the Pearl sub with PD and AE team to identify how to improve tilt / rotation performance
    - NOTE: If PAM issue, it may be useful to perform Pearl Sub level CT scan for better detailed result, and lastly try performing cross section of failures to see how the mis-alignment in the bracket really looks
15. If no clear root cause but still follows pearl module, request support from Apple team

<u>Possible root causes for this failure mode include:</u>
- Juliet module tilted or rotated in PAM assembly
- Pearl bracket tilted or rotated in Housing (FF assembly)
- CG alignment ring not installed properly
- Low MTF on Juliet (See applicable FA)
- Low system SNR (See applicable FA)
- Larger/Smaller Romeo SpotSize - see Romeo Module FA SOP
- Light source illuminating the scene un-intentionally (should not happen, could be test station or ISP FW issue)
- ISP FW issue applying incorrect image processing, degrading performance

G.9.H.Failure Mode: Probing

Probing Test identifies dedicated light sources in the frame

Failure Analysis:

1. Re-test on the Pearl test station to confirm the failure still happens (try several stations to make sure if follows the FF)
2. Re-test a known good unit in the same test station to make sure it is not a station problem
3. Create a radar for the failure (follow the Radar Creation rules in section above)
4. Check the Juliet and Romeo IQC test results, any failures or marginal performance for related metrics?
5. Take the unit to the Rushmor OQC station (Located in EQT) and run Probing pattern test to confirm the failure
6. Request support from Apple team

<u>Possible root causes for this failure mode include:</u>

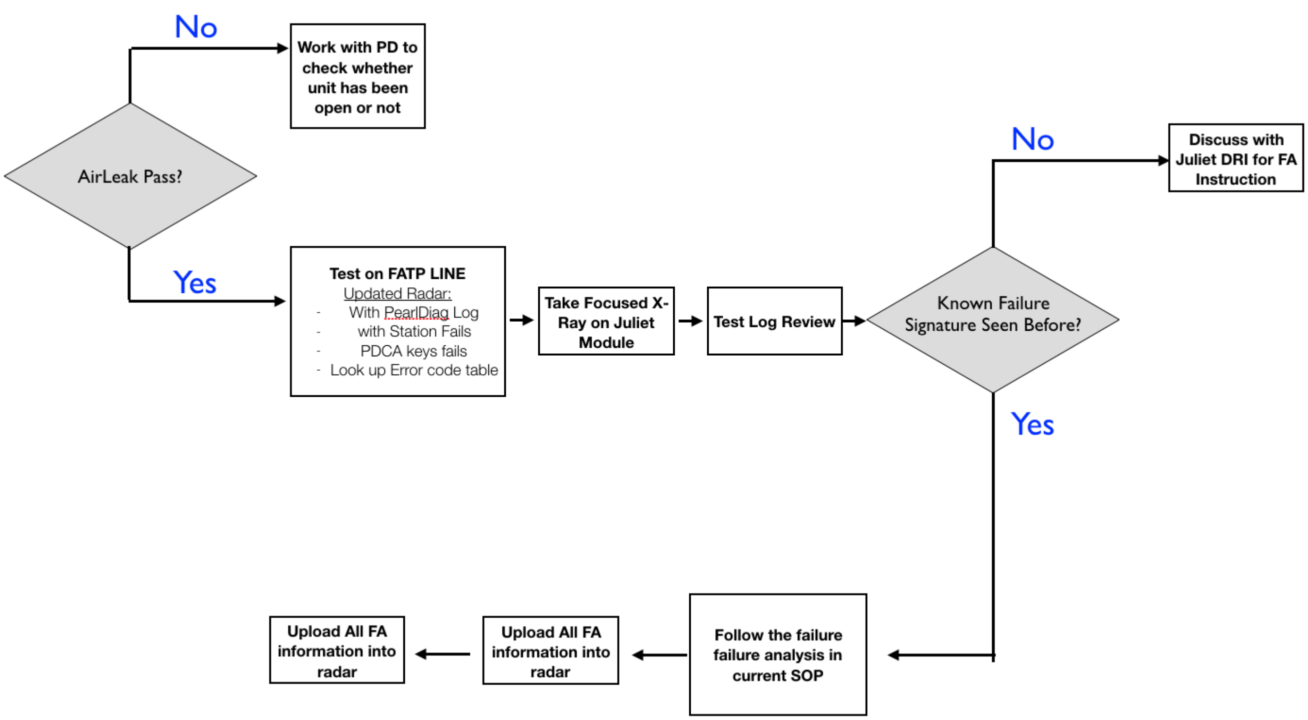
- Dead Emmiters
- Failed calibration

H. Juliet FA

The following section outlines the various actions that can be taken during failure analysis, later in this document, for each type of failure, it will specifically call out which items in the FA toolbox should be used to debug that specific issue.

NOTE: FA should always proceed automatically to the point just before disassembly of the form factor. Before that step, ensure proper approval is obtained from the relevant teams depending on the FATP rules in place (example: System EPM, System PD, REL/DQE Team).

H.1. Failure FA flow

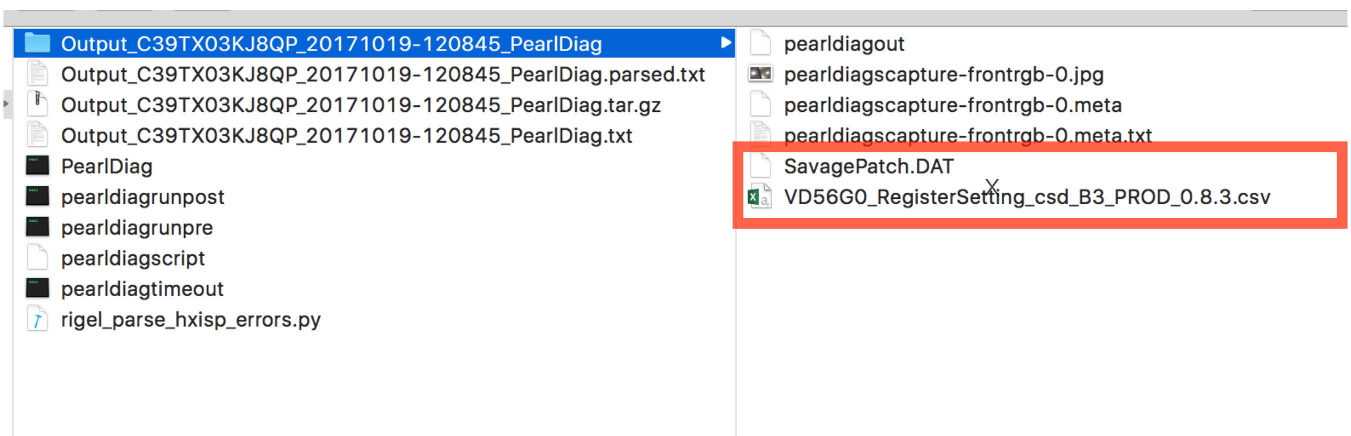


H.2.Radar Creation

For each unique failure mode, create a radar in the component related to the build in question, make sure to record all relevant information in the radar:

- Unit #
- Material type:
    - FATP IQC
    - FATP inline
    - FATP REL
- Failure rate
- Unit Serial Number
- Unit Config
- SW Bundle used for testing
- Pearl Sub Serial Number
- Pearl Sub Config
- Module Serial number
- Module Vendor
- Describe failure mode and post test logs from failing test station to the radar
- Always pull upstream test data (example: IQC, Juliet-SA, etc…) to see if the failure mode existed before
- Description of FA already done
- Raw images if failure mode related to sensor/optics
- Provisioning files
- Post all FA data collected to this radar (from all FA steps)
-

Provisioning files can be found running pearl diags, (both .dat and .csv file are needed in the radar). If file not available in the folder please do SW download and try again. if again file not present then mark as file not available in pearl diags folder.



If multiple units show the same failure mode, it is acceptable to put all modules under the same radar, in this case, create a tracker in excel to record all of the above information to review commonality

H.3.Re-Test

1. For any failure, make sure to perform AAB testing before checking it in for FA, if re-test pass, the normal policy is to let the unit continue down the line.
2. Create a radar for the unit or for the failure mode as explained above
3. Run Pearl Diags and upload the result of PearlDiag to the radar

H.4.Form Factor Cosmetic Inspection

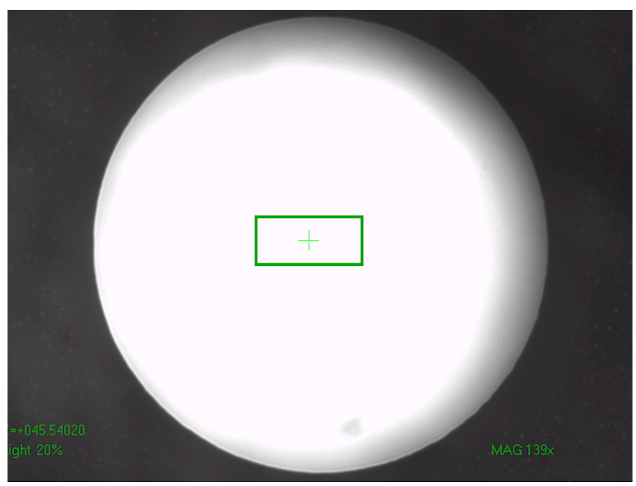
Inspect the assembled unit near the Juliet camera aperture using an IR dino-scope, capture images and observe for the following:

7. Gross misalignment
    a. Camera lens to camera window
    b. Black mask to lens concentricity
8. Contamination, scratches or particle defect on
    a. Lens surface
    b. Lens barrel surface
    c. camera window
9. Lens barrel interference (observe at a tilted angle, through camera window)
    a. Foam shift
    b. Foreign particle

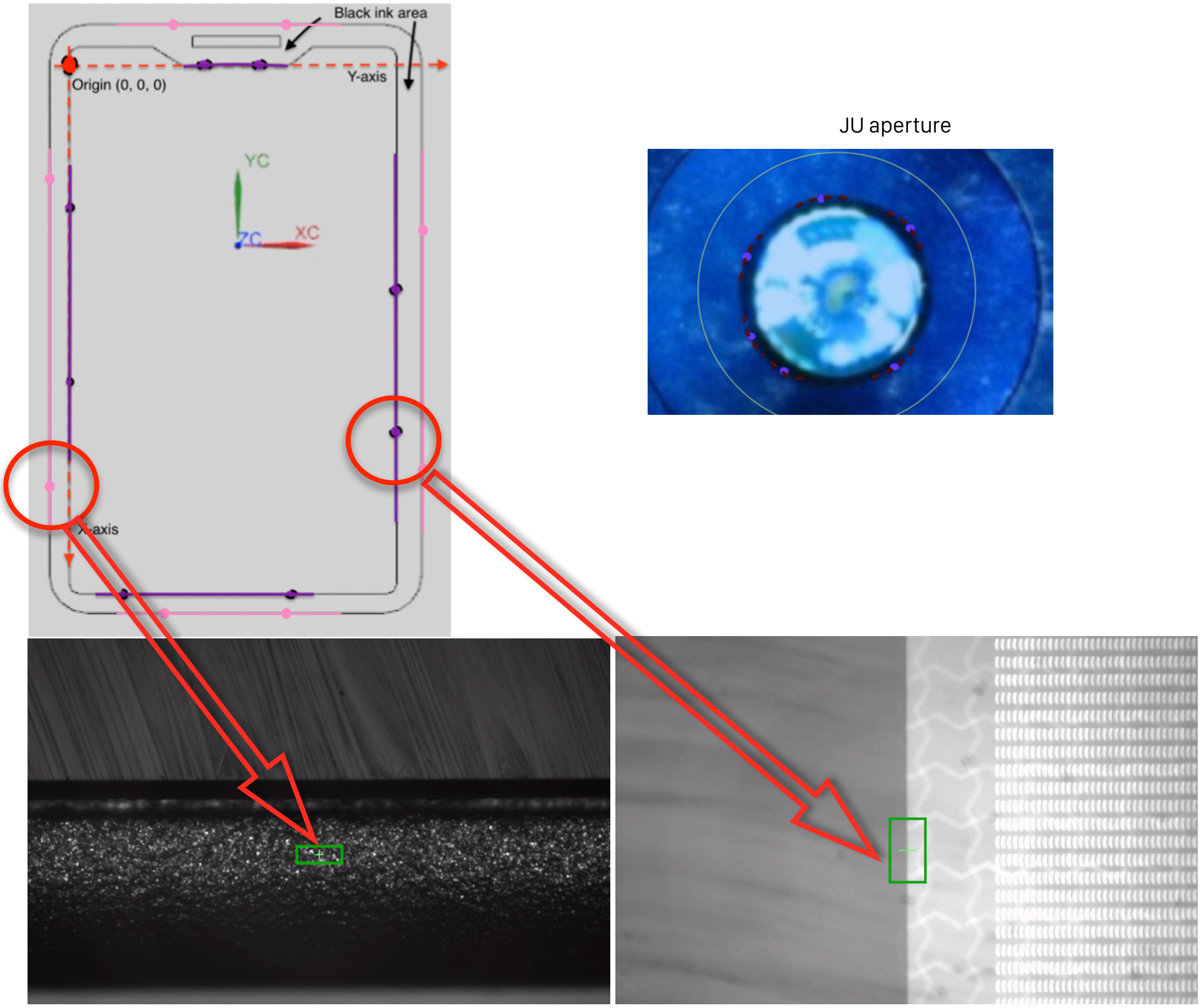
H.5.Form factor JU measurements

Perform OGP measurement on form factor:

1. **Construct Juliet Aperture Plane**, choose six points along the outside edge of black area around lens (as shown in red dot arcs) to construct Juliet Aperture Plane.



2. **Construct CG plane**, use points along four black ink lines (shown as purple lines) to construct CG plane. Please choose at least 2 points on each black ink line.
3. **Construct housing top surface**, use points along the edge between CG and housing (shown as pink link lines) to construct housing top surface. Please choose at least 2 points on each edge.
4. **Report**:



1. Z-distance between Juliet Aperture Plane and CG plane
2. Z-distance between Juliet Aperture Plane and housing top surface
3. Concentricity between JU lens and CG aperture (include the top edge as reference to calculate the concentricity)
4. Tilt between CG plane and JU aperture plane

H.6. Form Factor Manual Camera Control & Pearl Diags

Try to send manual commands to the camera to see what step is failing to narrow down root cause.

In Diags, can the camera be found? Can the SN be read? Does the NVM dump look normal? Does the camera pass DLI test?

