TMT-APS Use Cases

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TMT-APS Use Cases

1 Use Case Introduction

This document contains the use cases and activities for Alignment and Phasing System (APS). Use cases are high level procedures APS uses to perform various telescope alignments and calibrations. In general, use cases are made up of one or more *activities*. Examples of use cases are "Post Segment-Exchange Alignment" and "APS pre-observing internal calibrations". Example activities include "Coarse Tilt Alignment", "Broad Band Phasing", and "Narrow Band Phasing".

This document does not cover use cases that are specific to Assembly, Integrate and Verify (AIV) or commissioning. Those cases will be detailed in the APS integration and test plan. In addition this document does not currently cover off-nominal use cases.

1.1 Purpose

The goal is to use this document to communicate with other TMT sub-systems how we plan to operate APS in order to align and phase the telescope. These use cases and activities will also be used to help develop, derive and verify interfaces to external sub-systems, APS requirements, APS software requirements and requirements on other telescope sub-systems.

1.2 Overview

The Alignment and Phasing System (APS) is a Shack-Hartmann wavefront sensor responsible for the sensing and comanding of the pre-adaptive-optics wavefront quality of the Thirty Meter Telescope (TMT). In order to produce wavefronts of acceptable quality, APS will adjust the following parameters as required: segment pistons and tip/tilts, segment surface figure (via warping harness adjustments), rigid body degrees of freedom M3, and 3 of the rigid body degrees of freedom of M2 (piston/tip/tilt or alternatively piston/x and y translation).

The APS design and concept is based upon that of the Phasing Camera System (PCS), which plays a similar role for the Keck Observatory telescopes. APS will use algorithms similar, but more generalized and improved, to those developed and used successfully by PCS at Keck. The resulting APS solutions will be stored as desired sensor readings for M1 or desired actuator settings for M2 and M3. These data can be analyzed as a function of recorded elevation and/or temperature so that the appropriate calibrations can be constructed for nominal elevation and temperature corrections. (Note, however, that the construction of these calibration from the APS data is not itself an APS responsibility.)

The following list provides a brief overview of the APS use cases. Detailed explanations are provided for each of them in Chapter 2 of this document.

1. Post segment-exchange alignment: This use case re-aligns the telescope after new segments have been installed or exchanged. The current TMT baseline is that during normal operations ~8 segments will be exchanged in a single day every two weeks. That night this use case will be run to re-align the telescope. This use case nominally takes 2 hours to execute and would be started as soon as possible after the sun sets. Our current estimate is this procedure could be started 20 minutes (TBR) after sunset.

2. Maintenance alignment: This use case is used to re-align the telescope inbetween segment exchanges, as a type of tune-up alignment. The end result is the same as the Post segment-exchange alignment use case; however, this use case has a smaller capture range for segment piston, tip and tilt errors. The current TMT baseline calls for the telescope being aligned by APS at least monthly. So, if there are no segments exchanged in a given month then this use case would be executed. In addition this use case can be used to check/adjust the alignment just before specific observations that are very sensitive to wavefront errors. This use case nominally takes 30 minutes to execute.

3. Rigid body M3 alignment: APS has a requirement to align M3 in rigid body motion. The main impact of M3 motion is pupil motion, which APS can measure. This use case will align M3 at a single elevation angle. It is possible that the functionality of this use case can be combined as part of the maintenance and post-segment exchange use cases. Note that currently the APS requirements on pupil alignment accuracy are TBD.

4. Off-axis wavefront measurements: This use case is used to make off-axis wavefront measurements at any point in the telescope field of view. It will be used to diagnose telescope problems as well as confirm the telescope performance off-axis.

5. Measurement of segment warping harness influence functions: This use case will be used to make on-sky measurements of the segment warping harness influence functions. These measurements, potentially combined with the analytical influence functions, will be used to generate the control matrix for the warping harness used in the correcting rigid body and segment figure activity. This use case will likely only need to be executed during AIV, trouble shooting and/or periodically (yearly) to confirm the warping harness influence function aren't changing with time.

6. APS pre-observing checkout: This use case will execute a series of APS tests using internal light sources to confirm that it is functioning correctly. This standard procedure will be to execute this use case the day before a segment exchange starts in order to minimize telescope down time due to any APS problems. It will also be executed the day before any planned APS maintenance alignments

7. M1CS Sensor Calibration with Post Segment-Exchange Alignment: After segments are exchanged it will be necessary to perform calibration of the M1CS sensors. This use case will first execute the post segment-exchange alignment at a single elevation angle. After that the telescope is aligned at two additional elevation angles. At each elevation angle the segments are aligned in tip/tilt, broadband phasing is run with a 1 micron capture range and then narrowband phasing.

8. Collection of M2 and M3 gravity calibration data: This use case will align M2 and M3 at multiple elevation angles in order to provide the data needed for generation of calibration of M2 and M3 motion with telescope elevation angle. APS is responsible for collecting this data, but the other sub-systems are responsible for using this data to generate the needed calibrations.

9. APS pre-observing internal calibrations: There are several internal APS calibrations that need to be performed either before or during observing. The majority if not all of these can be executed using internal light sources during the day in an automated fashion. This use case is designed to execute these calibrations in order to minimize APS on-sky time.

1.3 Modeling Approach and Context

The information about APS operational scenarios is captured by following the Object Oriented System Engineering Method (OOSEM) in the Systems Modeling Language (SysML)
and leveraging executable models. This approach allows to carry out system level simulation of the system model in order to analyze the system architecture and design in terms
of temporal constraints and mass and power consumption w/r/t system requirements.

The following chapters give an overview of the principles of how information is captured, organized and analyzed. Furthermore the context of the subsequent use cases is defined which will help them understand and follow better.

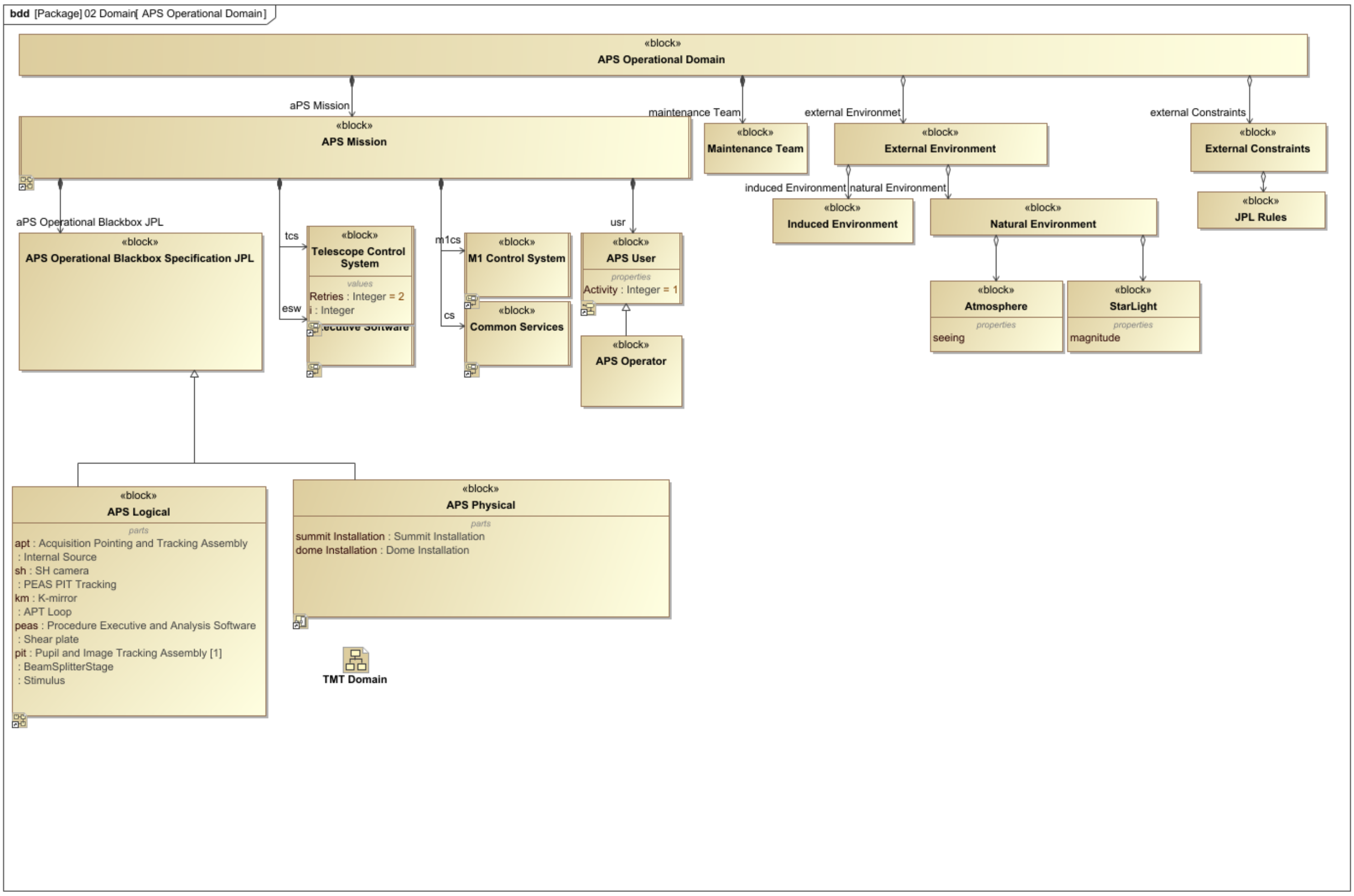
1.3.1 APS Operational Domain

OOSEM defines the following elements to define an architecture:

1. Operational Domain
   The operational domain specifies the context in which the mission (in our case aligning and phasing of the TMT) exists. The mission interacts with the context in some way or is constrained by it in some way.
2. Mission
   The mission encompasses all elements which are needed to achieve the goals (alignment and phasing). It encompasses elements which are external to APS (e.g. M1CS, TCS) and APS itself.
3. Black Box Specification
   The black box specification describes the functions, interfaces, measure of performance and other associated requirements without making assumptions about its internals. It defines
   the boundary of the system to be delivered (the system of interest) and the rest of the mission.
   The black box specification exists in two forms. A black blox specification provided by the customer which describes what the customer expects and a black box specification provided by the supplier which must
   comply with the customer's specification but might be more detailed, or more strict.
4. Logical Architecture
   The Logical architecture identifies Logical (synonymously used with logical or functional) elements regardless of their implementation but functionally and interface wise complying with the black box specification.
5. Physical Architecture
   The Physical architecture describes the specific implementation and technological choices which realize (implement) the Logical architecture.

The use cases and operational scenarios are defined at mission level. Their analysis helps to identify the interfaces if the APS black box, the flows in and out, its functions, and its high level behavior.
That is, what is the task of the APS black box in a particular operational scenario or use case.

APS Operational Domain

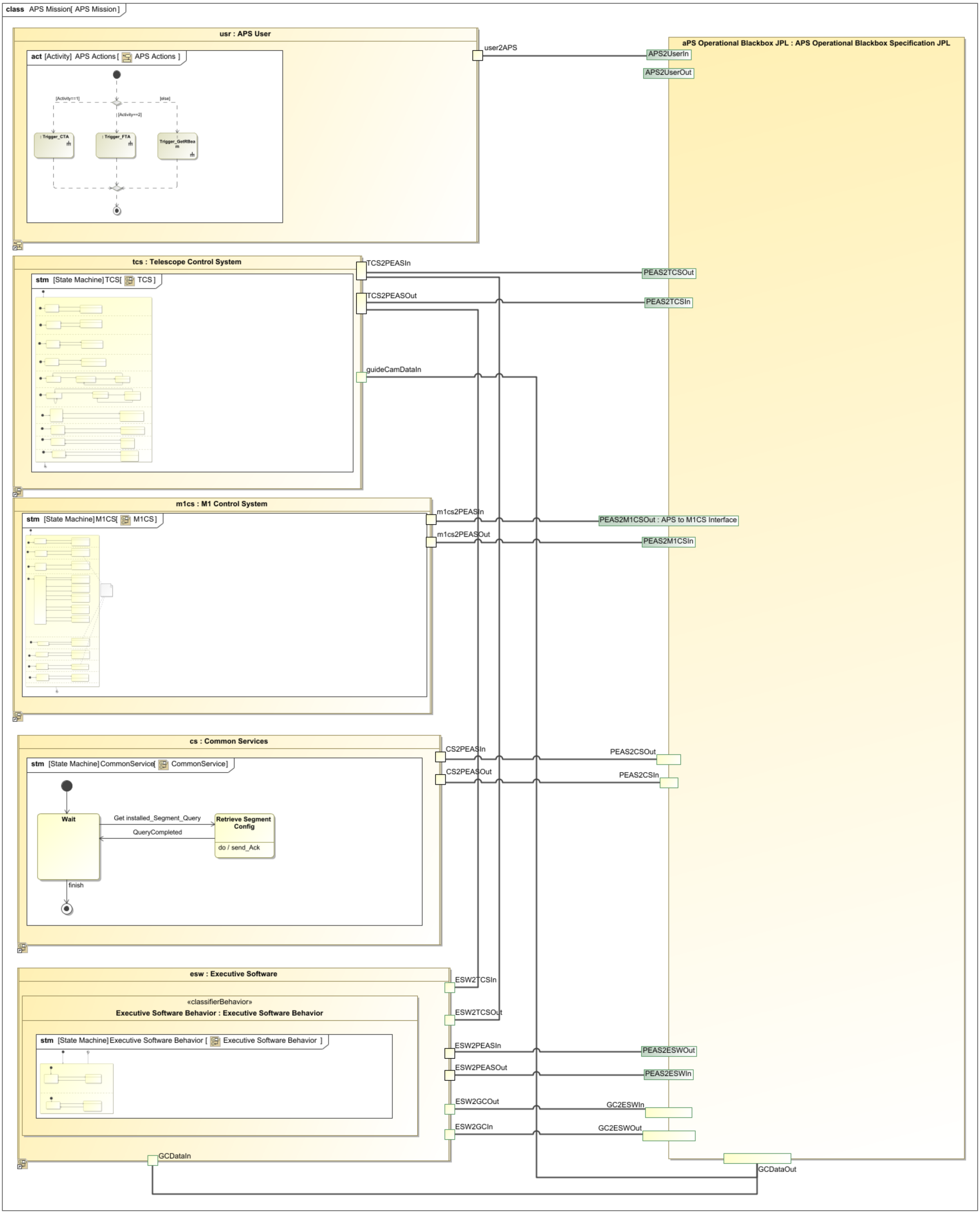


The SysML Block Definition Diagram (BDD) shows the composition hierarchy (indicated by the black diamond arrows) of the operational domain and the mission. It lists the interfaces (e.g., PEAS2M1CSOut) of the black box (SysML ports) and the Logical and Physical architectural elements which are specializations of the black box. The Logical element lists also its Logical elements (e.g., SH camera).

1.3.2 APS Mission

This section describes the structure and connections among the mission elements using a SysML internal block diagram (IBD). It shows how the elements from the BDD are connected up.

APS Mission



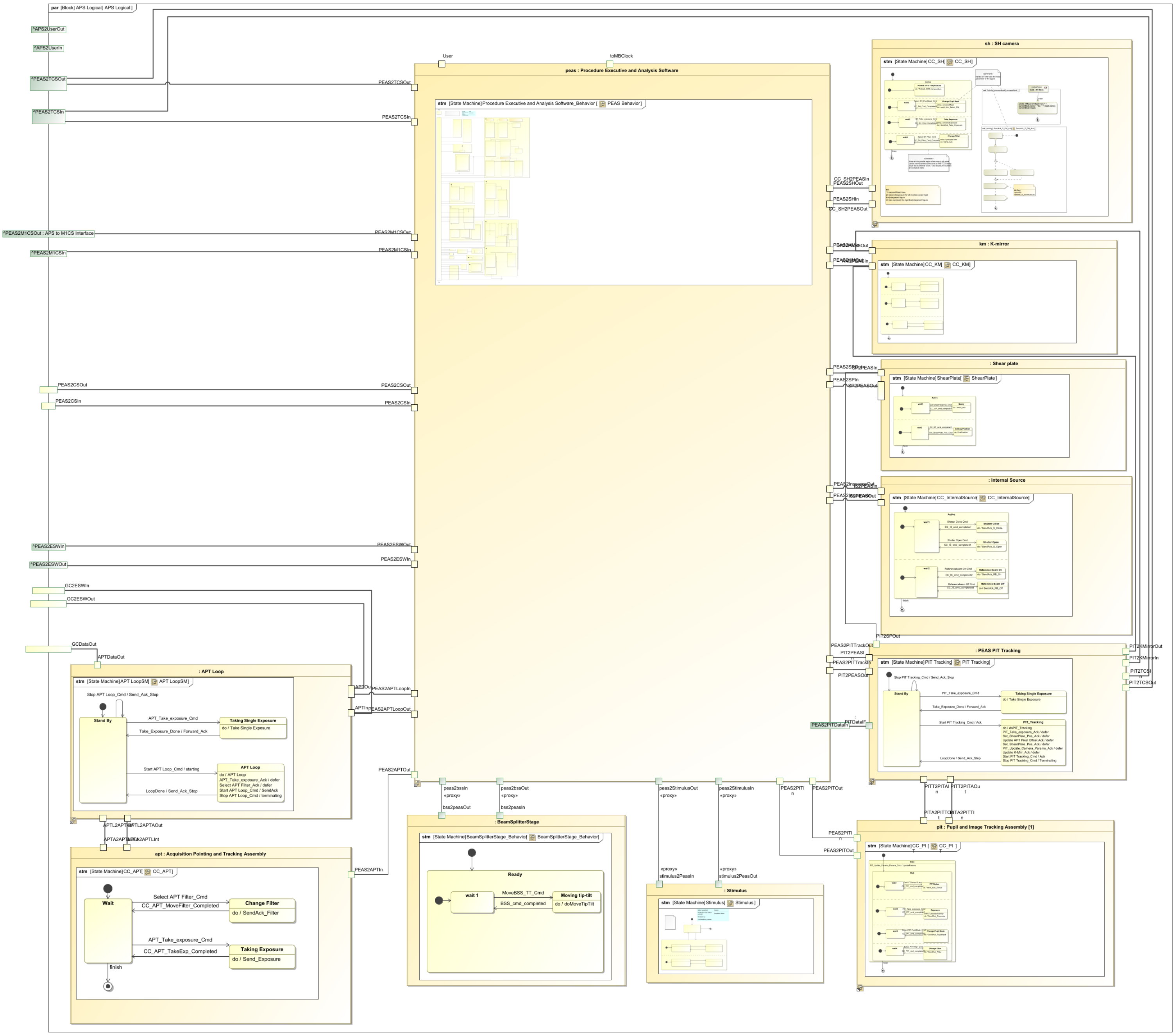
class APS Mission[APS Mission]
usr : APS User
act [Activity] APS Actions [APS Actions]
user2APS
aPS Operational Blackbox JPL : APS Operational Blackbox Specification JPL
APS2UserIn
APS2UserOut
tcs : Telescope Control System
stm [State Machine] TCS[TCS]
TCS2PEASIn
TCS2PEASOut
PEAS2TCSOut
PEAS2TCSIn
guideCamDataIn
m1cs : M1 Control System
stm [State Machine] M1CS[M1CS]
m1cs2PEASIn
m1cs2PEASOut
PEAS2M1CSOut : APS to M1CS Interface
PEAS2M1CSIn
cs : Common Services
stm [State Machine] CommonService[CommonService]
CS2PEASIn
CS2PEASOut
PEAS2CSOut
PEAS2CSIn
Wait
Get installed_Segment_Query
QueryCompleted
Retrieve Segment Config
do / send_Ack
finish
esw : Executive Software
«classifierBehavior»
Executive Software Behavior : Executive Software Behavior
stm [State Machine] Executive Software Behavior [Executive Software Behavior]
ESW2TCSIn
ESW2TCSOut
ESW2PEASIn
ESW2PEASOut
PEAS2ESWOut
PEAS2ESWIn
ESW2GCOut
ESW2GCIn
GC2ESWIn
GC2ESWOut
GCDataIn
GCDataOut

The diagram shows how the non-APS elements are connected via their interfaces to the APS black box. For most interchanges two ports exists: one where things flow out and one where things flow in. The behavior of all elements is specified with a state machine, which is visible here for all non-APS elements. For APS, behavior will be specified in the Logical Architecture. Some states have a so-called *do-behavior* which specifies what is going to happen while in this state. Sometimes you will also see *entry* and *exit* actions which specify what happens when entering or exiting a state.
do-behaviors, entry and exit actions are themselves specified with SysML activity diagrams. Those will send commands, replies (a request/response paradigm) or data (a pub/sub paradigm) across a port and a connector where it is received by another element which in turn processes the signal or data. Signals cause state transitions within the state machines. The state machines are elaborated as required to respond to a particular operational scenario or use case.

1.3.3 APS Logical

The Logical view shows the APS internal logical components and how they are interconnected. Their behavior is modeled with state machines and signals flow across ports and connectors.

APS Logical



This diagram shows the logical components of APS (e.g. Pupil and Image Tracking Assembly) and their behavior.

1.3.4 Modeling Use Cases with State Machines and Activities

Use Cases (operational scenarios) are modeled at several levels:

1. High-level mission level activities with APS as black box t provide an high level overview
2. Specifying state machines at component level for mission level and APS internal components
3. Activities specify the behavior in each state
4. Signals flow between components to trigger transitions in state machines and cause state changes.

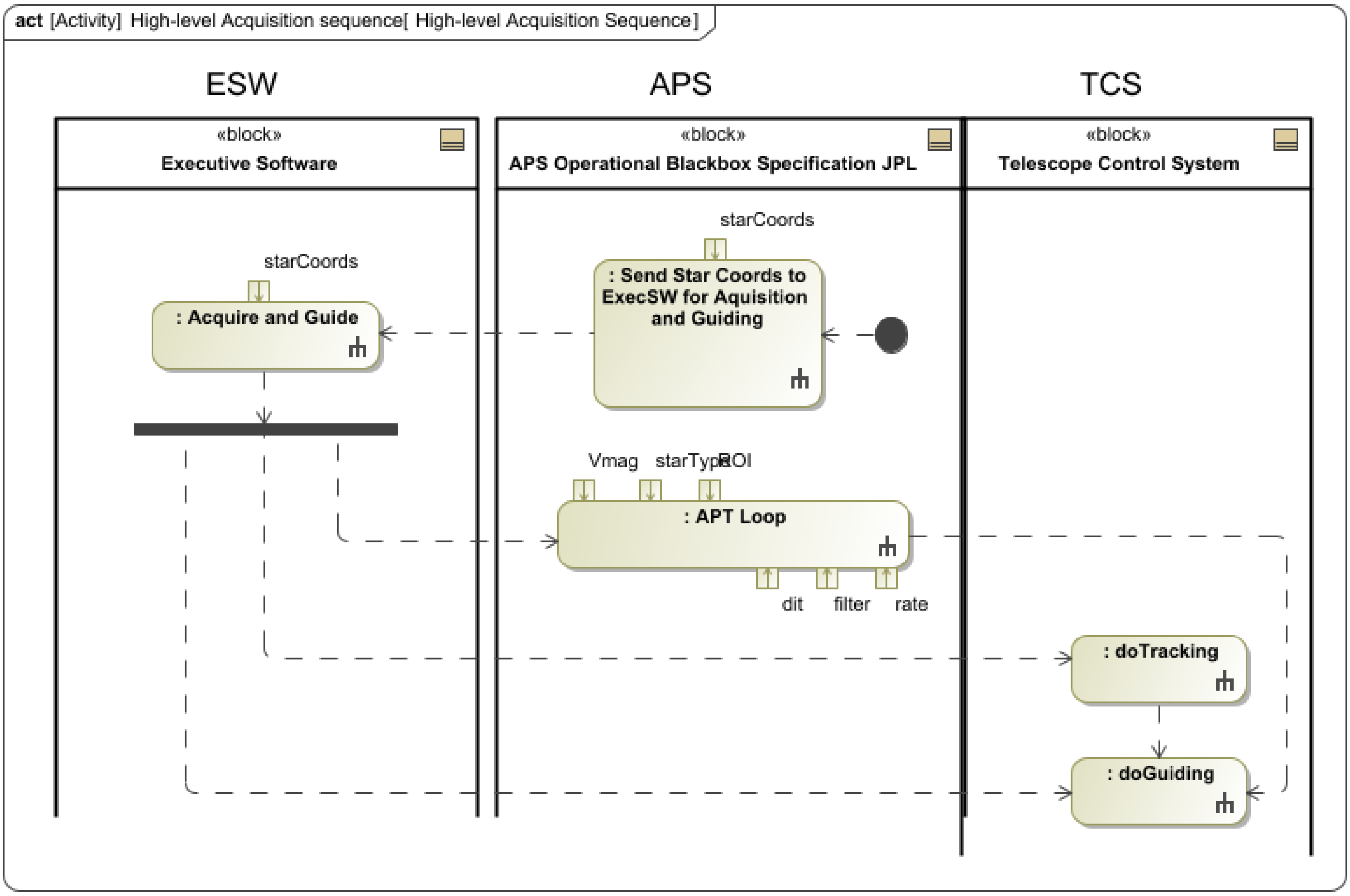
1.3.4.1 High Level

The high level operational view shows informally the most relevant interactions at mission level with the APS black box. Each swim lane represents a mission level element. In the executable model those actions might be deeply nested in do behaviors of a state of the concerned element.

Dashed lines indicate the flow of control. Black bars mean a fan-out or synchronization of control flows. If an action has more than one control flow coming in, all of them are required for it to run.

Control flows are indicative. They are actually signals sent and received by the different components, flowing over ports and connectors.

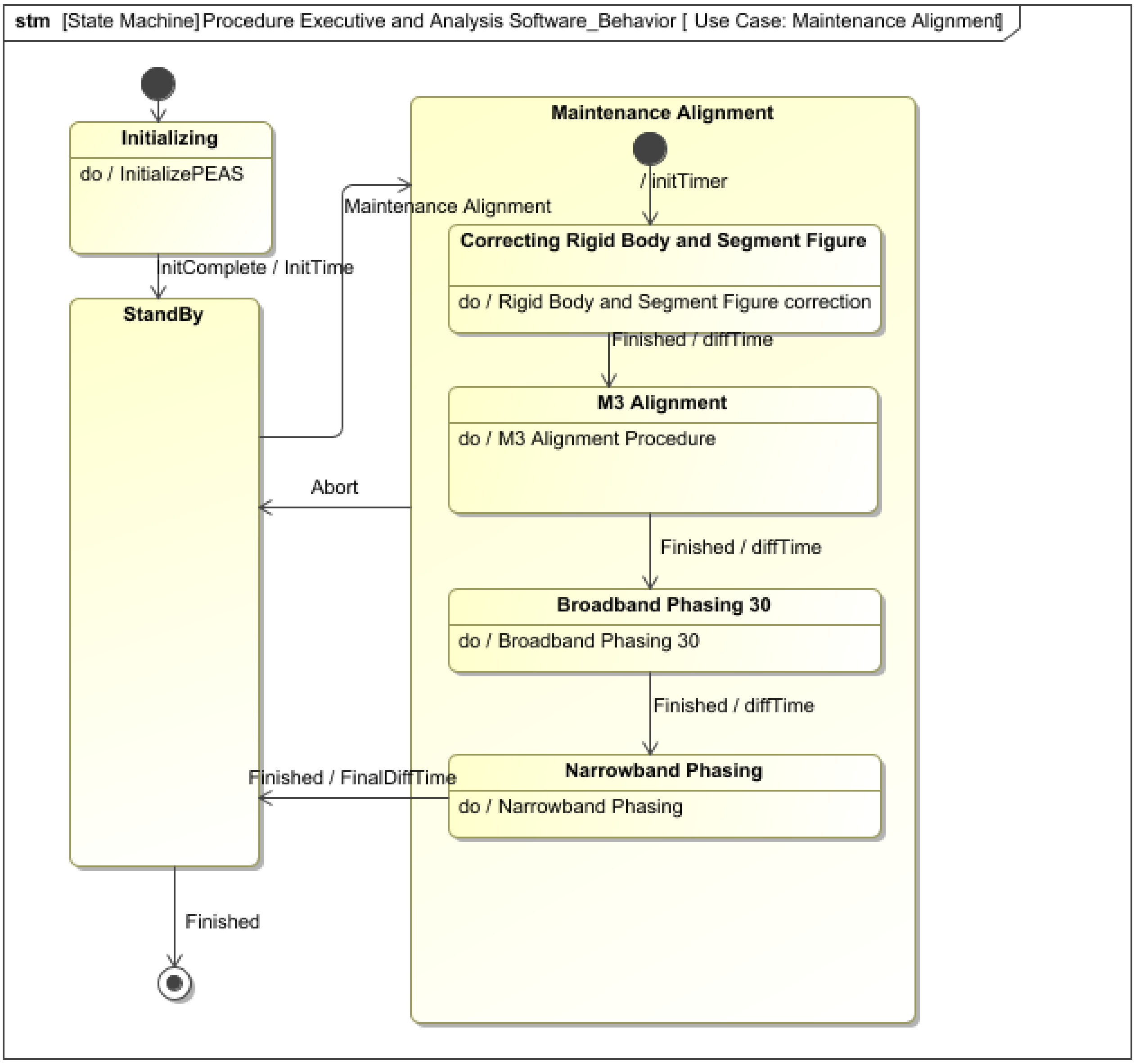
High-level Acquisition Sequence



This acquisition sequence is part of almost all APS use cases. The sequence is initiated from the APS side by sending a acquisition and guiding request to the ESW. The ESW communicates with the APS APT loop to obtain images and with the TCS to perform tracking and guiding actions.

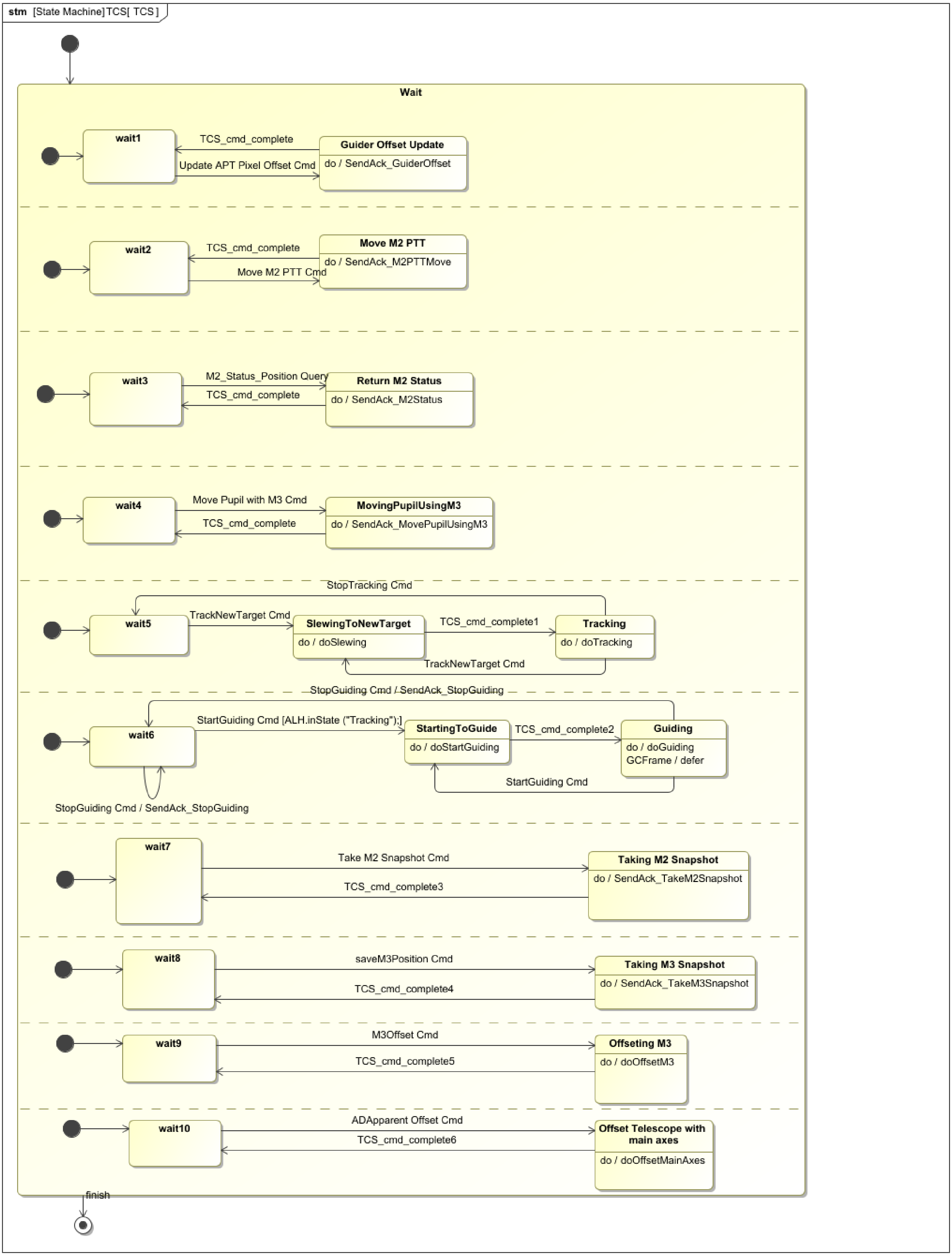
1.3.4.2 Use Case Core Behavior

Use Case: Maintenance Alignment



1.3.4.3 Component state machine

TCS



stm [State Machine]TCS[TCS]
Wait
wait1
TCS_cmd_complete
Update APT Pixel Offset Cmd
Guider Offset Update
do / SendAck_GuiderOffset
wait2
TCS_cmd_complete
Move M2 PTT Cmd
Move M2 PTT
do / SendAck_M2PTTMove
wait3
M2_Status_Position Query
TCS_cmd_complete
Return M2 Status
do / SendAck_M2Status
wait4
Move Pupil with M3 Cmd
TCS_cmd_complete
MovingPupilUsingM3
do / SendAck_MovePupilUsingM3
StopTracking Cmd
wait5
TrackNewTarget Cmd
SlewingToNewTarget
do / doSlewing
TCS_cmd_complete1
Tracking
do / doTracking
TrackNewTarget Cmd
StopGuiding Cmd / SendAck_StopGuiding
wait6
StartGuiding Cmd [ALH.inState ("Tracking");]
StartingToGuide
do / doStartGuiding
TCS_cmd_complete2
Guiding
do / doGuiding
GCFrame / defer
StartGuiding Cmd
StopGuiding Cmd / SendAck_StopGuiding
wait7
Take M2 Snapshot Cmd
TCS_cmd_complete3
Taking M2 Snapshot
do / SendAck_TakeM2Snapshot
wait8
saveM3Position Cmd
TCS_cmd_complete4
Taking M3 Snapshot
do / SendAck_TakeM3Snapshot
wait9
M3Offset Cmd
TCS_cmd_complete5
Offseting M3
do / doOffsetM3
wait10
ADApparent Offset Cmd
TCS_cmd_complete6
Offset Telescope with main axes
do / doOffsetMainAxes
finish

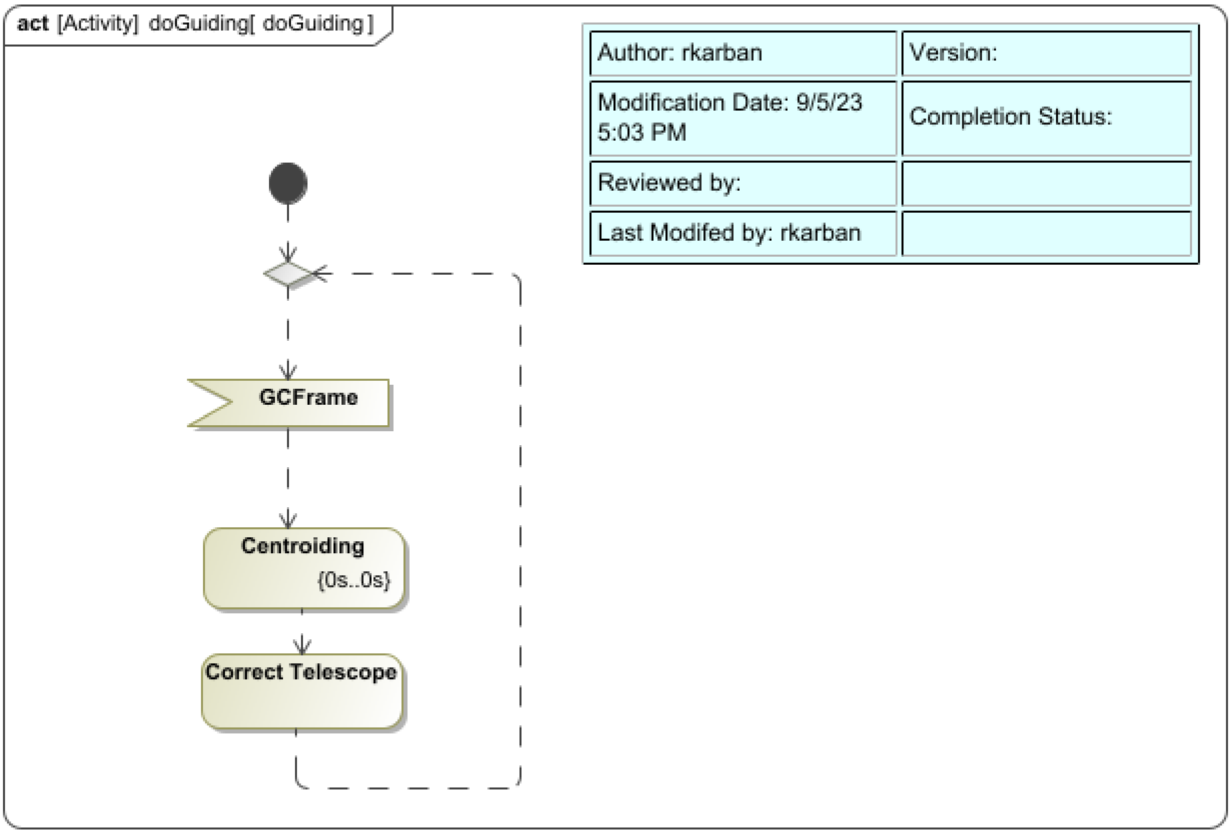
In the TCS state machine two regions take care of the tracking and guiding states.

When a command is received to slew to a new target the telescope will start moving and eventually transition into the tracking state.

If guiding is requested, TCS will start guiding, provided it is also in the state tracking (guarded transition) and eventually transition into the guiding state.

1.3.4.4 State specific behavior

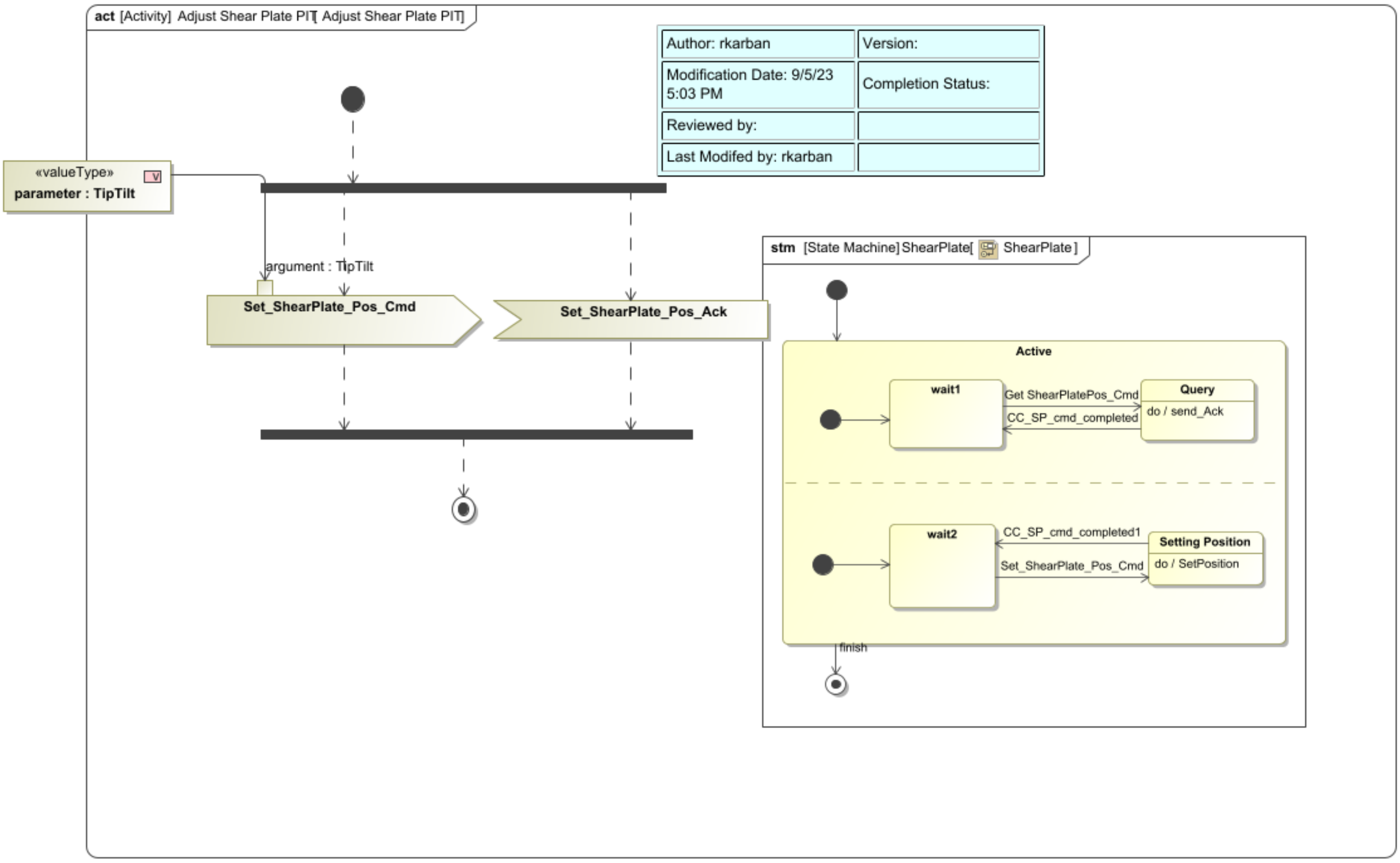
doGuiding



In the guiding state, TCS will receive frames (GCFrame) from the APS camera (taken in the APT loop) and process them, i.e. the centroiding will be done on TCS side.We assume it takes zero time because we care only about APS time in this scenarios.

The guiding reference point and plate scale is delivered by APS as part of the frame meta information.

Adjust Shear Plate PIT



In this behavior a command is sent over a particular port/interface, is processed by the receiving state machine, and waits for acknowledgement. The communication is asynchronous.

2 Use Cases

Here we show each of the top level APS use cases. These in general map directly to APS Level 1 requirements/functionality specified in the TMT OAD. Each of these use cases are comprised of lower level activities that are described in the next section. The SysML model can execute these in order to check time estimates, and track the time lapsed between each of the lower activities.

2.1 Post Segment-Exchange Alignment

2.1.1 Pupose of use case

This use case re-aligns the telescope after new segments have been installed or exchanged. The current TMT baseline is that during normal operations ~8 segments will be exchanged in a single day every two weeks. That night this use case will be run by the APS operator (typically the same person as the telescope operator) to re-align the telescope. Assuming the entrance requirements are met (all segments are within tip/tilt and piston capture range) then the time to run this test is independent of the number of “new” segments installed. Thus, this is the same use case that will nominally be used during AIV as new segments are installed and APS is used to align them.

2.1.2 Typical observing parameters

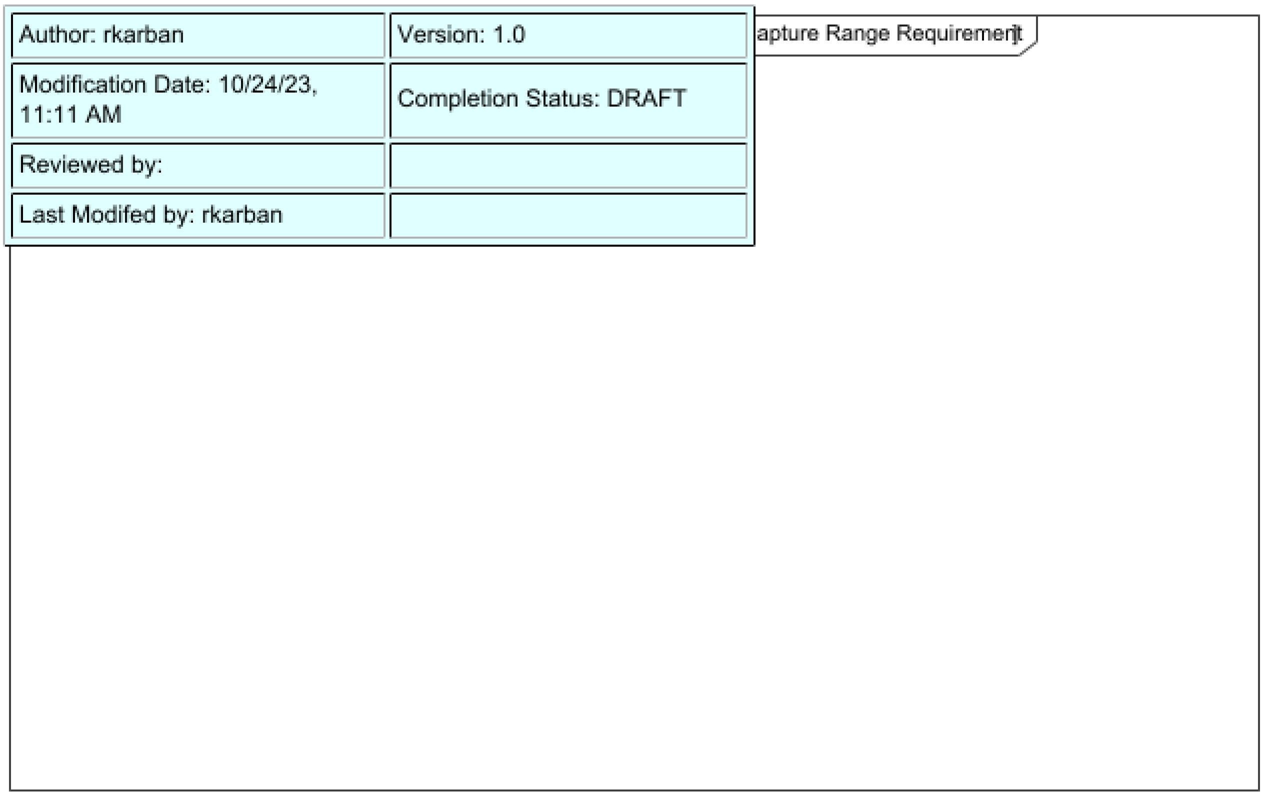
This use case will typically be executed as soon as possible after the segment exchange recovery process has completed, but no sooner then 20 minutes (TBD) after sunset. The first activity coarse alignment uses a 10nm bandwidth filter and is not very sensitive to sky background compared to the required accuracy of the measurements. Stars are usually selected to be ~1 hour East at a Declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The typical telescope elevation angle will be 70 degrees and will vary by less then a few degrees over 2 hours. The specific required star magnitudes and colors for each activity are described in Chapter 3. At Keck the required star magnitudes range between 4th and 6th magnitude (depending on the activity) and we expect the values for TMT to be similar (perhaps 0.5 magnitudes brighter). In practice we have never had problems finding stars at Keck so don't expect any problems with APS at TMT.

2.1.3 Entrance requirements and conditions

All telescope sub-systems should be operating in their nominal modes, including using the standard gravity/temperature look-up/calibration parameters. The use case "APS pre segment-exchange checkout" should have been executed the previous night and the use case "APS pre observing internal calibrations" should be executed before sunset.

The figure below shows the capture ranges that APS is required to handle for this use case.

Post-Segment Exchange Capture Range Requirement



Author: rkarban	Version: 1.0
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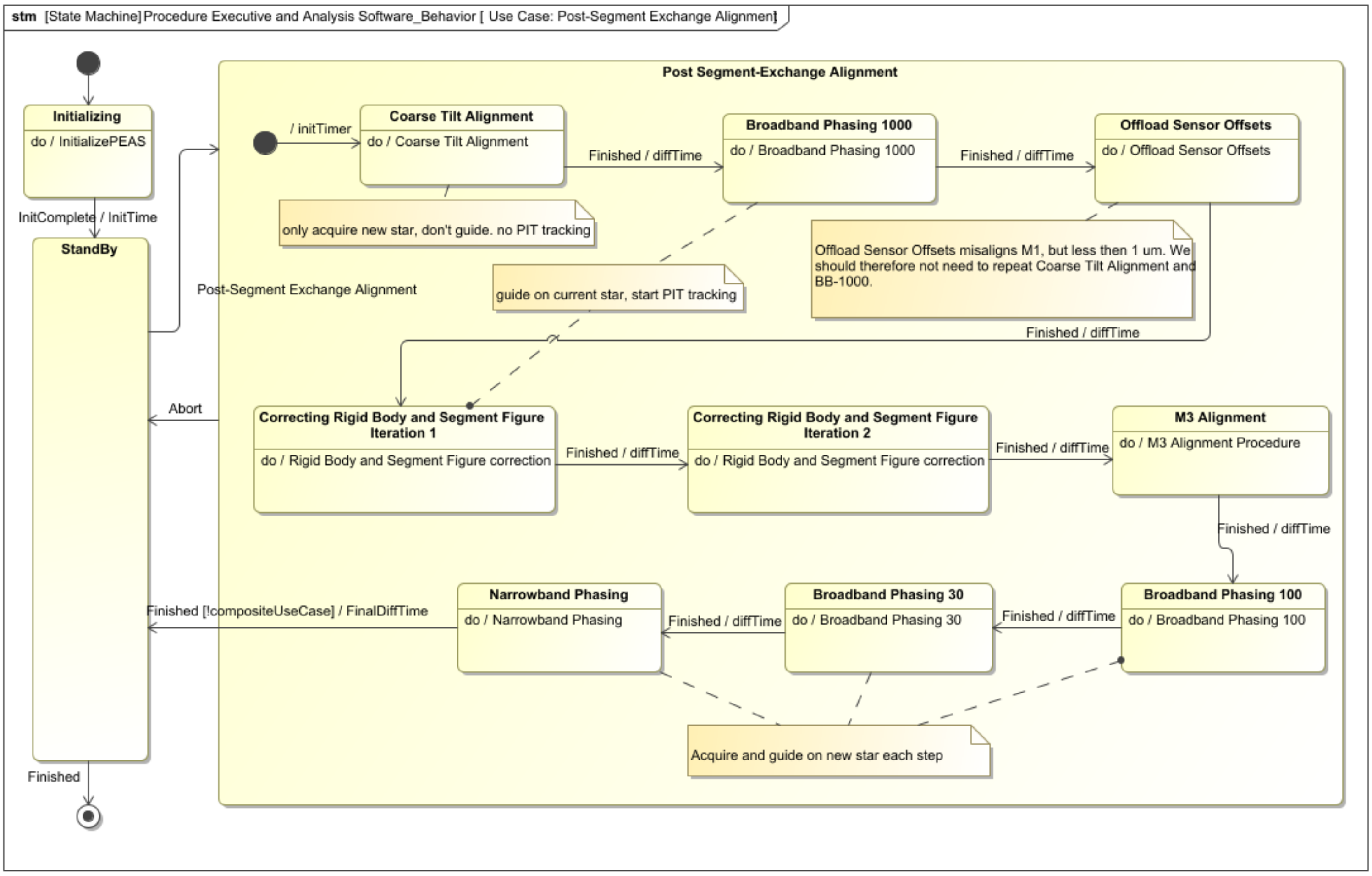
Reviewed by:	
Last Modifed by: rkarban	

2.1.4 Use case activity

The following figure shows the post-segment exchange alignment use case. It starts with APS in standby mode. A star is acquired and the coarse tilt alignment activity is executed which will capture and align the segments in tip/tilt. Once this activity has completed the broad band phasing 30 micron activity will be executed. As part of this activity the telescope will be requested to start guiding --- as we now have a single star image on the Aquisition Pointing Tracking (APT) camera --- and APS will close the Pupil-Image Tracking (PIT) loop using the same star used in the coarse tilt activity. This activity will reduce the initial segment piston errors to ~1 micron. At this point the M1CS will be commanded to minimize sensor readings to insure the M1CS sensors are in their most linear range. The next activity (Rigid body and segment figure) aligns M1 segments in tip/tilt, M2 in piston and either tip/tilt or x/y translation as well as measuring and the segment figures and correcting them via warping harness. Nominally this activity is repeat twice to allow for iteration of the segment figure adjustments. After this the segments are aligned to 30 nm RMS surface piston error using first the broad band phasing 3 micron and followed by the 1 micron activities. Each of these will require acquisition of new stars of the appropriate magnitude. The final M1 segment piston alignment is executed using the narrow band phasing activity which includes measurements with 2 different filters.

Use Case: Post-Segment Exchange Alignment

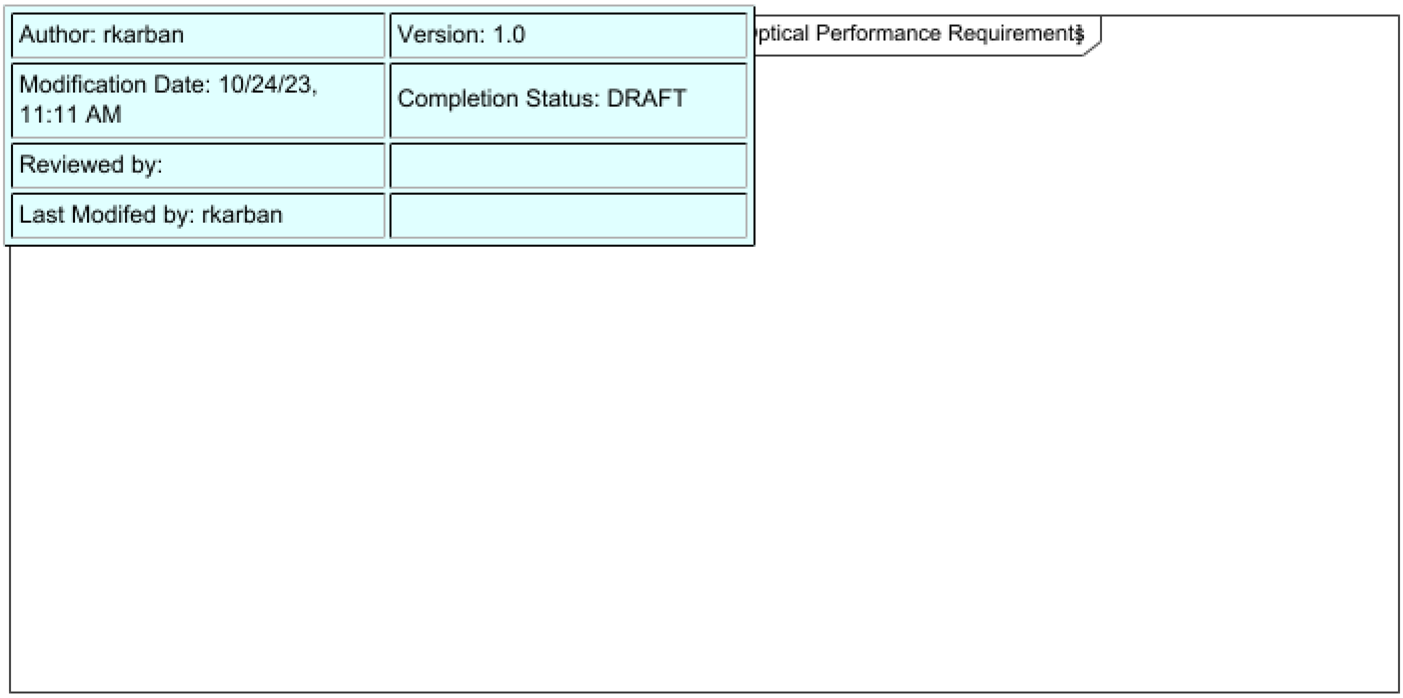


The Post-Segment Exchange Alignment activity will be executed after new segments have been added to the primary mirror.

2.1.5 Optical Performance Requirements

The following figure shows the APS Optical Performance requirements to be met at the end of the Post-Segment Exchange activity.

Post-Segment Exchange Optical Performance Requirements

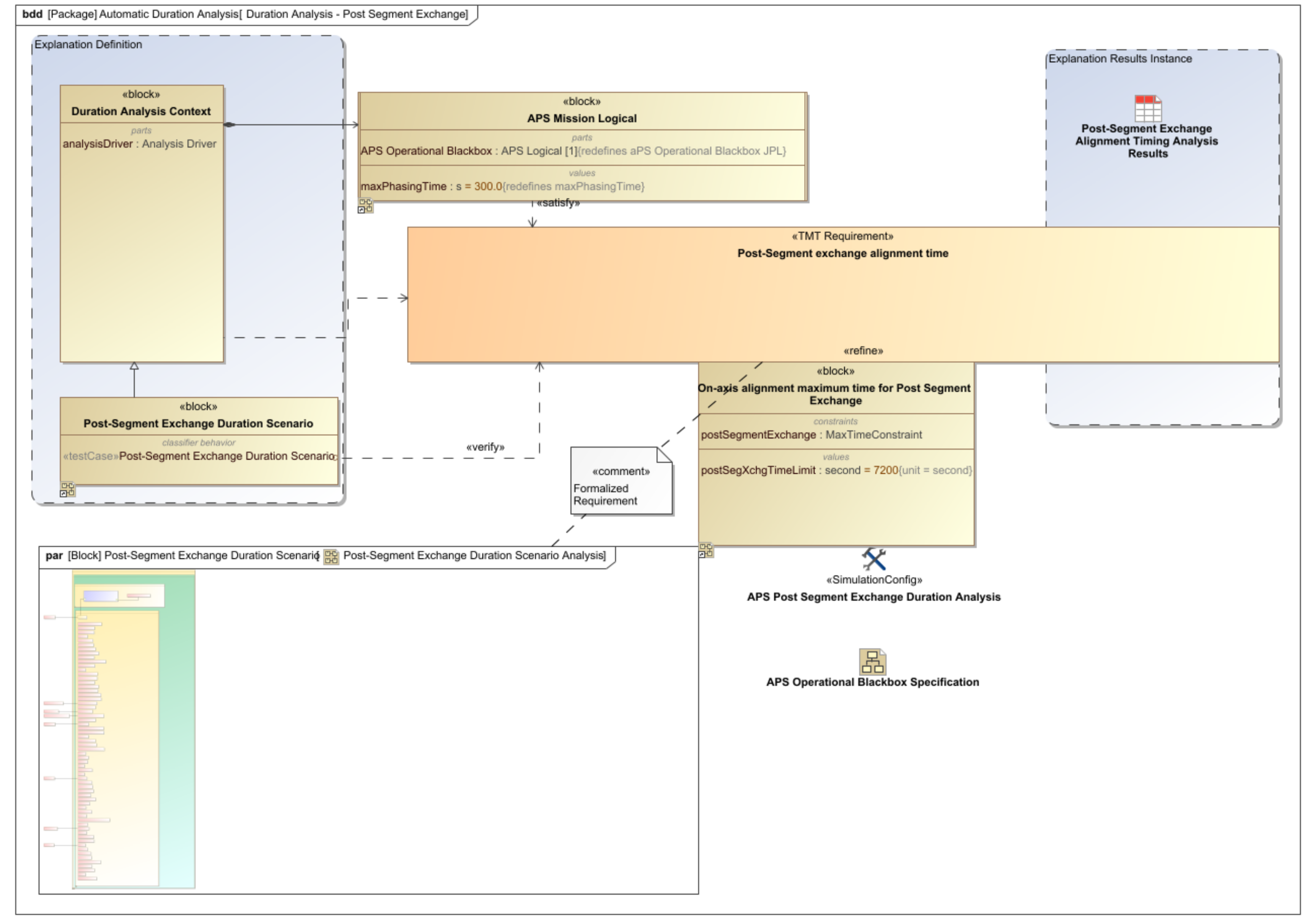


2.1.6 Time to execute

The table below shows our current bottom-up time estimate for each of the activities that make up this use case. The total time estimate is ~75 (TBR) minutes, which is to be compared with our requirement of 120 min (as shown in the figure below).

At Keck, we routinely perform post-segment exchange alignment in 120 minutes or less. However, at Keck the segment shapes are measured in a separate test, with each segment measured separately, but adjustment of the segment warping harnesses is manual and occurs the next day. We will measure the TMT segment shapes in parallel as part of the rigid body and segment figure activity and imidiatly adjust the segment shapes during the night via the motorized warping harnesses and iterate the control at least once. In addition the CCD read out time for APS is significantly faster then at Keck, ~10 vs ~55 seconds, given the post-segment exchange alignment takes ~60 frames, this accounts for 45 minutes. Given our bottom up estimate and our Keck experience we have a high degree of confidence we can met the 120 minute requirement.

Duration Analysis - Post Segment Exchange

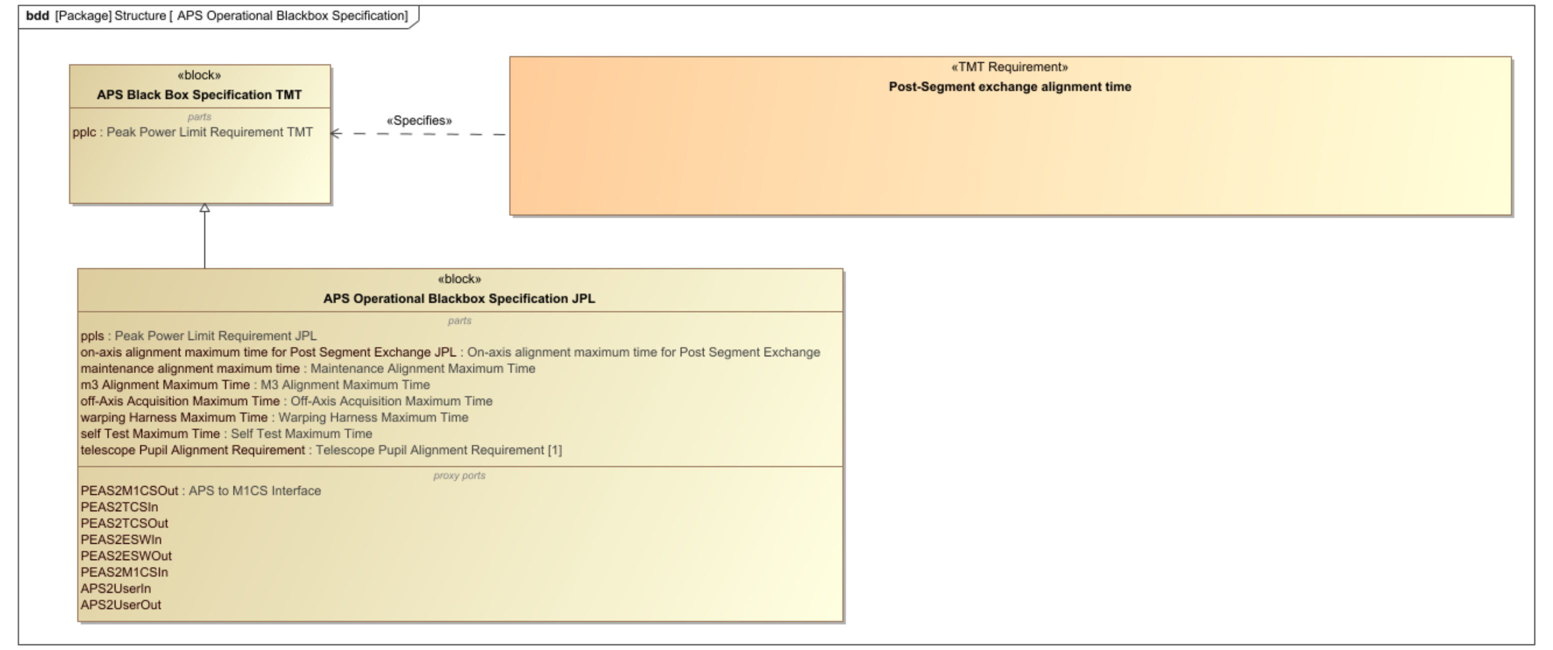


The duration performance of the Logical design is analyzed w/r/t to the black box specification.

Post-Segment Exchange Alignment Timing Analysis Results

#	Name	Classifier	postSegXchgTime Limit : second	tFinal : Real	postSegment Exchange : MaxTime Constraint	bBPhasing Stp : Integer	narrowbandFilter Steps : Integer	rigidBody Steps : Integer	RBDit : Integer	Phasing Dit : Integer	tCTA : Real	tBB1000 : Real	tMSR : Real	tRBS F1 : Real	tRBS F2 : Real	tM3 Align : Real	tBB100 : Real	tBB30 : Real	tNB : Real	tAcquisition : Real
1	post- Segment Exchange Duration Scenario at 2023.09.06 09.20	Post-Segment Exchange Duration Scenario																		
2	post- Segment Exchange Duration Scenario .aPS Mission Logical11	APS Mission Logical																		
3	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .usr	APS User																		
4	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox	APS Logical																		
5	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox.on-axis alignment maximum time for Post Segment Exchange JPL	On-axis alignment maximum time for Post Segment Exchange	7200 second		pass															
6	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox .peas	Procedure Executive and Analysis Software		4895		11	2	8	45	20	912	786	30	723	723	26	815	816	64	
7	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .esw	Executive Software																		36
8	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox	APS Logical																		
9	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox.on-axis alignment maximum time for Post Segment Exchange JPL	On-axis alignment maximum time for Post Segment Exchange	7200 second		pass															
10	post- Segment Exchange Duration Scenario .aPS Mission Logical11 .aps operational blackbox .peas	Procedure Executive and Analysis Software		4895		11	2	8	45	20	912	786	30	723	723	26	815	816	64	

APS Operational Blackbox Specification



The textual TMT timing requirements on the APS black box specification are formalized into constraints for the JPL APS black box specification.

2.2 Maintenance Alignment

2.2.1 Pupose of use case

This use case is used to re-align the telescope in between segment exchanges. The current TMT baseline is that the telescope will be aligned by APS at least monthly, so if there is not a segment exchange in a given month then this use case would be executed. As this use case measures (and optionally corrects for) all of the telescope degrees of freedom that APS can measure it is also useful for checking and adjusting the alignment just before specific observations that are very sensitive to wavefront errors. At Keck this is also used characterize drifts in telescope alignments as a function of time, elevation angle and/or temperature and will likely be used in a similar fashion at TMT.

2.2.2 Typical observing parameters

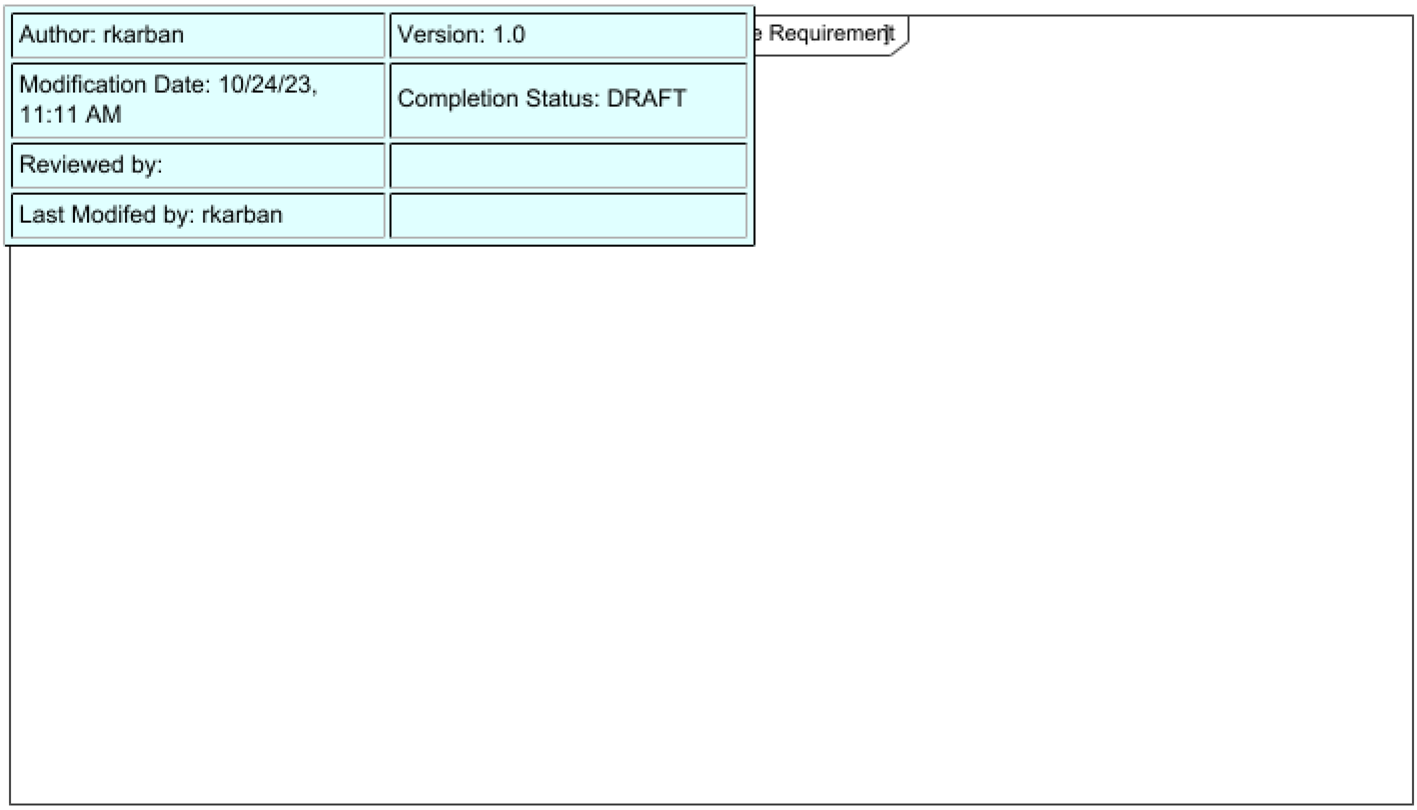
This use case can be executed anytime during the night, but no sooner then ~40 minutes (TBD) after sunset. Stars are usually selected to be ~1 hour to 30 minutes East at a declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The typical telescope elevation angle will be 70 degrees and will vary by less then a few degrees over the 30 minutes it takes to execute this use case. If this use case is being used for alignment at a elevation angle other then 70 degrees, then by selecting stars at the appropriate declination the change in telescope elevation angle can be similar to those used for the 70 degree elevation angle alignment. The specific required star magnitudes and colors for each activity are described in Chapter 3. At Keck the required star magnitudes range between 5th and 6th magnitude (depending on the activity) and we expect the values for TMT to be similar (perhaps 0.5 magnitudes brighter). In practice we have never had problems finding stars at Keck so don't expect any problems with APS at TMT.

2.2.3 Entrance requirements and conditions

<p>All telescope sub-systems should be operating in their nominal modes, including using the standard gravity/temperature look-up/calibration parameters. The APS pre-observing internal calibrations should have been executed before sunset.</p>

<p>The following requirements diagrams shows the starting conditions under which APS is required to capture the misalignments and correct them.</p>

Maintenance Alignment Capture Range Requirement

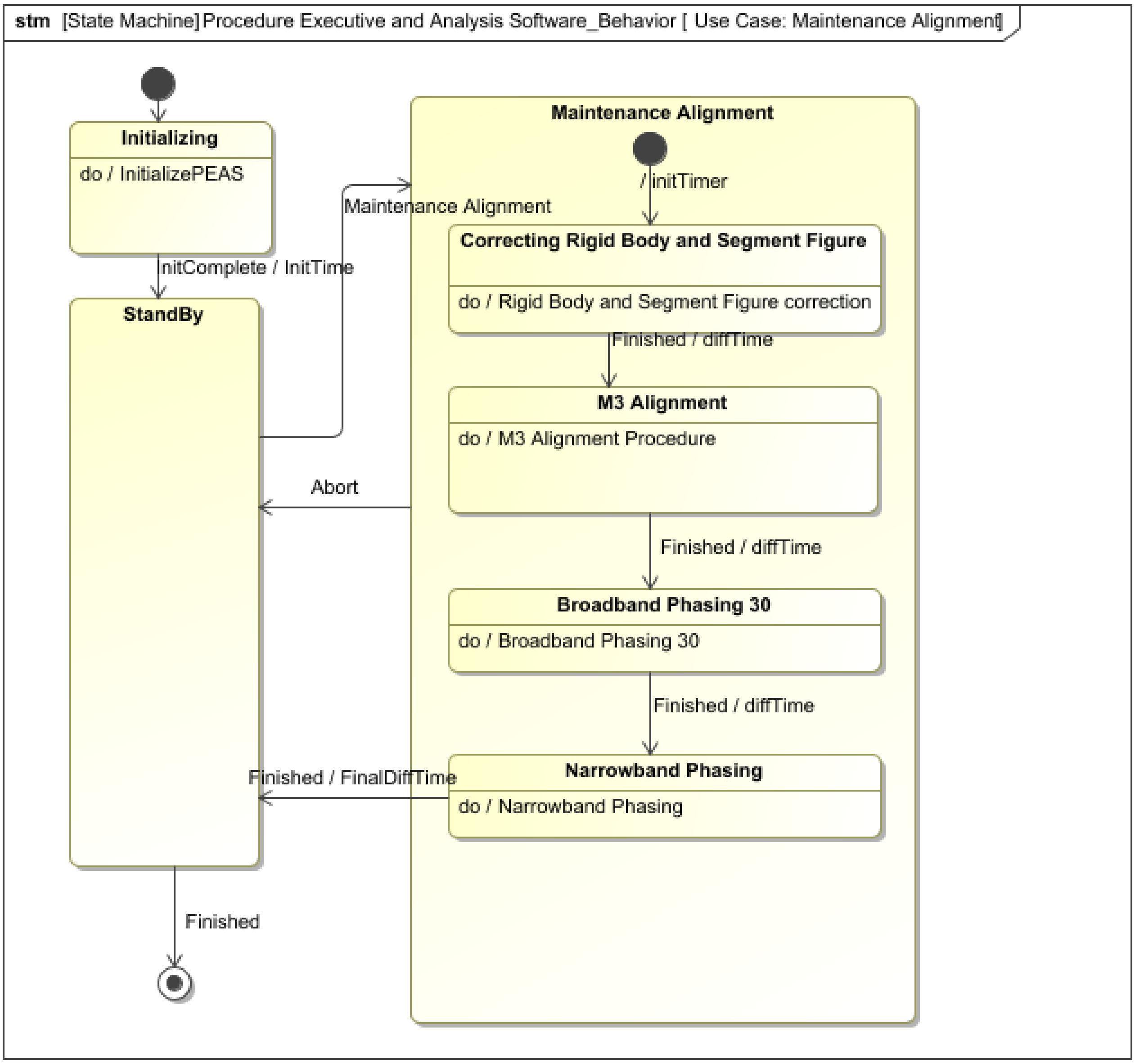


Author: rkarban	Version: 1.0
Modification Date: 10/24/23, 11:11 AM	Completion Status: DRAFT
Reviewed by:	
Last Modifed by: rkarban	

2.2.4 Use case activity

The figure below shows the maintenance alignment use case. It starts with APS in standby mode. A single iteration of the rigid body and segment figure activity is executed, averaging nominal six 45 second images. This activity aligns M1 segments in tip/tilt, M2 in piston and either tip/tilt or x/y translation as well as measuring and correcting the segment figures via warping harness. After this, the segments are phased to 30 nm RMS surface piston error using the broad band phasing 1 micron mode The final M1 segment piston alignment is executed using the narrow band phasing activity which includes measurements with 2 different filters. Each of these activities will require acquisition of new stars of the appropriate magnitude as specified in the description of each activity.