—> Another option to check all these items is to re-run QT0 test station

In H10isp in non-UI, does the “i” command return valid information for Camera 3 (Juliet)? Can you perform an NVM dump (“reloadnvm 3” then “getnvm 3”)? Does streaming work properly? Can you capture an image?

(NOTE: When capturing images, make sure to put an IR light source in front of the camera, like an IR dino-lite).

Run the PearlDiags tool to collect detailed logs with a lot of information, and review the log for critical functionality, similar to items described above.

H.7. CG Open Cosmetic Inspection

Open the CG and take photos and inspect for the following:

On the Housing Side with Bracket:

1. Finger smudge, damage or foreign particle on lens
2. Bent or Dented Bracket
    a. Take pictures of dent and corresponding location on CG
    b. Asses if damage was done before install or during snap
3. Flex cuts or scrapes (for the areas of the flex you can see)

CG Side with Align Ring:

1. Crack in Align Ring
2. Burs in Align Ring
3. CG / Aperture Smudge, Damage or Contamination

H.8. CG Open Manual Camera Control & Pearl Diags

After opening the CG, since Juliet is sharing some signals with other camera modules (power and I2C), make sure to unplug all other modules (RCAM, FCAM, Titus, Rosaline) and see if Juliet functionality can recover or not.

Try to send manual commands to the camera to see what step is failing to narrow down root cause (same as form factor manual & pearldiag command instructions).

H.9. Pearl Sub Cosmetic Inspection

Remove the Pearl Sub from the FF, take photos and inspect for the following:

On the Housing Side with Bracket:

1. Bent or Dented Bracket on back side
2. Missing or compressed “cow tongue” springs on back of lower bracket
3. Flex cuts or scrapes for the entire length of the flex
4. Juliet Substrate cracks (look on all exposed edges of the Juliet module for any substrate damage.
5. Look for all welding to be done properly and take pictures of them. Make sure no gap is present in welding locations.
6. Look on JU module for any dent, scratches, deformation. If any of these are present take picture and try to understand if any component nearby can cause the scratch, discuss with PD or apple DRI
7. Look at JU wings with high magnification, is there any dent or damage? Please document with pictures

H.10. Swap Testing

With the module removed from the rear housing, swap testing can be performed the following way:

- Reproduce the failure with the original combination
- Swap the original Juliet to a known good MLB and try to reproduce the failure
- Swap the original MLB/housing to a good Juliet and try to reproduce the failure
- Put the original parts back together and see if the fail can still be reproduced

NOTE: RCAM and Juliet are sharing some power supplies, so it is also recommended to unplug the RCAM when performing swap testing to see if it is causing any problems.

Put all feedback of the swap testing up on radar, depending on the failure mode, swap testing may involve retesting the swapped units on the FATP line testers, or just running PearlDiags or checking logs, whatever is necessary to reproduce the particular failure mode.

H.11. Juliet-SA Re-test

With the Pearl Sub removed from the form factor, it is important to re-test it at the Juliet-SA tester to see if the problem still exists (still fails) at the sub-assembly level, or if it is now passing, this can give a better idea of where to focus FA.

H.12. EE Open/Short Checks

With the Juliet B2B exposed, some basic electrical checks can be performed on the Juliet module B2B and/or the Juliet MLB B2B (depending which side looks like has the problem):

- Measure diode voltage on all B2B pins between the pin in question and GND
- Measure DCR between the pin in question and GND
- Look for shorts between any 2 pins on the Juliet B2B (in case any signal shorted to another)

NOTE1: Always compare all EE checks on the failing module to a known good module, the goal is to look for differences between good and bad modules

NOTE2: When measuring these items on the MLB side, make sure to unplug all other modules first so that you aren't measuring those modules on shared connections (all modules to unplug include RCAM, FCAM & Titus).

This is an example of pin measurement:

Porsche DVT Juliet camera reverse voltage and reverse resistance test (red pen connect PIN 22)

		Reverse Voltage(V)		Reverse resistance(Ω)				Reverse Voltage(V)		Reverse resistance(Ω)	
		good	Fail	good	Fail			good	Fail	good	Fail
23 19	PP1V1_CAM_JULIET_DVDD	0.2509	0.2489	6.982k	4.68k	20	PP1V1_CAM_JULIET_DVDD	0.2509	0.2489	6.982k	4.68k
1	GND	0	0	0	0	2	JULIET_PMU_TO_RIGEL_STROBE	0.5668	0.5601	235.53k	236.64K
3	90_MIPI_JULIET_TO_AP_DATA0_P	0.4127	0.4208	95.13k	97.29K	4	FCAM_TOJULIET_SYNC	0.5684	0.5624	237.69k	236.68K
5	90_MIPI_JULIET_TO_AP_DATA0_N	0.4154	0.4217	94.66k	97.85K	6	PP2V85_JULIET_AVDD_CONN	0.3715	0.3678	165.56k	166.74K
7	GND	0		0	0	8	GND	0	0	0	0
9	90_MIPI_JULIET_TO_AP_CLK_P	0.411	0.4242	94.29k	94.47K	10	PP1V8_JULIET_VDDIO_CONN	0.3833	0.4036	163.23k	183.79K
11	90_MIPI_JULIET_TO_AP_CLK_N	0.4114	0.4241	93.88k	97.98K	12	ISP_TO_JULIET_VDDIO_CONN	0.6305	0.6134	271.10k	262.12K
13	GND	0		0	0	14	I2C2_ISP_SDA	0.4269	0.4203	203.09k	197.35K
15	90_MIPI_JULIET_TO_AP_DATA1_P	0.4115	0.4232	93.05k	97.85K	16	I2C2_ISP_SCL	0.4257	0.4198	203.42k	197.00K
17	90_MIPI_JULIET_TO_AP_DATA1_N	0.4128	0.4238	93.53k	97.75K	18	AP_TO_JULIET_CLk_CONN	0.6282	0.6149	272.75k	265.30K
21 24	GND	0	0	0	0	22	GND	0	0	0	0

H.13. OGP Measurement (FF or Pearl Sub Level)

Often times some Juliet failures could be related to mis-alignment inside of the system. OGP is an IR Optical Measurement Microscope which can perform complex non-touch measurements at FF level (can see through the Juliet aperture) or at the Pearl Sub level. When necessary, the following inspections should be performed:

- Juliet Tilt relative to the CG
- Juliet Concentricity to the aperture
- Juliet Z position relative to the CG
- Juliet Tilt relative to bracket surrounding surface (at Pearl Sub level)

H.14. X-Ray inspection Procedure

When looking for flex or substrate damage X-Ray is the right first step to follow. Areas below in particular should be verified, but inspect the overall module to look for issues.

1. PAM Silver Epoxy - inspect between the stiffener and bracket, epoxy should be centered along the edge of the module & forming a connection with the stiffener
2. Flex routing - no unexpected folds or pinch points, flex path follows same as good system, no tears or trace cracks visible
3. B2B Connector - connector should be fully mated, with no pin-to-pin shorts, pin cracks, or adjacent trace cracks
4. Substrate - no cracks visible, no missing components

H.15. CT Scan Inspection Procedure

When x-ray cannot see the level of detail required, or if more precise inspection is needed, CT Scan is the right next option. Measure the following items depending on the issue being investigated:

1. Juliet tilt in system, relative to CG, rotation in system relative to edge of FF
2. Juliet tilt in bracket, relative to back & front bracket assembly, is it parallel or obvious tilt? For rotation in bracket, are the wings aligned to the bracket opening?
3. Pearl Bracket tilt and alignment in system, is it parallel to the CG?
4. Juliet to align ring interface - is it fully pressed into align ring?
5. PAM Silver Epoxy - inspect between the stiffener and bracket, epoxy should be centered along the edge of the module & forming a connection with the stiffener
6. Flex routing - no unexpected folds or pinch points, flex path follows same as good system, no tears or trace cracks visible
7. B2B Connector - connector should be fully mated, with no pin-to-pin shorts, pin cracks, or adjacent trace cracks
8. Substrate - no cracks visible, no missing components

H.16. Juliet Detailed FA H10ISP Script

See **appendix A** for a detailed FA script to run on Juliet any time a strange failure occurs, this does a full register dump of the image sensor and allows the Apple team to debug several possible issues.

H.17. Module Repair and Handling Guidelines

In any case where the Pearl Sub needs to be removed from the housing of the system. For example in repair for camera or other issues following should be observed.

5. Finger covers to be used at all times when handling the camera
6. Camera lens surface or lens barrel should never be handled directly
7. If the camera is to be stored outside the unit for any time period:
   a. New Unused clean Camera Cap should placed over the camera lens
   b. Camera with cap should be placed in a tray or equivalent box
   c. Bags can no longer be used for transfers of camera

I. Failure Specific FA Steps

This section described the different types of failures that can occur and the specific FA steps that should be performed for each type of failure.

I.1. Undocumented Failure Mode or Other Test Station Using Juliet (Timberlake, Pearl Cal, etc…)

If any strange/catastrophic failure occurs on any test station using Juliet but not documented in this FA SOP, start by running the QT0 test station as a very first step, and follow the QT0b FA steps if that station fails (do not open the unit without Apple team approval).

Also **run the test script in appendix A for any strange failures**, this performs a full register dump of the Juliet image sensor that the Apple team can use to debug a long list of potential issues.

I.2. QT0b Test Station

I.2.1.Failure Mode: Front1 Camera Not Detected

If Front1 camera cannot be detected this means I2C communication with Juliet is non-functional and the camera will not function at all.

Failure Analysis:

1. Re-test on the test station to confirm the failure
2. Create a radar for the failure (follow the Radar Creation rules in section above)
3. Reproduce the failure with manual diags commands sent to the FF
4. Perform FF level cosmetic inspection
5. Open the unit & remove the Pearl Sub (get necessary approvals before opening,
   and follow standard procedure for opening the unit)
6. Perform Pearl Sub level cosmetic inspection
7. Follow the swap testing procedure defined in the previous section, document the results and post to radar
   - If the failure follows the MLB, work with System EE team for next FA steps
   - If the failure follows the Juliet module, proceed to next step
8. Perform the EE Open/Short Checks, record the data and post to radar
9. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage

<u>Possible root causes for this failure mode include:</u>

- RCAM pulling down power rails causing Juliet to fail (if removing RCAM fixes the problem, this is the issue)
- Flex, Substrate or MLB damage causing I2C (SDA or SCL) signals to open/short
- Flex, Substrate or MLB damage causing DVDD signal to open/short (I2C will not work without the DVDD power supply)
- Flex, Substrate or MLB damage causing DOVDD signal to open/short (I2C will not work without the DOVDD power supply)

- NOTE: If DOVDD is broken on the MLB side, or shorted to GND anywhere, many things in the system will fail, not just Juliet, but an OPEN on DOVDD just to Juliet will cause I2C to fail

I.2.2.Failure Mode: Juliet ID Check Fail

The Juliet ID check is also just a simple I2C command to the image sensor to read the sensor ID.

Failure Analysis:

1. If an unexpected value is returned, the wrong image sensor may be used (or test station has wrong limits), contact Apple team for support
2. If I2C error occurred (no value returned), follow the same steps as Front1 Camera Not Detected failure (above).

I.2.3.Failure Mode: Read_Juliet_SN or Juliet NVM Failure

If there is a serial number or NVM failure, this means that either the incorrect value is being returned and failing the limits, or all zeros are being returned (empty NVM or NVM cannot be read).

Failure Analysis (incorrect value returned):

1. Re-test on the test station to confirm the failure
2. Create a radar for the failure (follow the Radar Creation rules in section above)
3. Check if the pass/fail criteria are matching the latest system ERS
   - If not, contact Apple DRI and HWTE to correct the test station
4. If the values are not matching expectation, then it could be a material mixing problem (old or unexpected material), review with System EPM to make sure correct modules were used
5. If necessary, open the unit to check the SN manually on the module and make sure it is the correct version / config of module suppose to be used
6. Retest on Juliet-SA or Juliet-IQC can help confirm the failure

Failure Analysis (all zeros / empty NVM / NVM cannot be read):

1. Check the Juliet is provisioned or not (the system unit goes through Non-UI station), if so, do purple restore and swdl
2. Re-test on the test station to confirm the failure
3. Create a radar for the failure (follow the Radar Creation rules in section above)
4. Reproduce the failure with manual diags commands sent to the FF
   - Confirm that Front1 camera can be found
   - Run the “camisp --id' command to make sure a non-zero value is returned
   - If both of these pass, it means I2C functionality should be ok
5. Perform FF level cosmetic inspection
6. Go to Form Factor JU measurements section
7. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
8. Perform Pearl Sub level cosmetic inspection
9. Follow the swap testing procedure defined in the previous section, document the results and post to radar

- If the failure follows the MLB, work with System EE team for next FA steps
- If the failure follows the Juliet module, proceed to next step

10. Perform the EE Open/Short Checks, record the data and post to radar
11. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage
12. If there are several failures of the same type, perform CT scan to inspect the flip chip connection between substrate and image sensor for any damage
13. Re-test at Juliet-SA tester to confirm the failure, if confirmed, and no other issues found, remove the Juliet module and return to module vendor for FA.
14. Go to step "JU-SA bracket opening procedure and data collection, housing measurements"

Possible root causes for this failure mode include:

- RCAM pulling down AVDD power rail causing Juliet to fail (if removing RCAM fixes the problem, this is the issue)
- Flex, Substrate or MLB damage causing AVDD signal to open/short (NVM reading cannot work without AVDD present, can return only zero values)
- NVM Could be completely empty (test escape, or some damage caused memory to erase, or AVDD power pin inside the sensor is damaged, making all output only zeros)
- Juliet is provisioned (the system unit goes through no-UI station)

I.2.4.Failure Mode: DLI (Data Line Integrity) Failure

DLI Test is outputting a test pattern from the image sensor and comparing it to a known reference (this verifies MIPI data transmission is working correctly). If this fails, then for some reason the test pattern output from the image sensor is not matching expectations.

Failure Analysis:

1. Re-test on the test station to confirm the failure
2. Create a radar for the failure (follow the Radar Creation rules in section above)
3. Reproduce the failure with manual diags commands sent to the FF
   - Confirm that Front1 camera can be found
   - Run the "camisp --id' command to make sure a non-zero value is returned
   - Check that NVM is being read correctly
   - If these pass, it means I2C & power functionality should be ok
4. Perform FF level cosmetic inspection
5. Go to Form Factor JU measurements section
6. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit):
   - Make sure alignment ring is within specs:
     - Height, thickness
     - Look for any deformation, detachment
7. Perform Pearl Sub level cosmetic inspection
8. Follow the swap testing procedure defined in the previous section, document the results and post to radar

- If the failure follows the MLB, work with System EE team for next FA steps
- If the failure follows the Juliet module, proceed to next step

9. Perform the EE Open/Short Checks, record the data and post to radar
10. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damageIR
11. Go to step “JU-SA bracket opening procedure and data collection, housing measurements”
12. If there are several failures of the same type, perform CT scan to inspect the flip chip connection between substrate and image sensor for any damage
13. Re-test at Juliet-SA tester to confirm the failure, if confirmed go to step “JU-SA bracket data collection, housing measurements and cut”

Possible root causes for this failure mode include:

- RCAM pulling down AVDD power rail causing Juliet to fail (if removing RCAM fixes the problem, this is the issue)
- Flex, Substrate or MLB damage causing AVDD signal to open/short (Image sensor cannot output data normally without AVDD power, note that NVM reading cannot work without AVDD present either, can return only zero values, so both should fail in this case)
- Flex, Substrate or MLB damage causing MIPI (Data0, Data1 or CLK, N or P) signal(s) to open/short (if MIPI signals are damaged, data will not transfer properly)
- ISP FW issue could be causing the output image of the image sensor to be incorrect (defect pixel correction or something else)
- PAM silver epoxy ingress between module stiffener and substrate, causing tie bars to short to ground (specifically MIPI signal)

I.2.5.Failure Mode: AVDD or DVDD LDO Failures

QT0 station performs LDO22 (DVDD) and LDO23 (AVDD) testing in addition to general Juliet camera testing. If any of the items below are failing, then Juliet FA should be performed:

- cpmu vldo22 (LDO22 voltage measurement for DVDD)
- cpmu ildo22 (LDO22 power-down current measurement for DVDD)
- cpmu vldo23 (LDO23 voltage measurement for for AVDD)
- cpmu ildo23 (LDO23 power-down current measurement for AVDD)

NOTE: The RCAM shares these power rails with Juliet, it is important to isolate if RCAM or Juliet is causing these failures during the swap test portion of the FA steps

These are the specs that can be found in system ERS:

APOLLO PMU Spec (J3xx P2)

Item	Name	Nominal	Min	Max
Digital voltage	VLDO22	1.2V	1100 mV	1300 mV
Digital current	ILDO22	-	0 mA	20 mA
Analog voltage	VLOD23	2.8V	2700 mV	3000 mV
Analog current	ILOD23	-	0 mA	20 mA
I/O voltage	BUCK3_SW1	1.8V	-	-

Failure Analysis:

1. Re-test on the test station to confirm the failure
2. Create a radar for the failure (follow the Radar Creation rules in section above)
3. Pull the Juliet-SA log to see if the failure existed at that time
4. Reproduce the failure with manual diags commands sent to the FF
    - Run the manual current and voltage check
5. Perform FF level cosmetic inspection
6. Go to Form Factor JU measurements section
7. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
8. Perform Pearl Sub level cosmetic inspection
9. Follow the swap testing procedure defined in the previous section, document the results and post to radar
    - If the failure follows the MLB, work with System EE team for next FA steps
    - If the failure follows the Juliet module, proceed to next step
    - Make sure to also try swapping the RCAM if the failure follows the MLB, it could be RCAM related
10. Perform the EE Open/Short Checks, record the data and post to radar
11. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage
    - Check specifically the silver epoxy location and if it has any risk to short to the substrate tie bars
12. If X-ray is hard to see any issue, select 1 or 2 failures to perform CT scan to inspect the substrate, flex and silver epoxy region
13. Re-test at Juliet-SA tester to confirm the failure
14. If silver epoxy is the suspected issues, work with PD and AE teams to carefully inspect the silver epoxy location from X-ray and CT scan results:
    - Is the silver epoxy centered along the camera side wall
    - Is there clearance from the edge of the module to the start of the Ag Epoxy
    - If any fails, work with PD & AE to improve silver epoxy location
15. If Silver epoxy is in the right location and clearance to edge of module is ok, and can measure short between signal and bracket, go to step "JU-SA bracket data collection, housing measurements and cut"

Possible root causes for this failure mode include:

- RCAM pulling down AVDD power rail causing Juliet to fail (if removing RCAM fixes the problem, this is the issue)
- Flex, Substrate or MLB damage causing AVDD or DVDD signal to open/short (open or short on either signal can cause LDO tests to fail)
- PAM silver epoxy ingress between module stiffener and substrate, causing tie bars to short to ground (specifically DVDD for LDO22 fails, this should never cause LDO23 or AVDD related failures)

```
ispcpu: [ISP: 5.940455] CH = 3 CMD = 0x0148 [CISP_CMD_CH_VALIDATE_CONFIG]
validateConfig:
  Result: 0
  ErrorCode: 65536
  ErrorString: PROJECTOR_STROBECOUNT
  script-command: MSECDELAY 200

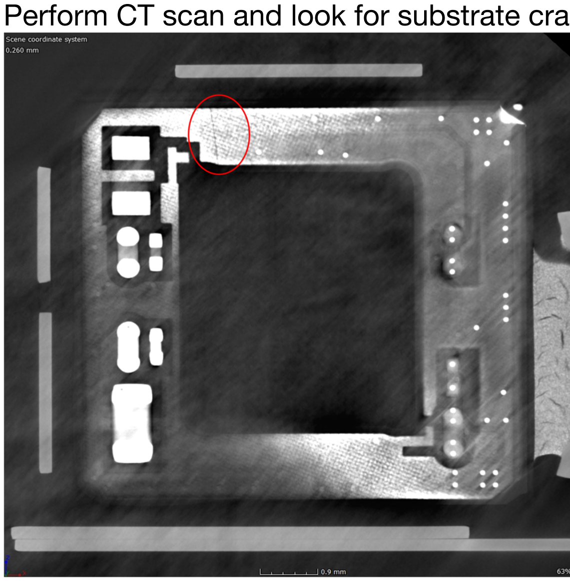
ispcpu: CStrobeRigel ValidateConfigB0 - Failed strobe count validation! (0 0 81)
ispcpu: [MSC] CH = 0x3 Validate:0 (Projector=65536 Sensor=0)
ispcpu: DopplerSafe: 0 @ 464338902
  framereceived: chan 3: frameCount=0x00000052 Yuv Raw Meta ---- --- ---- ----- -----
----  Aux:0 (66.659 msec)
```

Generic failure modes

I.2.6.Failure Mode: ROMEO_THERM/RO THERMAL TEST, Rosaline_Interposer_Test, RS_Test_front rigelCheck

This failure occurs when JU strobe is not triggering RO before capturing an image. Coverage for JU-Strobe and sync pin is only present at Burning station, no coverage at IQC or JU-SA.

Failure Analysis:
1. Re-test with AAB method to confirm test station is working properly
2. Create a radar for the failure (follow the Radar Creation rules in sections above)
3. Check if the unit was reworked at some point. If unit was reworked please note on radar explaining the rework done.
4. Perform FF level cosmetic inspection
5. Reproduce the failure with pearl diags commands sent to the FF
   - Confirm that Front1 camera can be found
   - Check pearl diags images, RO images should be dark if strobe signal is missing.
   - Check Pearl diags logs to confirm the failure
6. Perform CT scan and look for substrate crack or abnormalities



7. Go to Form Factor JU measurements section

8. Open the unit. Get necessary approvals before opening, and follow standard procedure for opening the unit
9. Perform Pearl Sub level cosmetic inspection
10. Follow the swap testing procedure defined in the previous section, document the results and post to radar
    - If the failure follows the MLB, work with System EE team for next FA steps
    - If the failure follows the Juliet module, proceed to next step
11. Perform the EE Open/Short Checks, record the data and post to radar
12. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage.
13. Go to step "JU-SA bracket data collection, housing measurements and cut"
14. Return the module to vendor

Possible root causes for this failure mode include:

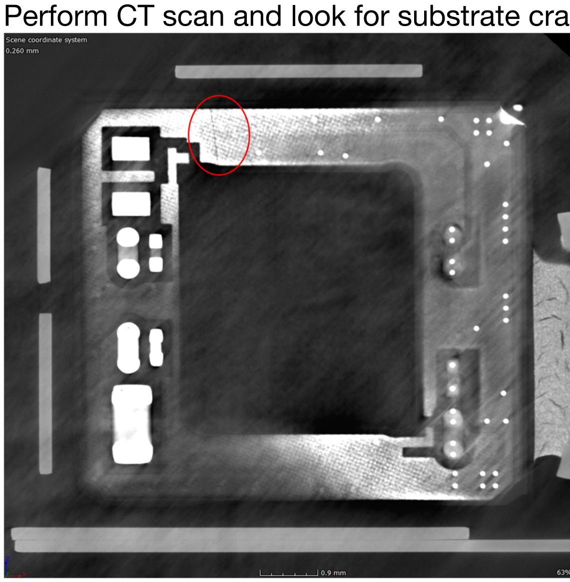
- Strobe pin on JU open

I.2.7.Failure Mode: SYNC (SYNCSTREAMSANITYCHECKVAL/SYNC/SYNC)

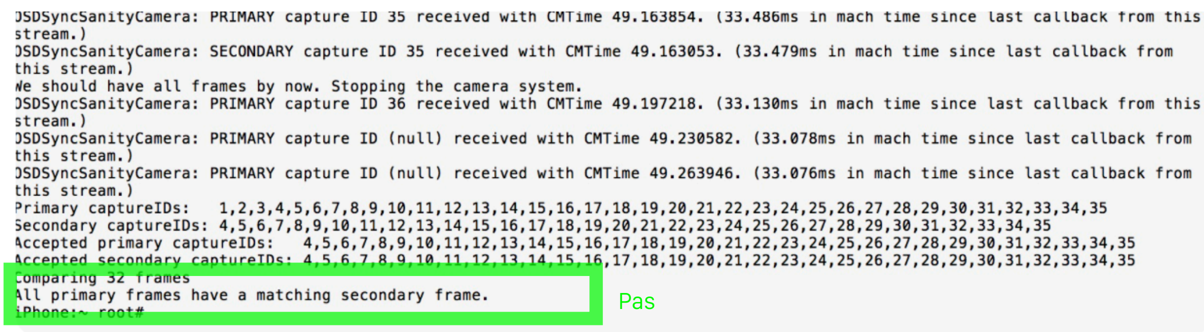
This failure occurs when FCAM is not triggering JU before capturing an IR image. Coverage for sync pin is also present in IQC and JU-SA.

Failure Analysis:

1. Re-test with AAB method to confirm test station is working properly
2. Create a radar for the failure (follow the Radar Creation rules in sections above)
3. Check if the unit was reworked at some point. If unit was reworked please note on radar explaining the rework done.
4. Perform FF level cosmetic inspection
5. Run pearl diags commands sent to the FF
6. Perform CT scan and look for substrate crack or abnormalities

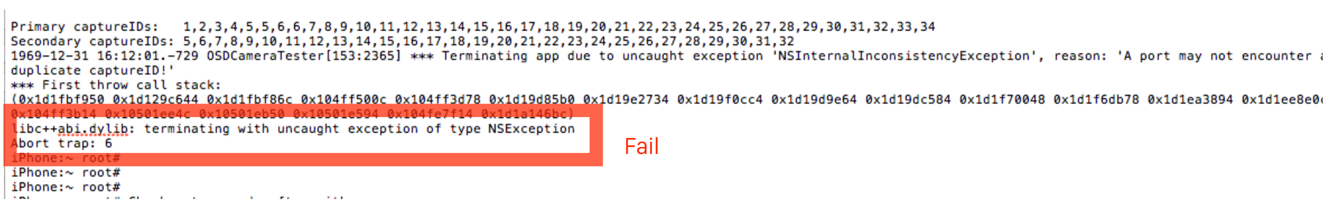


7. Go to [Form Factor JU measurements]() section
8. Open the unit. Get necessary approvals before opening, and follow standard procedure for opening the unit
9. Perform Pearl Sub level cosmetic inspection
10. Swap test and run the following command and compare with step 5 to confirm pass/fail (NonUI - /usr/local/bin/OSDCameraTester SyncStreamSanity --group pearl --primaryFormatIndex 1 --secondaryFormatIndex 0 --frameRate 30 --frames 20 --framesToWait 10):
    1. Swap 1 - system swap with good FCAM and manual test find fail, upload the log to radar
    2. Swap 2 - system swap with good Juliet and manual test find pass, upload the log to radar.
    3. Swap 3 - pearl sub swap with good system and manual test find fail, upload the log to radar.



```
OSDSyncSanityCamera: PRIMARY capture ID 35 received with CMTime 49.163854. (33.486ms in mach time since last callback from this stream.)
OSDSyncSanityCamera: SECONDARY capture ID 35 received with CMTime 49.163053. (33.479ms in mach time since last callback from this stream.)
We should have all frames by now. Stopping the camera system.
OSDSyncSanityCamera: PRIMARY capture ID 36 received with CMTime 49.197218. (33.130ms in mach time since last callback from this stream.)
OSDSyncSanityCamera: PRIMARY capture ID (null) received with CMTime 49.230582. (33.078ms in mach time since last callback from this stream.)
OSDSyncSanityCamera: PRIMARY capture ID (null) received with CMTime 49.263946. (33.076ms in mach time since last callback from this stream.)
Primary captureIDs:   1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
Secondary captureIDs: 4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
Accepted primary captureIDs:   4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
Accepted secondary captureIDs: 4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35
Comparing 32 frames
All primary frames have a matching secondary frame.
iPhone:~ root#
```

Pas



```
Primary captureIDs:   1,2,3,4,5,5,6,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34
Secondary captureIDs: 5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32
1969-12-31 16:12:01.-729 OSDCameraTester[153:2365] *** Terminating app due to uncaught exception 'NSInternalInconsistencyException', reason: 'A port may not encounter a duplicate captureID!'
*** First throw call stack:
(0x1d1fbf950 0x1d129c644 0x1d1fbf86c 0x104ff500c 0x104ff3d78 0x1d19d85b0 0x1d19e2734 0x1d19f0cc4 0x1d19d9e64 0x1d19dc584 0x1d1f70048 0x1d1f6db78 0x1d1ea3894 0x1d1ee8e0c 0x104ff3b14 0x10501ee4c 0x10501eb50 0x10501e594 0x104fe7f14 0x1d1a146bc)
libc++abi.dylib: terminating with uncaught exception of type NSException
Abort trap: 6
iPhone:~ root#
iPhone:~ root#
iPhone:~ root#
```

Fail

11. Perform the EE Open/Short Checks, record the data and post to radar
12. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage.
13. Go to step "[JU-SA bracket data collection, housing measurements and cut]()"
14. Return the module to vendor

<u>Possible root causes for this failure mode include:</u>
- Strobe pin on JU open
- Substrate crack
-

I.3. Midgard Test Station

I.3.1.Failure Mode: No image, cannot communicate with camera Error

This occurs when the camera cannot capture an image correctly at the test station.