Use Case: Maintenance Alignment



2.2.5 Optical Performance Requirements

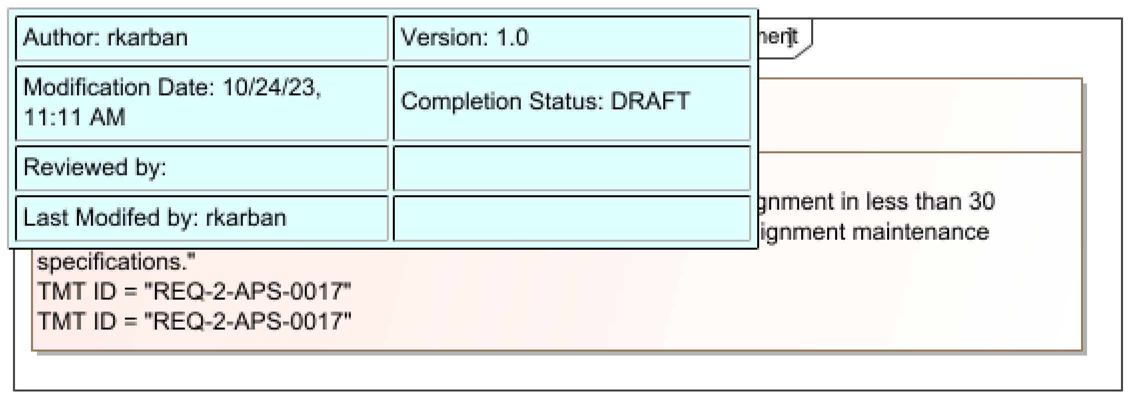
The APS Optical Peformance requirements to be met at the end of the Maintenance Alignment use case are the same as those for the Post-Segment Exchange use case. Refere to that section for those requirements.

2.2.6 Time to execute

The table below shows our current bottom-up time estimate for each of the activities that make up this use case. The total time estimate is 24 (TBR) minutes, which is to be compared with our requirement of 30 min (as shown in the figure below).

At Keck we routinely perform the similar measurements in 30 minutes or less. However, at Keck the segment shapes are not measured as part of this use case. APS will measure the TMT segment shapes in parallel as part of the rigid body and segment figure activity, so there is effectively no additional time needed. However, we will adjust the segment shapes during the night via the motorized warping harnesses and iterate the control at least once. Given our bottom up estimate and our Keck experience we have a high degree of confidence we can met the 30 minute requirement.

Maintenance Alignment Time Requirement



Maintenance Alignment Timing Analysis Results

#	maintenanceAlignmentTime Limit : second	tFinal : Real	tRBS F1 : Real	offAxisMeasurement Steps : Integer	RBDit : Integer	tM3 Align : Real	tBB30 : Real	tNB : Real	Phasing Dit : Integer	tAcquisition : Real
1										
2	1800 second									
3		1687	742	6	45	63	818	64	20	
4										38
5										
6										37

2.3 Rigid Body M3 Alignment

2.3.1 Pupose of use case

This use case aligns the M3 in rigid body such that the telescope pupil (M1) is positioned correctly at the APS instrument location. The use case may be executed at multiple elevation angles (and temperatures) in order to collect data to generate look up tables. It is expected that this use case may be executed as part of the maintenance alignment use case in order to update the “zero” point of M3. This use case was developed as a standalone use case so we could understand the steps and determine what the required software interfaces to the telescope need to be for this case.

There are still a few open issues with respect to this use case:

1. As mentioned above, It is likely that the functionality of this use case can be combined as part of the maintenance and post-segment exchange use cases. We will investigate this in the future as this would be a time efficient way to to update the M3 alignment.
2. Currently the OAD requirements on how well APS needs to align the telescope pupil (REQ-1-OAD-2250) are TBD. See section 2.3.5 for more details.

2.3.2 Typical observing parameters

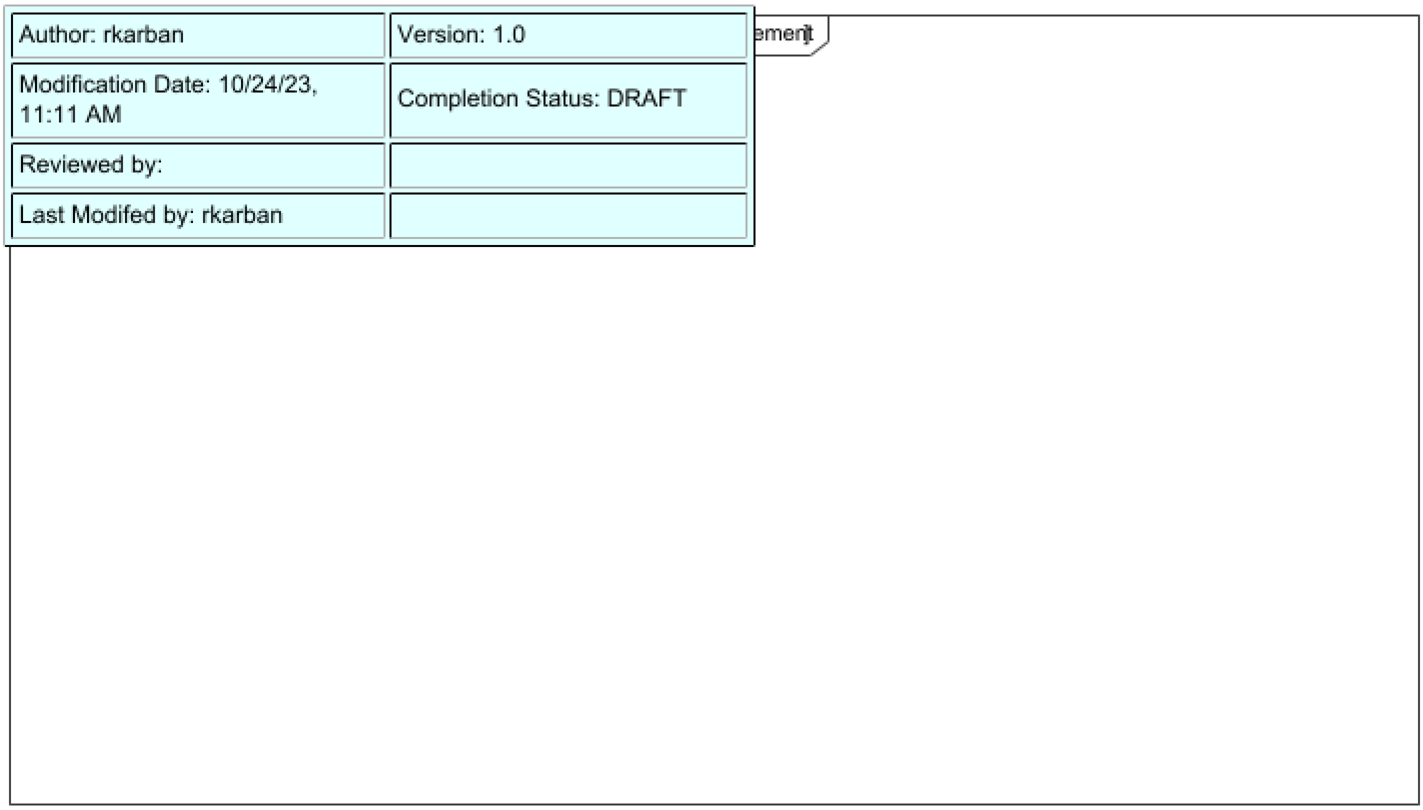
This use case can be executed anytime during the night, but no sooner then ~40 minutes (TBD) after sunset. Stars would usually selected to be ~1 hour to 30 minutes East at a declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The typical telescope elevation angle will be 70 degrees and will vary by less then a few degrees over the 30 minutes it takes to execute this use case. If this use case is being used for alignment at a elevation angle other then 70 degrees, then by selecting stars at the appropriate declination the change in telescope elevation angle can be similar to those used for the 70 degree elevation angle alignment. The specific required star magnitudes and colors for this test are between 5th and 6th magnitude (TBR). In practice we have never had problems finding stars at Keck in this magnitude range so don’t expect any problems with APS at TMT.

2.3.3 Entrance requirements and conditions

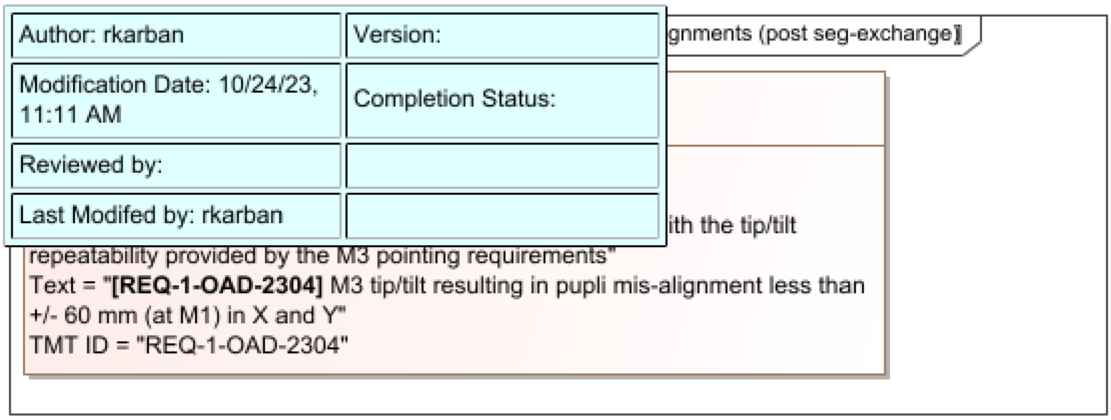
All telescope sub-systems should be operating in their nominal modes, including using the standard gravity/ temperature look-up/calibration parameters. The APS pre-observing internal calibrations should have been executed before sunset.

The following requirements diagrams show the current OAD starting conditions for pupil mis-alignment.

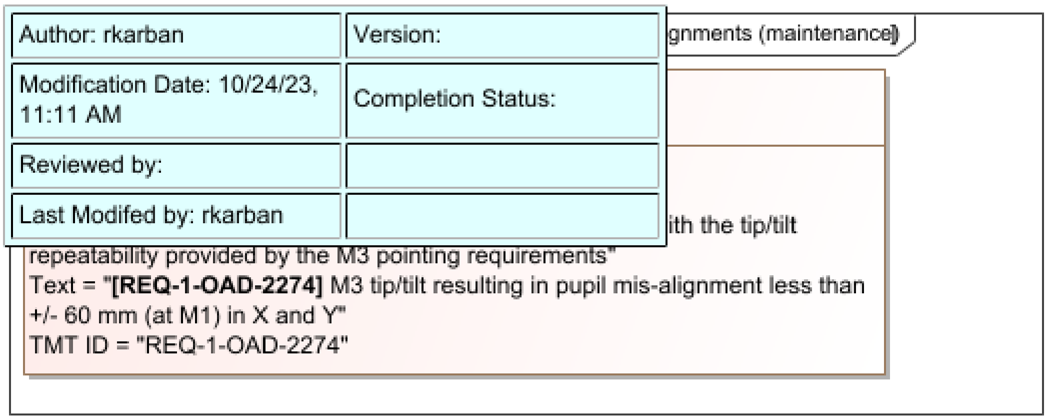
M3 Alignment Capture Range Requirement



Handling M3 repeatability alignments (post seg-exchange)



Handling M3 repeatability alignments (maintenance)



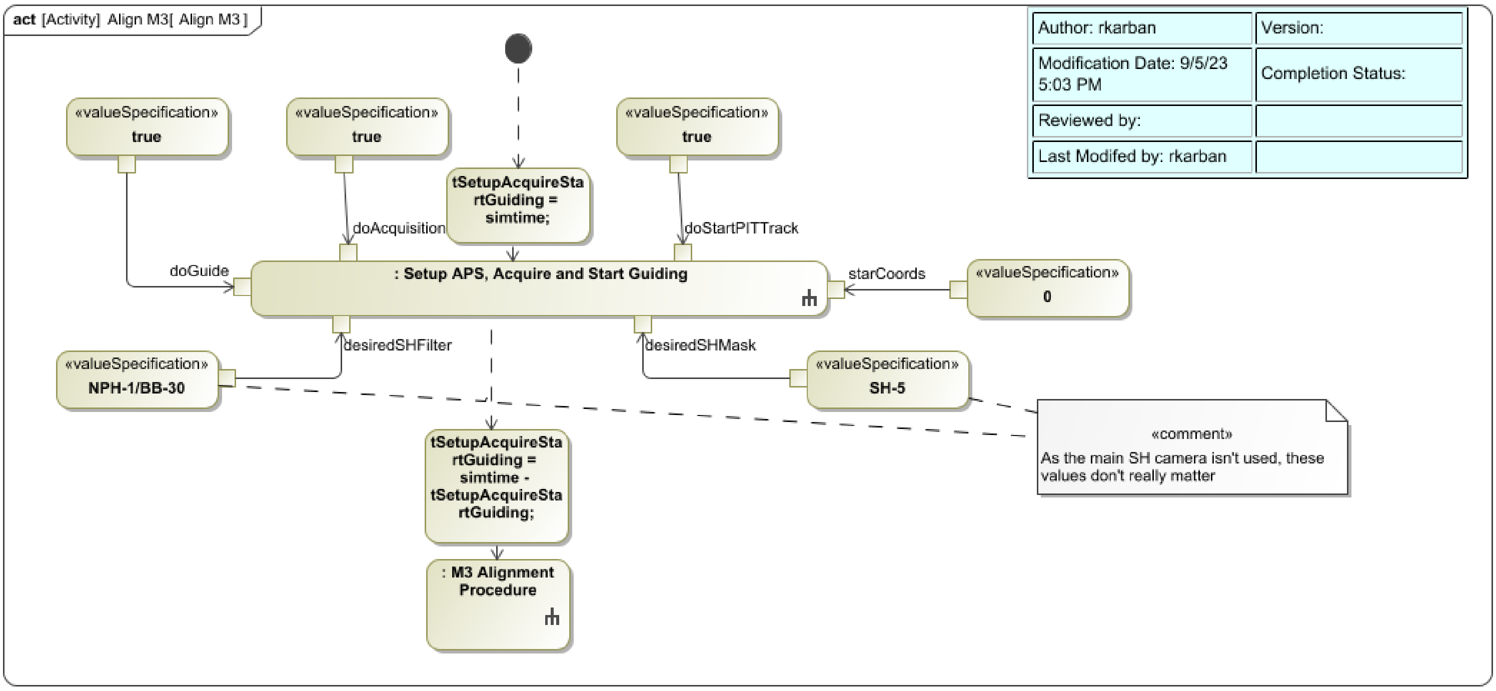
2.3.4 Use case activity

The figure below shows the “Align M3” activity which uses the Pupil Image Tracking (PIT) camera. The “Setup APS, Acquire and Start Guiding” activity is called first which results in the telescope acquiring the specified star and starting guiding on that star. In addition the APS PIT loop will have been started.

The PIT loop measures the pupil registration error and corrects by moving optics internal to APS. The “Align M3” activity then waits for the pupil registration loop to stabilize such that the errors are less then 10 mm (at M1). Once this occurs the position of the internal APS mechanisms is compared to a calibrated position and the absolute telescope pupil registration error is calculated. At this point a request is made to move the telescope pupil by the desired amount (meters at M1) and the internal APS optics are moved in the corresponding but opposite way.

The loop in the previous paragraph is then iterated until the telescope pupil registration error is less then some TBD value. At this point the position of M3 is “saved” via the “Take M3 snapshot command”

Align M3



2.3.5 Optical Performance Requirements

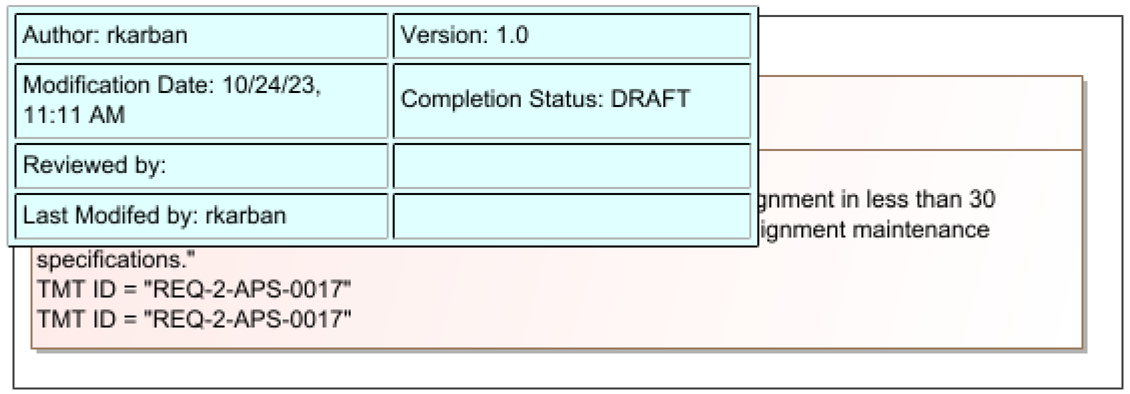
The APS requirement is governed by:
[REQ-1-OAD-2250] The APS shall position the pupil using M3 tip and tilt to an accuracy of TBD% of diameter of the pupil.

APS can and must align the telescope pupil to 10 mm (at M1) to the internal APS masks in order to minimize errors in measurements of the phase errors of the segments. However, the absolute alignment of the telescope pupil needs to take into account how well APS can calibrate the various pupil shifts occurring from the internal optics.

2.3.6 Time to execute

There is currently no explicit OAD requirement on how long this takes. Assuming this alignment is integrated into the post-segment and maintenance alignment use cases, then the execution time for those use case would still need to be met. It is not envisioned that this alignment will add a significant amount of time.

M3 Alignment Time Requirement



M3 Alignment Timing Analysis Results

#	Name	tFinal : Real	offAxisMeasurement Steps : Integer	offAxisMap Points : Integer	RBDit : Integer	tAcquisition : Real
1	m3 Alignment Duration Scenario at 2020.02.04 16.28					
2	m3 Alignment Duration Scenario .aPS Mission Logical					
3	m3 Alignment Duration Scenario .aPS Mission Logical .aps operational blackbox					
4	m3 Alignment Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	84	6	7	45	
5	m3 Alignment Duration Scenario .aPS Mission Logical .esw					38
6	m3 Alignment Duration Scenario .aPS Mission Logical .usr					
7	m3 Alignment Duration Scenario .aPS Mission Logical .aps operational blackbox					
8	m3 Alignment Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	84	6	7	45	
9	m3 Alignment Duration Scenario at 2023.09.08 07.09					
10	m3 Alignment Duration Scenario .aPS Mission Logical12					
11	m3 Alignment Duration Scenario .aPS Mission Logical12 .aps operational blackbox					
12	m3 Alignment Duration Scenario .aPS Mission Logical12 .aps operational blackbox .peas	152	6	7	45	
13	m3 Alignment Duration Scenario .aPS Mission Logical12 .esw					38
14	m3 Alignment Duration Scenario .aPS Mission Logical12 .usr					
15	m3 Alignment Duration Scenario .aPS Mission Logical12 .aps operational blackbox					
16	m3 Alignment Duration Scenario .aPS Mission Logical12 .aps operational blackbox .peas	152	6	7	45	

2.4 Off-Axis Measurements

2.4.1 Purpose of Use Case

The baseline TMT alignment scenario is that the global metrology system (GMS) will be used to build look-up tables as a function of gravity for M2 and M3. With on-axis measurements M2 tip/tilt can not be distinguished from M2 X/Y translation. The expected GMS measurement error is sufficient to constrain the M2 positions and associated off-axis errors and as a result APS needs only adjust M2 tip/tilt or M2 decenter. The APS alignment of M2 is done as part of the "Rigid Body and Segment Figure Correction" activity. Analysis (TMT.SEN.PRE.13.039.DRF02) has shown that a 100 micron M2 translation error corrected with M2 tip/tilt introduces a negligible amount of off-axis telescope aberrations. Specifically, at 7.5 arcmins off-axis correction of a 100 micron M2 translation error with M2 tip/tilt results in:

- A PSSN (worst case) of ~0.993 versus a requirement of ~0.96
- An 80% enclosed energy after removal of the telescope design error of less then 15 milli-arcseconds.
- An RMS WFE after removal of the telescope design error (~2,250 nm) of less then 75 nm.

The current estimate of the GMS accuracy is that it can measure the M2 decenter to better then 25 microns and the M2 tip/tilt to better then 5 arcseconds (TMT.SEN.TEC.16.021.DRF01).

This use case provides a method to measure the off-axis wavefront errors using APS and characterize them by Zernikes. This is mainly intended as a verification of the telescope alignment. APS will characterize, but not attempt to calculate M2 commands to correct the off-axis error. In addition APS will not attempt to reconstruct the surface of M3. We expect that these measurements will mainly be performed during the Assembly, Integration, and Verification phase of the project or for trouble-shooting purposes. PCS had no off-axis capability and thus was unable to diagnose off-axis performance problems experienced by some Keck instruments.

The relevant L1 OAD requirement is [REQ-1-OAD-2245], "The APS shall have the ability to make off axis measurements at any point in the telescope field of view and characterize the wavefront in terms of Zernikes." This requirement has been flown down to the L2 APS requirement as [REQ-2-APS-0084] "APS shall have the ability to make off-axis measurements at any point in the telescope field of view and characterize the wavefront in terms of 45 (TBR) Zernikes."

Off-axis wavefront characterization requires a sequence of 4 to 6 off-axis measurements made with the SH-2 lenslet array. In order to define a "baseline" use case was have assumed 6 off-axis measurements as shown in the figure below, which cover 93% of M3.

2.4.2 Typical Observing Parameters

This use case can be executed anytime during the night, but no sooner then ~40 minutes (TBD) after sunset. Stars would usually selected to be ~1 hour to 30 minutes East at a declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The typical telescope elevation angle will be 70 degrees and will vary by less then a few degrees over the ~45 minutes it takes to execute this use case. If this use case is being used for check the telescope image quality at elevation angles other then 70 degrees, then by selecting stars at the appropriate declination the change in telescope elevation angle can be similar to those used for the 70 degree elevation angle alignment. The specific required star magnitudes and colors for this test are between 5th and 6th magnitude (TBR). In practice we have never had problems finding stars at Keck in this magnitude range so don’t expect any problems with APS at TMT.

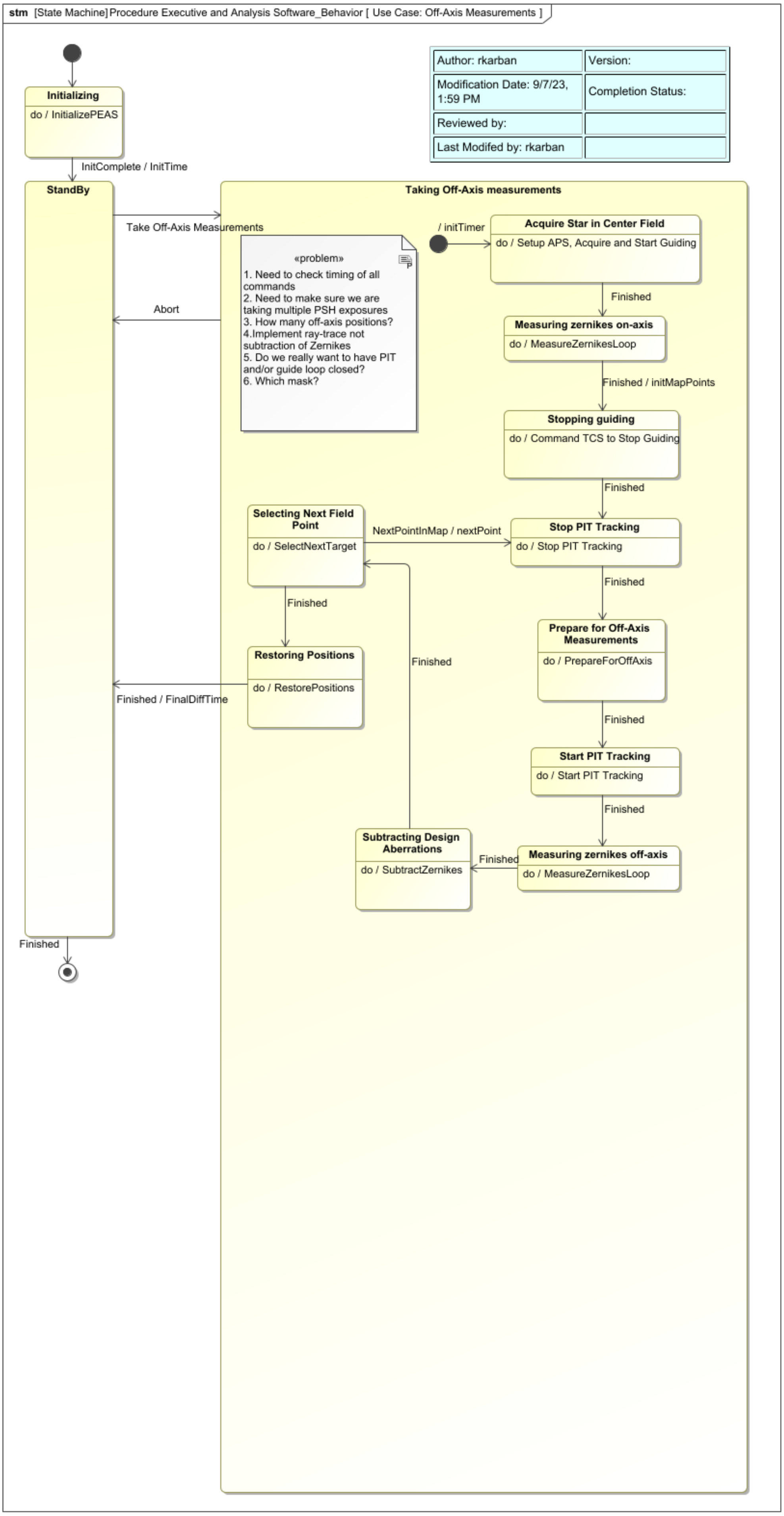
2.4.3 Entrance Requirements and conditions

All telescope sub-systems should be operating in their nominal modes, including using the standard gravity/ temperature look-up/calibration parameters. The APS pre-observing internal calibrations should have been executed before sunset.

There are currently no L1 requirements on how well aligned the telescope needs to be before this use case is executed. However, it is assumed that the telescope is aligned to the level specified at the end of the post segment-exchange/maintenance alignment use cases. Both of these use cases have the same optical performance requirements, refer to the "Optical Performance Requirements" section under "Post Segment-Exchange Alignment" use case for the details.

2.4.4 Use Case Activity

Use Case: Off-Axis Measurements



2.4.5 Optical Performance Requirements

APS will characterize the wavefront in terms of 45 (TBR) Zernikes (REQ-2-APS-0084). As this is a diagnostic mode there are no formal requirements of the measurement error. However, we expect the measurement errors to be consistent with a a Kolmogorov atmosphere with an equivalent r0 of 3.2m with 240 seconds of on sky integration (REQ-2-APS-0079). The equivalent RMS WFE is 181 nm. The measurement error of focus my be larger due to the need to refocus the telescope as part of the off-axis measurement process.

2.4.6 Time to Execute

The current estimated total time for measurement of the on-axis and 6 off-axis field points is 51 minutes. There are no requirements on the duration of this use case.

Off-Axis Measurements Timing Analysis Results

#	Name	tFinal : Real	offAxisMeasurement Steps : Integer	offAxisMap Points : Integer	RBDit : Integer	tAcquisition : Real
1	off- Axis Acquisition Duration Scenario at 2023.01.30 16.42					
2	off- Axis Acquisition Duration Scenario .aPS Mission Logical6					
3	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .usr					
4	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .aps operational blackbox					
5	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .aps operational blackbox .peas	3018	6	7	45	
6	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .esw					38
7	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .aps operational blackbox					
8	off- Axis Acquisition Duration Scenario .aPS Mission Logical6 .aps operational blackbox .peas	3018	6	7	45	
9	off- Axis Acquisition Duration Scenario at 2023.09.06 10.23					
10	off- Axis Acquisition Duration Scenario .aPS Mission Logical10					
11	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .aps operational blackbox					
12	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .aps operational blackbox .peas	3018	6	7	45	
13	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .esw					38
14	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .usr					
15	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .aps operational blackbox					
16	off- Axis Acquisition Duration Scenario .aPS Mission Logical10 .aps operational blackbox .peas	3018	6	7	45	

2.5 On-Sky Measurement of Segment Warping Harness Influence Functions

2.5.1 Purpose of Use Case

The baseline plan is to use theoretical warping harness influence function in the control of the segment surface shapes. However, due to manufacturing tolerances, etc these may be different then the actual influence functions. This use case is designed to measure the warping harness influence function on-sky. Details are discussed in TMT.CTR.PRE.15.073.DRF01. This procedure will certainly be executed during AIV and may be re-executed to check warping harness influence function's as well as trouble shoot any problems. We would envision this procedure being executed on the order of once per year once the telescope is in normal operation. This use case just covers collection of the data. The analysis of the collected data is currently planned to be executed off-line.

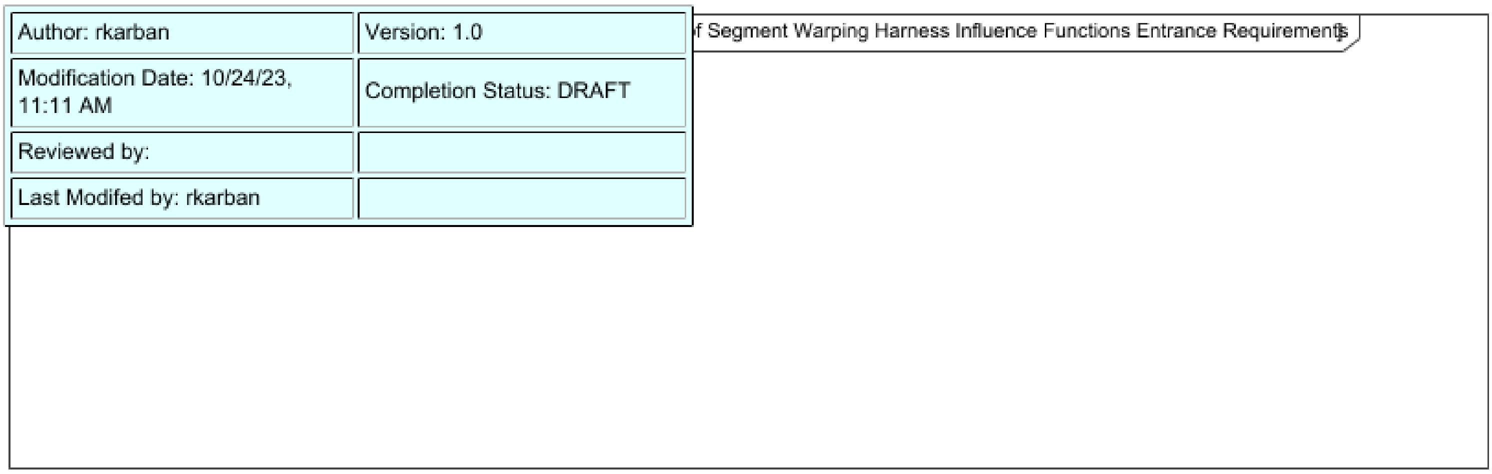
2.5.2 Typical Oberving Parameters

The total time to collect data on all warping harness motors is 10 hours, however, this can be broken down into groups of one-third (~3.5 hours) and data collected on different nights if required. The use case can be started as soon as ~40 minutes (TBD) after sunset. Stars should be selected to be ~2 hours East at a declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The required star magnitude is between 5th and 6th magnitude. In practice we have never had problems finding stars at Keck so don't expect any problems with APS at TMT.

2.5.3 Entrance Requirements and conditions

All telescope sub-systems should be operating in their nominal modes, including using the standard gravity/temperature look-up/calibration parameters. The APS pre-observing internal calibrations should have been executed before sunset.
The following requirements diagrams shows the nominal starting conditions.

On-Sky Measurement of Segment Warping Harness Influence Functions Entrance Requirements

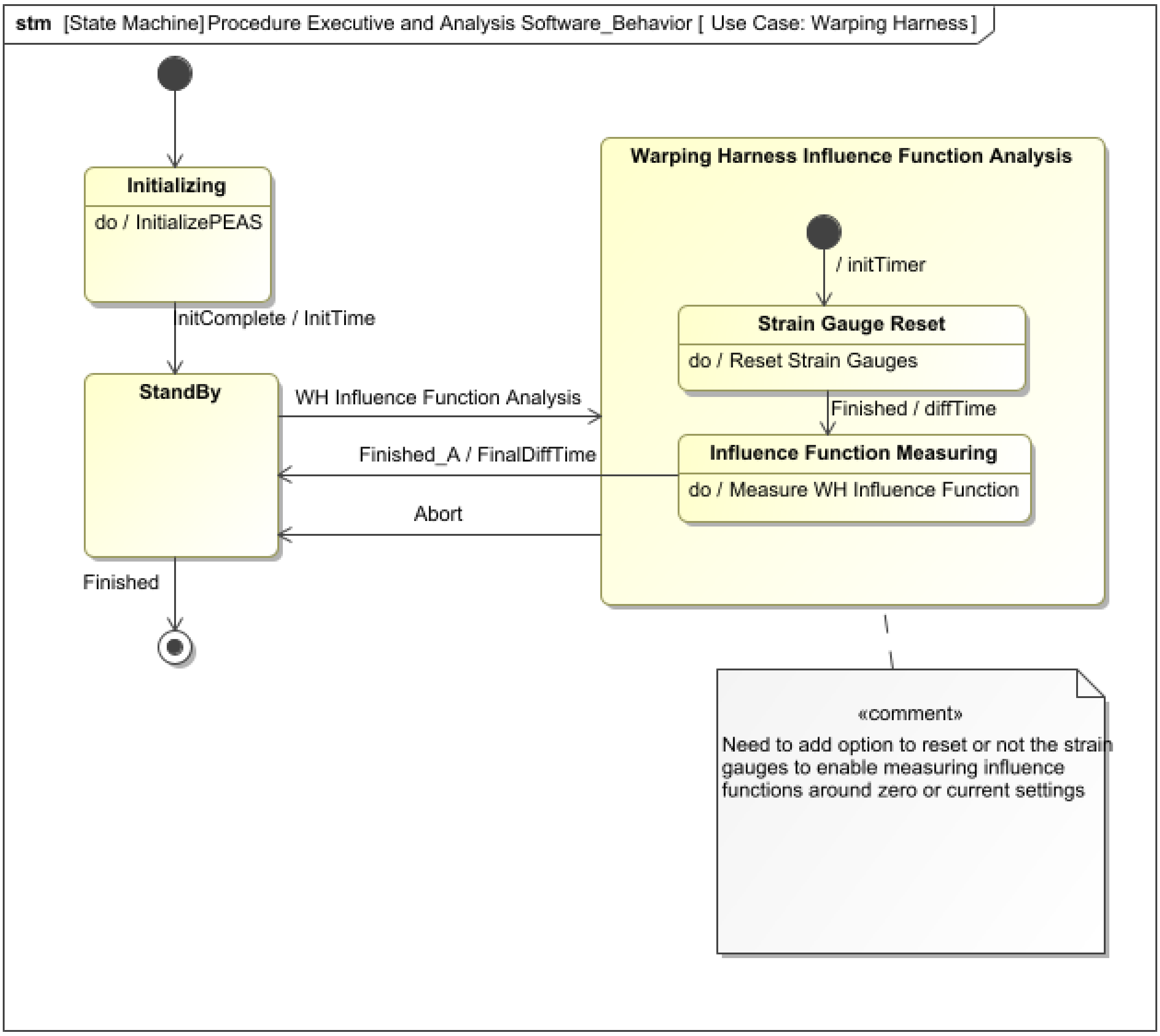


Author: rkarban	Version: 1.0
Modification Date: 10/24/23, 11:11 AM	Completion Status: DRAFT
Reviewed by:	
Last Modifed by: rkarban	

2.5.4 Use Case Activity

The figure below describes the start of this use case. Once the use case starts the "Strain Gauge Reset" activity sends a command to M1CS to move the warping harness motors to set all warping harness strains to a value of zero. Then the process of measuring the warping harness influence function's starts. The details of this activity are described in this document under "High Level Activities" [cf:Measure Warping Harness Influence Function.vlink] . Once the use case complete the strain values from the start of the use case are restored.

Use Case: Warping Harness



2.5.5 Optical Performance Requirements

This use case has no optical performance requirements as it does not change the alignment of the telescope

2.5.6 Time to Execute

The table below shows our current bottom-up time estimate. The total time estimate is 10 hours, which could be split into multiple nights. There is currently no explicit OAD requirement on how long this takes and as discussed above it will be executed on the order of once per year.

Warping Harness Influence Function Analysis Timing Analysis Results

#	Name	Classifier	tFinal : Real	tSG : Real	tAcquisition : Real
1	warping Harness Influence Function Analysis Duration Scenario at 2023.02.17 12.40	Warping Harness Influence Function Analysis Duration Scenario			
2	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68	APS Mission Logical			
3	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .usr	APS User			
4	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .aps operational blackbox	APS Logical			
5	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .aps operational blackbox . peas	Procedure Executive and Analysis Software	36667	600	
6	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .esw	Executive Software			38

#	Name	Classifier	tFinal : Real	tSG : Real	tAcquisition : Real
7	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .aps operational blackbox	APS Logical			
8	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical68 .aps operational blackbox .peas	Procedure Executive and Analysis Software	36667	600	
9	warping Harness Influence Function Analysis Duration Scenario at 2023.09.06 11.51	Warping Harness Influence Function Analysis Duration Scenario			
10	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical	APS Mission Logical			
11	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .usr	APS User			
12	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical			
13	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	36666	600	

#	Name	Classifier	tFinal : Real	tSG : Real	tAcquisition : Real
14	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .esw	Executive Software			38
15	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical			
16	warping Harness Influence Function Analysis Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	36666	600	

2.6 Self Test

2.6.1 Purpose of Use Case

This use case will execute a series of APS tests using internal light sources to confirm that it is functioning correctly and able to support observing. As shown in the table below the APS down time requirement assuming 50 hours of use per year (on-sky) allows for 1.0 hours of down time per year. So, we have implemented (as discussed in the requirement) a self test of APS that will be executed to verify APS is ready for observing.