Failure Analysis:

1. Retest on several Midgard stations to see if it is station specific or follow the FF
2. Retest the QT0b stations, if they fail, follow the related FA SOP (do no proceed here)
3. Test the Pearl Cal, Pearl Test 20 and Pearl Test 60 stations, any problem capturing images on these stations?
   - If no, then need to check with HWTE, could be a Midgard station issue
   - If yes, proceed to next step
4. Reproduce the failure with manual non-UI H9ISP commands sent to the FF
   - Run H9ISP, send the “on” and “start 3 127 0” commands
   - Hold IR light source (like dino-scope) in front of Juliet camera and observe the display, if you can see the light, camera is working, if all black, this is a failing observation
   - Compare to a good passing unit, any difference observed in behavior?
5. Run PearlDiags script and compare to a known good unit, any difference that can help indicate the problem?
6. If nothing is found from the above FA steps, contact Apple DRI, this is a unique failure.

I.3.2.Failure Mode: All light field failures on midgard — Gray spot, Blemish, Relative Illumination, Relative Uniformity, Light Defective Line (Flat Field Image Parametric Fail), PRNU

The flat field image test is verifying several image quality metrics for the Juliet camera, if any of them fail, something unexpected is being observed in the image that is causing the failure.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Check if the unit was reworked at some point. If unit was reworked please note on radar explaining the rework done.
4. Re-test a known good unit in the same test station to make sure it is not a station problem

5. Create a radar for the failure (follow the Radar Creation rules in section above)
6. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
7. Check the QT0b logs on PDCA, any failures that could contribute to this failure mode?
8. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
9. Re-test the unit on the QT0b stations
   - If it fails, follow the QT0b FA section of this document
   - If it passes, then you know that the majority of the basic camera electrical functionality is working normally (I2C, Power Supplies & MIPI)
10. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure. Also apply contrast stretch when comparing to a good unit to look for issues that are hard to see.
    - Look for blemishes or dots in the image, for dark corners or a shadow in the image, for bright or dark columns or rows, for anything strange compared to a normal passing image
11. Run Pearl Test 60 stations to confirm if fails or not, look at res test data and the image for anything strange or out of spec (could be related)
    - Any failing MTF scores?
    - Any failing Tilt or rotation? If yes, take OGP measurements as described in FA toolbox section to help confirm, if tilt is failing, follow tilt FA SOP
12. Try to reproduce the issue manually in the lab, start streaming with H9ISP commands and shine IR light, anything you can observe that is strange?
13. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
14. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any possible lens / module damage / contamination
    - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
15. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - NOTE: When swapping, swap the entire Pearl sub to new FF
    - If the failure follows the MLB, work with System EE team for next FA steps
    - If the failure follows the CG, perform more careful inspection of the CG
    - If the failure follows the Juliet module, proceed to next step
16. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the Midgard captured image, any difference? Similar issue?
    - If confirmed, and no other issues found, remove the Juliet module and return to module vendor for FA.

<u>Possible root causes for this failure mode include:</u>

- Fully or partially blocked Juliet aperture (protective films, foams, etc…)
- Dirt or contamination on the outside or inside of the CG (in Juliet aperture)
- Dirt or contamination on the Juliet lens surface
- Dirt or contamination inside the Juliet module (inside the lenses, on the IR filter, on the image sensor surface)
- Juliet concentricity to aperture is very bad (blocking some of the view of the camera, causing dark regions in the image)
- High Juliet tilt relative to the CG causing shadow or dark region in the image
- ESD or electrical damage to the image sensor, causing strange performance
- External or internal camera module damage causing a change in performance
- ISP FW issue applying incorrect image processing, degrading performance

I.3.3.Failure Mode: All dark testing failures on Midgard — Dark Defective Line, TempRNR (Dark Image Parametric Fail), PRNU, Row noise, all dark testing failures on Midgard

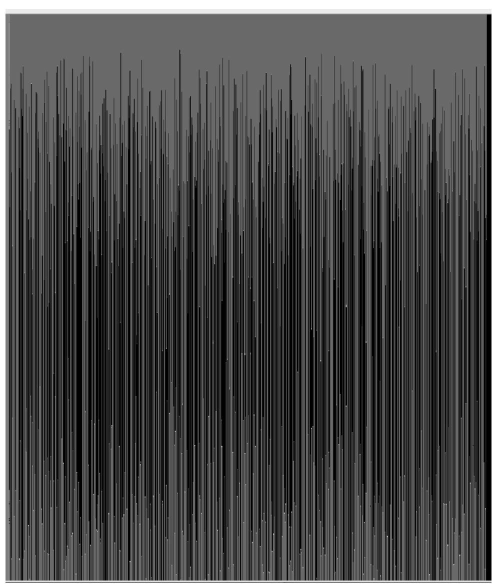
Test Type	Test Item
Dark	Sdelta_Col_Y
	Sdelta_Row_Y
	RowNoiseMC tempRnR
	RowNoiseMC tempRnR total
	RowNoiseMC total
	RowNoiseMC totalTemp
	RowNoiseMC_JU pTemp

The dark image test is verifying several image quality metrics for the Juliet camera, if any of them fail, something unexpected is being observed in the image that is causing the failure.

Failure Analysis:

1. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
2. Was the unit reworked? If yes place a note on radar expunging the rework done and procedure.
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?

6. Check the QT0B logs on PDCA, any failures that could contribute to this failure mode?
7. Check if the unit was reworked at some point. If unit was reworked please note on radar explaining the rework done.
8. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
9. Go to Form Factor JU measurements section
10. Re-test the unit on the QT0b stations
    - If it fails, follow the QT0b FA section of this document
    - If it passes, then you know that the majority of the basic camera electrical functionality is working normally (I2C, Power Supplies & MIPI)
11. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure. Also apply contrast stretch when comparing to a good unit to look for issues that are hard to see.
    - Is the image actually dark? If does not look like a mostly dark image then contact HWTE, maybe a light is turned on accidentally during the test
    - If the image is mostly dark, look for bright blemishes or dots in the image, any strange noise, bright corners in the image, for bright columns or rows, for anything strange compared to a normal passing image
    - Try adding contrast stretching to help find issues you cannot see without it, if the image has lines then follow "DLI SOP" (possible sensor crack)



12. Try to reproduce the issue manually in the lab, start streaming with H9ISP commands and shine IR light, anything you can observe that is strange?
    - Make sure there are no IR lights nearby
    - Any noise in the image you can see or other artifacts?

13. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
14. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any possible lens / module damage / contamination
    - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
15. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard)
    - NOTE: When swapping, swap the entire Pearl sub to new FF
    - If the failure follows the MLB, work with System EE team for next FA steps
    - If the failure follows the CG, perform more careful inspection of the CG
    - If the failure follows the Juliet module, proceed to next step
16. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the Midgard captured image, any difference? Similar issue?
    - If confirmed, and no other issues found, remove the Juliet module and return to module vendor for FA.

<u>Possible root causes for this failure mode include:</u>
- ESD or electrical damage to the image sensor, causing strange performance
- External or internal camera module damage causing a change in performance
- MLB power supply unstable or high noise causing performance degradation
- Light source illuminating the scene un-intentionally (should not happen, could be test station or ISP FW issue)
- ISP FW issue applying incorrect image processing, degrading performance

I.4. Pearl Test 20 or Pearl Test 60 Station

I.4.1. Failure Mode: No image, cannot communicate with camera Error

This occurs when the camera cannot capture an image correctly at the test station.

Failure Analysis:

1. Retest on several Pearl Test stations to see if it is station specific or follows FF
2. Retest the QT0b stations, if they fail, follow the related FA SOP (do no proceed here)
3. Test the Midgard, Pearl Cal, Pearl Test 20 and Pearl Test 60 stations, any problem capturing images on these stations?
    - If no, then need to check with HWTE, could be a Midgard station issue
    - If yes, proceed to next step

4. Reproduce the failure with manual non-UI H9ISP commands sent to the FF
    - Run H9ISP, send the “on” and “start 3 127 0” commands
    - Hold IR light source (like dino-scope) in front of Juliet camera and observe the display, if you can see the light, camera is working, if all black, this is a failing observation
    - Compare to a good passing unit, any difference observed in behavior?
5. Run PearlDiags script and compare to a known good unit, any difference that can help indicate the problem?
6. If nothing is found from the above FA steps, contact Apple DRI, this is a unique failure.

I.4.2.Failure Mode: MTF Parametric Failure (any ROI or MTF delta)

If the sharpness of the image is degraded in some way, then the MTF testing will fail at one of (or both) 20cm & 60cm distances.

NOTE: See system ERS for example chart image, and ROI naming compared to PDCA data names.

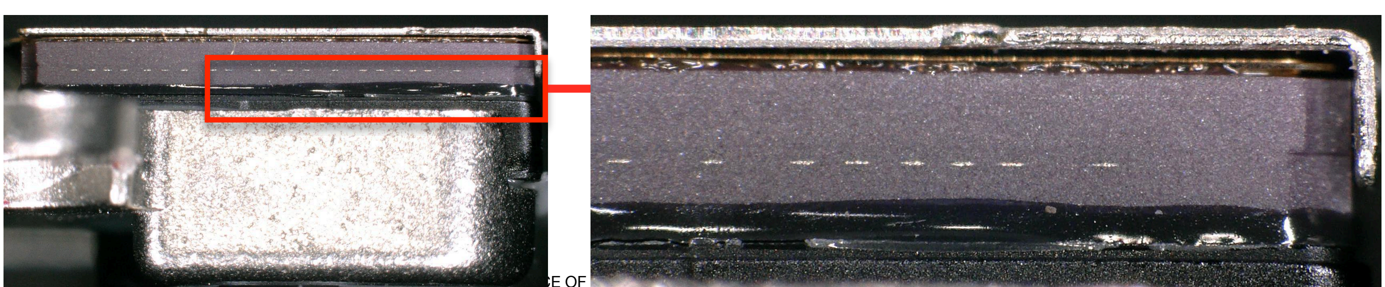
If system went through REL/ORT before continuing FA please confirm the MTF metrics are not within REL specs. If system is within REL specs please consider it as passing REL:

Test Type	Test Item	Unit	REL		
			Min	Max	Percentage Drift (REL-T0)/T0) <
SFR 60cm	J60_MTF_CENTER_N4_AVG_420	N/A	0.72*	1	-
	J60_MTF_30FP_N4_420_(0-1-2-3)	N/A	0.63*	1	12
	J60_MTF_60FP_N4_420_(0-1-2-3)	N/A	0.59*	1	15
	J60_MTF_85FP_N4_420_(0-1-2-3)	N/A	0.5*	1	20
	J60_MTF_30FP_N4_DELTA_420	N/A	0	0.14*	-
	J60_MTF_60FP_N4_DELTA_420	N/A	0	0.14*	-
	J60_MTF_85FP_N4_DELTA_420	N/A	0	0.17*	-
SFR 20cm	J20_MTF_CENTER_N8_AVG_420	N/A	0.78*	1	-
	J20_MTF_30FP_N8_420_(0-1-2-3)	N/A	0.73*	1	12
	J20_MTF_60FP_N8_420_(0-1-2-3)	N/A	0.69*	1	15
	J20_MTF_85FP_N8_420_(0-1-2-3)	N/A	0.63*	1	20
	J20_MTF_30FP_N8_DELTA_420	N/A	0	0.17*	-

	J20_MTF_60FP_N8_DELTA_ 420	N/A	0	0.17 *	-
	J20_MTF_85FP_N8_DELTA_ 420	N/A	0	0.22 *	-

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
   - Any big concentricity shift? If so, it could shift Juliet more into the spline and cause MTF degradation
   - Any lens or CG aperture damage/contamination? This could cause MTF to degrade
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
   - Look for blemishes or dots in the image, dark areas or shadows in the image (un-even lighting)
   - Is there any noticeable blurriness in the image (compared to good unit)? Is the blurriness uniform across the whole image or only part of the image?
   - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
   - Any failing Tilt or rotation? If yes, take OGP measurements as described in FA toolbox section to help confirm, if tilt is failing, follow tilt FA SOP
   - Any other strange problem with the image that doesn't align with normal passing unit?
8. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
9. Check for JU Module AA glue delamination as in the example below and uploading "poke test video and cosmetic pictures of AA glue in all visible JU corners while in bracket



10. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any possible lens / module damage / contamination
    - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
11. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)
    - NOTE: When swapping, swap the entire Pearl sub to new FF
    - If the failure follows the CG, perform more careful inspection of the CG, keep the CG in the FA lab and return the rest of the unit to the line (need to work with PD to perform CG FA)
    - If the failure follows the Juliet module, proceed to next step
12. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
13. If the failure still exists, but original Juliet-SA test is pass, there could be some camera performance degradation due to assembly process
    - Compare all 20cm and 60cm MTF values at the following stations:
        - Original IQC record
        - Original Juliet-SA record
        - Pearl Test 20/60 record
        - Juliet-SA re-test record
    - Did 20cm and 60cm both get worse? Did one get better?
        - If both got worse, then its either a de-focus towards infinity (lens barrel got closer to image sensor) or some kind of damage or contamination in the optical path
        - If 20cm got better and 60cm got worse, then its a defocus towards macro (lens got further away from image sensor)
14. If no clear root cause, remove the Juliet module and return to vendor for FA.

<u>Possible root causes for this failure mode include:</u>

- Fully or partially blocked Juliet aperture (protective films, foams, etc…)
- Dirt or contamination on the outside or inside of the CG (in Juliet aperture)
- Dirt or contamination on the Juliet lens surface
- Dirt or contamination inside the Juliet module (inside the lenses, on the IR filter, on the image sensor surface)
- Juliet concentricity to aperture is very bad (causing spline interference or blocking view of camera)
- High Juliet tilt relative to the CG causing ROIs to be outside of the image
- External/internal module damage/contamination causing change in performance
- ISP FW issue applying incorrect image processing, degrading performance
- Mechanical deformation of the barrel, causing change in focus (could be caused by mechanical applied pressure, or environmental conditions like REL, PAM thermal curing ovens, etc…)

I.4.3.Failure Mode: xTilt, yTilt or Rotation Parametric Failures

If any of the alignment items are failing, this means that relative to the outer dimensions of the FF (device edges and CG) that there is some mis-alignment of the Juliet module causing these items to fail.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
    - Any big concentricity shift?
    - Any lens or CG aperture damage/contamination?
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
    - Are all of the ROIs visible for all image heights? Or are some blocked or outside of the image?
    - Is tilt or rotation failure obvious from image review?
    - Any other strange problem with the image that doesn't align with normal passing unit?
8. Take OGP measurements on FF level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
9. If this is a new failure more for the build, or a noticeable outlier, add to the CT scan list and look for all relevant measurements as called out in FA toolbox
10. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
11. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
    - Look for any Juliet rotation or tilt issues relative to the bracket, any difference compared to a good unit?
    - Look at the alignment ring on the CG side, is it placed properly? Any difference compared to a good unit?
    - Any dented flexes, foams or other components that look like they were causing interference?
12. Take OGP measurements on Pearl Sub level as described in FA toolbox section to help confirm (only possible for tilt failures, not rotation)
13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)

- If the failure follows the FF (CG or housing), perform more careful inspection of the alignment ring and housing, review this unit with the PD team to help identify the root cause
- If the failure follows the Juliet module, proceed to next step

14. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
    - If evidence points to PAM assembly issue, review the Pearl sub with PD and AE team to identify how to improve tilt / rotation performance
    - NOTE: If PAM issue, it may be useful to perform Pearl Sub level CT scan for better detailed result, and lastly try performing cross section of failures to see how the mis-alignment in the bracket really looks
15. If no clear root cause but still follows Juliet module, request support from Apple team

Possible root causes for this failure mode include:
- Juliet module tilted or rotated in PAM assembly
- Pearl bracket tilted or rotated in Housing (FF assembly)
- CG alignment ring not installed properly
- Sensor flex stuck between CG alignment ring and shoulder of Juliet module causing assembly issue induced tilt

I.4.4.Failure Mode: IRPP shift

IRPP0, IRPP1 are detected in pearl cal station. The station will not give an error but when comparing current IRPP with T0 IRPP if there is a shift of more than 8um the unit will be flagged by Apple DRI.

This can happen after JU module is exposed to high mechanical stress and the lens barrel has some kind of deformation w.r.t the sensor.

Failure Analysis:

1. Re-test on the test station to confirm the failure (pearl cal, rack 1)
2. Make sure to run Pearl diags to save provisioning file if not yet done.
3. Create a radar for the failure (follow the Radar Creation rules in section above)
4. Compare T0 IRpp_0 and IRpp_1 with value after REL. Please write down the values in radar and tracker.
5. Compare Midgard optical center before versus after REL:
    1. oc_JU_raw oc_xshift
    2. oc_JU_raw oc_yshift
6. Retest subassembly in ICCB station
7. Compare Subassembly ICCB optical center before versus after REL:
    3. oc_JU_raw oc_xshift
    4. oc_JU_raw oc_yshift
8. Perform FF level cosmetic inspection
9. Go to Form Factor JU measurements section
10. Perform Pearl Sub level cosmetic inspection
11. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)

12. Do a swapping test with a golden unit: reassembled the pearl into system unit without HAM glue; test through Midgard, Pearl 20, Pearl 60 and Pearl cal to compare the IRPP between golden system unit and original system unit
13. Go to step "JU-SA bracket data collection, housing measurements and cut"
14. Return module at vendor

Possible root causes for this failure mode include:
- Lens deformation
- Module deformation

I.4.5.Failure Mode: CTF (contrast) Parametric Failure

If the contrast in the Juliet captured image is reduced for some reason, the CTF metric will fail.

Failure Analysis:

1. Make sure that there is nothing covering the Juliet camera aperture on top of the CG, remove any protective films and clean the CG surface with a soft cloth
2. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
3. Re-test a known good unit in the same test station to make sure it is not a station problem
4. Create a radar for the failure (follow the Radar Creation rules in section above)
5. Check the Juliet-SA and Juliet-IQC test results, any failures or marginal performance for related metrics?
6. Perform FF level cosmetic inspection, pay special attention to the Juliet aperture, any contamination, blockage of the camera lens, lens damage, etc…)
   - Any lens or CG aperture damage/contamination? This could cause contrast to degrade
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure.
   - Look for haze in the image (like a cloudy image), is it visible?
   - Is there any noticeable blurriness in the image (compared to good unit)? Is MTF also failing? If yes, follow MTF fail SOP.
   - Any other strange problem with the image that doesn't align with normal passing unit?
8. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
9. Perform Pearl Sub level cosmetic inspection and CG inside cosmetic inspection
   - Look for any possible lens / module damage / contamination
   - Look for any CG damage / contamination (compare to good unit if needed), check the inside and outside of the CG
10. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard and Pearl Test 60)

- If the failure follows the CG, perform more careful inspection of the CG, keep the CG in the FA lab and return the rest of the unit to the line (need to work with PD to perform CG FA)
- If the failure follows the Juliet module, proceed to next step

11. Re-test at Juliet-SA tester to confirm the failure
    - Inspect the image compared to the FATP captured image, any difference? Similar issue?
12. If no clear root cause, remove the Juliet module and return to vendor for FA.

<u>Possible root causes for this failure mode include:</u>
- Dirt or contamination on the outside or inside of the CG (in Juliet aperture)
- Dirt or contamination on the Juliet lens surface
- Dirt or contamination inside the Juliet module (inside the lenses, on the IR filter, on the image sensor surface)
- Scratches on the coverglass in front of Juliet aperture
- Smudge or skin oil on the coverglass in front of Juliet aperture
- External/internal module damage/contamination causing change in performance
- ISP FW issue applying incorrect image processing, degrading performance

I.5. Test Stations using Juliet to capture Titus or Rosaline Images

I.5.1. Failure Mode: Dark Image but expect Titus or Rosaline pattern (spots or flood image)

There are several test stations where Juliet is support to capture an image of the Titus or Rosaline output pattern (spots or flood), if this does not happen, and only a dark image is captured, this is a failure.

NOTE: If there are any Rigel faults, or Titus_Self_Test failures, follow the related SOP for those items (not documented here). This FA is ONLY for failures that DO NOT have any Rigel faults.

Failure Analysis:

1. Re-test on the test station to confirm the failure still happens (try several stations to make sure if follows the FF)
2. Re-test a known good unit in the same test station to make sure it is not a station problem
3. Create a radar for the failure (follow the Radar Creation rules in section above)
4. Check the QToB logs on PDCA, any failures that could contribute to this failure mode?
5. Perform FF level cosmetic inspection
6. Re-test the unit on the QT0b stations
    - If it fails, follow the QT0b FA section of this document
    - If it passes, then you know that the majority of the basic camera electrical functionality is working normally (I2C, Power Supplies & MIPI)
7. Download the images for the failing test from PDCA or the tester on the line and inspect the image, anything you can see that is abnormal? Compare to a good passing image to be sure. This FA assumes that the

images are showing as totally black when they should be capturing Titus or Rosaline pattern.

8. Try to reproduce the issue manually in the lab using the Pearl Diags script, do you see the same problem compared to a good unit (dark images)?
9. Run the Juliet detailed FA script in Appendix A of this document
10. Start a streaming session with either Rosaline or Titus pulsing, during the streaming, send the following I2C command several times (10~15 times):
    - i2cread 3 0x55 0x08 1 1
    - This is reading a Rigel pulse counting register, if it always stays at zero, or the value isn't change very much, then the STROBE signal is not pulsing properly, if you see this proceed to next FA steps (if not, contact Apple)
11. Open the unit & remove the Pearl Sub (get necessary approvals before opening, and follow standard procedure for opening the unit)
12. Perform Pearl Sub level cosmetic inspection
13. Follow the swap testing procedure defined in the previous section, document the results and post to radar (for each step, run Midgard)
    - If the failure follows the MLB, work with System EE team for next FA steps
    - If the failure follows the Juliet module, proceed to next step
14. Perform the EE Open/Short Checks, record the data and post to radar
15. If EE Open/Short checks fail, perform X-ray checks for relevant flex and/or substrate damage
16. If X-ray is hard to see any issue, select 1 or 2 failures to perform CT scan to inspect the substrate, flex and silver epoxy region
    - In CT scan, also check the flip chip / stud bump region to look for any mis-aligned bump bonds or damage at sensor to substrate interface
17. If the EE Open/Short Checks pass, remove the module from the Pearl sub and return to the vendor for FA (something internal to the module is broken)

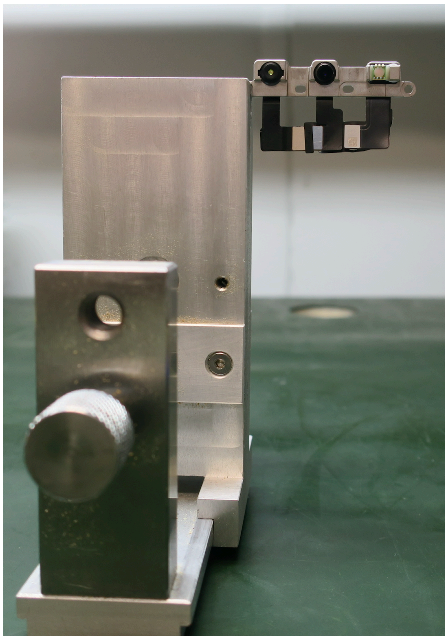
<u>Possible root causes for this failure mode include:</u>

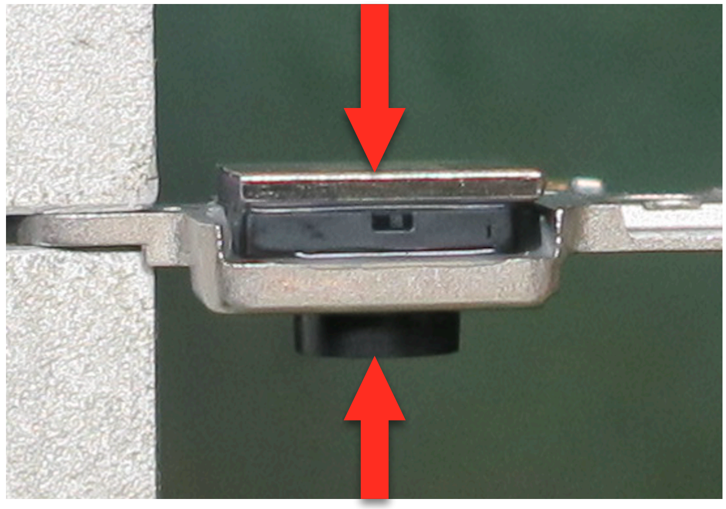
- Juliet STROBE signal is not working properly, so Rigel driver is never given the signal to fire the Titus or Rosaline projectors (so there is no pattern output for Juliet to capture)
    - This could be due to flex damage causing open or short on STROBE
    - This could be due to MLB damage causing open or short on STROBE
    - This could be due to substrate damage causing open or short on STROBE
    - This could be due to sensor or module assembly damage causing open or short on STROBE

I.6. JU-SA bracket data collection, housing measurements and cut

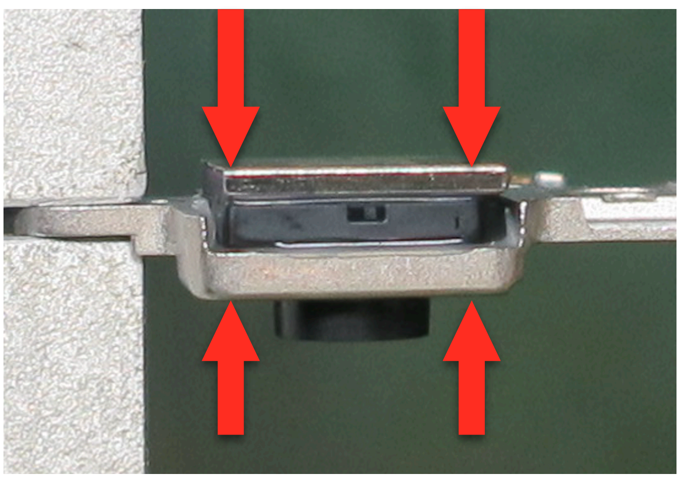
This section is dedicated to bracket, glue and housing measurements. Make sure to upload pictures of the following visual inspection and measurements as well. Please save all the information in a single excel file with pictures.