- In order to minimize what would be significant down-time to the observatory this test shall be executed the day before any planned segment exchange. If APS can not be repaired before the end of day then the segment exchange will be delayed until APS is repaired.
- In the case of a planned APS maintenance alignment this test shall be executed the day before the planned observing. If APS can not be repaired before the end of the day then the maintenance alignment will be delayed until APS is repaired.

APS Down Time Requirement

Author: rkarban	Version: 1.0
Modification Date: 10/24/23, 11:11 AM	Completion Status: DRAFT
Reviewed by:	
Last Modifed by: rkarban	

2.6.2 Typical Oberving Parameters

Not applicable.

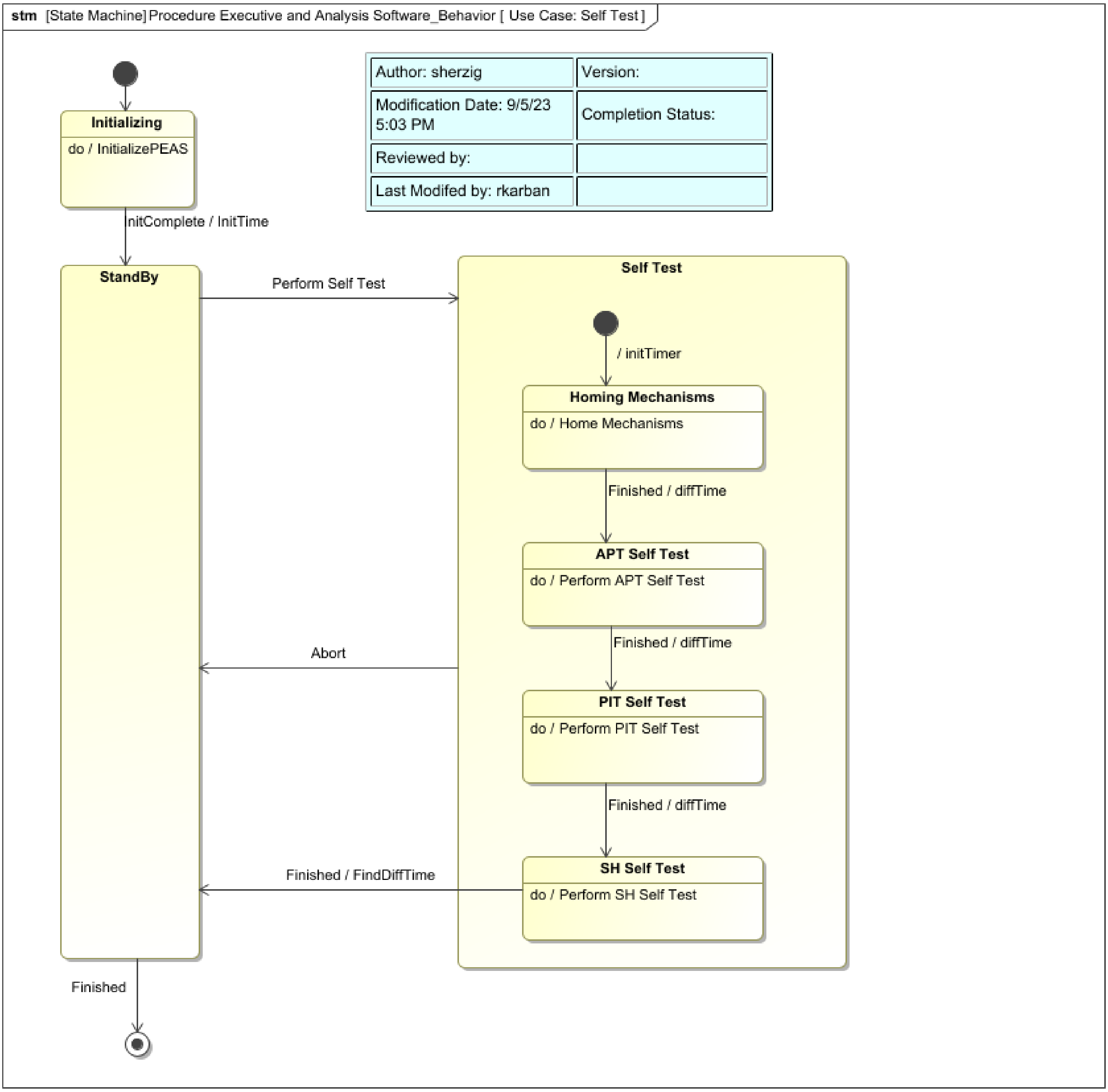
2.6.3 Entrance Conditions

APS should be in it's normal operating configuration with all detectors already cooled.

2.6.4 Use Case Activity

The figure below describes the start of this use case. The use case starts by homing all APS mechanisms and then proceeds to test each of the APS optical paths and detectors: APT, PIT and SH. The details of this activity are described in this document under "High Level Activities" [cf:Self Test.vlink] .

Use Case: Self Test



2.6.5 Exit Conditions

On completion of this use case APS will either report that it passed the self test and is ready to observe or that an error occurred and provide a description of the error.

2.6.6 Time to Execute

The table below shows our current bottom-up time estimate. The total time estimate is 9 minutes. There is currently no OAD requirement on how long this takes.

Self Test Timing Analysis Results

#	Name	Classifier	tFinal : Real	tSelfTest Homing : Real	tSelfTestAP T : Real	tSelfTestPI T : Real	tSelfTestS H : Real	tAcquisition : Real
1	self Test Duration Scenario at 2023.02.01 15.23	Self Test Duration Scenario						
2	self Test Duration Scenario .aPS Mission Logical1	APS Mission Logical						
3	self Test Duration Scenario .aPS Mission Logical1 .usr	APS User						
4	self Test Duration Scenario .aPS Mission Logical1 .aps operational blackbox	APS Logical						
5	self Test Duration Scenario .aPS Mission Logical1 .aps operational blackbox .peas	Procedure Executive and Analysis Software	484	122	160	132	70	
6	self Test Duration Scenario .aPS Mission Logical1 .esw	Executive Software						0
7	self Test Duration Scenario .aPS Mission Logical1 .aps operational blackbox	APS Logical						
8	self Test Duration Scenario .aPS Mission Logical1 .aps operational blackbox .peas	Procedure Executive and Analysis Software	484	122	160	132	70	
9	self Test Duration Scenario at 2023.09.06 11.23	Self Test Duration Scenario						
10	self Test Duration Scenario .aPS Mission Logical	APS Mission Logical						
11	self Test Duration Scenario .aPS Mission Logical .usr	APS User						
12	self Test Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical						
13	self Test Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	483	121	160	132	70	
14	self Test Duration Scenario .aPS Mission Logical .esw	Executive Software						0
15	self Test Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical						
16	self Test Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	483	121	160	132	70	

2.7 M1CS Sensor Calibration with Post Segment-Exchange Alignment

2.7.1 Purpose of Use Case

This use case performs two functions:

1. It re-aligns the telescope after new segments have been installed or exchanged.
2. It performs a calibration of the M1CS sensors at two additional telescope elevation angles, providing a total of 3 calibration angles in order to update the M1CS sensor calibration coefficients.

The current TMT baseline is that during normal operations 8 to 10 segments will be exchanged in a single day every two weeks. That night this use case will be run by the APS operator (typically the same person as the telescope operator) to re-align the telescope. Assuming the entrance requirements are met (all segments are within tip/tilt and piston capture range) then the time to run this test is independent of the number of “new” segments installed. Thus, this is the same use case that will nominally be used during AIV as new segments are installed and APS is used to align them.

The initial telescope alignment after the segments are installed occurs at nominally a telescope elevation angle of 60 degrees and includes all of the steps outlined in section 2.1 Post Segment-Exchange Alignment. The current assumption per conversations with the JPL M1CS group is that for each additional M1CS sensor calibration telescope zenith angle APS will perform the following alignment procedures:

- Correct segment rigid body positions
- Broadband Phasing with a 1 micron capture range
- Narrowband phasing

The results of this use case will be used by the M1CS to update the sensor calibration coefficients. Note that the sensor calibration coefficients are estimated using data both from the current APS run, as well as prior runs that include data taken at different telescope temperatures.

Note that as the needed M1CS sensor calibration alignments are updated then this use case will also need to be updated and the time to execute will also change.

2.7.2 Typical Observing Parameters

This use case will typically be executed as soon as possible after the segment exchange recovery process has completed, but no sooner then 20 minutes (TBD) after sunset. The first activity coarse alignment uses a 10nm bandwidth filter and is not very sensitive to sky background compared to the required accuracy of the measurements. Stars are usually selected to be ~1 hour East at a Declination of 0 or 40 degrees in order to minimize changes in telescope elevation. The specific required star magnitudes and colors for each activity are described in Chapter 3. At Keck the required star magnitudes range between 4th and 6th magnitude (depending on the activity) and we expect the values for TMT to be similar (perhaps 0.5 magnitudes brighter). In practice we have never had problems finding stars at Keck so don’t expect any problems with APS at TMT.

During the initial segment re-alignment the typical telescope elevation angle will be 60 degrees and will vary by less then a few degrees over 2 hours. After the telescope nominal alignment is complete the process of M1CS sensor calibration will start and stars will be acquired at the specified elevation angles.

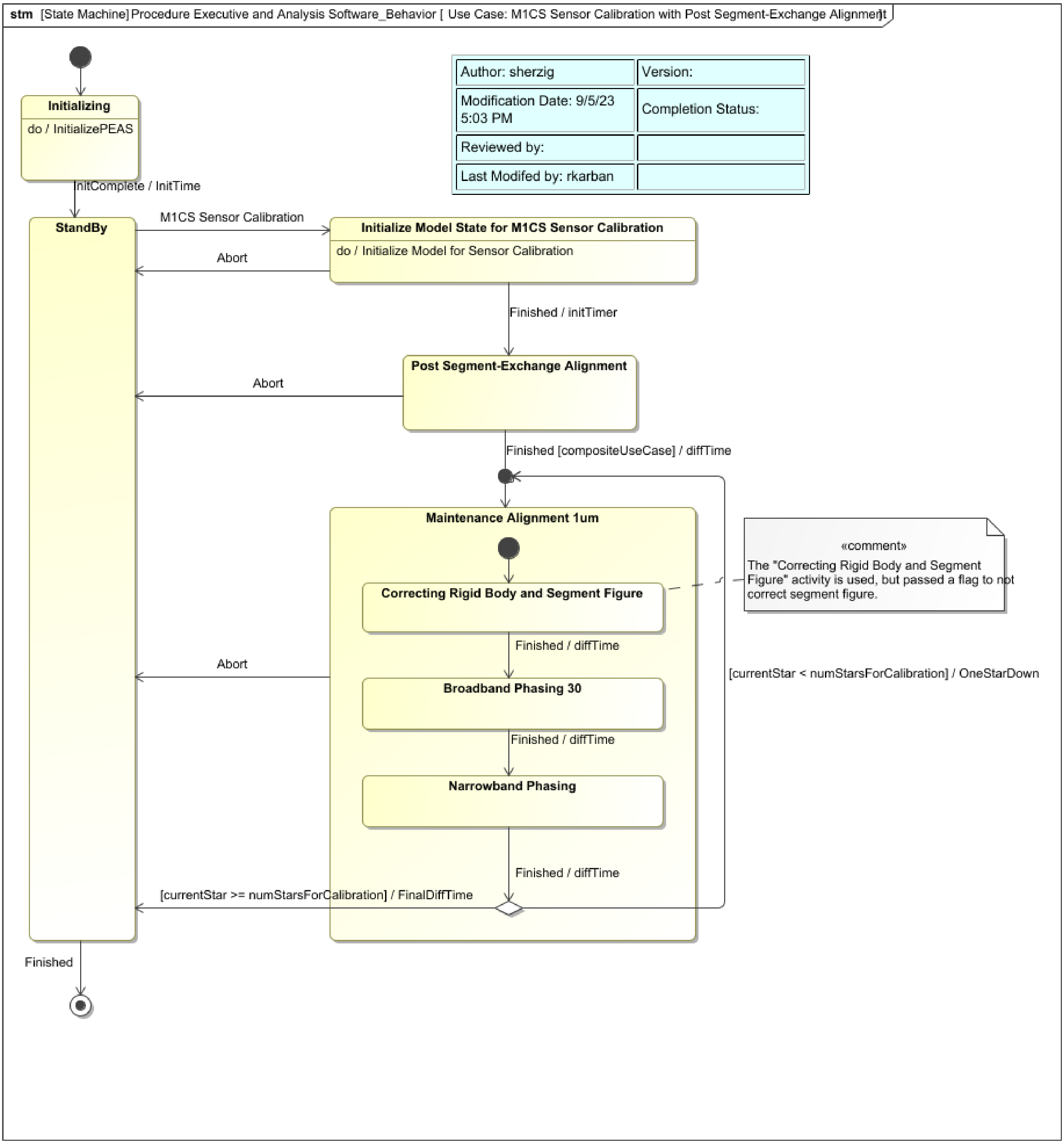
2.7.3 Entrance Requirements and conditions

The entrance requirements for this use case are the same as that for Post Segment-Exchange Alignment and are specified in Section 2.1.3 Post Segment-Exchange Alignment ([cf:entrance requirements and conditions.name]).

2.7.4 Use Case Activity

The figure below shows the M1CS sensor calibration and post-segment exchange use case. It starts with APS in standby mode. Then the Post-Segment Exchange Alignment use case is executed (2.1 [cf:post-Segment Exchange Alignment.name]). After that the Maintenance alignment use case is executed at two difference elevation angles. The only difference between this and the "standard" Maintenance alignment use case is that the segment figures/warping harness will not be adjusted.

Use Case: M1CS Sensor Calibration with Post Segment-Exchange Alignment



2.7.5 Optical Performance Requirements

The optical performance requirements for this use case are the same as that for Post Segment-Exchange Alignment and are specified in Section 2.1.5 Post Segment-Exchange Alignment ([cf:Post-Segment Exchange Optical Performance Requirements.name])

2.7.6 Time to Execute

The table below shows our current bottom-up time estimate for each of the activities that make up this use case. The total time estimate is ~141 (TBR) minutes for the post-segment exchange alignment and two additional M1CS sensor calibration alignments. There is currently no requirement that directly maps to this use case. As specified this alignment is essentially the post-segment installation alignment (Section 2.1) and two Maintenance Alignments (Section 2.2). The requirements for those use cases are 120 and 30 minutes respectively, so reasonable top level requirement for this use case (as defined) is 120 + 2*30 or 180 minutes.

Note that as the needed M1CS sensor calibration alignments are updated then this use case will also need to be updated and the time to execute will also change.

M1CS Sensor Calibration Timing Analysis Results

#	Name	Classifier	tFinal : Real	bBPhasing Stp : Integer	narrowbandFilter Steps : Integer	rigidBody Steps : Integer	RBDit : Integer	Phasing Dit : Integer	tCTA : Real	tBB1000 : Real	tMSR : Real	tRBS F1 : Real	tRBS F2 : Real	tBB100 : Real	tBB30 : Real	tNB : Real	tCalibRBS F : Real	tCalibB B1 : Real	tCalibN B : Real	tAcquisition : Real
1	m1CS Sensor Calibration Duration Scenario at 2023.02.01 15.15	M1CS Sensor Calibration Duration Scenario																		
2	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5	APS Mission Logical																		
3	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .usr	APS User																		
4	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .aps operational blackbox	APS Logical																		
5	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .aps operational blackbox .peas	Procedure Executive and Analysis Software	8228	11	2	8	45	20	912	791	30	728	728	815	816	69	754 754	815 815	69 98	
6	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .esw	Executive Software																		36
7	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .aps operational blackbox	APS Logical																		
8	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical5 .aps operational blackbox .peas	Procedure Executive and Analysis Software	8228	11	2	8	45	20	912	791	30	728	728	815	816	69	754 754	815 815	69 98	
9	m1CS Sensor Calibration Duration Scenario at 2023.09.06 10.48	M1CS Sensor Calibration Duration Scenario																		
10	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7	APS Mission Logical																		
11	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .usr	APS User																		
12	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .aps operational blackbox	APS Logical																		
13	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .aps operational blackbox .peas	Procedure Executive and Analysis Software	8201	11	2	8	45	20	912	786	30	723	723	815	816	64	759 755	815 815	98 64	
14	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .esw	Executive Software																		35
15	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .aps operational blackbox	APS Logical																		
16	m1CS Sensor Calibration Duration Scenario .aPS Mission Logical7 .aps operational blackbox .peas	Procedure Executive and Analysis Software	8201	11	2	8	45	20	912	786	30	723	723	815	816	64	759 755	815 815	98 64	

2.8 M2 and M3 Rigid Body Gravity Calibration

2.8.1 Purpose of Use Case

This use case is used to align the M2 (Piston and either tip/tilt or x/y decenter) and M3 rigid body degrees of freedom at multiple elevation angles. This data is then used by TCS to build gravity look up tables to insure the M2 and M3 stay aligned as the telescope tracks stars.

This use case will be executed during AIV, likely multiple times. It should also be re-executed on a routine bases (~1/yr) to insure proper telescope alignment and as a diagnostic for other potential telescope problems.

2.8.2 Typical Oberving Parameters

This use case can be executed anytime during the night, but no sooner then ~40 minutes (TBD) after sunset. Stars would usually selected to be ~1 hour to 30 minutes East at a declination of 0 or 40 degrees in order to minimize changes in telescope elevation. Telescope elevation angles will be selected between ~30 and 80 Deg. elevation and will vary by less then a few degrees over the 30 minutes it takes to execute this use case. The specific required star magnitudes and colors for this test are between 5th and 6th magnitude (TBR). In practice we have never had problems finding stars at Keck in this magnitude range so don’t expect any problems with APS at TMT.

2.8.3 Entrance Requirements and Conditions

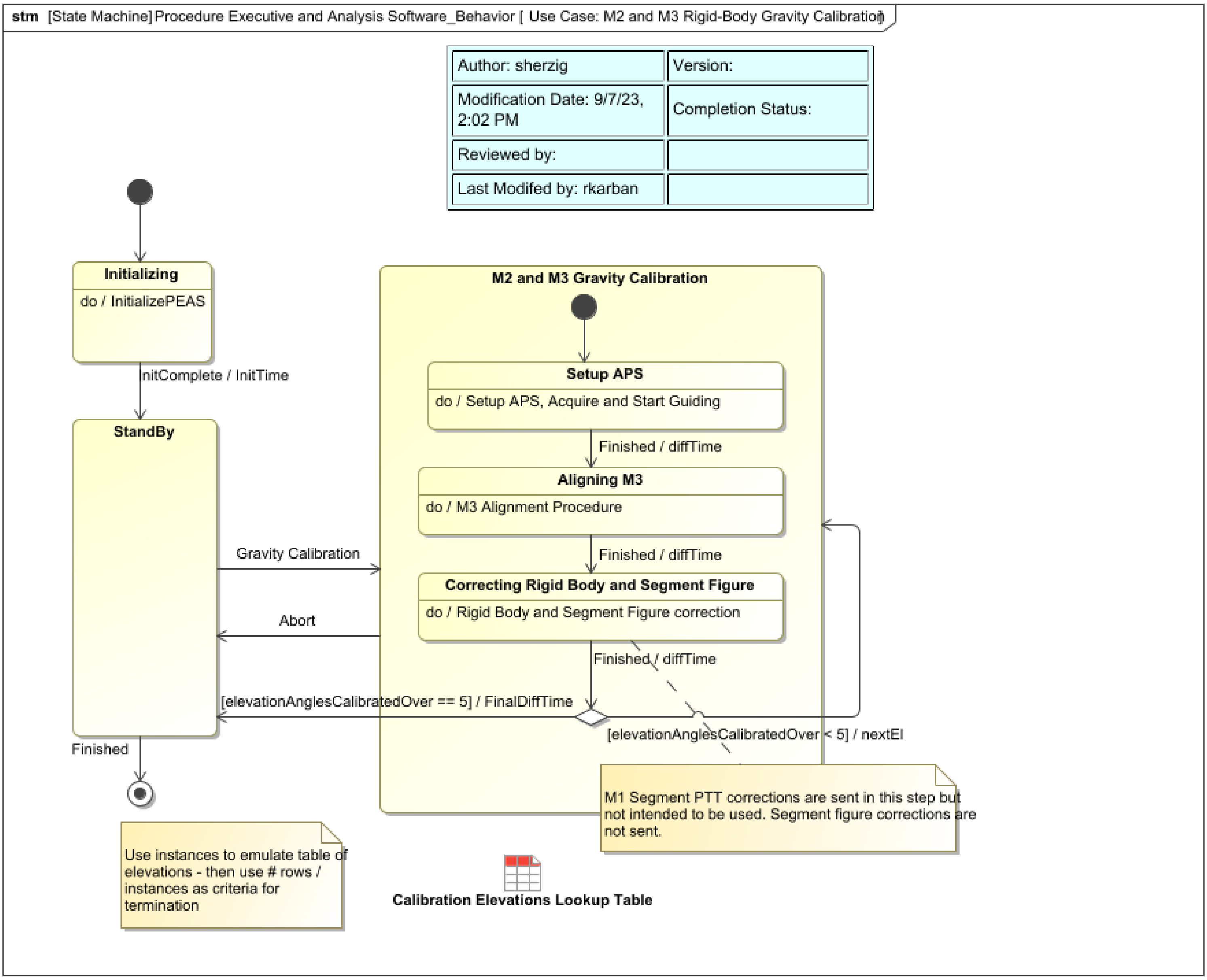
The entrance requirements for this use case are the same as that for Maintenance Alignment and are specified in Section 2.2.3 Maintenance Alignment ([cf:entrance requirements and conditions.name]).

2.8.4 Use Case Activity

The figure below shows the use case activity state machine. It starts with APS in standby mode. Then the Rigid Body M3 Alignment use case is executed (2.3 [cf:Rigid Body M3 Alignment.name]). During this use case a star is acquired at the specified elevation angle. After the M3 use case completes the Rigid Body and Segment Figure Correction Activity (3.3 [cf:Rigid Body and Segment Figure correction.name]) is executed. During this process commands are sent to align M2 and optionally the M1 segments in tip/tilt, commands to the warping harness to correct the M1 segment figures are calculated, but not sent.

The above procedure is repeated for each elevation angle specified in the Calibration Elevation Lookup Table. The current assumption is 6 stars at elevation angles between 30 and 80 Deg.

Use Case: M2 and M3 Rigid-Body Gravity Calibration



Calibration Elevations Lookup Table

#	Name	elevation Angle : Real
1	row1	80
2	row2	70
3	row3	60
4	row4	50
5	row5	40
6	row6	30

2.8.5 Optical Performance Requirements

There are no specific optical performance requirements associated for this use case. However, in general the M3 will be aligned to the same performance requirements specified in section 2.3.5, Rigid Body M3 Alignment Optical Performance Requirements. The M2 will in general be aligned to the same optical performance requirements specified in 2.2.5 Maintenance Alignment Optical Performance Requirements.

2.8.6 Time to Execute

The table below shows our current bottom-up time estimate of 70 minutes. There is currently no requirement that directly maps to this use case. As specified this alignment is essentially the Rigid Body M3 Alignment (Section 2.3) and Rigid Body and Segment Figure Correction Activity (Section 3.3) executed 6 times. The time estimate for these two activities are 1.3 and 10.8 respectively, so the total time estimate from these would be 6 * (1.3 + 10.8) = 73 minutes. This is similar to the bottoms up estimate, but as expected longer and this first order estimate also includes the time to send commands to adjust the warping harness actuators.

Gravity Calibration Timing Analysis Results

#	Name	Classifier	tFinal : Real	tCalibAlign M3 : Real	tCalibRBS F : Real	tAcquisition : Real
1	gravity Calibration Duration Scenario at 2023.04.14 22.01	Gravity Calibration Duration Scenario				
2	gravity Calibration Duration Scenario .aPS Mission Logical	APS Mission Logical				
3	gravity Calibration Duration Scenario .aPS Mission Logical .usr	APS User				
4	gravity Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical				
5	gravity Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	5095	64 66 66 66 66 64	733 734 733 734 734 733	
6	gravity Calibration Duration Scenario .aPS Mission Logical .esw	Executive Software				0
7	gravity Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox	APS Logical				
8	gravity Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	Procedure Executive and Analysis Software	5095	64 66 66 66 66 64	733 734 733 734 734 733	
9	gravity Calibration Duration Scenario at 2023.09.06 11.14	Gravity Calibration Duration Scenario				
10	gravity Calibration Duration Scenario .aPS Mission Logical47	APS Mission Logical				
11	gravity Calibration Duration Scenario .aPS Mission Logical47 .usr	APS User				
12	gravity Calibration Duration Scenario .aPS Mission Logical47 .aps operational blackbox	APS Logical				
13	gravity Calibration Duration Scenario .aPS Mission Logical47 .aps operational blackbox .peas	Procedure Executive and Analysis Software	5222	114 81 114 114 81 81	723 723 723 723 723 723	
14	gravity Calibration Duration Scenario .aPS Mission Logical47 .esw	Executive Software				37

#	Name	Classifier	tFinal : Real	tCalibAlign M3 : Real	tCalibRBS F : Real	tAcquisition : Real
15	gravity Calibration Duration Scenario .aPS Mission Logical47 .aps operational blackbox	APS Logical				
16	gravity Calibration Duration Scenario .aPS Mission Logical47 .aps operational blackbox .peas	Procedure Executive and Analysis Software	5222	114 81 114 114 81 81	723 723 723 723 723 723	

2.9 Wavefront Calibration

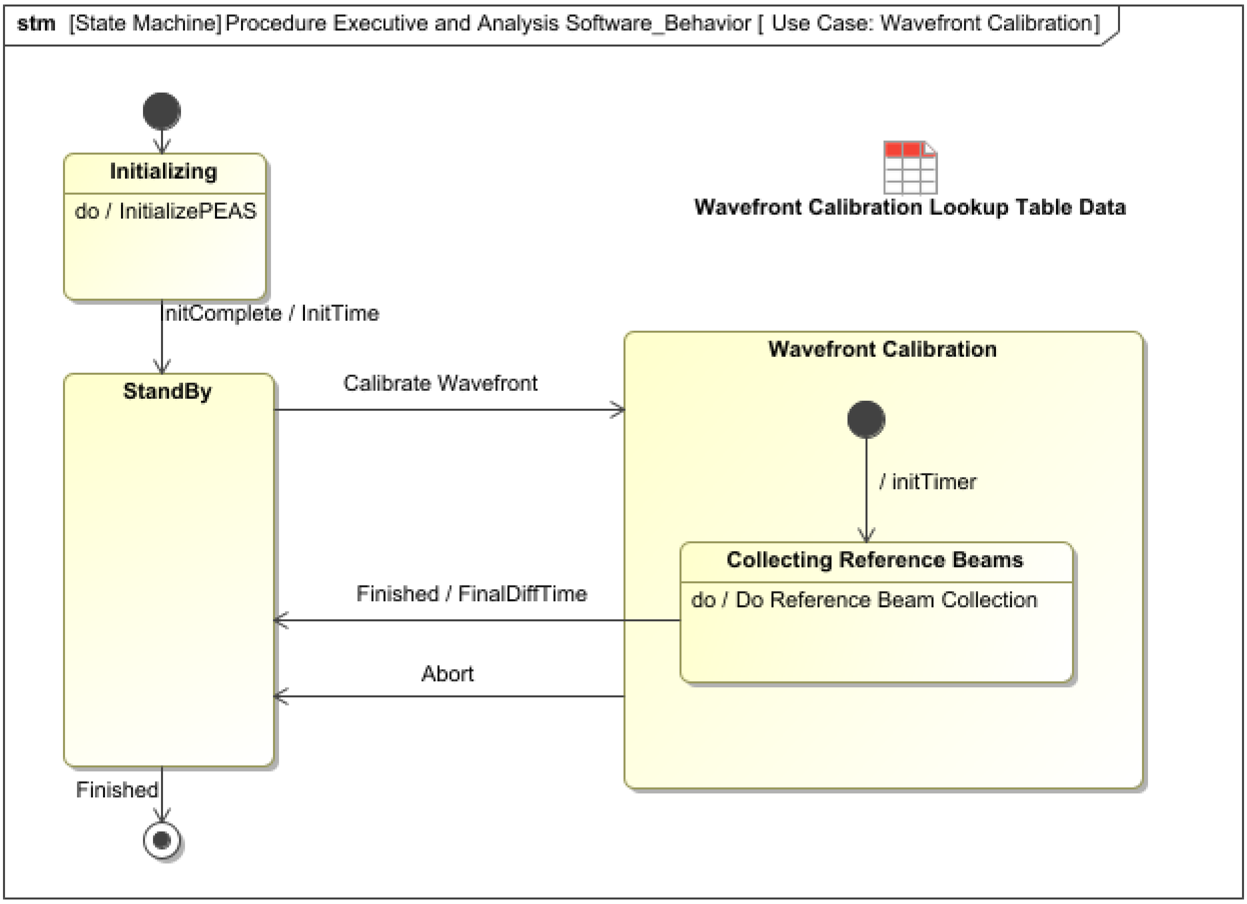
2.9.1 Purpose of Use Case

2.9.2 Typical Oberving Parameters

2.9.3 Entrance Requirements and conditions

2.9.4 Use Case Activity

Use Case: Wavefront Calibration



State Machine of the Maintenance Alignment Use Case.

2.9.5 Optical Performance Requirements

2.9.6 Time to Execute

Wavefront Calibration Timing Analysis Results

#	Name	tFinal : Rea l
1	wavefront Calibration Duration Scenario at 2019.11.01 11.17	
2	wavefront Calibration Duration Scenario .aPS Mission Logical	
3	wavefront Calibration Duration Scenario .aPS Mission Logical .usr	
4	wavefront Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox	
5	wavefront Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	4954
6	wavefront Calibration Duration Scenario .aPS Mission Logical .esw	
7	wavefront Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox	
8	wavefront Calibration Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	4954
9	wavefront Calibration Duration Scenario at 2023.09.06 11.29	
10	wavefront Calibration Duration Scenario .aPS Mission Logical3	
11	wavefront Calibration Duration Scenario .aPS Mission Logical3 .usr	
12	wavefront Calibration Duration Scenario .aPS Mission Logical3 .aps operational blackbox	
13	wavefront Calibration Duration Scenario .aPS Mission Logical3 .aps operational blackbox .peas	4954
14	wavefront Calibration Duration Scenario .aPS Mission Logical3 .esw	
15	wavefront Calibration Duration Scenario .aPS Mission Logical3 .aps operational blackbox	
16	wavefront Calibration Duration Scenario .aPS Mission Logical3 .aps operational blackbox .peas	4954
17	wavefront Calibration Duration Scenario at 2023.09.08 07.15	
18	wavefront Calibration Duration Scenario .aPS Mission Logical4	
19	wavefront Calibration Duration Scenario .aPS Mission Logical4 .usr	
20	wavefront Calibration Duration Scenario .aPS Mission Logical4 .aps operational blackbox	
21	wavefront Calibration Duration Scenario .aPS Mission Logical4 .aps operational blackbox .peas	4954
22	wavefront Calibration Duration Scenario .aPS Mission Logical4 .esw	
23	wavefront Calibration Duration Scenario .aPS Mission Logical4 .aps operational blackbox	
24	wavefront Calibration Duration Scenario .aPS Mission Logical4 .aps operational blackbox .peas	4954

2.10 Pupil Registration Relative to SH and PIT

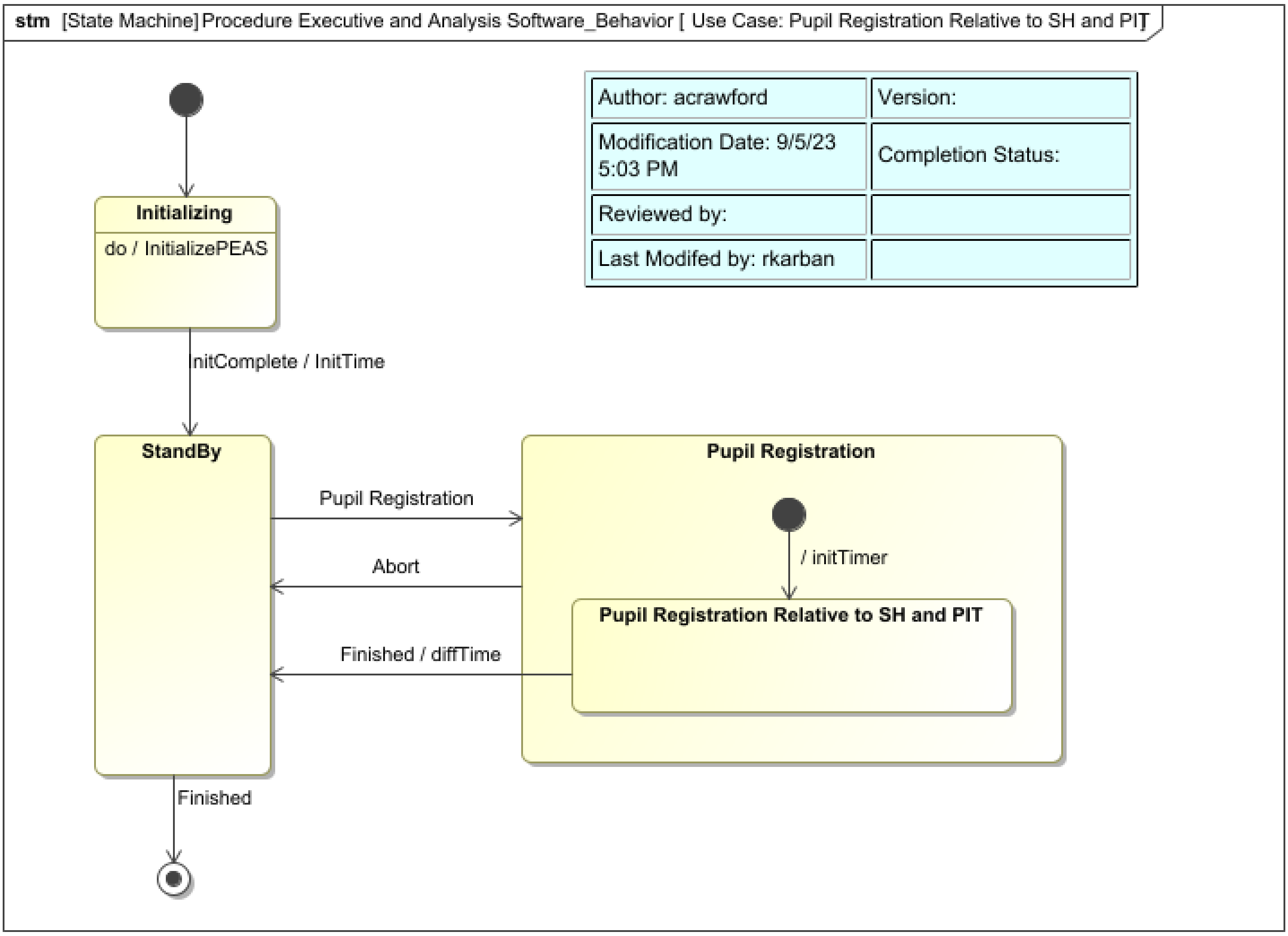
2.10.1 Purpose of Use Case

2.10.2 Typical Oberving Parameters

2.10.3 Entrance Requirements and conditions

2.10.4 Use Case Activity

Use Case: Pupil Registration Relative to SH and PIT



2.10.5 Optical Performance Requirements

2.10.6 Time to Execute

Pupil Registration Relative to SH and PIT Results

#	Name	tFinal : Real
1	pupil Registration Duration Scenario at 2019.11.01 12.51	
2	pupil Registration Duration Scenario .aPS Mission Logical .aps operational blackbox	
3	pupil Registration Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	109
4	pupil Registration Duration Scenario .aPS Mission Logical .esw	

2.11 Reference Point Tracking on APT Camera Relative to PIT and SH

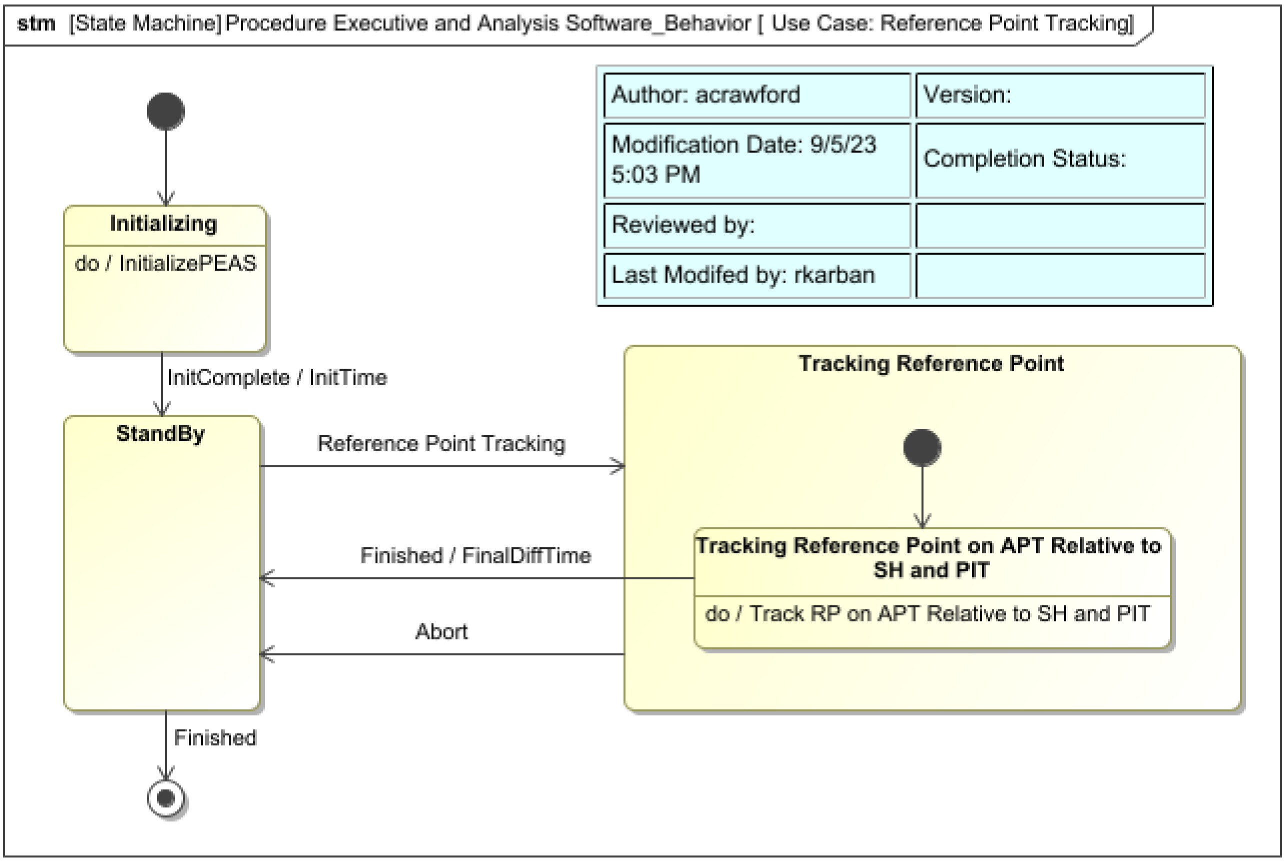
2.11.1 Purpose of Use Case

2.11.2 Typical Oberving Parameters

2.11.3 Entrance Requirements and conditions

2.11.4 Use Case Activity

Use Case: Reference Point Tracking



2.11.5 Optical Performance Requirements

2.11.6 Time to Execute

Reference Point Tracking on APT Camera Relative to PIT and SH Results

#	Name	tFinal : Rea l
1	reference Point Tracking Duration Scenario at 2020.02.05 16.40	
2	reference Point Tracking Duration Scenario .aPS Mission Logical .aps operational blackbox .peas	118
3	reference Point Tracking Duration Scenario .aPS Mission Logical .esw	

3 High Level Activities

This chapter describes high level APS activities. The first is Acquisition and guiding which is used whenever a new star is acquired or if guiding is requested on a star that has already been acquired. The remaining activities are alignment activities and are described in more detail in the APS Algorithms document.