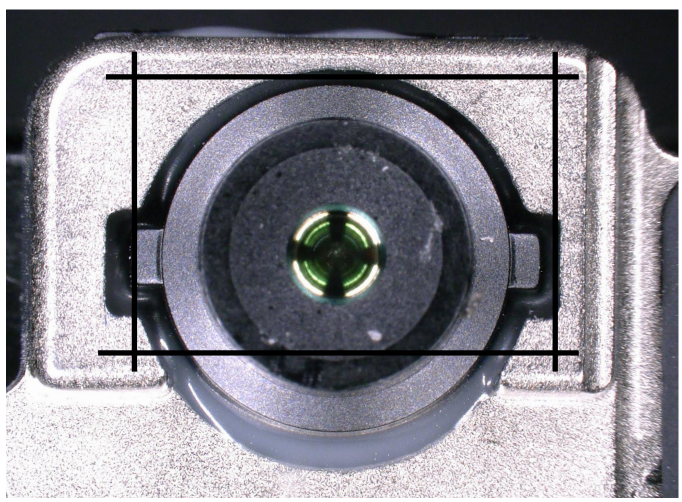
Bracket positioning for OMM/OGP test:



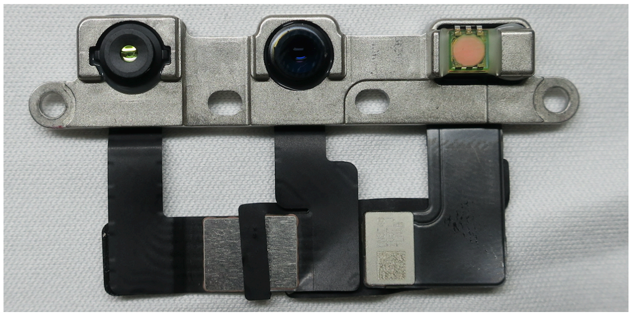


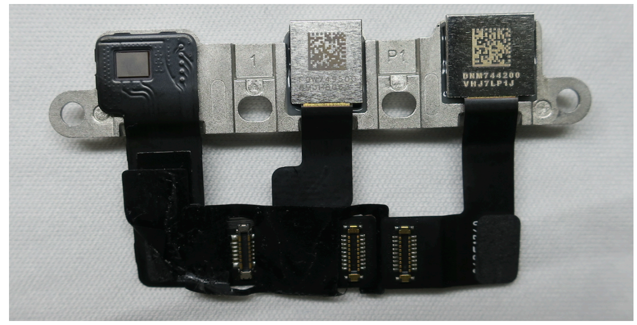
1. Total JU lens to bracket height (4 points)
2. Bottom bracket to top bracket (4 edges thickness)



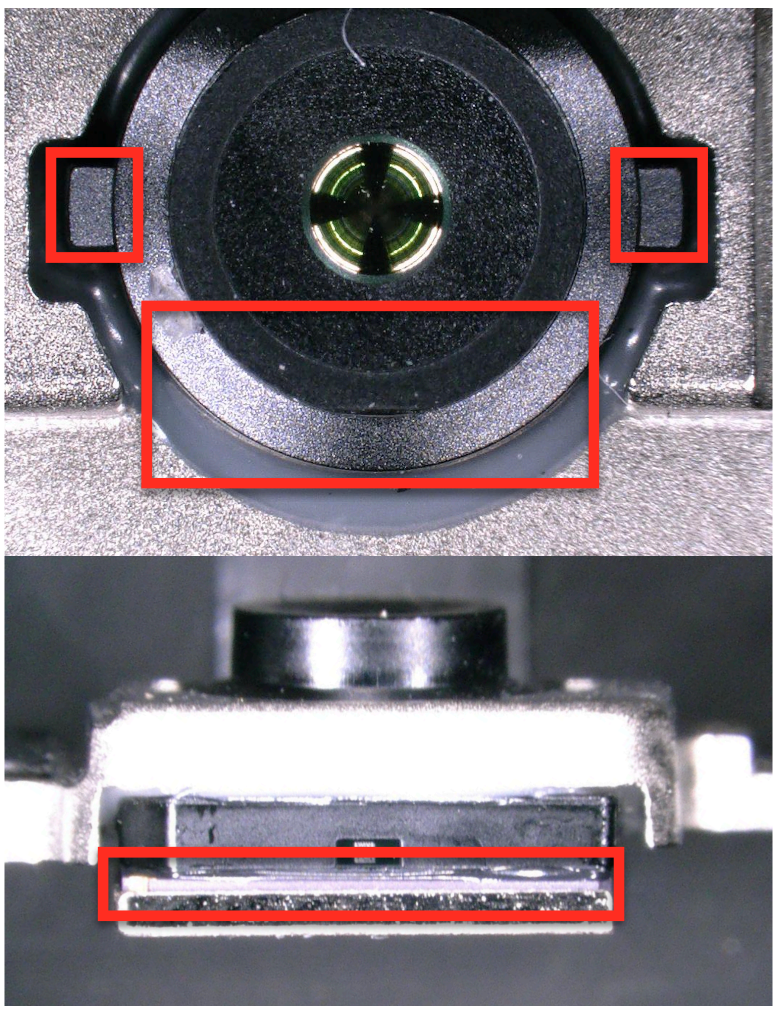


3. Visual inspection of the bracket (top and bottom). Check for any delamination/crack between the substrate and lens holder. Look for any abnormal in the bracket compared to a reference bracket.

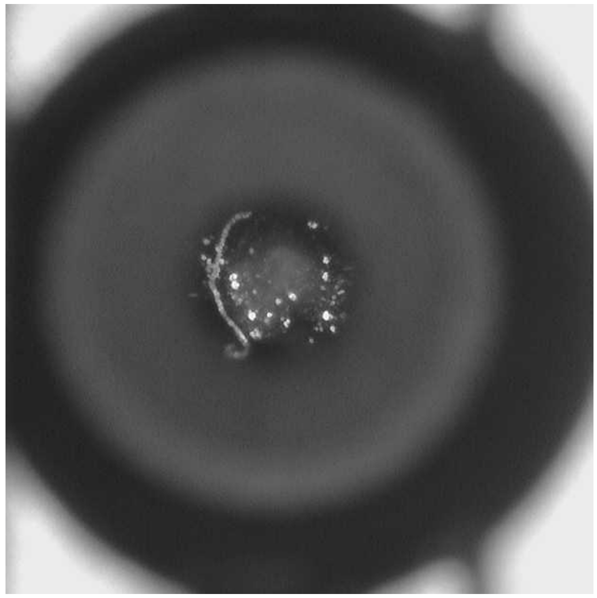




4. Take high resolution images of JU lens barrel look for any dent in the lens. If dents are present please discuss with PD to determine what component could have caused it (i.e alignment ring, surrounding components..). pay particular attention to area in red boxes and take pictures.



5. Look for any glue overflow on the top bracket, glue must be below top bracket surface
6. Check for any scratch/dent near the housing area of Ju-module and the screw area. Take photos if any
7. Check for any dirt/glue remains between the lens and sensor by tuning focus depth



8 cap the lens of Juliet and wrap the flex with tape; after protection, use saw or pliers to cut the Juliet module from the bracket

if JU-SA bracket delamed

8. Take photo on the delamed surface both on lensholder and substrate and identify any glue remained on the edge
9. Cut Juliet with some portion of bracket off
10. Return JU module to vendor for additional FA

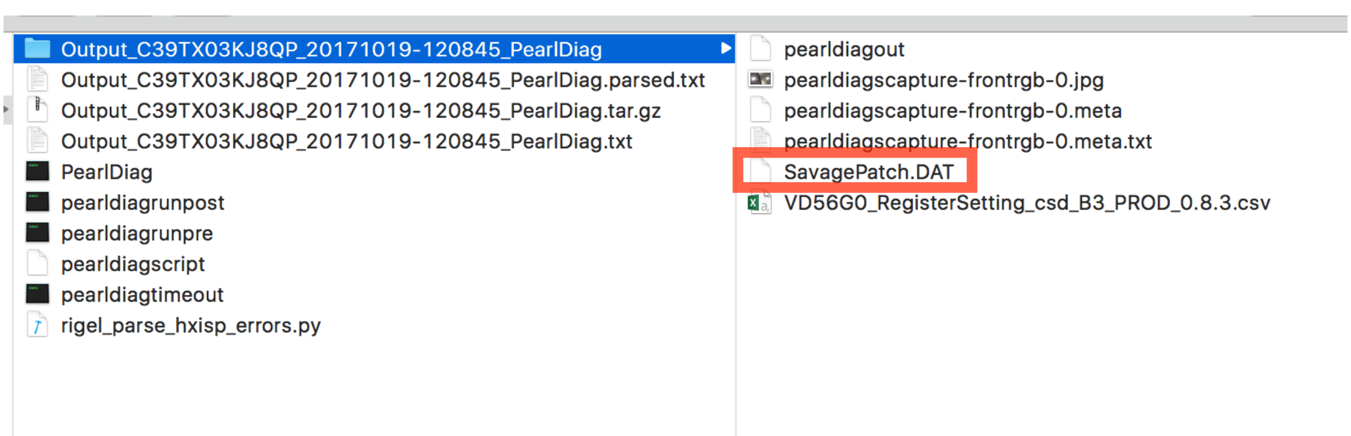
I.7. JU-SA retesting with Provisioned SA (REL units)

1. Download pearl diags <rdar://problem/29282343> Pearl Diagnostics tools
2. Install “NewCoreAutomation.pkg” and “NewTestAutomation” if not already installed on system

3. Open the PearDiag_vx folder

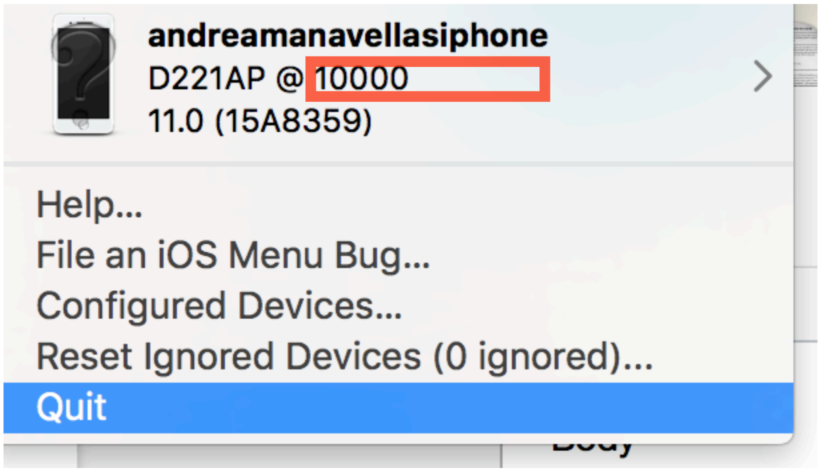
4. Connect the unit with a “Kenzi” cable and Double click on “PearlDiag” with the unit connected

5. A terminal window will open and “pearldiags” will run. At the end a new folder containing the provisioning file will be saved in the same directory. The “SavagePatch.DAT” is the provisioning file\



6. Now connect the JU-SA main board (the board used by the JU-SA tester)

7. Open “iOS Menu” and look at the port connection



8. Open a new terminal and write: /usr/local/bin/tcprelay --portoffset 10000 873 23 (where 10000 is the plot # found in the above picture”

```
andreas-MacBook-Pro:~ andreamanavella$ /usr/local/bin/tcprelay --portoffset 10000 873 23
starting. built Aug 11 2017 13:27:52
Listening on [::1]:10873 for service 873
Listening on [::1]:10023 for service 23
```

9. Open a new terminal and write:
   9.1. **telnet localhost 10023** (where 10023 is the plot # found in the above picture + 23”
   9.2. When asked for username: **root**
   9.3. When asked for password: **alpine**

```
andreas-MacBook-Pro:~ andreamanavella$ telnet localhost 10023
Trying ::1...
Connected to localhost.
Escape character is '^]'.
login: root
Password:
Last login: Thu Oct 19 12:32:33 on ttys000
andrea-manavellas-iPhone:~ root#
```

10. Open a new terminal and write:

rsync -Pav /Users/andreamanavella/Documents/SavagePatch.DAT rsync://root@localhost:14873/root/usr/standalone/firmware/Savage/SavagePatch.DAT

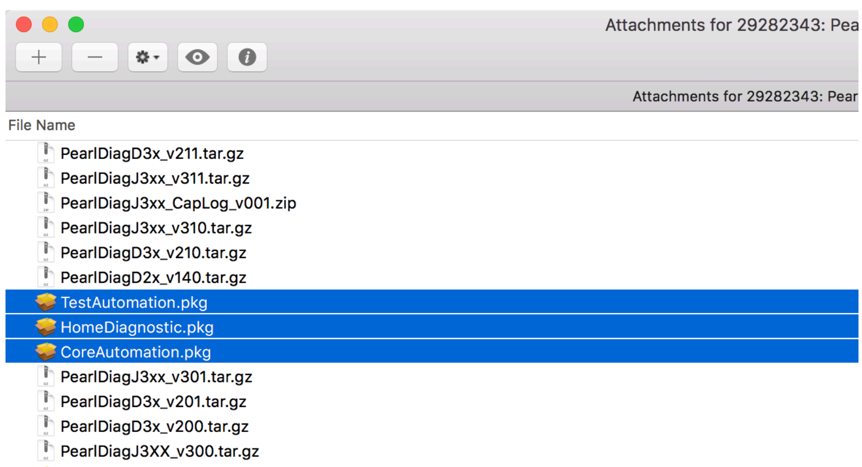
Where: "/Users/andreamanavella/Documents/SavagePatch.DAT" is the location of your .DAT file found running pearldiags
Where 10873 is the port # above + 873 : "rsync://root@localhost:10873/root/usr/standalone/firmware/Savage/SavagePatch.DAT"

From now you can retest the SA as for regular SA.

I.8. Getting ready to run Pearl diags

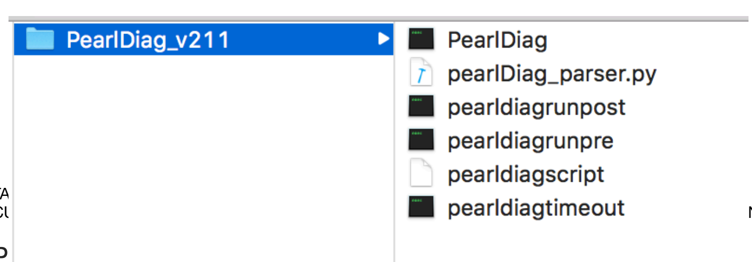
1. Go to the following radar : <rdar://problem/29282343> Pearl Diagnostics tools

2. Download and install the latest version of following packages:
   - TestAutomation.pkg
   - HomeDiagnostic.pkg
   - CoreAutomation.pkg

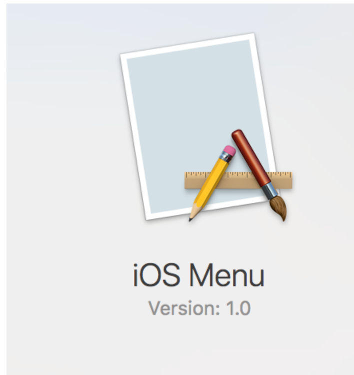


3. Download the latest PearlDiag according to the project, for example in the above screenshot if you need to test D32 download PearlDiagD3x_v211.tar.gz

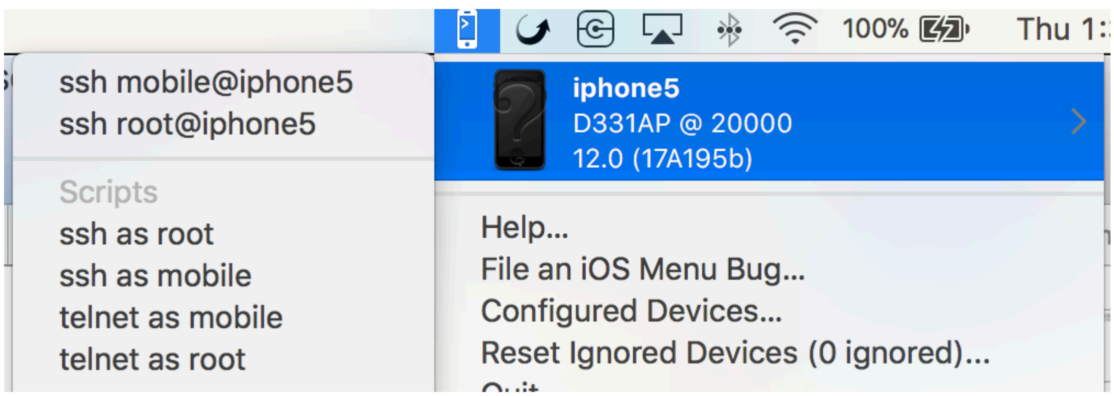
4. Unzip the file, you should have the following folder