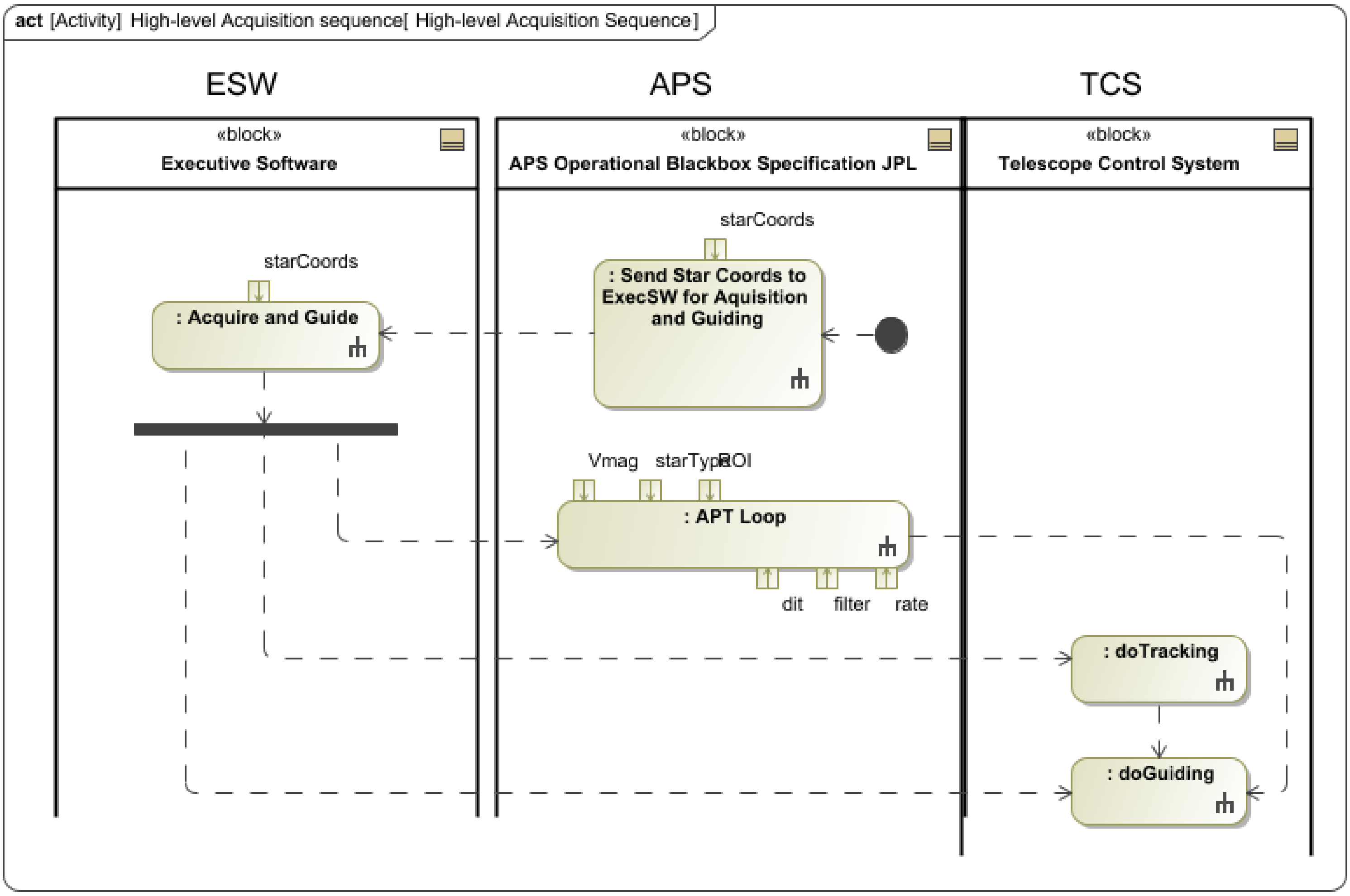
3.1 Acquisition & Guiding

3.1.1 Overview

This activity describes the process that APS will use to acquire and guide on stars. The APS top level software, called Procedure Execution and Analysis Software (PEAS) is at the ESW level and will initiate this activity. The APS optical bench system contains a camera/system called Acquisition, Pointing and Tracking (APT) that provides the needed functionality for the ESW and TCS to acquire and guide. The APT is commanded via the APS Instrument Control System (ICS). All (at least seeing limited) instruments will be required to provide a similar functionality.

The following diagrams give a high-level overview of the interactions among different functions and components for the acquisition sequence.

High-level Acquisition Sequence

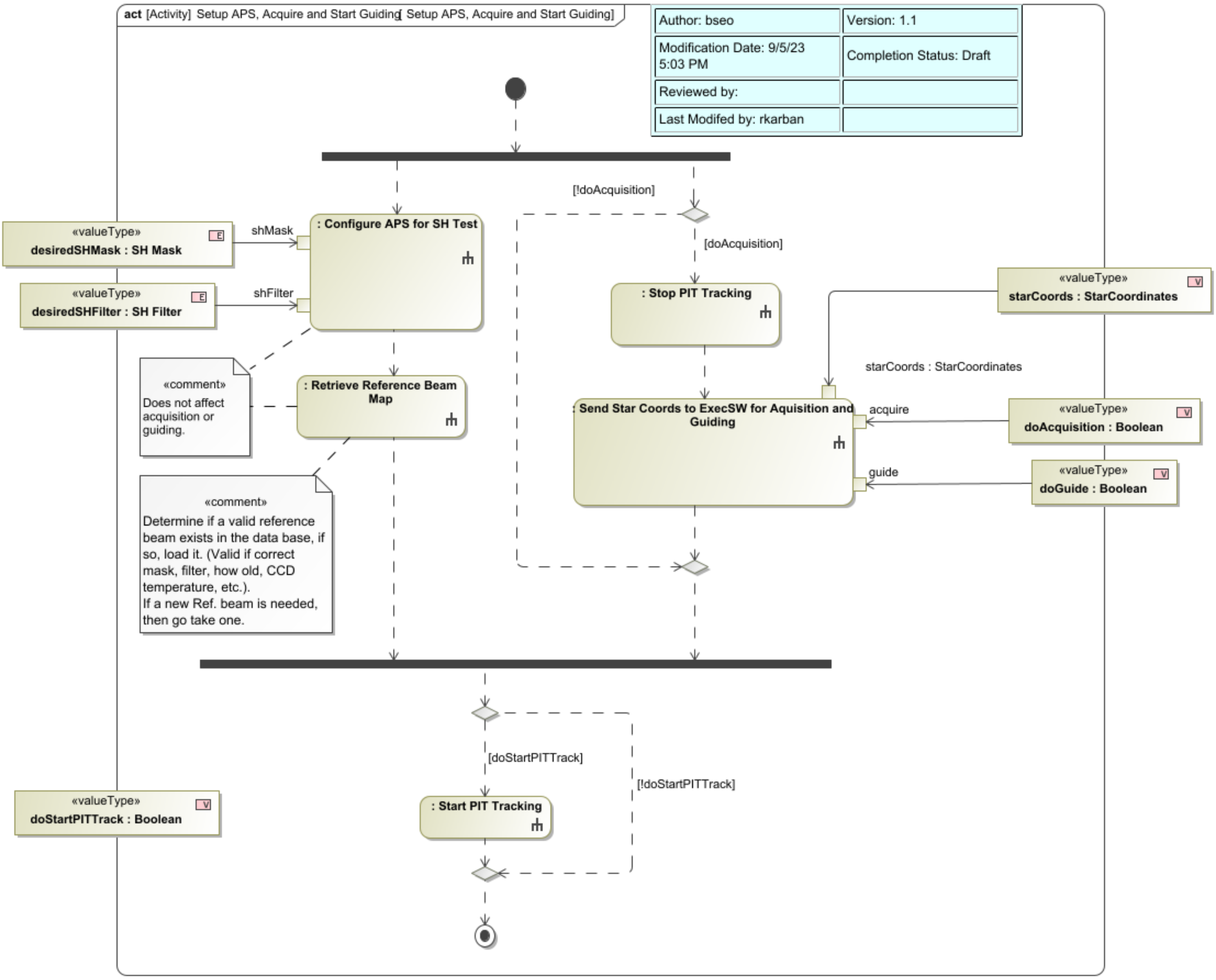


This acquisition sequence is part of almost all APS use cases. The sequence is initiated from the APS side by sending a acquisition and guiding request to the ESW. The ESW communicates with the APS APT loop to obtain images and with the TCS to perform tracking and guiding actions.

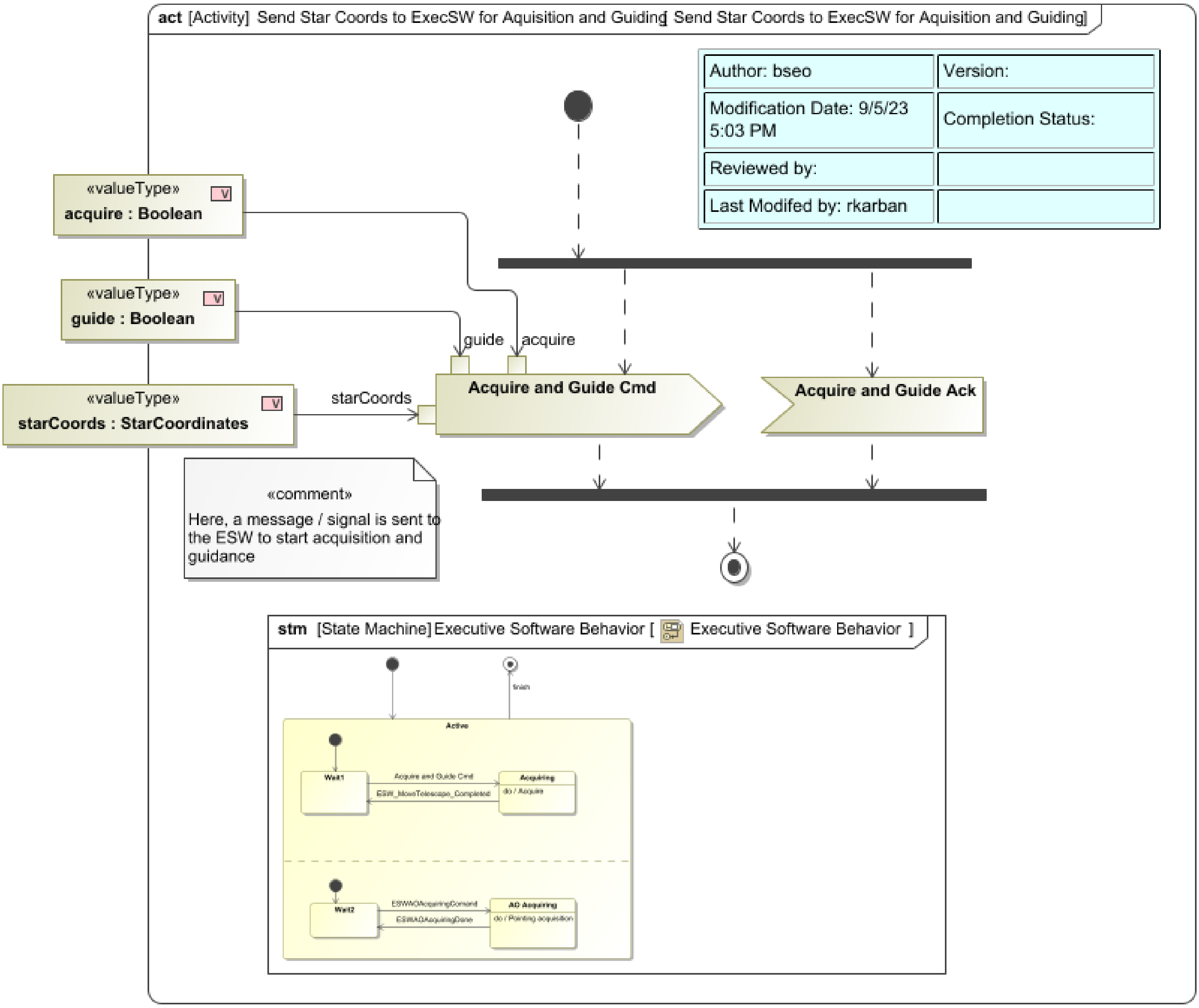
3.1.2 APS

The following diagrams show the interactions between APS, TCS and the Executive software for acquisition and guiding. The general principle is that ESW and TCS uses instrument provided cameras (like the APS APT camera) for both acquisition and guiding.

Setup APS, Acquire and Start Guiding



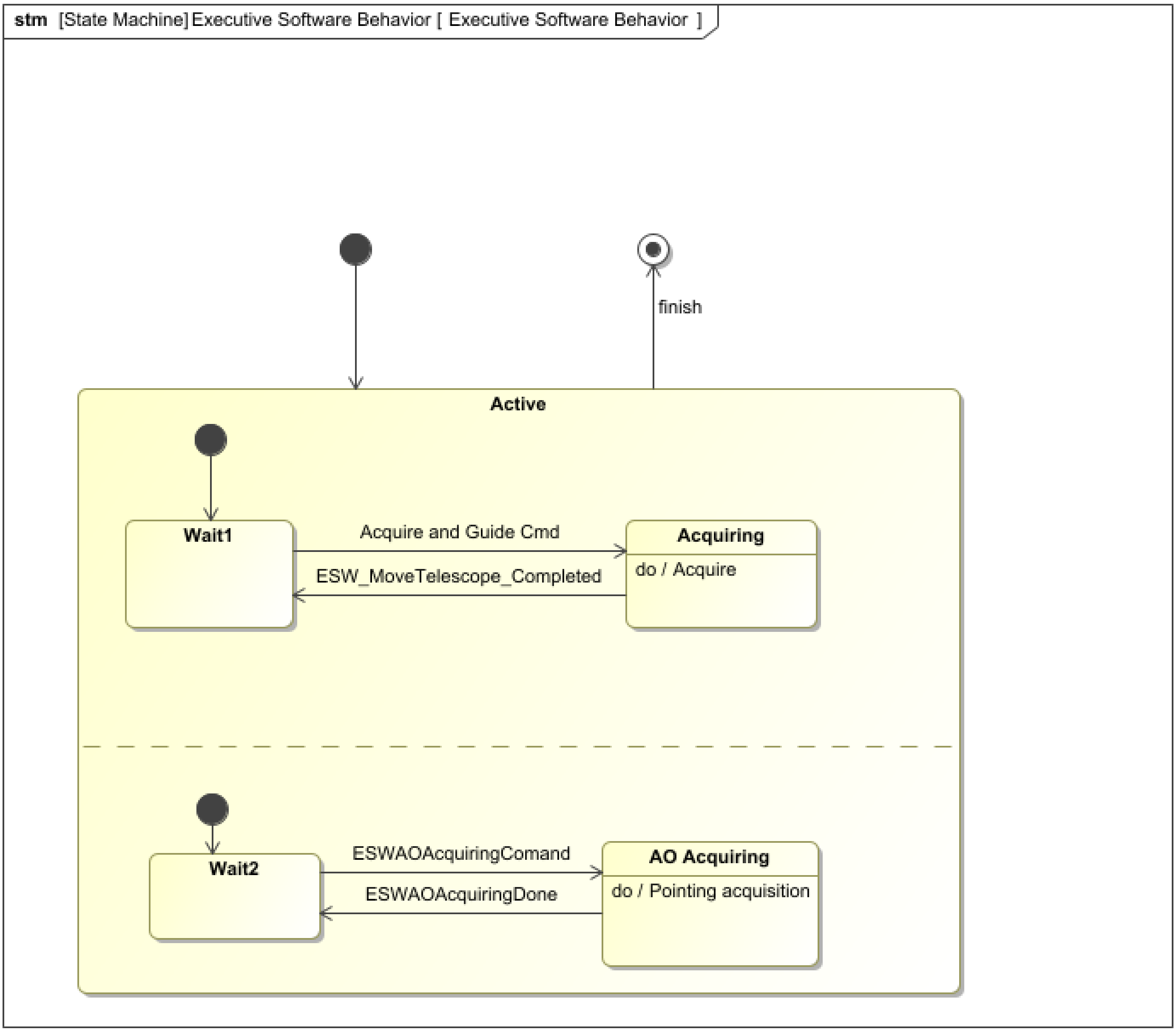
Send Star Coords to ExecSW for Aquisition and Guiding



The three parameters (Star coordinates [name or RA/DEC], Acquire object [boolean], Guide on object [boolean]) are sent from APS with the command Acquire and Guide Ack to the Executive Software.

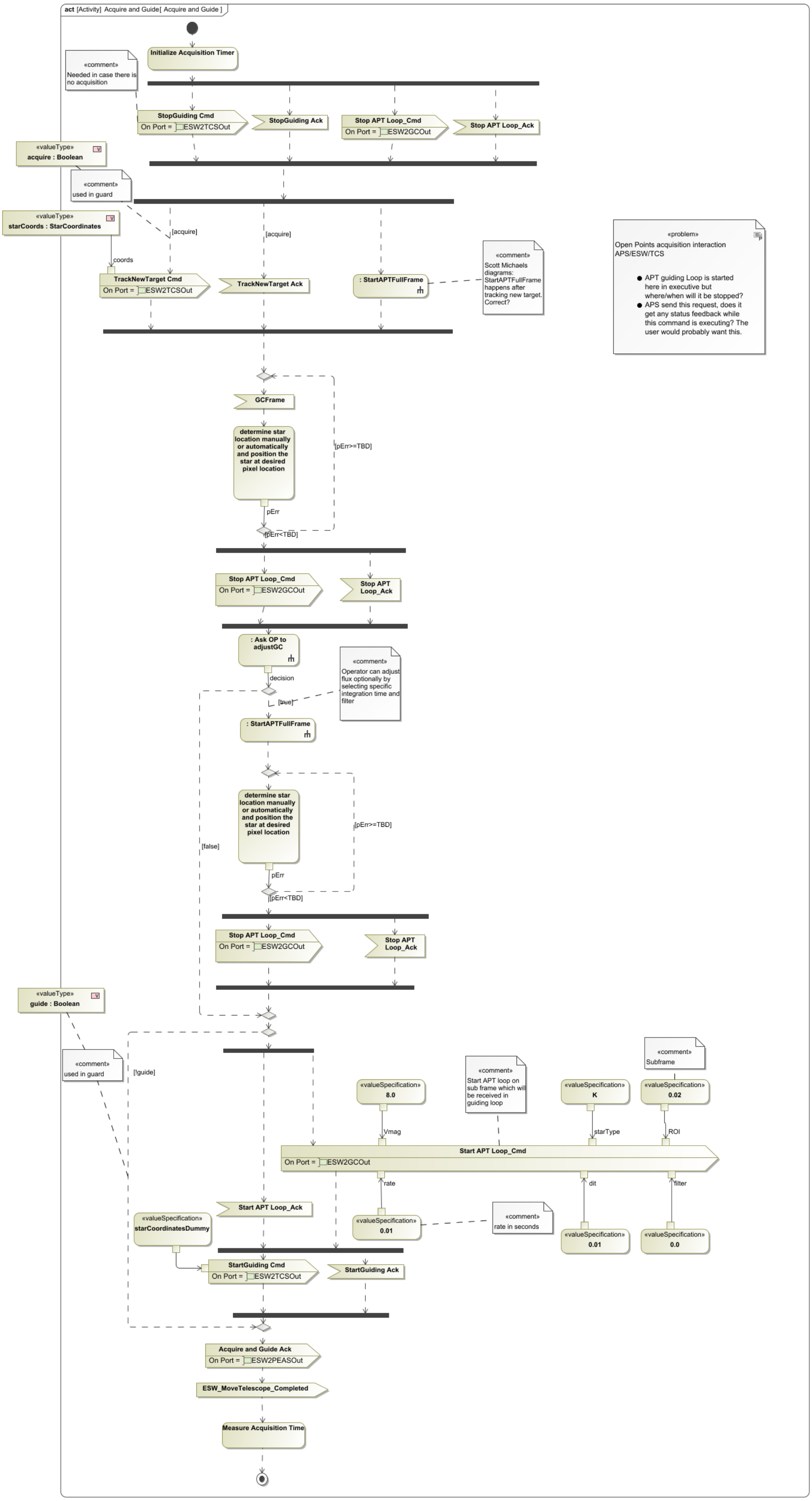
3.1.3 Executive SW

Executive Software Behavior



The Executive Software receives the command Acquire and Guide Cmd and transitions to the state Acquiring where it performs the activity Acquire.

Acquire and Guide



The activity Acquire starts with stopping the guiding loop. If the parameter acquire is set to true a command is sent to TCS in order to slew to a new target and start tracking. In parallel, a command is sent to APS to start the APT loop. The command comprises several parameters which control the APT loop:

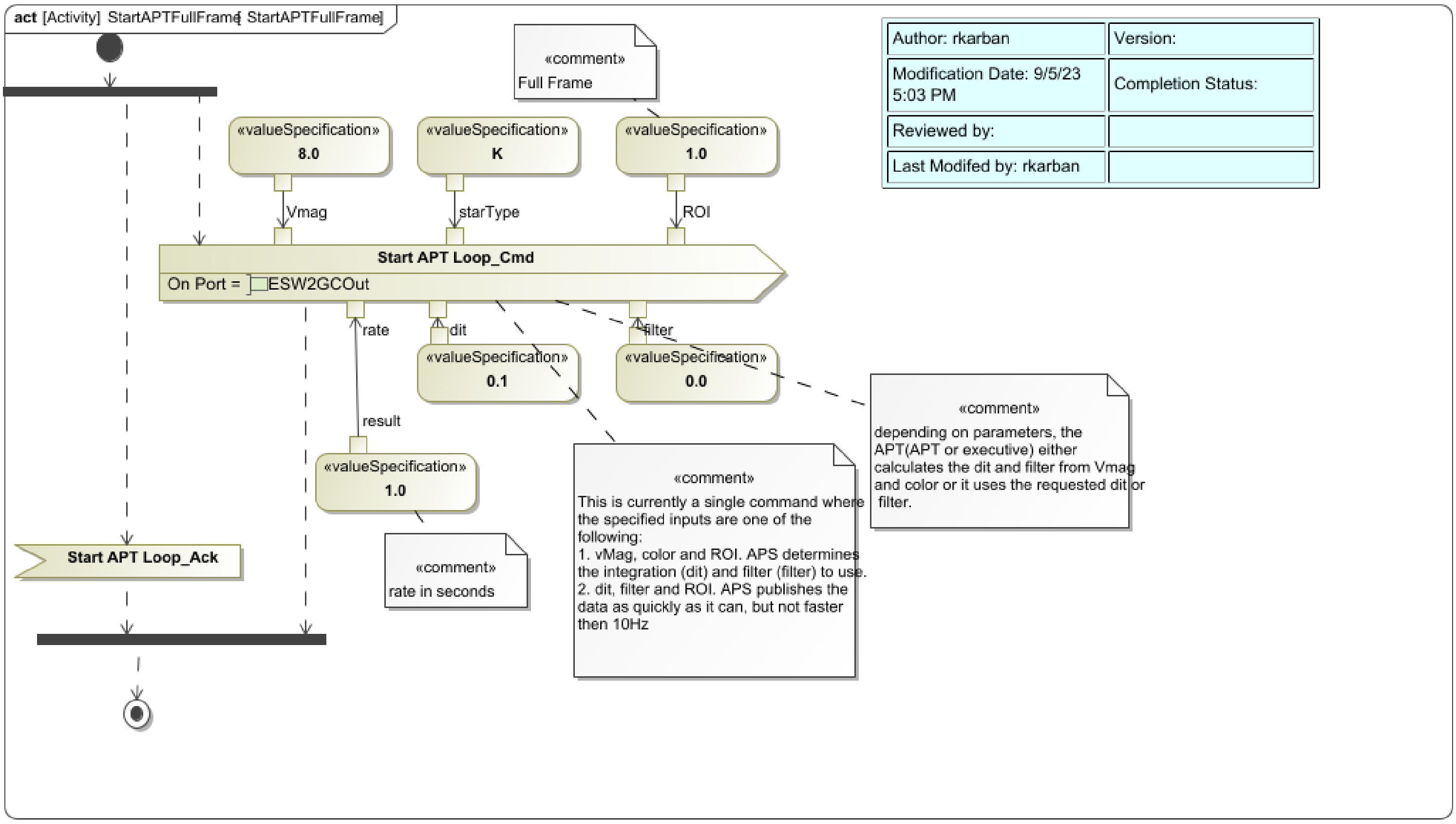
- The star magnitude
- The star color
- The region of interest (full frame or sub frame)
- The integration time
- The filter

In the command to start the APT loop the region of interest (ROI) to be read out must be specified. Then either the star magnitude (Vmag) and color is specified in which case APS will determine an optimal filter and integration time to use in order to achieve a TBD SNR and a frame rate as close to 10Hz as possible (but not faster). Alternatively in the command to start the APT loop the filter and integration time can be specified, in which case the frames will be published at a rate up to 10Hz if allowed by the specified parameters.

As soon as the acknowledgment has been received the activity waits for the reception of the full frame images in order to center the star on the detector with a certain pointing error. In an additional step the APT loop parameters can be adjusted, e.g. to take into account the actual flux observed on the detector.

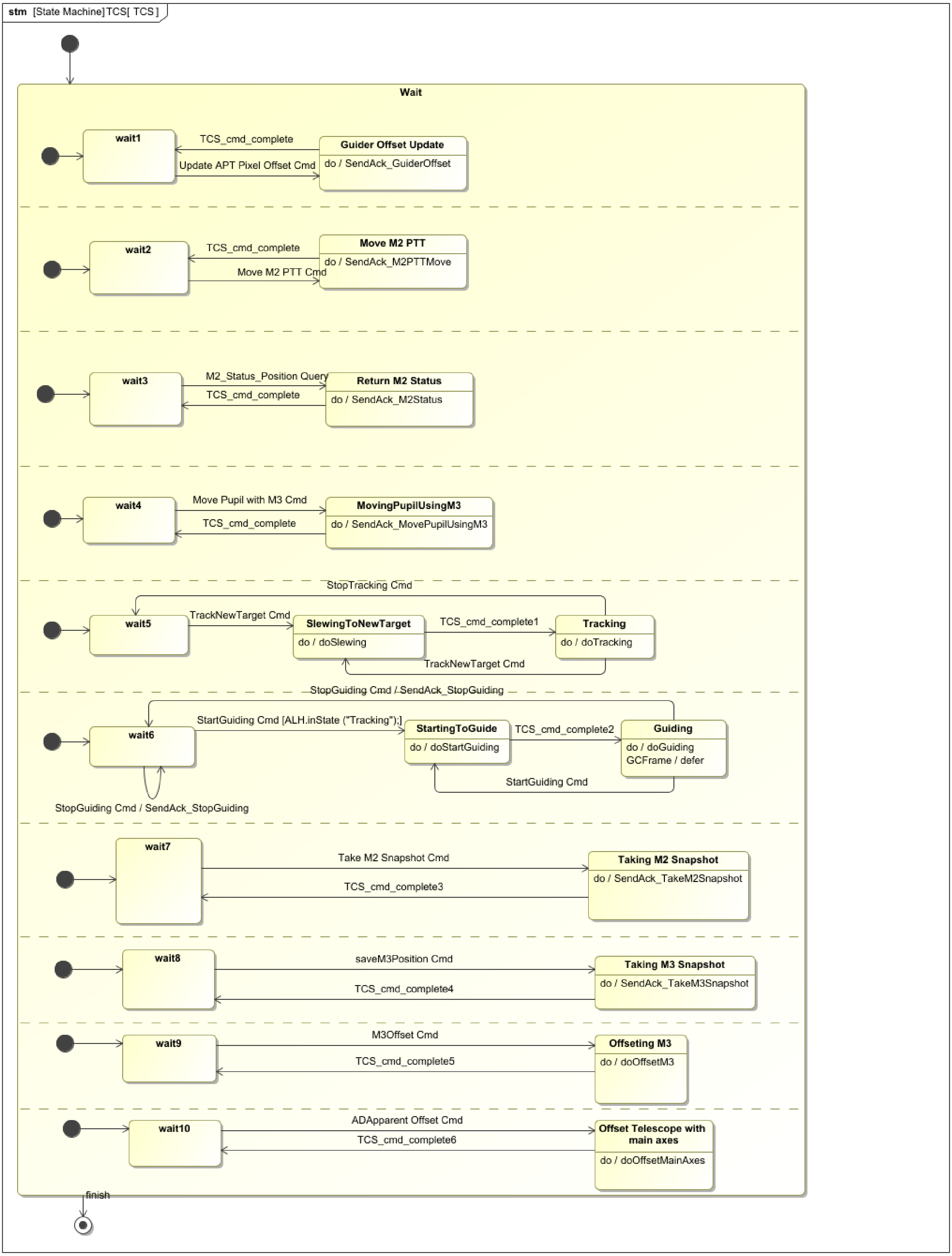
If guiding was requested the APT loop is started using values appropriate for guiding, such as a sub-region of interest of the frame. ESW then sends a command to TCS to start guiding. After receiving the acknowledgment that this command has started, ESW returns a acquire and guide acknowledgment to APS.

StartAPTFullFrame



3.1.4 TCS

TCS



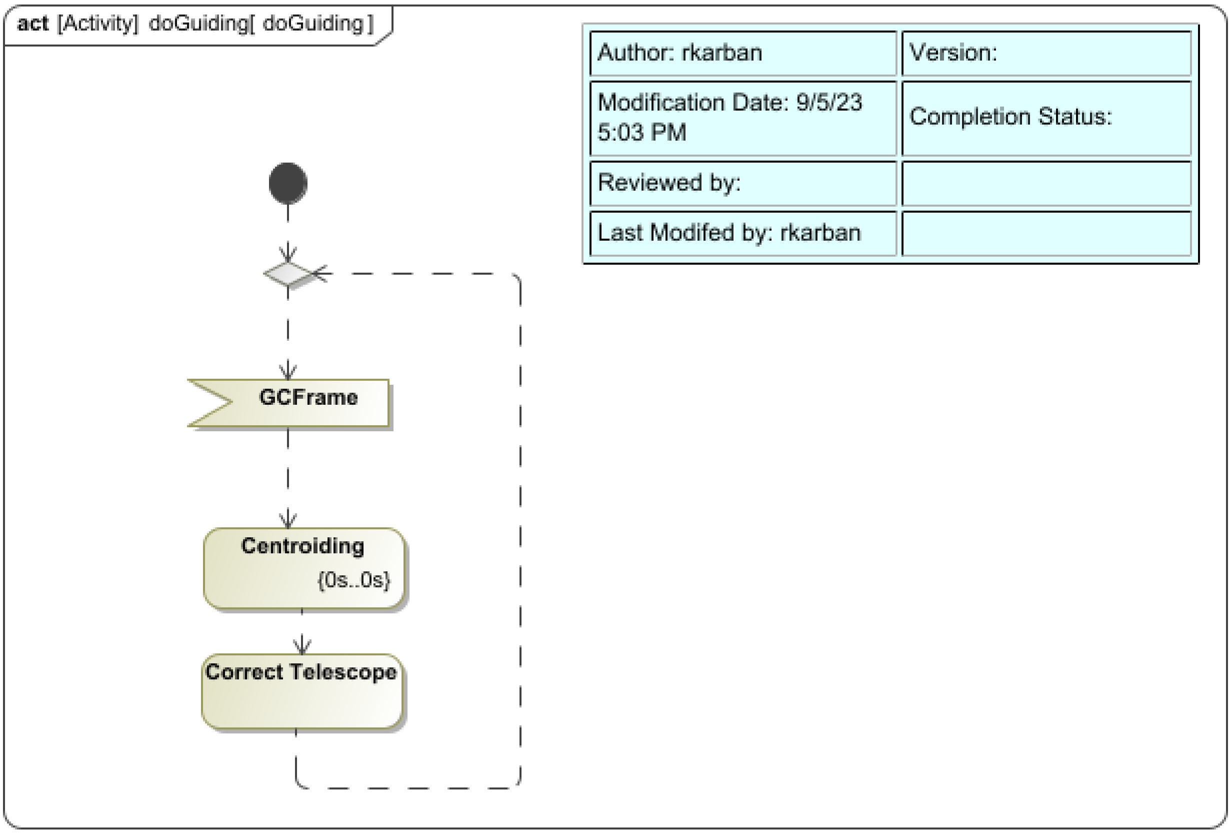
stm [State Machine]TCS[TCS]
Wait
wait1
TCS_cmd_complete
Update APT Pixel Offset Cmd
Guider Offset Update
do / SendAck_GuiderOffset
wait2
TCS_cmd_complete
Move M2 PTT Cmd
Move M2 PTT
do / SendAck_M2PTTMove
wait3
M2_Status_Position Query
TCS_cmd_complete
Return M2 Status
do / SendAck_M2Status
wait4
Move Pupil with M3 Cmd
TCS_cmd_complete
MovingPupilUsingM3
do / SendAck_MovePupilUsingM3
StopTracking Cmd
wait5
TrackNewTarget Cmd
SlewingToNewTarget
do / doSlewing
TCS_cmd_complete1
Tracking
do / doTracking
TrackNewTarget Cmd
StopGuiding Cmd / SendAck_StopGuiding
wait6
StartGuiding Cmd [ALH.inState ("Tracking");]
StartingToGuide
do / doStartGuiding
TCS_cmd_complete2
Guiding
do / doGuiding
GCFrame / defer
StartGuiding Cmd
StopGuiding Cmd / SendAck_StopGuiding
wait7
Take M2 Snapshot Cmd
TCS_cmd_complete3
Taking M2 Snapshot
do / SendAck_TakeM2Snapshot
wait8
saveM3Position Cmd
TCS_cmd_complete4
Taking M3 Snapshot
do / SendAck_TakeM3Snapshot
wait9
M3Offset Cmd
TCS_cmd_complete5
Offseting M3
do / doOffsetM3
wait10
ADApparent Offset Cmd
TCS_cmd_complete6
Offset Telescope with main axes
do / doOffsetMainAxes
finish

In the TCS state machine two regions take care of the tracking and guiding states.

When a command is received to slew to a new target the telescope will start moving and eventually transition into the tracking state.

If guiding is requested, TCS will start guiding, provided it is also in the state tracking (guarded transition) and eventually transition into the guiding state.

doGuiding



In the guiding state, TCS will receive frames (GCFrame) from the APS camera (taken in the APT loop) and process them, i.e. the centroiding will be done on TCS side.We assume it takes zero time because we care only about APS time in this scenarios.

The guiding reference point and plate scale is delivered by APS as part of the frame meta information.

3.2 Coarse Tilt Alignment

The purpose of the coarse tilt alignment procedure is to capture segments in tip/tilt after their initial installation or after a segment exchange. The segment installation requirements for TMT are that the one-dimensional tip/tilt errors on the sky shall be less than ±20 arcseconds (maximum, not RMS). The APS field of view in the main or Shack-Hartman channel is 25 arcsec in diameter, set by vignetting in the K-mirror and enforced via a field stop the the telescope focus. Thus the APS tip/tilt capture range is nominally only ±12.5 arcsec. This test uses the SH-0 mask which has a single sub-aperture per segment. This mask has a nominal subimage spacing at the detector of 78 arcseconds, much greater then the field of view radius. As a result if the segment subimages are within the 25 arcsec FoV, then there is never any question of which subimage corresponds to which segment. That is, as a subimage moves away from its nominal position, it will disappear before it can cross into a region of the CCD that is assigned to another segment. This test does not need a very well aligned telescope pupil, in principle the single subaperture just needs to be within ±~0.6m so that it is on the correct segment. This tolerance along with the likely hood of subimage confusion means both that there are no segment subapertures on the SH-0 mask and the pupil image tracking loop (PIT) is not needed.