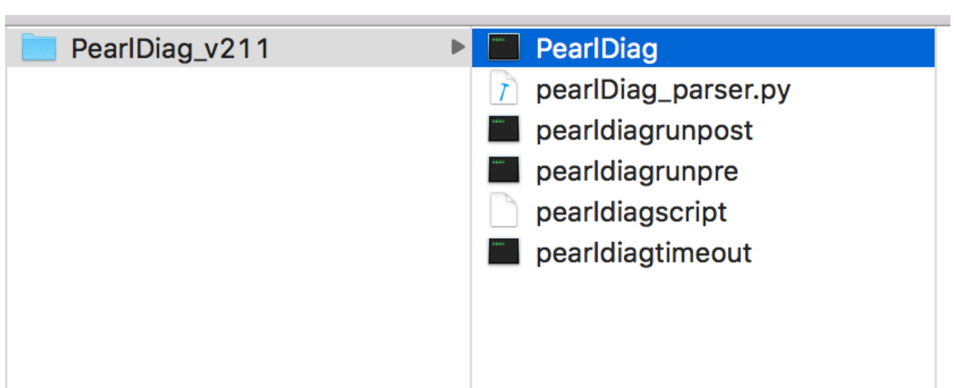
5. Connect the phone, open the app iOs Menu

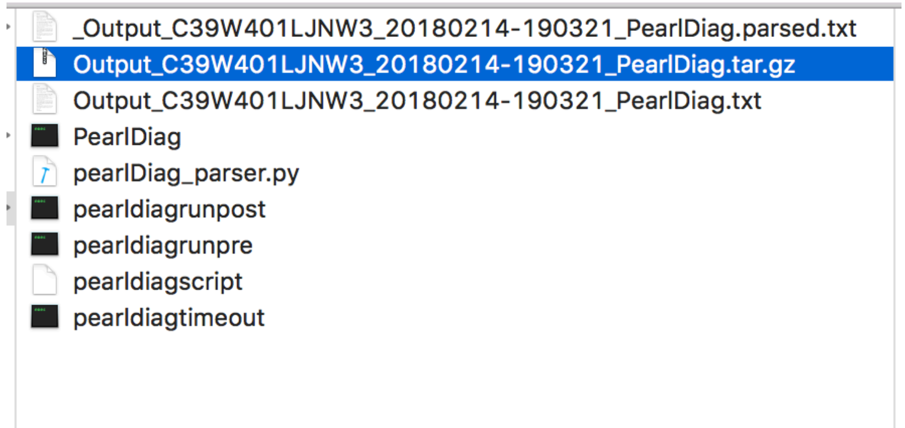


6. Your unit should appear listed. If not try disconnecting and reconnecting multiple times. If this still does not work open a terminal and type “mobdev pair”. This will help pair the device.

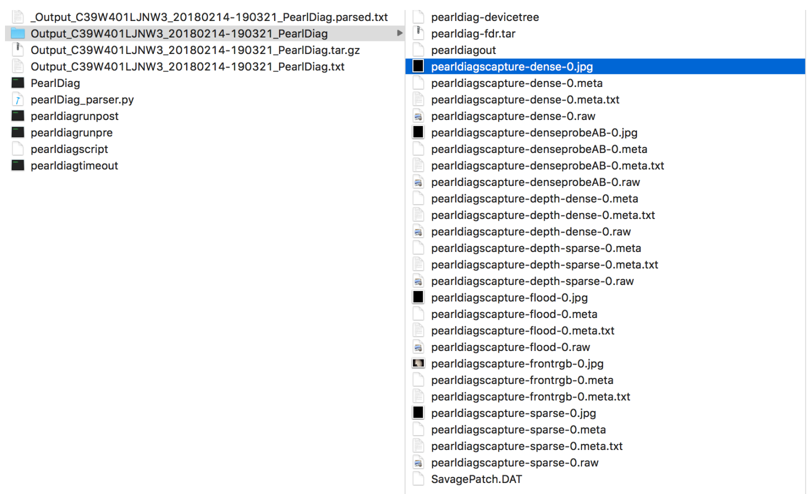


7. Prepare the setup. While running PearlDiags Juliet should be illuminated by an IR source if Romeo is not connected.
8. Once the device is in iOs Menu, go to PearlDiags folder and double click on PearlDiag executable





9. After Running PearlDiags few new items will be created in the same folder, unzip the Output folder highlighted in the following example:
10. The following files will be available, different .jpg files are taken in different conditions. If only JU is connected then there will be only one



capture. To make sure the module is working properly open it and look at the image, it should be similar to the below picture.

I.9. Juliet Debug Script

```
Forget
fwlog on
v off
on
propertywrite 3 0x500 0
i
start 3 127 0
msecdelay 100

i2cread 2 0x18 0x0000 2 4
i2cread 2 0x18 0x0004 2 4
i2cread 2 0x18 0x0008 2 4
i2cread 2 0x18 0x000C 2 4
i2cread 2 0x18 0x0010 2 4
i2cread 2 0x18 0x0014 2 4
i2cread 2 0x18 0x0018 2 4
i2cread 2 0x18 0x001C 2 4
i2cread 2 0x18 0x0020 2 4
i2cread 2 0x18 0x0024 2 4
i2cread 2 0x18 0x0028 2 4
i2cread 2 0x18 0x002C 2 4
i2cread 2 0x18 0x0030 2 4
i2cread 2 0x18 0x0034 2 4
i2cread 2 0x18 0x0038 2 4
i2cread 2 0x18 0x003C 2 4
i2cread 2 0x18 0x0040 2 4
i2cread 2 0x18 0x0044 2 4
i2cread 2 0x18 0x0048 2 4
i2cread 2 0x18 0x004C 2 4
i2cread 2 0x18 0x0050 2 4
i2cread 2 0x18 0x0054 2 4
i2cread 2 0x18 0x0058 2 4
i2cread 2 0x18 0x005C 2 4
i2cread 2 0x18 0x0060 2 4
i2cread 2 0x18 0x0064 2 4
i2cread 2 0x18 0x0068 2 4
i2cread 2 0x18 0x006C 2 4
i2cread 2 0x18 0x0070 2 4
i2cread 2 0x18 0x0074 2 4
i2cread 2 0x18 0x0078 2 4
i2cread 2 0x18 0x007C 2 4
i2cread 2 0x18 0x0080 2 4
i2cread 2 0x18 0x0084 2 4
i2cread 2 0x18 0x0088 2 4
i2cread 2 0x18 0x008C 2 4
i2cread 2 0x18 0x0090 2 4
i2cread 2 0x18 0x0094 2 4
i2cread 2 0x18 0x0098 2 4
i2cread 2 0x18 0x009C 2 4
i2cread 2 0x18 0x00A0 2 4
i2cread 2 0x18 0x00A4 2 4
i2cread 2 0x18 0x00A8 2 4
i2cread 2 0x18 0x00AC 2 4
i2cread 2 0x18 0x00B0 2 4
i2cread 2 0x18 0x00B4 2 4
i2cread 2 0x18 0x00B8 2 4
i2cread 2 0x18 0x00BC 2 4
i2cread 2 0x18 0x00C0 2 4
i2cread 2 0x18 0x00C4 2 4
i2cread 2 0x18 0x00C8 2 4
i2cread 2 0x18 0x00CC 2 4
i2cread 2 0x18 0x00D0 2 4
i2cread 2 0x18 0x00D4 2 4
i2cread 2 0x18 0x00D8 2 4
i2cread 2 0x18 0x00DC 2 4
i2cread 2 0x18 0x00E0 2 4
i2cread 2 0x18 0x00E4 2 4
i2cread 2 0x18 0x00E8 2 4
i2cread 2 0x18 0x00EC 2 4
i2cread 2 0x18 0x00F0 2 4
i2cread 2 0x18 0x00F4 2 4
i2cread 2 0x18 0x00F8 2 4
i2cread 2 0x18 0x00FC 2 4
i2cread 2 0x18 0x0100 2 4
i2cread 2 0x18 0x0790 2 4
i2cread 2 0x18 0x0794 2 4
i2cread 2 0x18 0x0798 2 4
i2cread 2 0x18 0x079C 2 4
i2cread 2 0x18 0x07A0 2 4
i2cread 2 0x18 0x07A4 2 4
i2cread 2 0x18 0x07A8 2 4
i2cread 2 0x18 0x07C0 2 2
i2cread 2 0x18 0x07D0 2 3
i2cread 2 0x18 0x07E0 2 3
i2cread 2 0x18 0x07E4 2 3
i2cread 2 0x18 0x07E8 2 3
i2cread 2 0x18 0x0800 2 1

i2cread 2 0x18 0x0310 2 4
i2cread 2 0x18 0x0314 2 4
i2cread 2 0x18 0x0318 2 4
i2cread 2 0x18 0x031C 2 4
i2cread 2 0x18 0x0320 2 4
i2cread 2 0x18 0x0324 2 4
i2cread 2 0x18 0x0328 2 4
i2cread 2 0x18 0x032C 2 4
i2cread 2 0x18 0x0330 2 4
i2cread 2 0x18 0x0334 2 4
i2cread 2 0x18 0x0338 2 4
i2cread 2 0x18 0x033C 2 4
i2cread 2 0x18 0x0340 2 4
i2cread 2 0x18 0x0344 2 4
i2cread 2 0x18 0x0348 2 4
i2cread 2 0x18 0x034C 2 4
i2cread 2 0x18 0x0350 2 4
i2cread 2 0x18 0x0354 2 4
i2cread 2 0x18 0x0358 2 4
```

```
i2cread 2 0x18 0x035C 2 4
i2cread 2 0x18 0x0360 2 4
i2cread 2 0x18 0x0364 2 4
i2cread 2 0x18 0x0368 2 4
i2cread 2 0x18 0x036C 2 4
i2cread 2 0x18 0x0370 2 4
i2cread 2 0x18 0x0374 2 4
i2cread 2 0x18 0x0378 2 4
i2cread 2 0x18 0x037C 2 4
i2cread 2 0x18 0x0380 2 4
i2cread 2 0x18 0x0384 2 4
i2cread 2 0x18 0x0388 2 4
i2cread 2 0x18 0x038C 2 4
i2cread 2 0x18 0x0390 2 4
i2cread 2 0x18 0x0394 2 4
i2cread 2 0x18 0x0398 2 4
i2cread 2 0x18 0x039C 2 4
i2cread 2 0x18 0x03A0 2 4
i2cread 2 0x18 0x03A4 2 4
i2cread 2 0x18 0x03A8 2 4
i2cread 2 0x18 0x03AC 2 4
i2cread 2 0x18 0x03B0 2 4
i2cread 2 0x18 0x03B4 2 4
i2cread 2 0x18 0x03B8 2 4
i2cread 2 0x18 0x03BC 2 4
i2cread 2 0x18 0x03C0 2 4
i2cread 2 0x18 0x03C4 2 4
i2cread 2 0x18 0x03C8 2 4
i2cread 2 0x18 0x03CC 2 4
i2cread 2 0x18 0x03D0 2 4
i2cread 2 0x18 0x03D4 2 4
i2cread 2 0x18 0x03D8 2 4
i2cread 2 0x18 0x03DC 2 4
i2cread 2 0x18 0x03E0 2 4
i2cread 2 0x18 0x03E4 2 4
i2cread 2 0x18 0x03E8 2 4
i2cread 2 0x18 0x03EC 2 4
i2cread 2 0x18 0x03F0 2 4
i2cread 2 0x18 0x03F4 2 4
i2cread 2 0x18 0x03F8 2 4
i2cread 2 0x18 0x03FC 2 4
i2cread 2 0x18 0x0400 2 4
i2cread 2 0x18 0x0404 2 4
i2cread 2 0x18 0x0408 2 4
i2cread 2 0x18 0x040C 2 4
i2cread 2 0x18 0x0410 2 4
i2cread 2 0x18 0x0414 2 4
i2cread 2 0x18 0x0418 2 4
i2cread 2 0x18 0x041C 2 4
i2cread 2 0x18 0x0420 2 4
i2cread 2 0x18 0x0424 2 4
i2cread 2 0x18 0x0428 2 4
i2cread 2 0x18 0x042C 2 4
i2cread 2 0x18 0x0430 2 4
i2cread 2 0x18 0x0434 2 4
i2cread 2 0x18 0x0438 2 4
i2cread 2 0x18 0x043C 2 4
i2cread 2 0x18 0x0440 2 4
i2cread 2 0x18 0x0444 2 4
i2cread 2 0x18 0x0448 2 4
i2cread 2 0x18 0x044C 2 4
i2cread 2 0x18 0x0450 2 4
i2cread 2 0x18 0x0454 2 4
i2cread 2 0x18 0x0458 2 4
i2cread 2 0x18 0x045C 2 4
i2cread 2 0x18 0x0460 2 4
i2cread 2 0x18 0x0464 2 4
i2cread 2 0x18 0x0468 2 4
i2cread 2 0x18 0x046C 2 4
i2cread 2 0x18 0x0470 2 4
i2cread 2 0x18 0x0474 2 4
i2cread 2 0x18 0x0478 2 4
i2cread 2 0x18 0x047C 2 4
i2cread 2 0x18 0x0480 2 4
i2cread 2 0x18 0x0484 2 4
i2cread 2 0x18 0x0488 2 4
i2cread 2 0x18 0x048C 2 4
i2cread 2 0x18 0x0490 2 4
i2cread 2 0x18 0x0494 2 4
i2cread 2 0x18 0x0498 2 4
i2cread 2 0x18 0x049C 2 4
i2cread 2 0x18 0x04A0 2 4
i2cread 2 0x18 0x04A4 2 4
i2cread 2 0x18 0x04A8 2 4
i2cread 2 0x18 0x04AC 2 4
i2cread 2 0x18 0x04B0 2 4
i2cread 2 0x18 0x04B4 2 4
i2cread 2 0x18 0x04B8 2 4
i2cread 2 0x18 0x04BC 2 4
i2cread 2 0x18 0x04C0 2 4
i2cread 2 0x18 0x04C4 2 4
i2cread 2 0x18 0x04C8 2 4
i2cread 2 0x18 0x04CC 2 4
i2cread 2 0x18 0x04D0 2 4
i2cread 2 0x18 0x04D4 2 4
i2cread 2 0x18 0x04D8 2 4
i2cread 2 0x18 0x04DC 2 4
i2cread 2 0x18 0x04E0 2 4
i2cread 2 0x18 0x04E4 2 4
i2cread 2 0x18 0x04E8 2 4
i2cread 2 0x18 0x04EC 2 4
i2cread 2 0x18 0x04F0 2 4
i2cread 2 0x18 0x04F4 2 4
i2cread 2 0x18 0x04F8 2 4
i2cread 2 0x18 0x04FC 2 4
i2cread 2 0x18 0x0500 2 4
i2cread 2 0x18 0x0504 2 4
i2cread 2 0x18 0x0508 2 4
i2cread 2 0x18 0x050C 2 4
i2cread 2 0x18 0x0510 2 4
i2cread 2 0x18 0x0514 2 4
i2cread 2 0x18 0x0518 2 4
```