The effective capture range of the coarse alignment activity will be increased by performing a search via re-pointing the mirror segments. Our proposed approach is to:

1. Take an image with the SH-0 mask, if all segments are found the continue as normal to analyze the image and send commands to M1CS.
2. If not all segments are found then tilt those segments not found by 20 arcseconds on-sky (TBR) and repeat step 1.

A raster search pattern will be used and 9 images will provide a ±30 arcsecond on-sky capture range.

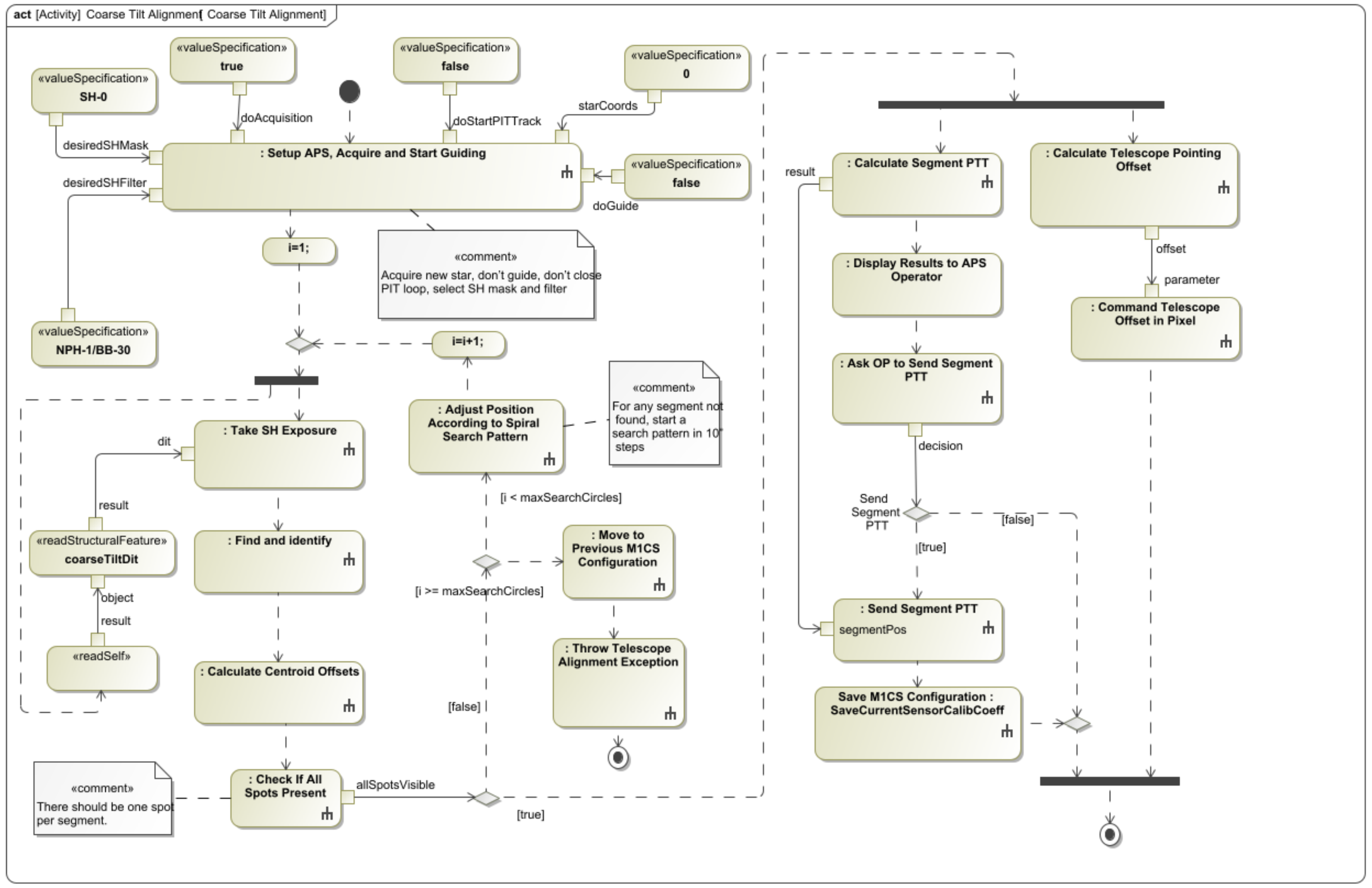
The coarse tilt alignment procedure will correct the segment image tip/tilts to within 0.3 arcseconds (one dimension, RMS) within the capture range of the *rigid body and segment figure* alignment activity. The specific details of the coarse tilt alignment algorithms are described in the APS Algorithms Document. During AIV we can confirm this activity is working as expected by executing it twice in a row and looking at the RMS and maximum segment tip/tilt. During normal operations we will likely execute this activity once and move on to the next activity. If this activity fails to reach the needed exit condition and it's not caught by the APS software then it will be obvious in the next activity as subimages will be overlapping. At Keck the equivalent activity (coarse tilt) has been executed hundred's of times without any failures, so we don't expect any problems.

See the APS Algorithms document (TMT.CTR.TEC.15.022.DRF01, https://docushare.tmt.org/docushare/dsweb/Get/Document-46441) and/or the APS Logical Design Report (TMT.TEL.CDD.07.002.RELO1, https://docushare.tmt.org/docushare/dsweb/Get/Document-9546) for additional details regarding this activity including detailed descriptions of the algorithms, filter, mask, etc., that are used.

Relevant activity parameters:

- Entrance requirement: segment tip/tilt errors less then ±20 arcseconds (one-dimensional, maximum, Not RMS) on the sky.
- Exit condition: segment tip/tilt errors within the capture range of the *rigid body and segment figure* alignment activity, which is estimated to be ±~3 arcseconds (one-dimensional) on the sky.
- Filter: 611nm with a bandpass of 10 nm
- Pupil Mask: SH-0, which has one subaperture per segment.
- PIT loop status: open (not used)
- Star magnitude: 5-6
- Star spectral type: K
- Integration time for a single frame: ~20 seconds
- Number of frames used per measurement: 1
- Number of frames used per activity: 9

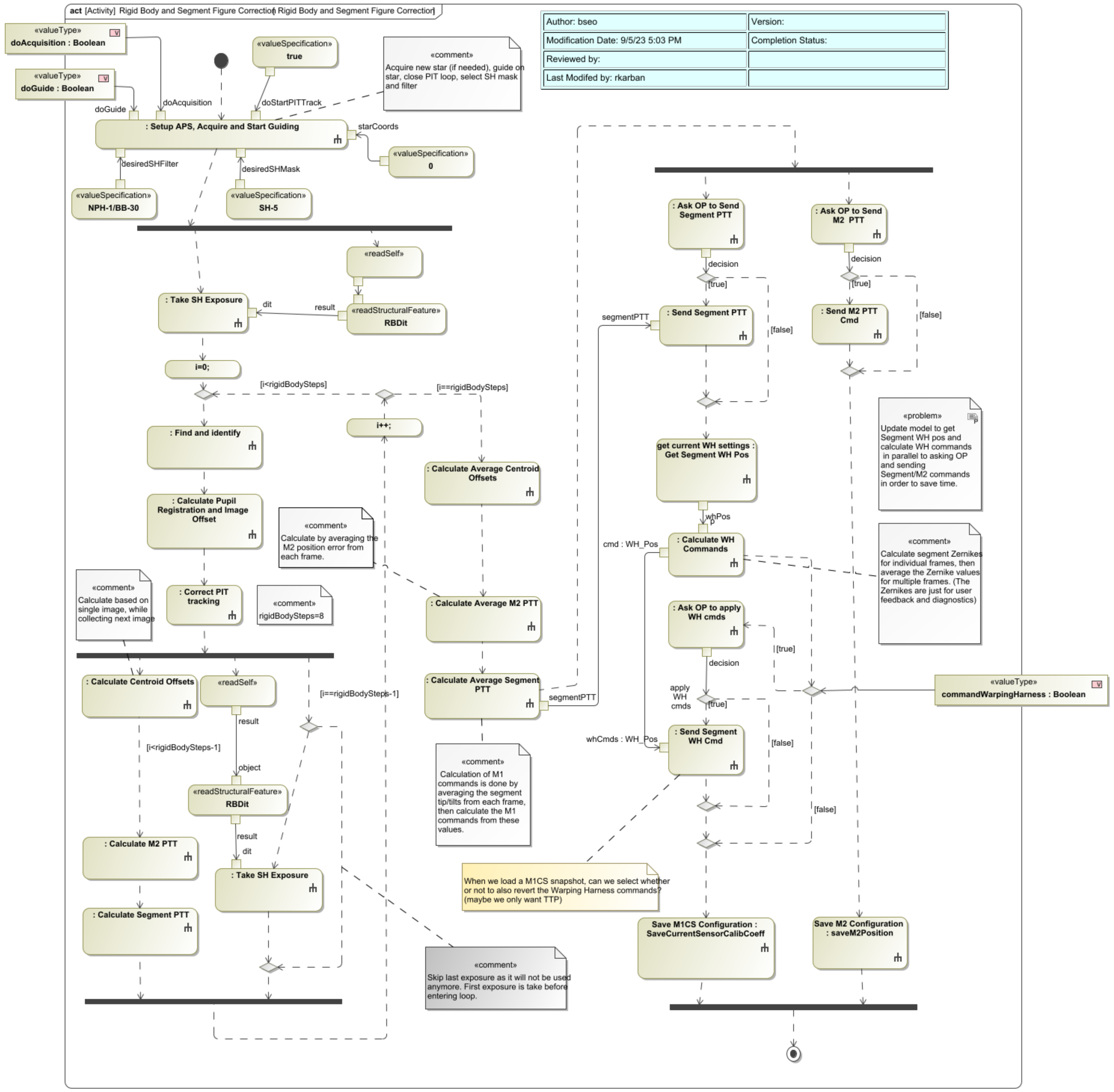
Coarse Tilt Alignment



3.3 Rigid Body and Segment Figure Correction

The fine tilt alignment procedure will sample each segment in 37 points and is designed to take the segment surface tip/tilts from the nominal 0.2-arcsecond errors that result from coarse tilt alignment and reduce these to the ultimate accuracy of 0.02 arcsec rms in each dimension. In order to reduce the errors to this low level we will have to average over several different realizations of atmospheric turbulence; a typical exposure sequence will consist of perhaps eight integrations of 40 to 60 seconds each. Since this procedure nominally constrains only the segment tip/tilts, further constraints must be imposed in order to constrain the segment pistons. Normally, the segment pistons are constrained so that the changes to the rms intersegment edge height are minimized.

Rigid Body and Segment Figure Correction



3.4 Broad Band Phasing

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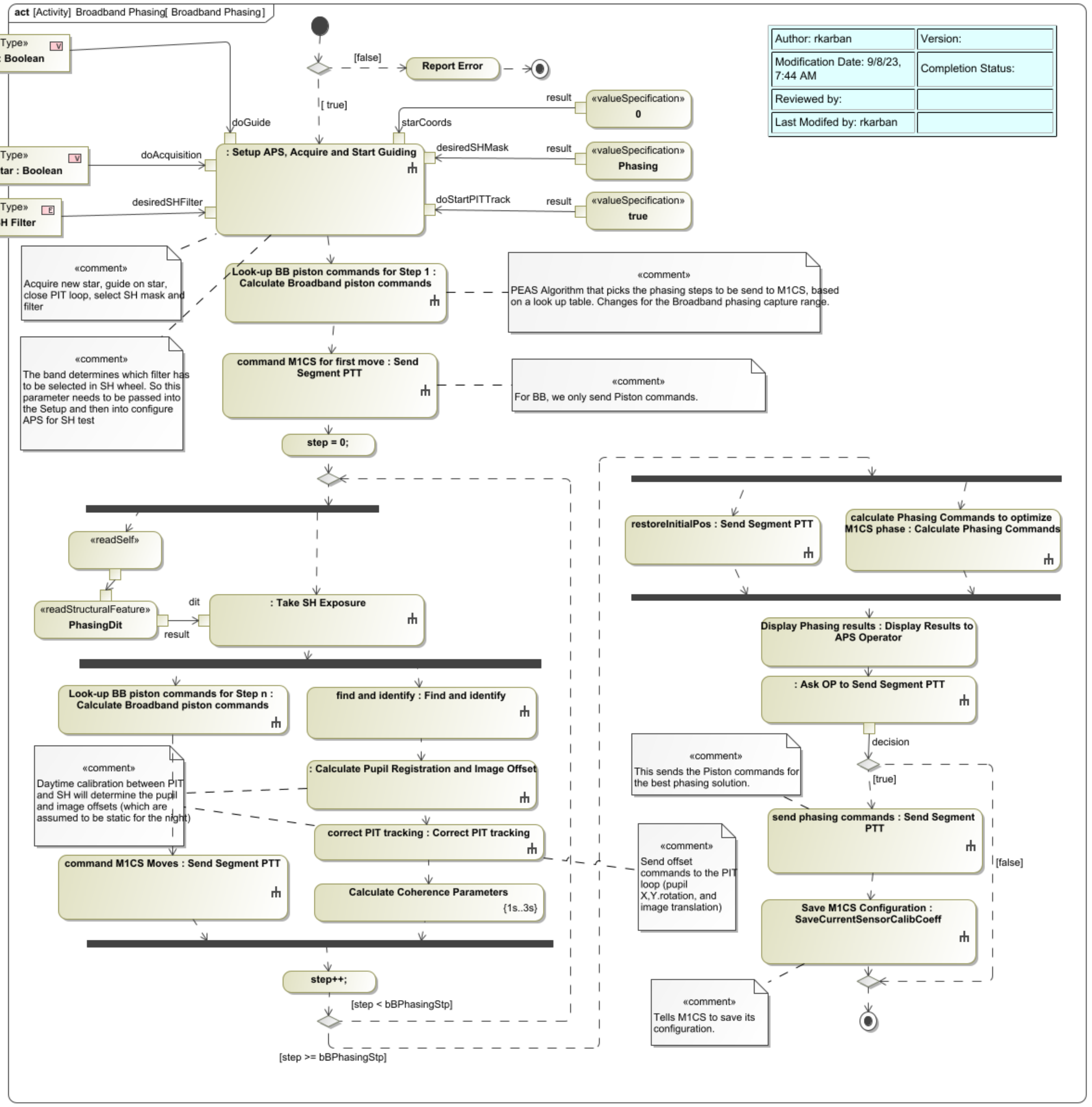
comment:smichael

Broadband Phasing



3.5 Narrow Band Phasing

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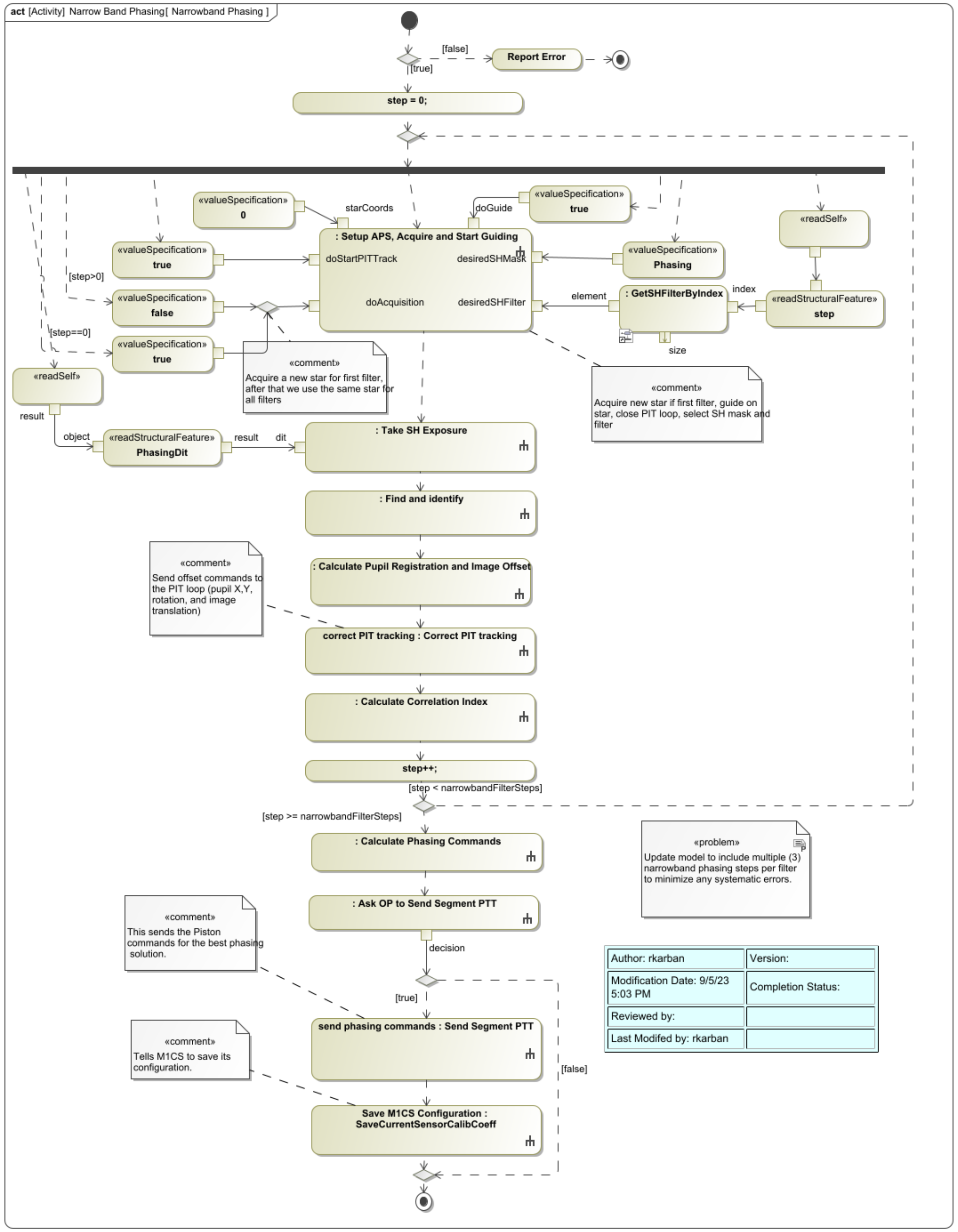
comment:smichael

Narrowband Phasing



Author: rkarban	Version:
Modification Date: 9/5/23 5:03 PM	Completion Status:
Reviewed by:	
Last Modifed by: rkarban	

3.6 Measure Warping Harness Influence Function

This purpose of this activity is to collect the on-sky data needed to measure the the warping harness influence functions. Details are discussed in TMT.CTR.PRE.15.073.DRF01. This activity starts with a well aligned mirror (M1 tip/tilt/piston and M2 rigid body) as described in [cf:Entrance Requirements and conditions.vlink] . This total activity takes ~10 hours to measure all warping harness influence functions, all segments are measured in parallel. The nominal plan is to measure the influence functions using three (3) different stars and measure seven (7) warping harness influence functions per star which will take ~3.5 hours per star.

For each group of warping harness influence functions to be measured on a specific star the following procedure is followed: APS is configured for the test, a star is acquired, guiding is started and the PIT loop is closed. Then for each warping harness influence function to be measured on the current star:

1. 8 frames of Shack-Hartmann data are collected
2. The current warping harness influence function to be measured is set to +45% (TBR) of it's stroke limit for all segments
3. 8 frames of Shack-Hartmann data are collected
4. The current warping harness influence function to be measured is set to +45% (TBR) of it's stroke limit for all segments
5. 8 frames of Shack-Hartmann data are collected
6. The current warping harness influence function to be measured is set to zero for all segments

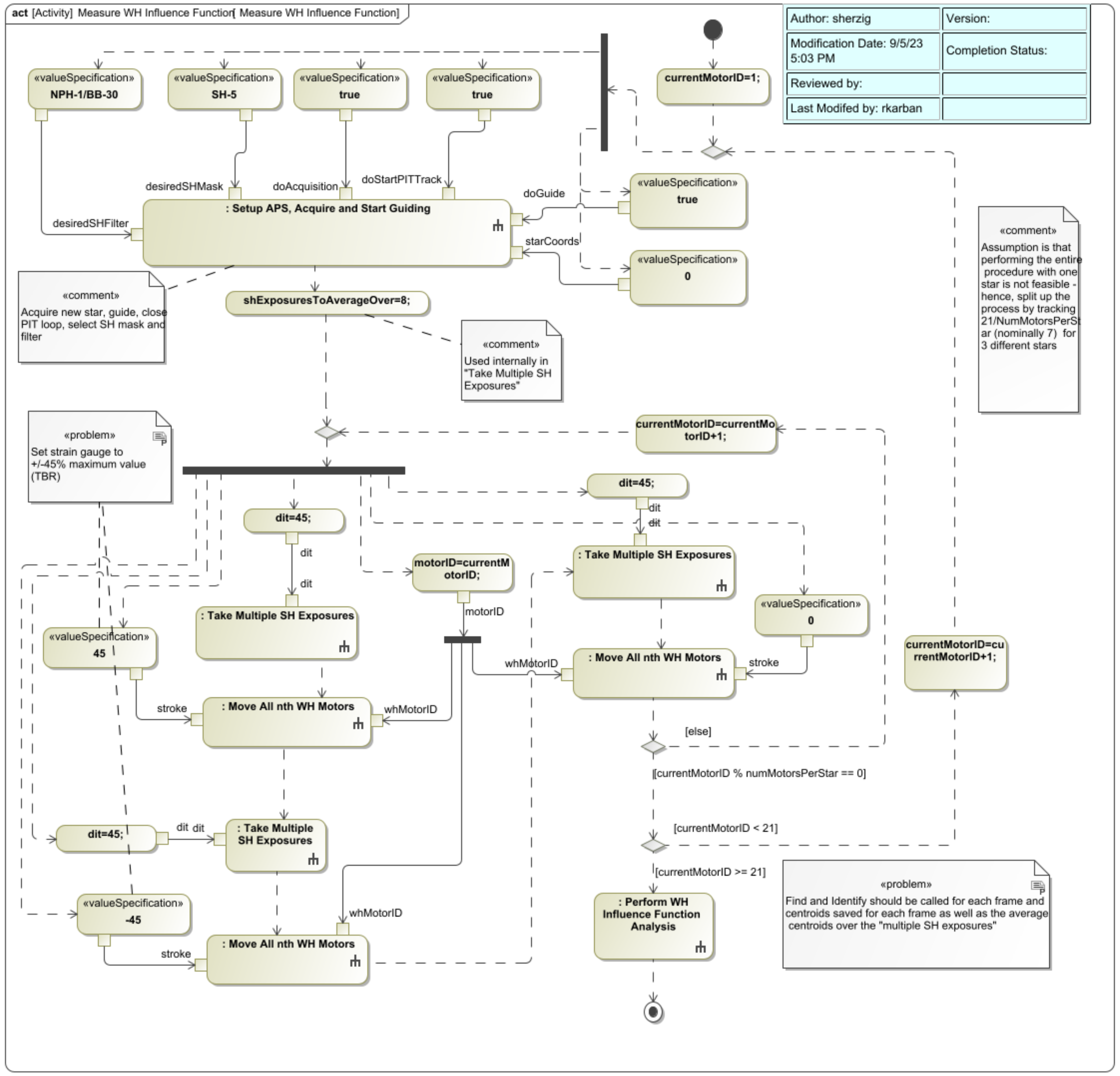
When all data has been collected PEAS-PCS will calculate the centroid offsets for each segment and each set of Shack-Hartmann frames (8 frame average). The remaining data analysis will be performed off-line and can not be defined and/or developed until the first set of data is collected. However, the data analysis will likely include the following:

- Comparing the on-sky measured influence functions to the theoretical influence functions.
- Comparing and/or combining the on-sky measured influence functions among segments of the same type.
- Comparison of the measured influence functions over the lifetime of the telescope.
- Blending together the on-sky and theoretical influence functions to generate a better estimate of the influence functions.

Relevant activity parameters:

- Entrance requirement: [cf:Entrance Requirements and conditions.vlink]
- Exit condition: No change in telescope alignment
- Filter: 611nm with a bandpass of 10 nm
- Pupil Mask: SH-5 (TBR), which has 91 subapertures per segment.
- PIT loop status: open (not used)
- Star magnitude: 5-6
- Star spectral type: K
- Integration time for a single frame: ~45 seconds
- Number of frames used per measurement: 8
- Number of frames used per activity: 504

Measure WH Influence Function

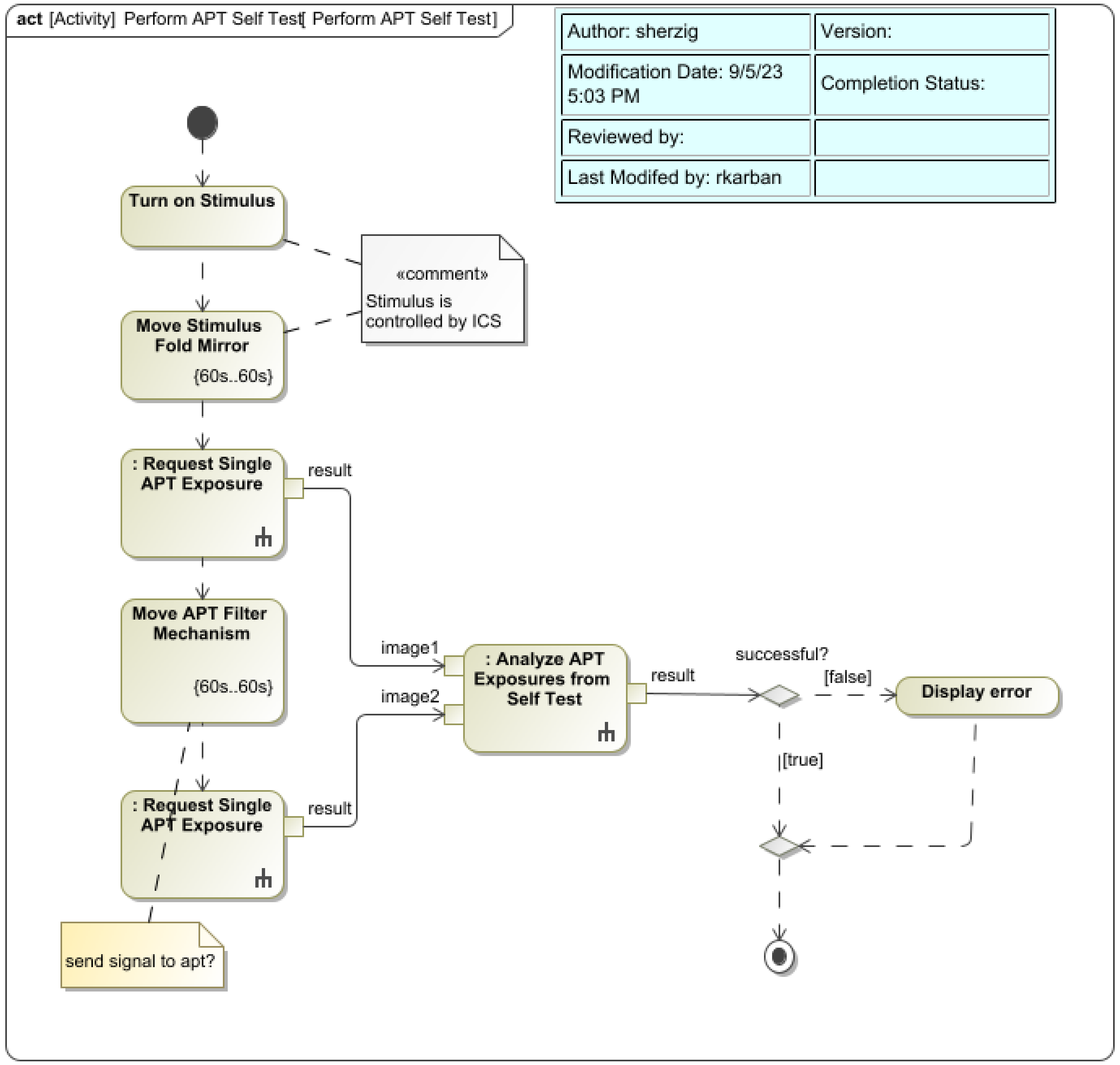


3.7 Self Test

This section described the activities that are part of the APS self test use case.

The figure below shows the APT self test activity. The purpose of this activity is to verify proper operation of the APT hardware and software. The stimulus is turned on and a fold mirror moved so that the light enters APS. A single APT exposure is taken, the APT filter is changed and another APT exposure is taken. These images are then analyzed to insure that each image contains a single PSF and that the counts on the detector match the expected values. If there is an error the user is informed.

Perform APT Self Test

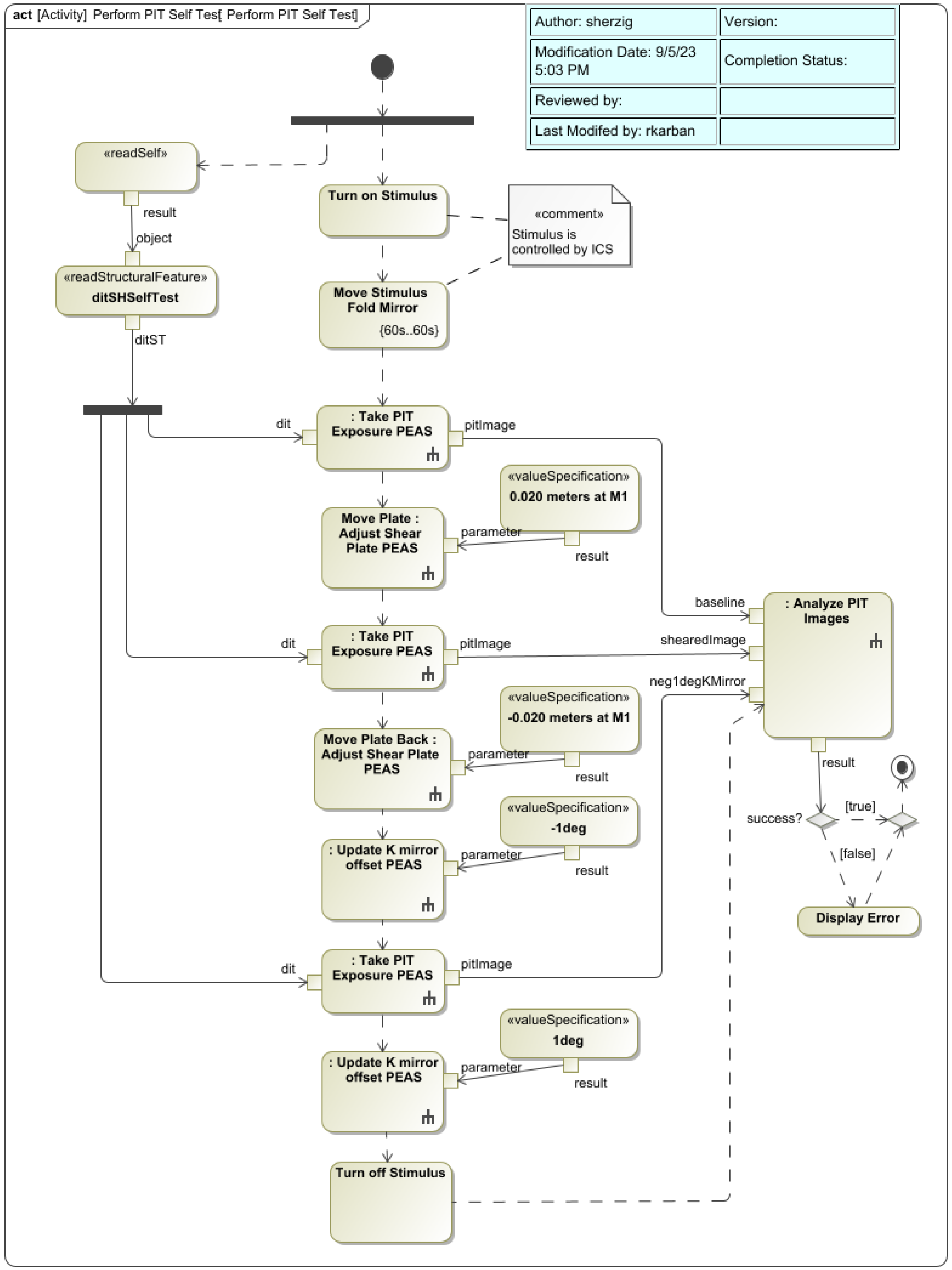


The figure below shows the PIT self test activity. The purpose of this activity is to verify proper operation of the PIT hardware and software. The stimulus is turned on and a fold mirror moved so that the light enters APS. This activity then:

1. Takes a single PIT exposure
2. Moves the shear plate to generate a change in the pupil registration as compared to the stimulus mask
3. Takes a single PIT exposure
4. Moves the shear plate back to it's original position
5. Updates the K-Mirror rotation angle
6. Takes a single PIT exposure
7. Moves the K-Mirror back to it's original position
8. Turns off the stimulus off

The three PIT images are then analyzed to insure that each image measures the correct pupil motion and/or pupil rotation and that the subimage intensity in the images matche the expected value. If there is an error the user is informed.

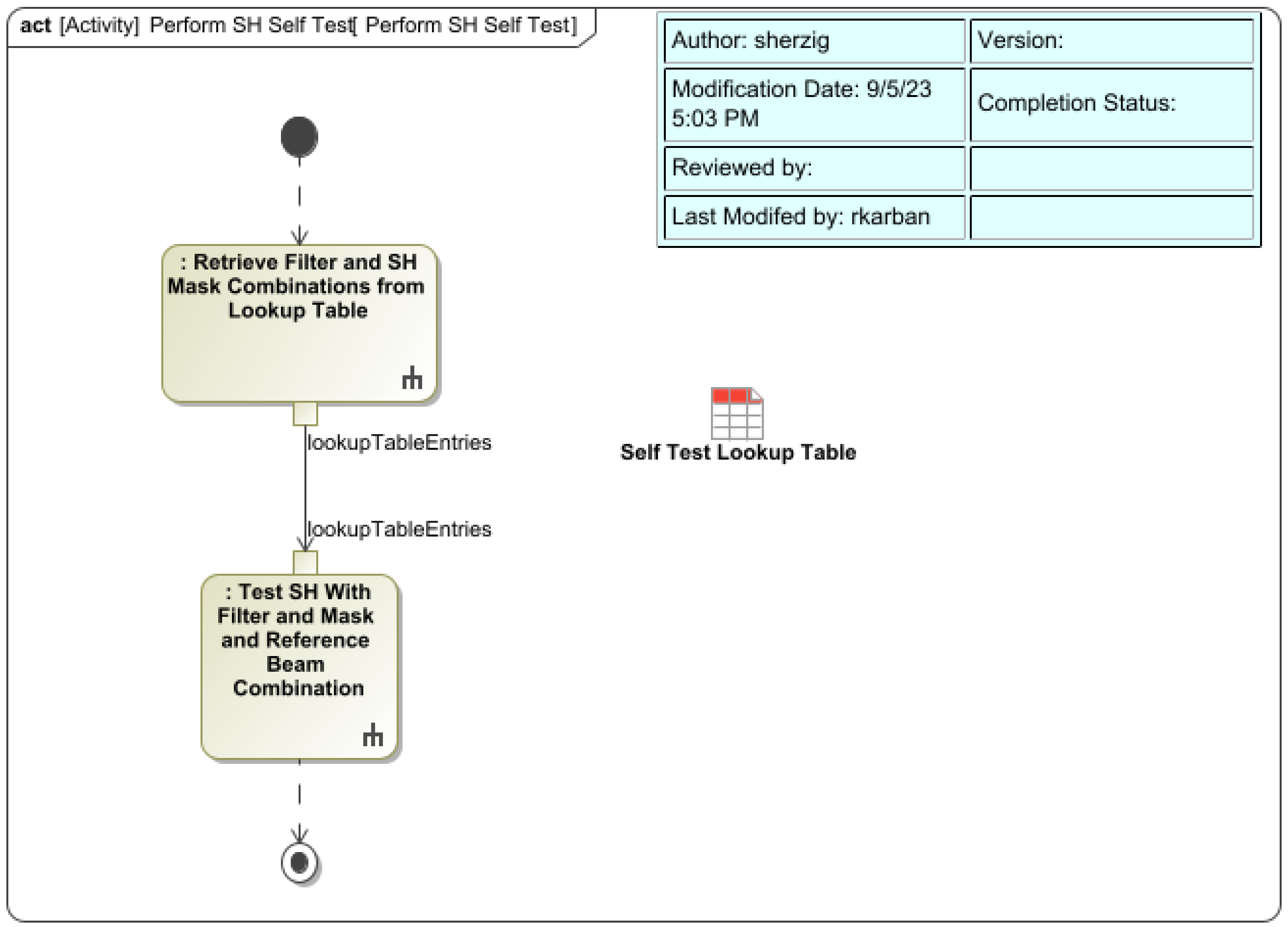
Perform PIT Self Test



The figure below shows the SH self test activity. The purpose of this activity is to verify proper operation of the SH hardware and software. The following steps are executed for each of the SH mask and filter combinations shown in the lookup table below the figure. For each entry in the table this activity:

1. Configures APS for the selected filter and mask
2. Turns on the appropriate reference beam
3. Takes a single SH exposure of the appropriate length
4. Turns off the reference beam
5. Analyzes the image to insures it can locate all of the subimages (Find and Identify) and compare the subimage intensity in the images to the expected value
6. If there is an error the activity stops and informs the user

Perform SH Self Test



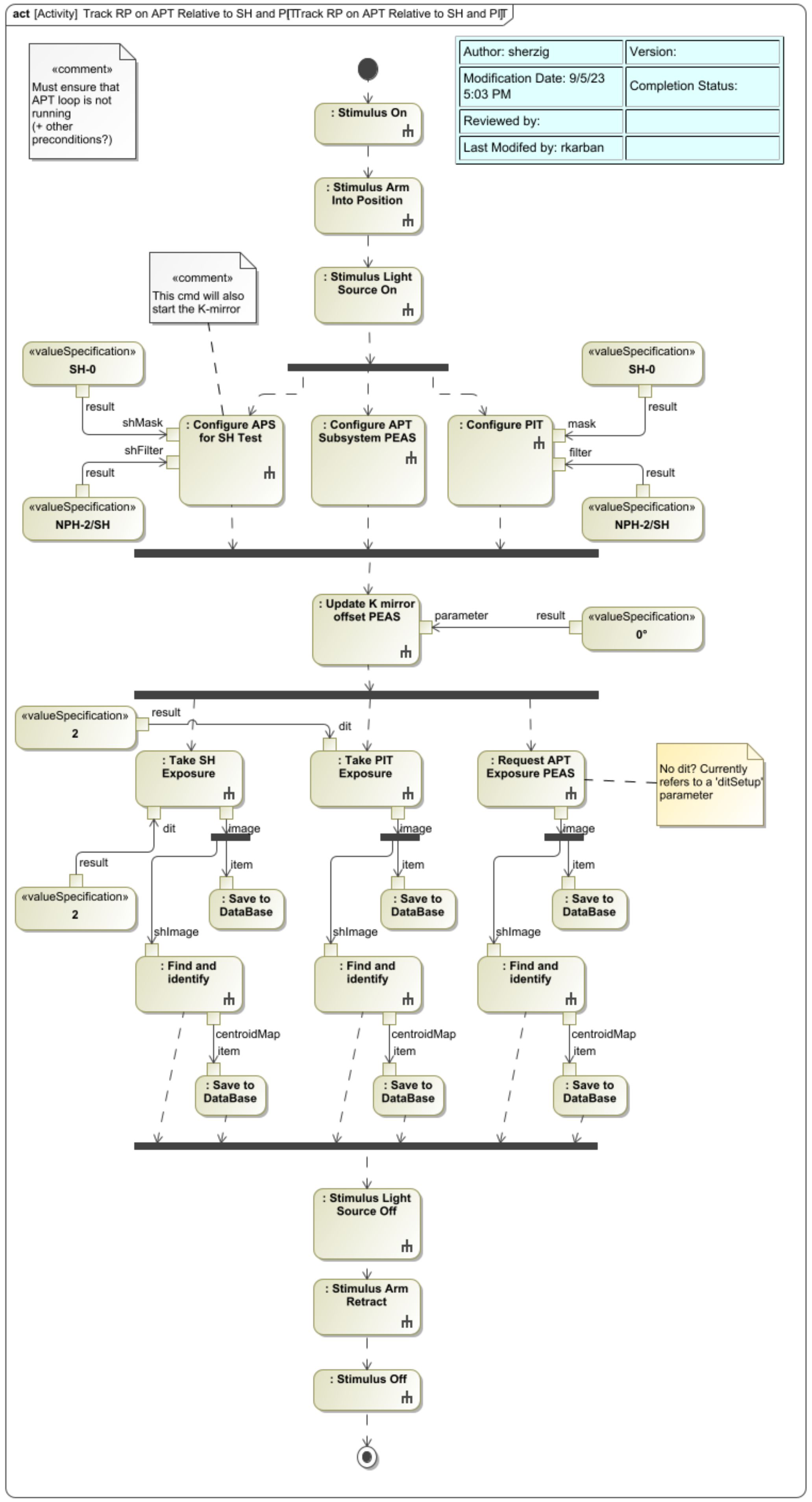
Self Test Lookup Table

#	Name	mask : SH Mask	filter : SH Filter	reference Beam : ReferenceBeam Type
1	row2	SH-0	NPH-1/BB-30	870nm
2	row3	Phasing		870nm
3	row1	Phasing	NPH-1/BB-30	870nm

#	Name	mask : SH Mask	filter : SH Filter	reference Beam : ReferenceBeam Type
4	row4	Phasing		870nm
5	row5	SH-5	NPH-1/BB-30	870nm

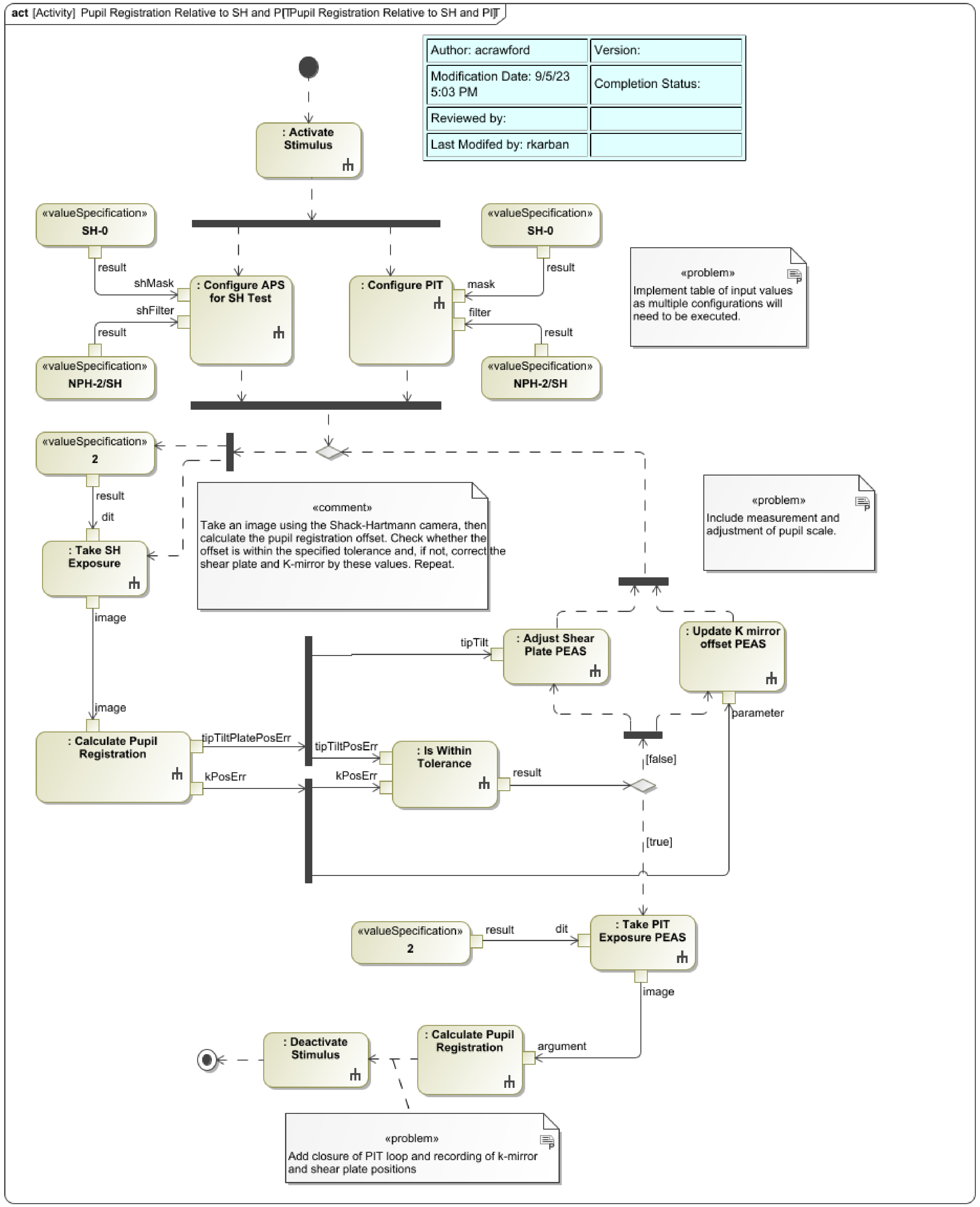
3.8 Track RP on APT Relative to SH and PIT

Track RP on APT Relative to SH and PIT

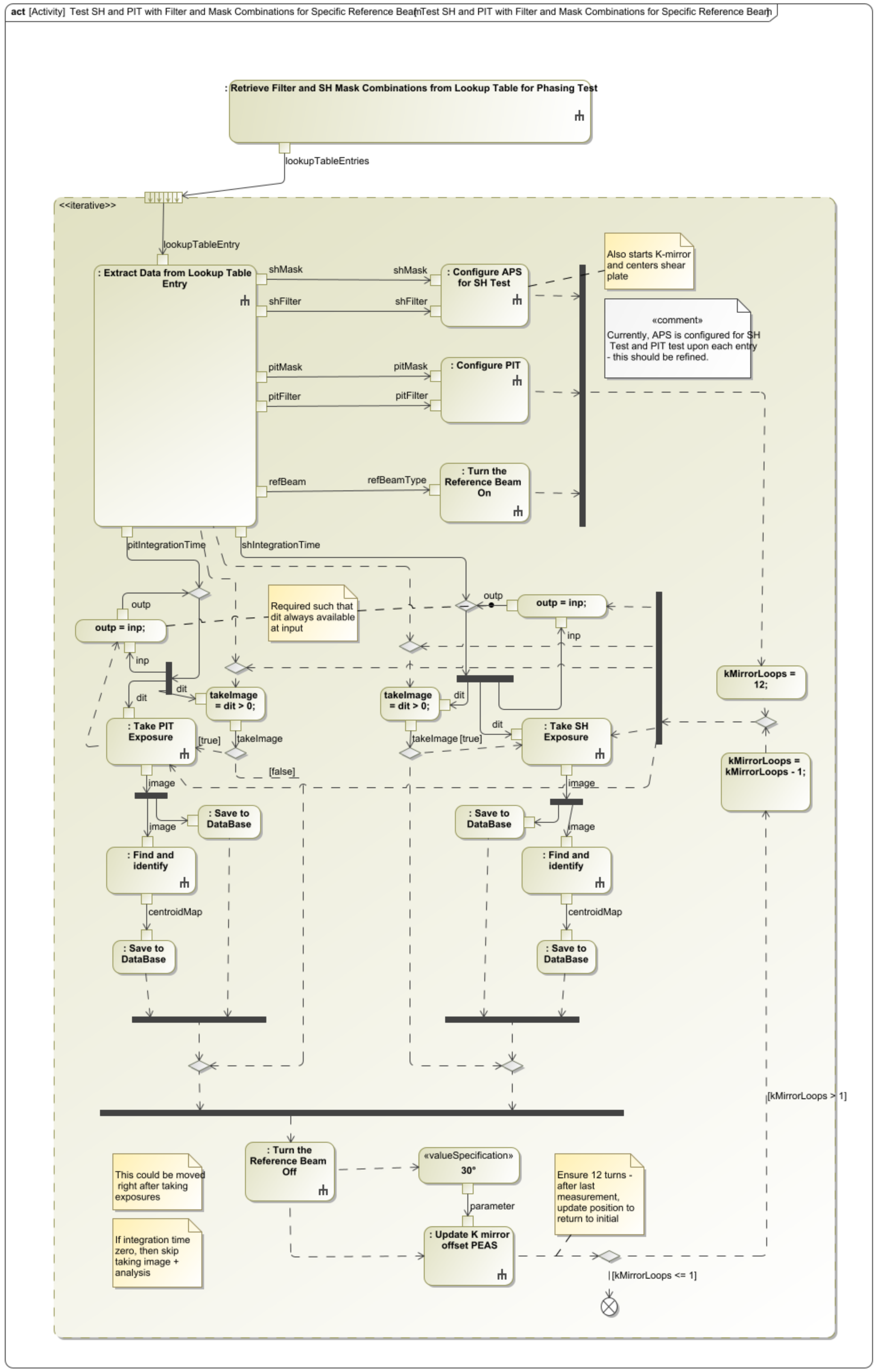


3.9 Pupil Registration Relative to SH and PIT

Pupil Registration Relative to SH and PIT



Test SH and PIT with Filter and Mask Combinations for Specific Reference Beam



Wavefront Calibration Lookup Table Data

#	Name	reference Beam : ReferenceBeam Type	shMask : SH Mask	shFilter : SH Filter	pit Mask : PIT Mask	pit Filter : PIT Filter	integrationTimeSH : Real	integrationTimePIT : Real
1	entry001	650mm	SH-0	NPH-2/SH	SH-0	BB-1	30	15
2	entry002	650mm	SH-5	NPH-2/SH	SH-0	BB-3	30	10
3	entry003	650mm	SH-6	NPH-2/SH	SH-2	BB-1	30	15
4	entry004	650mm	Phasing	NPH-2/SH	SH-2	BB-3	30	10
5	entry005	650mm	SH-2	NPH-2/SH			30	0
6	entry006	890nm	Phasing	BB-100	SH-2	BB-10	6	7
7	entry007	890nm	Phasing	NPH-1/BB-30	SH-0	BB-10	2	7
8	entry008	890nm	Phasing	BB-3			1	0
9	entry009	700mm	Phasing	BB-1			4	0
10	entry010	650mm	Phasing	Open			4	0

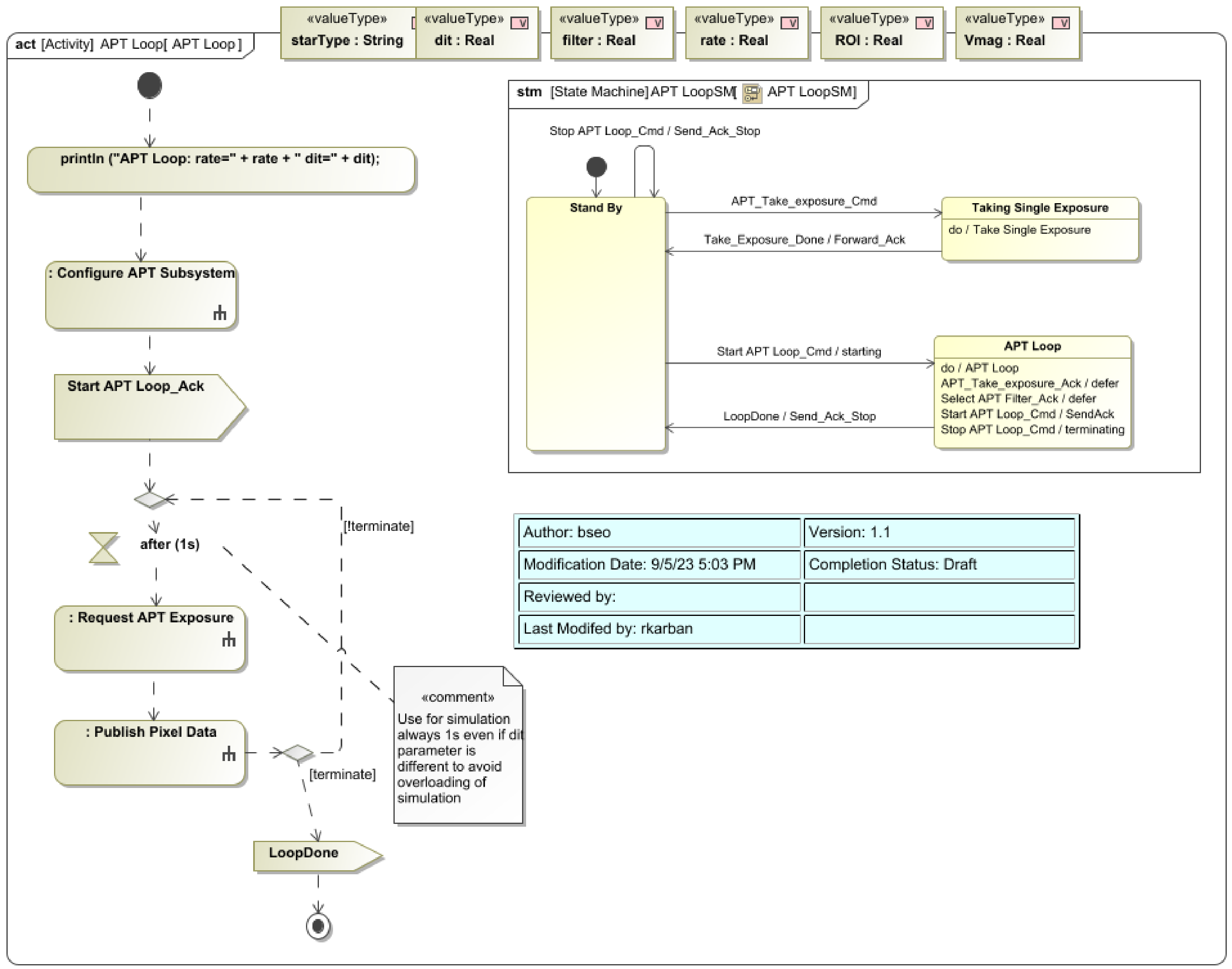
4 Lower Level Activities

4.1 Acquisition or Guider Loop

The current baseline is that APS will publish the needed pixel data for guiding and TCS will subscribe to this pixel data and perform the needed functions for guiding. In the figure below we show an activity diagram that describes the baseline APS activity. The activity starts with the assumption that the telescope is tracking a star and the star has been acquired on the APT CCD within ~4 (TBR) arcseconds of the desired APS tracking point.
In the following we provide a brief description of each of the blocks shown in the figure:

- “Configure APT Subsystem”: The ICS configures APT with the ICS parameters. The ICS parameters are provided by TCS in general. If not provided, ICS uses its default values based on the star information from GAS. ICS parameters include the APT filters, integration time and region of interest of the detector to read out.
- “Take APT Exposure”: The APS ICS takes a CCD exposure.
- "Publish Pixel Data”: The APS ICS publishes the pixel data from the APT CCD.

APT Loop



4.2 PIT Loop

The pupil image and tracking (PIT) loop actively measures and corrects both the pupil position (translation and rotation) as well as the image position (telescope position). This mode does not exist at Keck. This procedure is different than most APS procedures as it runs concurrently with all alignment procedures. The telescope pupil must be correctly position to ~10 mm which is 0.03% of the TMT diameter.

Once the PIT procedure starts running it will continue to run until either APS selects a new star or APS observations are completed for the night. The PIT camera will take an image and determine the pupil translation, pupil rotation and image location. These values are compared to the desired values and the pupil tilt plate, K-mirror and telescope pointing are commanded as needed. Then another image is taken and this loop repeats at a rate of once every ~10 seconds.

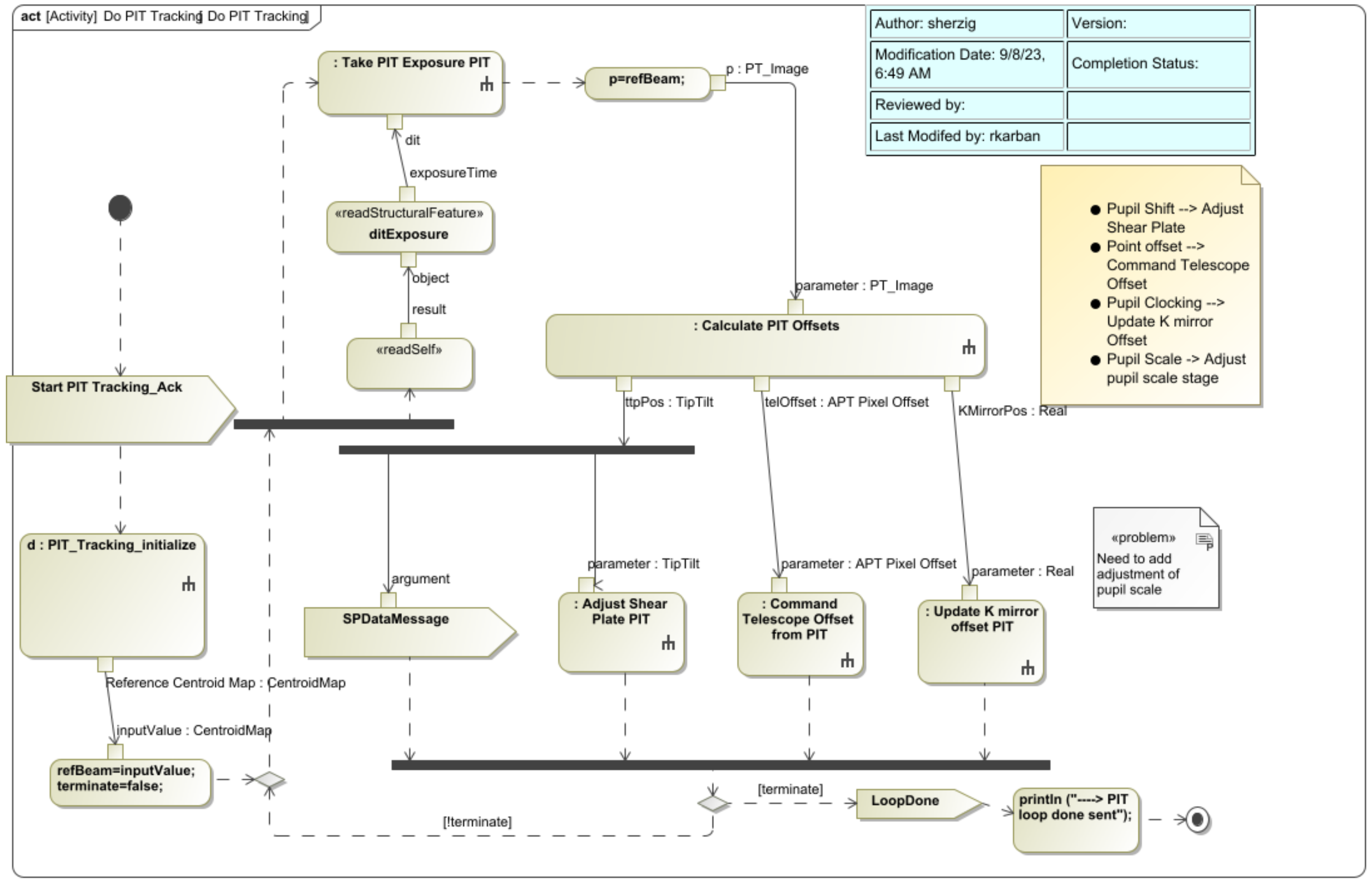
In the figure below we show an activity diagram that describes the baseline activity. The activity starts with the assumption that the telescope is tracking or guiding a star and the star has been acquired on the APT CCD within ~1 (TBR) arcseconds of the desired APS tracking point.

In the following we provide a brief description of each of the blocks shown in the figure:

- “Check Telescope Guiding”: PEAS will check the guiding residuals published by the TCS to insure the telescope is guiding to some TBD accuracy before starting the PIT loop.
- “Take PIT Exposure”: The PIT CCD takes an exposure of the specified length and publishes the pixel data.

- “Calculate PIT Offsets”: PEAS will execute a series of algorithms which will result in the calculation of the error in the desired star location, pupil translation and pupil rotation.
- “Adjust Shear Plate”: PEAS will command the APS ICS to move the tilt plate in order to adjust the telescope pupil in translation.
- “Command Telescope Offset”: PEAS sends to TCS the desired telescope motion in units of APT camera pixels. This is currently the same command if the telescope is guiding or just tracking.
- “Update K mirror offset:” PEAS will command the APS ICS to change the K-mirror offset. The K-mirror tracks the telescope pupil rotation, so it always rotating. The K-mirror offset does not change this tracking (or tracking rate), but does change the reference rotation between the static telescope pupil orientation and the internal APS pupil rotation.

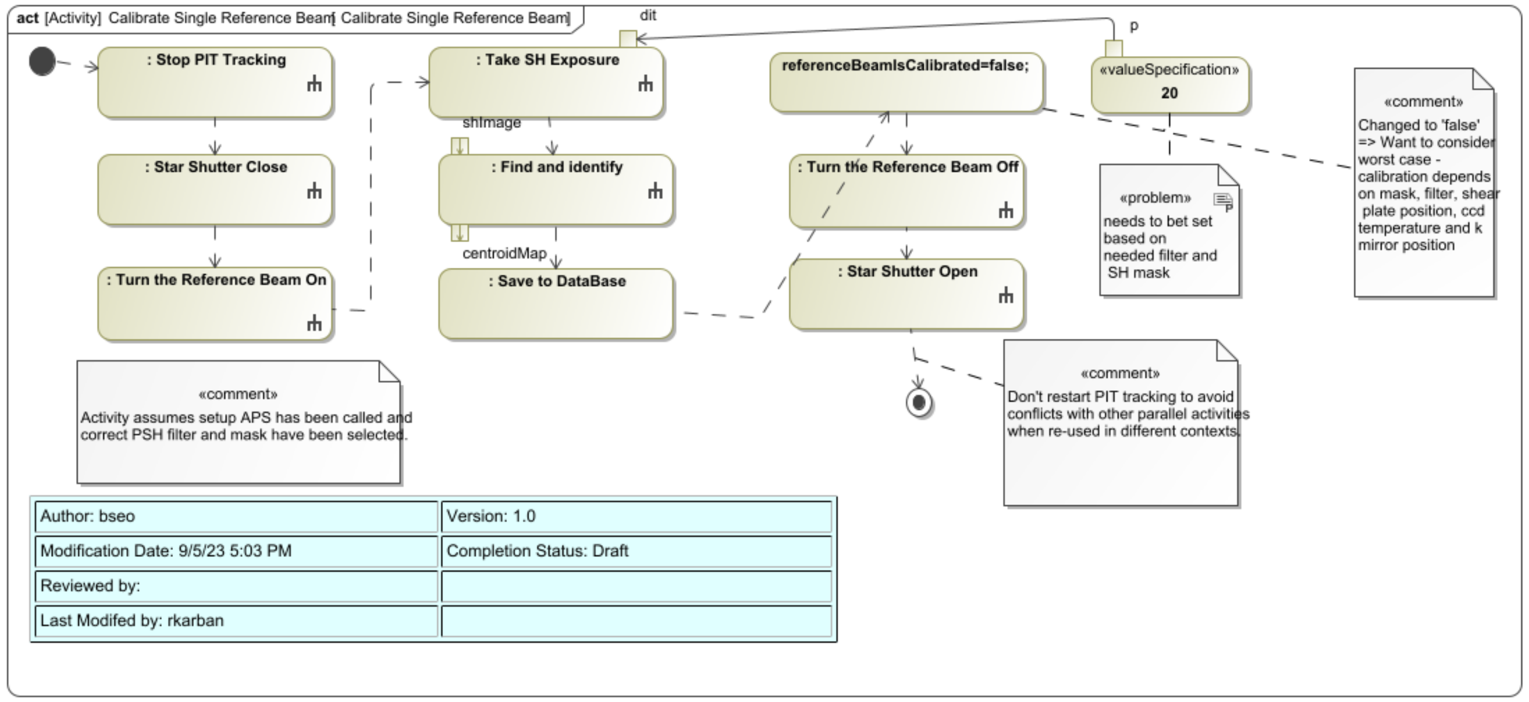
Do PIT Tracking



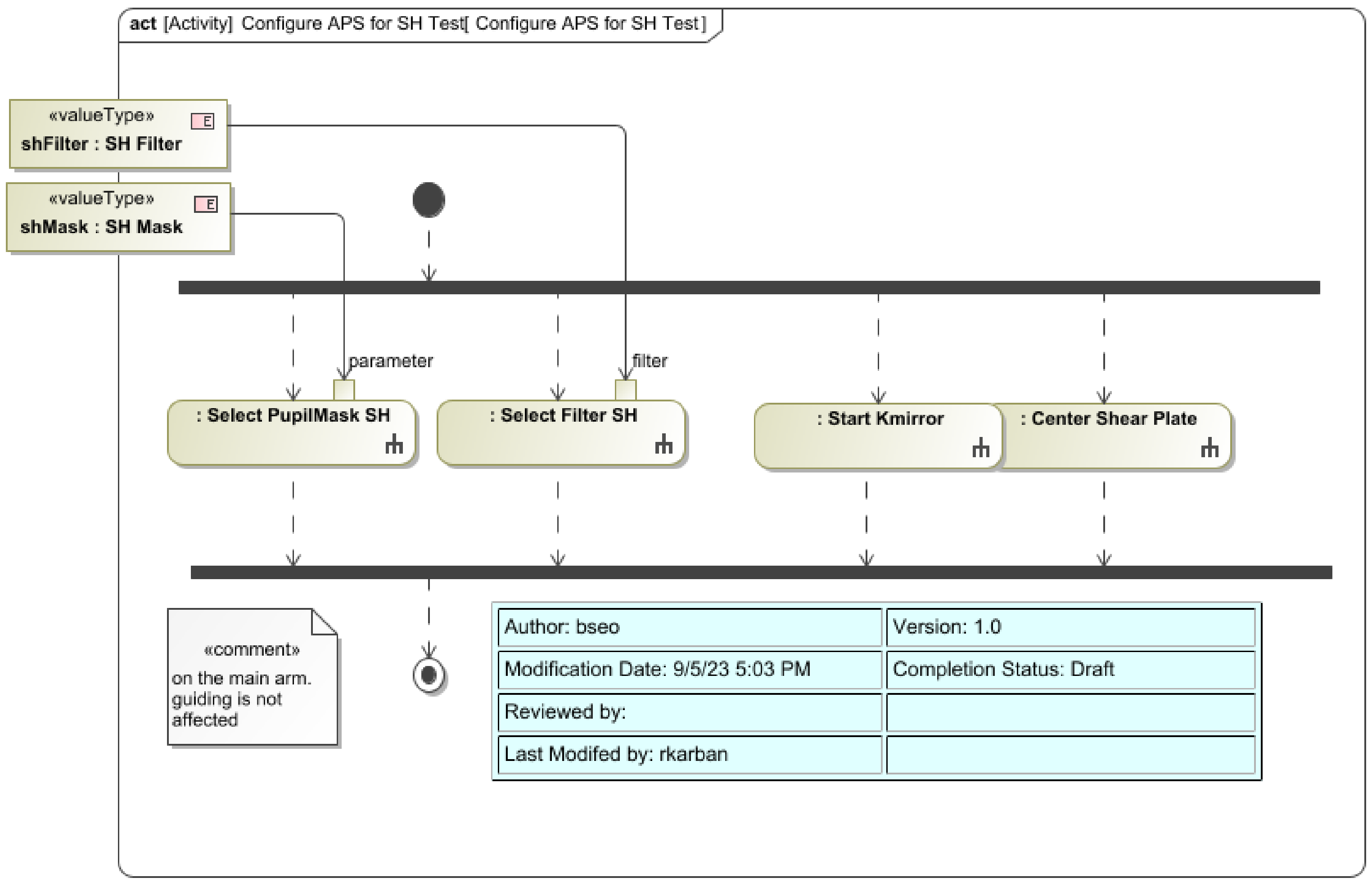
4.3 Setup and configuration procedures

The following procedures are at a lower level of execution and used to calibrate, configure, or set up the instrument.

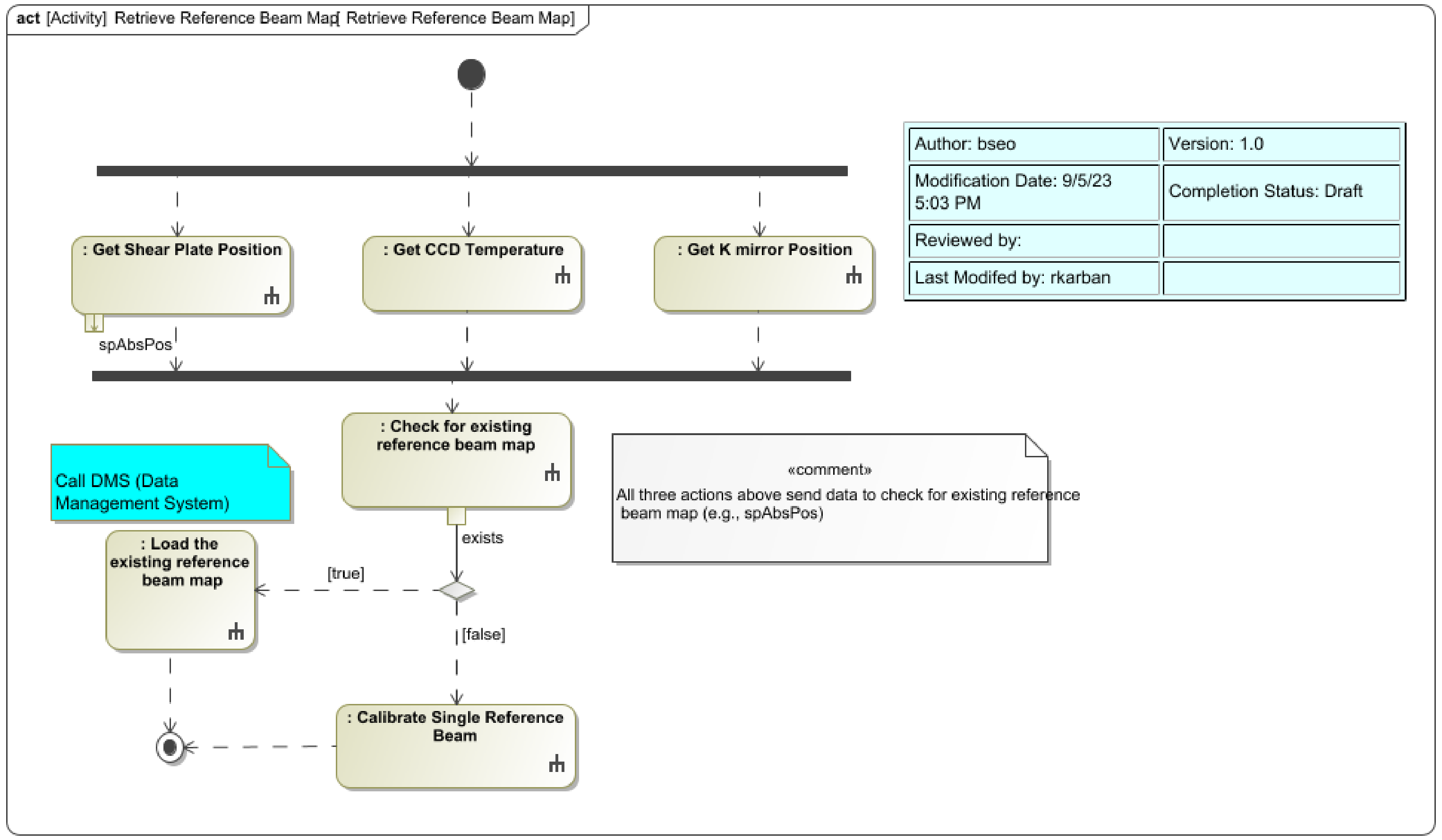
Calibrate Single Reference Beam



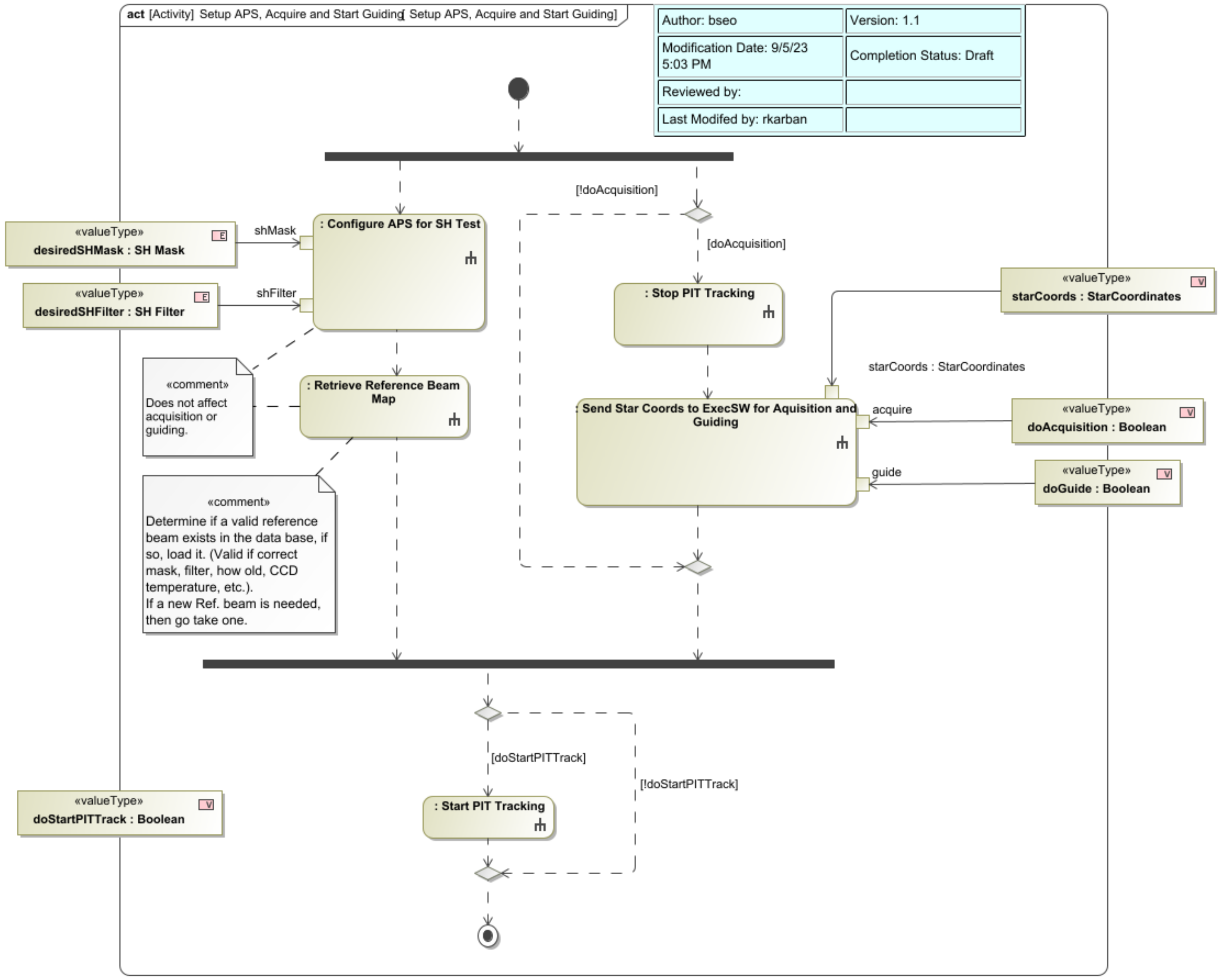
Configure APS for SH Test



Retrieve Reference Beam Map



Setup APS, Acquire and Start Guiding



5 Timing Tables

Behavior Durations

#	Name	Specification	Constrained Element	Owner Of Constrained Element
1		1s		
2	dAnalyzeAPT Exposures	10s..10s	Analyze Images	Analyze APT Exposures from Self Test
3	dAnalyzePIT Images	30s..30s	Analyze PIT Images	Analyze SH Image
4	dAnalyzePIT Images	30s..30s	Analyze PIT Images	Analyze PIT Images
5	dAPTMove Filter	10s..10s	Move APT Filter	SendAck_Filter