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i2cread 2 0x18 0x051C 2 4
i2cread 2 0x18 0x0520 2 4
i2cread 2 0x18 0x0524 2 4
i2cread 2 0x18 0x0528 2 4
i2cread 2 0x18 0x052C 2 4
i2cread 2 0x18 0x0530 2 4
i2cread 2 0x18 0x0534 2 4
i2cread 2 0x18 0x0538 2 4
i2cread 2 0x18 0x053C 2 4
i2cread 2 0x18 0x0540 2 4
i2cread 2 0x18 0x0544 2 4
i2cread 2 0x18 0x0548 2 4
i2cread 2 0x18 0x054C 2 4
i2cread 2 0x18 0x0550 2 4
i2cread 2 0x18 0x0554 2 4
i2cread 2 0x18 0x0558 2 4
i2cread 2 0x18 0x055C 2 4
i2cread 2 0x18 0x0560 2 4
i2cread 2 0x18 0x0564 2 4
i2cread 2 0x18 0x0568 2 4
i2cread 2 0x18 0x056C 2 4
i2cread 2 0x18 0x0570 2 4
i2cread 2 0x18 0x0574 2 4
i2cread 2 0x18 0x0578 2 4
i2cread 2 0x18 0x057C 2 4
i2cread 2 0x18 0x0580 2 4
i2cread 2 0x18 0x0584 2 4
i2cread 2 0x18 0x0588 2 4
i2cread 2 0x18 0x058C 2 4
i2cread 2 0x18 0x0590 2 4
i2cread 2 0x18 0x0594 2 4
i2cread 2 0x18 0x0598 2 4
i2cread 2 0x18 0x059C 2 4
i2cread 2 0x18 0x05A0 2 4
i2cread 2 0x18 0x05A4 2 4
i2cread 2 0x18 0x05A8 2 4
i2cread 2 0x18 0x05AC 2 4
i2cread 2 0x18 0x05B0 2 4
i2cread 2 0x18 0x05B4 2 4
i2cread 2 0x18 0x05B8 2 4
i2cread 2 0x18 0x05BC 2 4
i2cread 2 0x18 0x05C0 2 4
i2cread 2 0x18 0x05C4 2 4
i2cread 2 0x18 0x05C8 2 4
i2cread 2 0x18 0x05CC 2 4
i2cread 2 0x18 0x05D0 2 4
i2cread 2 0x18 0x05D4 2 4
i2cread 2 0x18 0x05D8 2 4
i2cread 2 0x18 0x05DC 2 4
i2cread 2 0x18 0x05E0 2 4
i2cread 2 0x18 0x05E4 2 4
i2cread 2 0x18 0x05E8 2 4
i2cread 2 0x18 0x05EC 2 4
i2cread 2 0x18 0x05F0 2 4
i2cread 2 0x18 0x05F4 2 4
i2cread 2 0x18 0x05F8 2 4
i2cread 2 0x18 0x05FC 2 4
i2cread 2 0x18 0x0600 2 4
i2cread 2 0x18 0x0604 2 4
i2cread 2 0x18 0x0608 2 4
i2cread 2 0x18 0x060C 2 4
i2cread 2 0x18 0x0610 2 4
i2cread 2 0x18 0x0614 2 4
i2cread 2 0x18 0x0618 2 4
i2cread 2 0x18 0x061C 2 4
i2cread 2 0x18 0x0620 2 4
i2cread 2 0x18 0x0624 2 4
i2cread 2 0x18 0x0628 2 4
i2cread 2 0x18 0x062C 2 4
i2cread 2 0x18 0x0630 2 4
i2cread 2 0x18 0x0634 2 4
i2cread 2 0x18 0x0638 2 4
i2cread 2 0x18 0x063C 2 4
i2cread 2 0x18 0x0640 2 4
i2cread 2 0x18 0x0644 2 4
i2cread 2 0x18 0x0648 2 4
i2cread 2 0x18 0x064C 2 4
i2cread 2 0x18 0x0650 2 4
i2cread 2 0x18 0x0654 2 4
i2cread 2 0x18 0x0658 2 4
i2cread 2 0x18 0x065C 2 4
i2cread 2 0x18 0x0660 2 4
i2cread 2 0x18 0x0664 2 4
i2cread 2 0x18 0x0668 2 4
i2cread 2 0x18 0x066C 2 4
i2cread 2 0x18 0x0670 2 4
i2cread 2 0x18 0x0674 2 4
i2cread 2 0x18 0x0678 2 4
i2cread 2 0x18 0x067C 2 4
i2cread 2 0x18 0x0680 2 4
i2cread 2 0x18 0x0684 2 4
i2cread 2 0x18 0x0688 2 4
i2cread 2 0x18 0x068C 2 4
i2cread 2 0x18 0x0690 2 4
i2cread 2 0x18 0x0694 2 4
i2cread 2 0x18 0x0698 2 4
i2cread 2 0x18 0x069C 2 4
i2cread 2 0x18 0x06A0 2 4
i2cread 2 0x18 0x06A4 2 4
i2cread 2 0x18 0x06A8 2 4
i2cread 2 0x18 0x06AC 2 4
i2cread 2 0x18 0x06B0 2 4
i2cread 2 0x18 0x06B4 2 4
i2cread 2 0x18 0x06B8 2 4
i2cread 2 0x18 0x06BC 2 4
i2cread 2 0x18 0x06C0 2 4
i2cread 2 0x18 0x06C4 2 4
i2cread 2 0x18 0x06C8 2 4
i2cread 2 0x18 0x06CC 2 4
i2cread 2 0x18 0x06D0 2 4
i2cread 2 0x18 0x06D4 2 4
i2cread 2 0x18 0x06D8 2 4
```

```
i2cread 2 0x18 0x06DC 2 4
i2cread 2 0x18 0x06E0 2 4
i2cread 2 0x18 0x06E4 2 4
i2cread 2 0x18 0x06E8 2 4
i2cread 2 0x18 0x06EC 2 4
i2cread 2 0x18 0x06F0 2 4
i2cread 2 0x18 0x06F4 2 4
i2cread 2 0x18 0x06F8 2 4
i2cread 2 0x18 0x06FC 2 4
i2cread 2 0x18 0x0700 2 4
i2cread 2 0x18 0x0704 2 4
i2cread 2 0x18 0x0708 2 4
i2cread 2 0x18 0x070C 2 4

i2cwrite 3 0x40 0x4000 2 1 0x17
i2cread 3 0x40 0x4001 2 1
i2cread 3 0x40 0x4002 2 1
msecdelay 100
i2cwrite 3 0x40 0x4000 2 1 0x16
i2cread 3 0x40 0x4001 2 1
i2cread 3 0x40 0x4002 2 1
msecdelay 100
i2cwrite 3 0x40 0x4000 2 1 0x1B
i2cread 3 0x40 0x4001 2 1
i2cread 3 0x40 0x4002 2 1
msecdelay 100
i2cwrite 3 0x40 0x4000 2 1 0x1A
i2cread 3 0x40 0x4001 2 1
i2cread 3 0x40 0x4002 2 1

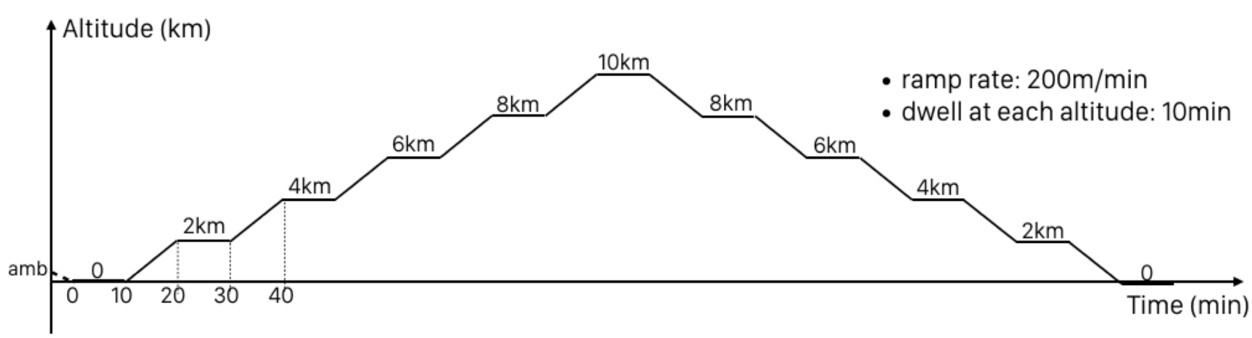
msecdelay 100
off
delay 1
q
```

J. Compliance Validation DOE

During engineering builds, in order to make sure the MB capacitance function meets design requirement, and the budget for capacitance drift is set reasonably, a series of MB cap sense DOE is planed, as part of the LHZ-free and OK2Ramp validation requirement. Such DOEs consist of module level and system level testings.

J.1. Cap Drift Over Environmental Conditions

In-situ cap reading is collected by running the cap logger script on systems, while they are in the environmental chambers. Two environmental variables are studied: over temperature and over altitude. Below is the chamber profile setting:

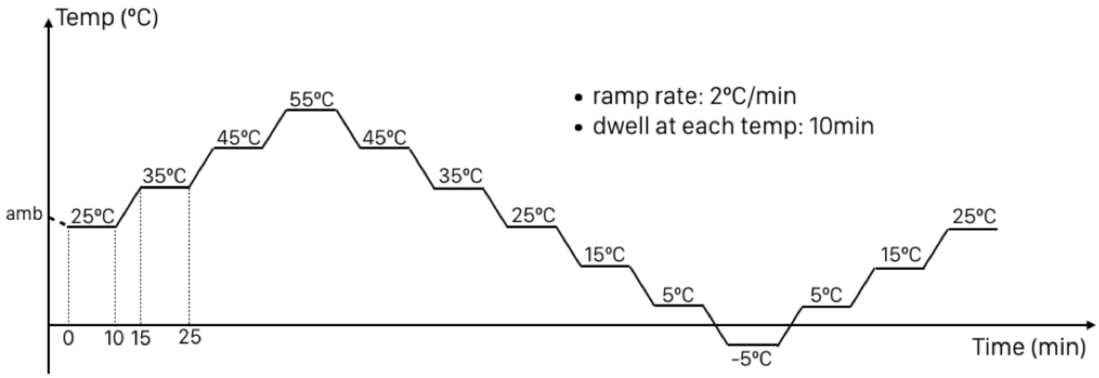


Temperature profile (RH: UNC, Altitude: UNC, 1 atm)

Altitude profile (temperature: 25°C, RH: UNC)

DOE SOP:

- Make sure sys



- Make sure system charged, and transfer the cap logger script to system (file transfer SOP can be found in Appendix B)
- Use iOS Menu to ssh to system, then use the following command to start cap logger
    - cd Caplogger/cap_bg_logger
    - ./start_long
- Run above environmental chamber profile with units powered on.
- Stop cap logger script after chamber test, using the following command:
    - ./stop_long
- collect logs and upload to radar

Log file naming protocol:
NumOfPcs_ConfigCode_TestCondition/UnitNum_SerialNumber_TestCondition/RawLogFileName
Example:
63pcs_4S5G2_After Alpha/8654_C39WQ01XK946_After Alpha/LONG_BRICK_CAPLOG.C39WQ01XK946.20180526122206.csv
Cap logger script available @ rdar://problem/34374668

K. File transfer using rsync command

During FA or DOE, it's ofter required to transfer files between a mac computer and the phone system. This SOP describes one way of doing such file transfer to and from DUT phone, using rsync command (standard Linux system command).

Make sure iOS menu is installed on the local mac
connect the DUT, and confirm iOS menu detected the connection
click the iOS menu icon and select *Preferences,* from the list of devices, find the connected one and the its Port Offset value. Default Port Offset is 10022.
The command to transfer file from mac to DUT is

```
RSYNC_PASSWORD=alpine rsync -avP LocalFileName rsync://
root@localhost:PortNumRemotePathName
```

Where,
LocalFileName is the location of the file to be transferred;
PortNumber is composed of the first two digit in the Port Offset and 873. For example, if the Port Offset is 10022, the corresponding PortNumber is 10873.
RemoteFileName is the abs path for the file on DUT.
A typical complete command could be:

```
RSYNC_PASSWORD=alpine rsync -avP ./* rsync://root@localhost:10873/root/var/root/Pearl/
```

Likewise, the command to transfer files from DUT to local computer could be

```
RSYNC_PASSWORD=alpine rsync -avP  rsync://root@localhost:10873/root/var/root/Pearl/ ./
```

Change History

Version	Description	Date	By
1	Original document based on J4xx Pearl ERS	3/27/20	P. Lu
2	Nomenclature update: Rack 1->Rack 4, Rack 2->Rack 5 Rack 4 specs - CamAng_1: [1.5, 4.5] -> [-1.5, 1.5] (new bracket) - RGBdist_0 USL: 1.5 -> 5 - RGBdist_1 USL: 1.5-> 15 - RGBdist_2 USL: 1.82-> 32 (new FCAM) Flow diagram update to reflect new Rack numbering	4/8/20	P. Lu
3	Rack 4 specs. Te be reevaluated after P1. - RGBdist_0 USL: 5 -> 10 - RGBdist_1 USL: 15-> 20 - RGBdist_2 USL: 32-> 50 (new FCAM) - RGBreprojectionError USL: 0.5 -> 1.5 (new FCAM)	4/9/20	P. Lu