#	Name	Specification	Constrained Element	Owner Of Constrained Element
6	dAPTTake Exposure	ditSetup s..ditSetup s	defaultAPTImage	APT Take Exposure
7	dCalCamPointing Offsets	300s..300s	CalibrateCameraPointingOffsets	Calibrate Camera Pointing Offsets
8	dCalcCentroid Offsets	0s..1s	Execute Centroid Offset Calculation	Calculate Centroid Offsets
9	dCalcPupilRegistration Offset	0.5s..1s	Calculate Pupil Registration Offset	Calculate Pupil Registration and Image Offset
10	dCalcRMSForM2AndSegmentPT T	1s..3s	Calculate RMS for M2 and Segment PTT Cmds	Calculate RMS for M2 and Segment PTT cmds
11	dCalcStore Zernikes	1s..2s	Calculate zernikes and store	MeasureZernikes
12	dCalculateBBPiston Commands	0s..1s	Calculate BB piston commands.	Calculate Broadband piston commands
13	dCalculateCoherence Parameters	1s..3s	Calculate Coherence Parameters	Broadband Phasing
14	dCalculateCorrelation Index	1s..3s	Calculate Correlation Index	Calculate Correlation Index
15	dCalculateM1MinimizeSensor Reading s	15s..30s	Calculate Minimize Sensor Readings	Calculate M1 Minimize Sensor Readings
16	dCalculateM2PT T	1s..1s	Calculate M2 PTT	Calculate M2 PTT
17	dCalculatePhasing Commands	0s..1s	Calculate Phasing Commands	Calculate Phasing Commands
18	dCalculatePIT Offsets	1s..1s	Calculate Centroid Offsets and Pupil Registration:Calculate Centr oid Offsets and Pupil Registration pixelOffset	Calculate PIT Offsets Calculate Centroid Pixel Offset
19	dCalculatePupil Registration	1s..1s	ZeroTipTilt 0.0	Calculate Pupil Registration
20	dCalculateWH Commands	10s..10s	Calculate WH Commands	Calculate WH Commands
21	dCalibrateWarping Harness	400s..600s		
22	dCheckMirrorIs Phaseable	5s..5s	Perform Phaseability Check	Check Mirror is Phaseable
23	dCheckMirrorIs Phaseable	5s..5s		
24	dCheckMirror Phasability	1s..1s	Check Mirror Phaseability	Check Mirror Phasebility
25	dCheckPIT Tracking	0s..1s	Check PIT Tracking	Check PIT is tracking
26	dClose Shutter	0.5s..1s	Close Shutter	SendAck_S_Close
27	dCorrectPIT Tracking	0s..1s	Correct PIT Tracking	Correct PIT tracking
28	dDetermineCamera Parameter	0.1s..0.3s	Determine_Camera_parameter	PIT_Tracking_initialize
29	dFindAnd Identify	10s..10s	Execute Find and Identity Algorithm	Find and identify
30	dHomeKMirror	60s..60s	Home Shear Plates	Home All Mechanisms
31	dHome Mechanisms	60s..60s	Home all Wheels	Home All Mechanisms

#	Name	Specification	Constrained Element	Owner Of Constrained Element
32	dHomeWheels	60s..60s	Home K-Mirror	Home All Mechanisms
33	dLoadReferenceBeam Map	5s..5s	Load Reference Beam Maps	Load the existing reference beam map
34	dLookupCentroid Map	1s..1s	defaultCentroidMap	Read Reference Centroid Map from Database
35	dMoveAPTFilter Mechanism	60s..60s	Move APT Filter Mechanism	Perform APT Self Test
36	dMoveBeamSplitterTT Stage	0s..13s	Move Beam Splitter TT Stage	doMoveTipTilt
37	dMoveSH Filter	0s..13s	Move SH filter	SendAck_Filter
38	dMoveSH Filter	0s..13s	Move SH filter	SendAck_Filter
39	dMove Stimulus	60s..60s	Move Stimulus Fold Mirror Move Stimulus Fold Mirror	Perform APT Self Test Perform PIT Self Test
40	dOpenShutter	0.5..1s	Open Shutter	SendAck_S_Open
41	dPistonTipTilt Calculation	1s..1s	Execute Piston Tip Tilt Calculation	Calculate Segment PTT
42	dPITReadout Time	1s..1s	Read Out Detector	SendAck_Exposure
43	dPITTake Exposure	ditSetup s..ditSetup s	PIT Take Exposure	SendAck_Exposure
44	dReadM1 Configuration	0.5s..1s	Read Current M1 Configuration	Load M1CS Configuration
45	dRetrieveKMirror Pos	0s..0.5s	Retrieve K Mirror Pos	SendAck_getPos
46	dRetrieveNextCircleSpiral Search	1s..1s	Execute Spiral Search Algorithm	Determine Next Search Circle Location
47	dRetrievePIT Status	0s..0.5s	Retrieve PIT Status	SendAck_Status
48	dRetrieve Temp	10s	Retrieve Temp	Publish_CCD_temperature
49	dRetrieveTiltPlate Position	1s..1s	Retrieve Tilt Plate Position	SendAck
50	dRetrieve Zernikes	0s..0.5s	Retrieve Reference Zernikes	SubtractZernikes
51	dSelectMasks	0s..13s	Select Phasing Mask Select Pupil Mask	SendAck_S_PM_Ack
52	dSelectMasks	0s..13s	Select Phasing Mask Select Pupil Mask	SendAck_PupilMask
53	dSetShearPlate Position	1s..17s	Set Position	SetPosition
54	dSetWHStrain	100s..120s		
55	dSHReadout Time	10s..10s	Read Out Detector	SendAck_Take_Exposure
56	dSHTake Exposure	ditSetup s..ditSetup s	SH Take Exposure	SendAck_Take_Exposure
57	dStartK Mirror	1s..1s	Start K Mirror	SendAck_StartKM
58	dSubtract Zernikes	1s..1s	Subtract Actual from Reference Zernikes	SubtractZernikes

#	Name	Specification	Constrained Element	Owner Of Constrained Element
59	dSwitchRBOff	0s..0.5s	Switch RB Off	SendAck_RB_Off
60	dSwitchRBOn	0s..0.5s	Switch RB On	SendAck_RB_On
61	dTelescopePointing Offset	10s..10s	Execute Telescope Pointing Offset Calculation	Calculate Telescope Pointing Offset
62	dtMoveArm	30s..30s	Move Arm	Move Arm Into Light Path
63	dtMoveArm	30s..30s	Move Arm	Move Arm Out of Light Path
64	dtStimulus Off	0s..1s	Turn Off	Send Ack Stimulus Off
65	dtStimulusOn	0s..1s	Turn On	Send Ack Stimulus On
66	dtTurnLightSource On	0s..0s	Turn Light Source On	Turn Light Source On
67	dtTurnLightSource On	0s..0s	Turn Light Source Off	Turn Light Source Off
68	dUpdateK Mirror	1s..1s	Update K mirror	SendAck_UpdateKM
69	dUpdatePITCamera Params	0.5s..1s	Update Params	UpdateParams
70	pitStabilizationMin Duration	60s..60s	Minimum Stabilization Time	Wait for PIT to Stabilize
71	testtime	1s..3s	TestAction	Template Activity
72	timetakingact	5s..15s	Do something	Template Activity

Actions and Constraints

#	Name	Behavior	Constrained by	Owner
1	Zeroing sensor readings		d_Zero_Sensor_Readings=15s..30s	ZeroSensorReadings
2	Update Params		dUpdatePITCameraParams=0.5s..1s	UpdateParams
3	Update K mirror		dUpdateKMirror=1s..1s	SendAck_UpdateKM
4	update APT pixel		dUpdateAPTPixel=1s..1s	SendAck_GuiderOffset
5	Turning WH Off		dWhOff=0s..0s	SendAck_WH_Off
6	Turning On WH		dTurnWhOn=0s..0s	SendAck_WH_On
7	Turn the Reference Beam On			Retrieve Reference Beam Map
8	Turn the Reference Beam Off			Retrieve Reference Beam Map
9	Turn on Stimulus			Perform PIT Self Test
10	Turn on Stimulus			Perform APT Self Test
11	Turn On		dtStimulusOn=0s..1s	Send Ack Stimulus On
12	Turn off Stimulus			Perform PIT Self Test

#	Name	Behavior	Constrained by	Owner
13	Turn Off		dtStimulusOff=0s..1s	Send Ack Stimulus Off
14	Turn Light Source On		dtTurnLightSourceOn=0s..0s	Turn Light Source On
15	Turn Light Source Off		dtTurnLightSourceOn=0s..0s	Turn Light Source Off
16	TestAction		testtime=1s..3s	Template Activity
17	Taking Snapshot		duration=0s..1s	SendAck_TakeSnapshot
18	Switch RB On		dSwitchRBOn=0s..0.5s	SendAck_RB_On
19	Switch RB Off		dSwitchRBOff=0s..0.5s	SendAck_RB_Off
20	Subtract Actual from Reference Zernikes		dSubtractZernikes=1s..1s	SubtractZernikes
21	Stop PIT Tracking			Retrieve Reference Beam Map
22	Start PIT Tracking			Retrieve Reference Beam Map
23	Start K Mirror		dStartKMirror=1s..1s	SendAck_StartKM
24	SH Take Exposure		dSHTakeExposure=ditSetup s..ditSetup s	SendAck_Take_Exposure
25	Set Position		dSetShearPlatePosition=1s..17s	SetPosition
26	send phasing commands	Send Segment PTT		Broadband Phasing
27	send phasing commands	Send Segment PTT		Narrow Band Phasing
28	Select Pupil Mask		dSelectMasks=0s..13s	SendAck_PupilMask
29	Select Pupil Mask		dSelectMasks=0s..13s	SendAck_S_PM_Ack
30	Select Phasing Mask		dSelectMasks=0s..13s	SendAck_S_PM_Ack
31	Select Phasing Mask		dSelectMasks=0s..13s	SendAck_PupilMask
32	Save to Database			Retrieve Reference Beam Map
33	Save M2 Configuration	saveM2Position		Rigid Body and Segment Figure Correction
34	Save M1CS Configuration	SaveCurrentSensorCalibCoeff		Coarse Tilt Alignment
35	Save M1CS Configuration	SaveCurrentSensorCalibCoeff		Rigid Body and Segment Figure Correction
36	Save M1CS Configuration	SaveCurrentSensorCalibCoeff		Broadband Phasing
37	Save M1CS Configuration	SaveCurrentSensorCalibCoeff		Narrow Band Phasing
38	Retrieve Tilt Plate Position		dRetrieveTiltPlatePosition=1s..1s	SendAck
39	Retrieve Temp		dRetrieveTemp=10s	Publish_CCD_temperature
40	Retrieve Reference Zernikes		dRetrieveZernikes=0s..0.5s	SubtractZernikes
41	Retrieve PIT Status		dRetrievePITStatus=0s..0.5s	SendAck_Status

#	Name	Behavior	Constrained by	Owner
42	Retrieve K Mirror Pos		dRetrieveKMirrorPos=0s..0.5s	SendAck_getPos
43	Retrieve Configuration		duration=1s..3s	SendAck
44	restoreInitial Pos	Send Segment PTT		Broadband Phasing
45	Report Error			Broadband Phasing
46	Report Error			Narrow Band Phasing
47	Read Sensors		d_ReadM1Sensors=0s..1s	GetSensorReadings
48	Read Out Detector		dSHReadoutTime=10s..10s	SendAck_Take_Exposure
49	Read Out Detector		dPITReadoutTime=1s..1s	SendAck_Exposure
50	Read Current M1 Configuration		dReadM1Configuration=0.5s..1s	Load M1CS Configuration
51	PIT Take Exposure		dPITTakeExposure=ditSetup s..ditSetup s	SendAck_Exposure
52	Perform Phaseability Check		dCheckMirrorIsPhaseable=5s..5s	Check Mirror is Phaseable
53	Open Star Shutter			Retrieve Reference Beam Map
54	Open Shutter		dOpenShutter=0.5..1s	SendAck_S_Open
55	Moving Segment		duration=30s..30s	SendAck_PTT_move
56	Move Stimulus Fold Mirror		dMoveStimulus=60s..60s	Perform APT Self Test
57	Move Stimulus Fold Mirror		dMoveStimulus=60s..60s	Perform PIT Self Test
58	Move SH filter		dMoveSHFilter=0s..13s	SendAck_Filter
59	Move SH filter		dMoveSHFilter=0s..13s	SendAck_Filter
60	Move segment		duration=45s..120s	SendAck_WH_move
61	Move Plate Back	Adjust Shear Plate PEAS		Perform PIT Self Test
62	Move Plate	Adjust Shear Plate PEAS		Perform PIT Self Test
63	move m2 ptt		duration=10s..10s	SendAck_M2PTTMove
64	Move Beam Splitter TT Stage		dMoveBeamSplitterTTStage=0s..13s	doMoveTipTilt
65	Move Arm		dtMoveArm=30s..30s	Move Arm Into Light Path
66	Move Arm		dtMoveArm=30s..30s	Move Arm Out of Light Path
67	Move APT Filter Mechanism		dMoveAPTFilterMechanism=60s..60s	Perform APT Self Test
68	Move APT Filter		dAPTMoveFilter=10s..10s	SendAck_Filter
69	Minimum Stabilization Time		pitStabilizationMinDuration=60s..60s	Wait for PIT to Stabilize

#	Name	Behavior	Constrained by	Owner
70	Look-up BB piston commands for Step n	Calculate Broadband piston commands		Broadband Phasing
71	Look-up BB piston commands for Step 1	Calculate Broadband piston commands		Broadband Phasing
72	Load the existing map			Retrieve Reference Beam Map
73	Load Reference Beam Maps		dLoadReferenceBeamMap=5s..5s	Load the existing reference beam map
74	Home Shear Plates		dHomeKMirror=60s..60s	Home All Mechanisms
75	Home K-Mirror		dHomeWheels=60s..60s	Home All Mechanisms
76	Home all Wheels		dHomeMechanisms=60s..60s	Home All Mechanisms
77	Get original position			RestoreM2M3AxisBSSPositions
78	Get next point from Map			PrepareForOffAxis
79	get M1CS status		dGetM1CSStatus=0s..0.5s	SendAck_Status
80	get m2 position		dGetM2Position=0s..0.5s	SendAck_M2Status
81	get current WH settings	Get Segment WH Pos		Rigid Body and Segment Figure Correction
82	find and identify	Find and identify		Broadband Phasing
83	Extract Items from Table Entry			
84	Execute Telescope Pointing Offset Calculation		dTelescopePointingOffset=10s..10s	Calculate Telescope Pointing Offset
85	Execute Spiral Search Algorithm		dRetrieveNextCircleSpiralSearch=1s..1s	Determine Next Search Circle Location
86	Execute Piston Tip Tilt Calculation		dPistonTipTiltCalculation=1s..1s	Calculate Segment PTT
87	Execute Find and Identity Algorithm		dFindAndIdentify=10s..10s	Find and identify
88	Execute Centroid Offset Calculation		dCalcCentroidOffsets=0s..1s	Calculate Centroid Offsets
89	Do something		timetakingact=5s..15s	Template Activity
90	Display Results to APS Operator			Retrieve Reference Beam Map
91	Display Phasing results	Display Results to APS Operator		Broadband Phasing
92	Display Error			Perform PIT Self Test
93	Display Error			
94	Display error			Perform APT Self Test
95	Determine_Camera _parameter		dDetermineCameraParameter=0.1s..0.3s	PIT_Tracking_initialize
96	d	PIT_Tracking_initialize		Do PIT Tracking

#	Name	Behavior	Constrained by	Owner
97	Correct PIT Tracking		dCorrectPITTracking=0s..1s	Correct PIT tracking
98	correct PIT tracking	Correct PIT tracking		Broadband Phasing
99	correct PIT tracking	Correct PIT tracking		Narrow Band Phasing
100	Configure APS for PIT Test			
101	command M1CS Moves	Send Segment PTT		Broadband Phasing
102	command M1CS for first move	Send Segment PTT		Broadband Phasing
103	Close Star Shutter			Retrieve Reference Beam Map
104	Close Shutter		dCloseShutter=0.5s..1s	SendAck_S_Close
105	Check PIT Tracking		dCheckPITTracking=0s..1s	Check PIT is tracking
106	Check Mirror Phaseability		dCheckMirrorPhasability=1s..1s	Check Mirror Phasebility
107	Call(List Size)	ListSize		TestListFunctions
108	Call(List Get)	ListGet		TestListFunctions
109	Call(GenerateListTest Data)	GenerateListTestData		TestListFunctions
110	CalibrateCameraPointing Offsets		dCalCamPointingOffsets=300s..300s	Calibrate Camera Pointing Offsets
111	Calculate zernikes and store		dCalcStoreZernikes=1s..2s	MeasureZernikes
112	Calculate Zernike Deltas			
113	Calculate WH Commands		dCalculateWHCommands=10s..10s	Calculate WH Commands
114	Calculate Shear Plate Motion			M3 Alignment Procedure
115	Calculate RMS for M2 and Segment PTT Cmds		dCalcRMSForM2AndSegmentPTT=1s..3s	Calculate RMS for M2 and Segment PTT cmds
116	Calculate Pupil Registration Offset		dCalcPupilRegistrationOffset=0.5s..1s	Calculate Pupil Registration and Image Offset
117	Calculate Piston from alpha / delta Offset			PrepareForOffAxis
118	calculate Phasing Commands to optimize M1CS ph ase	Calculate Phasing Commands		Broadband Phasing
119	Calculate Phasing Commands		dCalculatePhasingCommands=0s..1s	Calculate Phasing Commands
120	Calculate Next Search Position Segment PTT			Adjust Position According to Spiral Search Pattern
121	Calculate Minimize Sensor Readings		dCalculateM1MinimizeSensorReadings=15s. .30s	Calculate M1 Minimize Sensor Readings
122	Calculate M2 PTT		dCalculateM2PTT=1s..1s	Calculate M2 PTT
123	Calculate Fore- Optics Beam Splitter Assembly Off set from alpha/delta			PrepareForOffAxis

#	Name	Behavior	Constrained by	Owner
124	Calculate Correlation Index		dCalculateCorrelationIndex=1s..3s	Calculate Correlation Index
125	Calculate Coherence Parameters		dCalculateCoherenceParameters=1s..3s	Broadband Phasing
126	Calculate Centroid Offsets and Pupil Registration	Calculate Centroid Offsets and Pupil Registration	dCalculatePITOffsets=1s..1s	Calculate PIT Offsets
127	Calculate Centroid Map Pixel Offset	Calculate Centroid Pixel Offset		Calculate Centroid Offsets and Pupil Registration
128	Calculate BB piston commands.		dCalculateBBPistonCommands=0s..1s	Calculate Broadband piston commands
129	Before			Wait for PIT to Stabilize
130	Analyze PIT Images		dAnalyzePITImages=30s..30s	Analyze PIT Images
131	Analyze PIT Images		dAnalyzePITImages=30s..30s	Analyze SH Image
132	Analyze Images		dAnalyzeAPTExposures=10s..10s	Analyze APT Exposures from Self Test
133	After			Wait for PIT to Stabilize
134				APT Loop
135		Acquire and Guide		Acquire
136		Adjust Shear Plate PIT		Do PIT Tracking
137		APT Loop		APT Loop
138		Ask OP to apply WH cmds		Rigid Body and Segment Figure Correction
139		Ask OP to Send Segment PTT		Coarse Tilt Alignment
140		Ask OP to Send Segment PTT		Broadband Phasing
141		autotick		autotick
142		Broadband Phasing		Broadband Phasing 30
143		Broadband Phasing		Broadband Phasing 100
144		Broadband Phasing		Broadband Phasing 1000
145		Calculate Average Centroid Of fsets		Rigid Body and Segment Figure Correction
146		Calculate Average M2 PTT		Rigid Body and Segment Figure Correction
147		Calculate Average Segment PT T		Rigid Body and Segment Figure Correction
148		Calculate Centroid Offsets		Coarse Tilt Alignment
149		Calculate Centroid Offsets		Retrieve Reference Beam Map
150		Calculate Centroid Offsets		Calculate Average Centroid Offsets

#	Name	Behavior	Constrained by	Owner
151		Calculate Centroid Offsets		Rigid Body and Segment Figure Correction
152		Calculate M2 PTT		Calculate Average M2 PTT
153		Calculate M2 PTT		Rigid Body and Segment Figure Correction
154		Calculate PIT Offsets		Do PIT Tracking
155		Calculate Pupil Registration and Image Offset		Broadband Phasing
156		Calculate Pupil Registration and Image Offset		Rigid Body and Segment Figure Correction
157		Calculate Segment PTT		Calculate Average Segment PTT
158		Calculate Segment PTT		Coarse Tilt Alignment
159		Calculate Segment PTT		Rigid Body and Segment Figure Correction
160		Calculate Telescope Pointing Offset		Coarse Tilt Alignment
161		Calculate WH Commands		Rigid Body and Segment Figure Correction
162		Calibrate Single Reference Beam		Retrieve Reference Beam Map
163		Check for existing reference beam map		Retrieve Reference Beam Map
164		Coarse Tilt Alignment		Coarse Tilt Alignment
165		Command Telescope Offset in Pixel		Coarse Tilt Alignment
166		Command Telescope Offset from PIT		Do PIT Tracking
167		Configure APS for SH Test		Setup APS, Acquire and Start Guiding
168		Configure APT Subsystem		APT Loop
169		Correct PIT tracking		Rigid Body and Segment Figure Correction
170		Display Results to APS Operator		Coarse Tilt Alignment
171		Do PIT Tracking		doPIT_Tracking
172		Find and identify		Retrieve Reference Beam Map
173		Find and identify		Rigid Body and Segment Figure Correction
174		Find and identify		Coarse Tilt Alignment

#	Name	Behavior	Constrained by	Owner
175		Find and identify		Calibrate Single Reference Beam
176		Get_Installed_Segment		Configure APS for SH Test
177		Set APT Integration Time		Configure APT Subsystem
178		Set APT ROI		Configure APT Subsystem
179		Get CCD Temperature		Retrieve Reference Beam Map
180		Get K mirror Position		Retrieve Reference Beam Map
181		Get PIT Reference		Do PIT Tracking
182		Get Shear Plate Position		Retrieve Reference Beam Map
183		Narrow Band Phasing		Narrowband Phasing
184		Publish Pixel Data		APT Loop
185		Retrieve Reference Beam Map		Setup APS, Acquire and Start Guiding
186		Rigid Body and Segment Figur e Correction		Rigid Body and Segment Figure correction
187		Save to DataBase		Calibrate Single Reference Beam
188		Select Filter APT		Configure APT Subsystem
189		Select Filter SH		Configure APS for SH Test
190		Select PupilMask SH		Configure APS for SH Test
191		Send_Ack_Stop		Send_Ack_Stop
192		Send_Exposure		Send_Exposure
193		SendAck		send_Ack
194		SendAck		send_Ack
195		Publish_CCD_temperature		Publish_CCD_temperature
196		SendAck_Exposure		SendAck_Exposure
197		SendAck_Filter		SendAck_Filter
198		SendAck_getPos		SendAck_getPos
199		SendAck_GuiderOffset		SendAck_GuiderOffset
200		SendAck_M2PTTMove		SendAck_M2PTTMove
201		SendAck_M2Status		SendAck_M2Status
202		SendAck_PTT_move		SendAck_PTT_move

#	Name	Behavior	Constrained by	Owner
203		SendAck_RB_Off		SendAck_RB_Off
204		SendAck_RB_On		SendAck_RB_On
205		SendAck_S_Close		SendAck_S_Close
206		SendAck_S_Open		SendAck_S_Open
207		SendAck_S_PM_Ack		send_Ack_Select_PM
208		SendAck_StartKM		send_Ack_startkm
209		SendAck_Status		send_Ack_Status
210		SendAck_Status		SendAck_Status
211		SendAck_Take_Exposure		SendAck_Take_Exposure
212		SendAck_TakeSnapshot		SendAck_TakeSnapshot
213		SendAck_WH_move		SendAck_WH_move
214		SendAck_WH_Off		SendAck_WH_Off
215		SendAck_WH_On		SendAck_WH_On
216		Send M2 PTT Cmd		Rigid Body and Segment Figure Correction
217		Send Segment PTT		Rigid Body and Segment Figure Correction
218		Send Segment PTT		Coarse Tilt Alignment
219		Send Segment WH Cmd		Rigid Body and Segment Figure Correction
220		Send Star Coords to ExecSW for Aquisition and Guiding		Setup APS, Acquire and Start Guiding
221		Setup APS, Acquire and Start Guiding		Broadband Phasing
222		Setup APS, Acquire and Start Guiding		Coarse Tilt Alignment
223		Star Shutter Close		Calibrate Single Reference Beam
224		Star Shutter Open		Calibrate Single Reference Beam
225		Start Kmirror		Configure APS for SH Test
226		Start PIT Tracking		Setup APS, Acquire and Start Guiding
227		Stop PIT Tracking		Calibrate Single Reference Beam
228		Request APT Exposure		APT Loop
229		Take PIT Exposure PIT		Do PIT Tracking

#	Name	Behavior	Constrained by	Owner
230		Take SH Exposure		Calibrate Single Reference Beam
231		Take SH Exposure		Broadband Phasing
232		Take SH Exposure		Narrow Band Phasing
233		Take SH Exposure		Coarse Tilt Alignment
234		Take SH Exposure		Rigid Body and Segment Figure Correction
235		Take SH Exposure		Rigid Body and Segment Figure Correction
236		Trigger_CTA		APS Actions(classifier behavior)
237		Trigger_FTA		APS Actions(classifier behavior)
238		Trigger_GetRBeam		APS Actions(classifier behavior)
239		Turn the Reference Beam Off		Calibrate Single Reference Beam
240		Turn the Reference Beam On		Calibrate Single Reference Beam
241		Update K mirror offset PIT		Do PIT Tracking
242		Calculate Correlation Index		Narrow Band Phasing
243		Calculate Phasing Commands		Narrow Band Phasing
244		Setup APS, Acquire and Start Guiding		Rigid Body and Segment Figure Correction
245		Find and identify		Narrow Band Phasing
246		Center Shear Plate		Configure APS for SH Test
247		APT Take Exposure		Send_Exposure
248		Check Mirror Phasebility		InitializePEAS
249		Get_Installed_Segment		InitializePEAS
250		Zeroing Sensor Readings		Offload Sensor Offsets
251		Acquire and Guide		High-level Acquisition sequence
252		Activate Stimulus		Pupil Registration Relative to SH and PIT
253		Adjust Position According to Sp iral Search Pattern		Coarse Tilt Alignment
254		Adjust Shear Plate PEAS		M3 Alignment Procedure
255		Adjust Shear Plate PEAS		Pupil Registration Relative to SH and PIT
256		Adjust Shear Plate PEAS		Center Shear Plate
257		Align M3		Align M3 doBehavior

#	Name	Behavior	Constrained by	Owner
258		Analyze APT Exposures from Self Test		Perform APT Self Test
259		Analyze Map		
260		Analyze PIT Images		Perform PIT Self Test
261		Analyze SH Image		
262		APT Loop		High-level Acquisition sequence
263		Ask OP to Send M2 PTT		Rigid Body and Segment Figure Correction
264		Ask OP to Send Segment PTT		Rigid Body and Segment Figure Correction
265		Ask OP to Send Segment PTT		Narrow Band Phasing
266		Broadband Phasing		Broad Band Phasing
267		Broadband Phasing		Broadband Phasing 30
268		Calculate Centroid Offsets		
269		Calculate Pupil Registration		Calculate Centroid Offsets and Pupil Registration
270		Calculate Pupil Registration		Pupil Registration Relative to SH and PIT
271		Calculate Pupil Registration		Pupil Registration Relative to SH and PIT
272		Calculate Pupil Registration and Image Offset		Narrow Band Phasing
273		Calibrate Warping Harness		Reset Strain Gauges
274		Check If All Spots Present		Coarse Tilt Alignment
275		Check if Cameras Cooled Down		Home Mechanisms
276		Command TCS to Stop Guiding		Command TCS to Stop Guiding
277		Command Telescope Offset in ADApparent		PrepareForOffAxis
278		Command Telescope Offset in ADApparent		RestoreM2M3AxisBSSPositions
279		Configure APS for SH Test		
280		Configure APS for SH Test		Pupil Registration Relative to SH and PIT
281		Configure APS for SH Test		
282		Configure APS for SH Test		

#	Name	Behavior	Constrained by	Owner
283		Configure APS for SH Test		Track RP on APT Relative to SH and PIT
284		Configure APT Subsystem		Take Single Exposure
285		Configure APT Subsystem PE AS		Track RP on APT Relative to SH and PIT
286		Configure PIT		Track RP on APT Relative to SH and PIT
287		Configure PIT		
288		Configure PIT		Pupil Registration Relative to SH and PIT
289		Configure PIT		
290		Create Zero Vector		Move All nth WH Motors
291		Deactivate Stimulus		Pupil Registration Relative to SH and PIT
292		Determine Next Search Circle Location		Adjust Position According to Spiral Search Pattern
293		doGuiding		High-level Acquisition sequence
294		doMoveTipTilt		doMoveTipTilt
295		doTracking		High-level Acquisition sequence
296		Extract Data from Lookup Table Entry		
297		Extract Data from Lookup Table Entry		
298		Extract Filter and Mask from Table Entry		
299		Find and identify		
300		Find and identify		Track RP on APT Relative to SH and PIT
301		Find and identify		
302		Find and identify		
303		Find and identify		
304		Find and identify		Calculate PIT Offsets
305		Find and identify		Track RP on APT Relative to SH and PIT
306		Find and identify		
307		Find and identify		
308		Find and identify		

#	Name	Behavior	Constrained by	Owner
309		Find and identify		Track RP on APT Relative to SH and PIT
310		GenerateListForSHFilterStep		GetSHFilterByIndex
311		Get Centroid Map		PIT_Tracking_initialize
312		Get SH Self Test Integration Ti me		
313		Get Shear Plate Position		M3 Alignment Procedure
314		GetSHFilterByIndex		TestNB_SHFilter
315		GetSHFilterByIndex		Narrow Band Phasing
316		Home All Mechanisms		Home Mechanisms
317		Home Mechanisms		Home Mechanisms
318		Is Within Tolerance		Pupil Registration Relative to SH and PIT
319		ListSize		GetSHFilterByIndex
320		Load Averaged SH Images		Perform WH Influence Function Analysis
321		Load M1CS Configuration		Move to Previous M1CS Configuration
322		Load the existing reference bea m map		Retrieve Reference Beam Map
323		M3 Alignment Procedure		Align M3
324		M3 Alignment Procedure		M3 Alignment Procedure
325		M3 Alignment Procedure		M3 Alignment Procedure
326		M3 Alignment Procedure		M3 Alignment Procedure
327		Measure WH Influence Functio n		Measure WH Influence Function
328		MeasureZernikes		MeasureZernikesLoop
329		MeasureZernikesLoop		MeasureZernikesLoop
330		MeasureZernikesLoop		MeasureZernikesLoop
331		Move All nth WH Motors		Measure WH Influence Function
332		Move All nth WH Motors		Measure WH Influence Function
333		Move All nth WH Motors		Measure WH Influence Function
334		Move Arm Into Light Path		Move Arm Into Light Path
335		Move Arm Out of Light Path		Move Arm Out of Light Path

#	Name	Behavior	Constrained by	Owner
336		Move Fore-Optics Beam Splitter Assembly		RestoreM2M3AxisBSSPositions
337		Move Fore-Optics Beam Splitter Assembly		PrepareForOffAxis
338		Move to Previous M1CS Configuration		Coarse Tilt Alignment
339		Narrow Band Phasing		Narrow Band Phasing
340		Narrow Band Phasing		Narrowband Phasing
341		Offset Pupil Location with M3		M3 Alignment Procedure
342		Perform APT Self Test		Perform APT Self Test
343		Perform PIT Self Test		Perform PIT Self Test
344		Perform SH Self Test		Perform SH Self Test
345		Perform WH Influence Function Analysis		Measure WH Influence Function
346		Pupil Registration Relative to SH and PIT		Pupil Registration Relative to SH and PIT
347		Read Reference Centroid Map from Database		Get Centroid Map
348		Reference Beam Collection		Reference Beam Collection
349		Reference Beam Collection		Do Reference Beam Collection
350		Request APT Exposure		Take Single Exposure
351		Request APT Exposure PEAS		Track RP on APT Relative to SH and PIT
352		Request Single APT Exposure		Perform APT Self Test
353		Request Single APT Exposure		Perform APT Self Test
354		Reset Strain Gauges		Reset Strain Gauges
355		RestoreM2M3AxisBSSPositions		RestorePositions
356		Retrieve Filter and SH Mask Combinations from Lookup Table		Perform SH Self Test
357		Retrieve Filter and SH Mask Combinations from Lookup Table for Phasing Test		Reference Beam Collection

#	Name	Behavior	Constrained by	Owner
358		Retrieve Filter and SH Mask Combinations from Lookup Table for Phasing Test		Test SH and PIT with Filter and Mask Combinations for Specific Reference Beam
359		Rigid Body and Segment Figure Correction		Rigid Body and Segment Figure correction
360		Rigid Body and Segment Figure Correction		Rigid Body and Segment Figure correction
361		Rigid Body and Segment Figure Correction		Rigid Body and Segment Figure correction
362		Rigid Body and Segment Figure Correction		Rigid Body and Segment Figure correction
363		Save to DataBase		Track RP on APT Relative to SH and PIT
364		Save to DataBase		
365		Save to DataBase		Track RP on APT Relative to SH and PIT
366		Save to DataBase		
367		Save to DataBase		
368		Save to DataBase		Track RP on APT Relative to SH and PIT
369		Save to DataBase		
370		Save to DataBase		Track RP on APT Relative to SH and PIT
371		Save to DataBase		
372		Save to DataBase		
373		Save to DataBase		Track RP on APT Relative to SH and PIT
374		Save to DataBase		
375		Save to DataBase		
376		Save to DataBase		
377		Save to DataBase		
378		Save to DataBase		Track RP on APT Relative to SH and PIT
379		Select Filter APT PEAS		Configure APT Subsystem PEAS
380		Select Filter PIT		Configure PIT
381		Select PupilMask PIT		Configure PIT
382		SelectNextTarget		SelectNextTarget

#	Name	Behavior	Constrained by	Owner
383		SelectNextTarget		Template Activity
384		Send Ack Stimulus Off		Send Ack
385		Send Ack Stimulus On		Send Ack
386		Send M2 PTT Cmd		PrepareForOffAxis
387		Send M2 PTT Cmd		RestoreM2M3AxisBSSPositions
388		Send M3 Offset		PrepareForOffAxis
389		Send M3 Offset		RestoreM2M3AxisBSSPositions
390		Send Segment PTT		Adjust Position According to Spiral Search Pattern
391		Send Segment PTT		Move to Previous M1CS Configuration
392		Send Star Coords to ExecSW f or Aquisition and Guiding		High-level Acquisition sequence
393		Send_Ack_Start		Ack
394		Send_Ack_Start		Ack
395		Send_Ack_Stop		Send_Ack_Stop
396		Send_Ack_Stop		Send_Ack_Stop
397		Send_Ack_Stop		Send_Ack_Stop
398		SendAck_Filter		SendAck_Filter
399		SendAck_Filter		send_Ack
400		SendAck_PupilMask		SendAck_PupilMask
401		SendAck_UpdateKM		SendAck_UpdateKM
402		Set APT Integration Time		Configure APT Subsystem PEAS
403		Set APT ROI		Configure APT Subsystem PEAS
404		Set WH Strain		Move All nth WH Motors
405		Setup APS, Acquire and Start Guiding		Measure WH Influence Function
406		Setup APS, Acquire and Start Guiding		Narrow Band Phasing
407		Setup APS, Acquire and Start Guiding		Align M3
408		Setup APS, Acquire and Start Guiding		Setup APS, Acquire and Start Guiding

#	Name	Behavior	Constrained by	Owner
409		Setup APS, Acquire and Start Guiding		Setup APS, Acquire and Start Guiding
410		Star Shutter Close		Home Mechanisms
411		Start PIT Tracking		M3 Alignment Procedure
412		Start PIT Tracking		Start PIT Tracking
413		Stimulus Arm Into Position		Activate Stimulus
414		Stimulus Arm Into Position		Track RP on APT Relative to SH and PIT
415		Stimulus Arm Retract		Track RP on APT Relative to SH and PIT
416		Stimulus Arm Retract		Deactivate Stimulus
417		Stimulus Light Source Off		Track RP on APT Relative to SH and PIT
418		Stimulus Light Source Off		Deactivate Stimulus
419		Stimulus Light Source On		Track RP on APT Relative to SH and PIT
420		Stimulus Light Source On		Activate Stimulus
421		Stimulus Off		Track RP on APT Relative to SH and PIT
422		Stimulus Off		Deactivate Stimulus
423		Stimulus On		Activate Stimulus
424		Stimulus On		Track RP on APT Relative to SH and PIT
425		Stop PIT Tracking		M3 Alignment Procedure
426		Stop PIT Tracking		Setup APS, Acquire and Start Guiding
427		Stop PIT Tracking		Stop PIT Tracking
428		SubtractZernikes		SubtractZernikes
429		Take Multiple SH Exposures		Measure WH Influence Function
430		Take Multiple SH Exposures		Measure WH Influence Function
431		Take Multiple SH Exposures		Measure WH Influence Function
432		Take PIT Exposure		Track RP on APT Relative to SH and PIT
433		Take PIT Exposure		
434		Take PIT Exposure		
435		Take PIT Exposure PEAS		
436		Take PIT Exposure PEAS		Perform PIT Self Test

#	Name	Behavior	Constrained by	Owner
437		Take PIT Exposure PEAS		Perform PIT Self Test
438		Take PIT Exposure PEAS		Perform PIT Self Test
439		Take PIT Exposure PEAS		Pupil Registration Relative to SH and PIT
440		Take PIT Exposure PIT		Take Single Exposure
441		Take SH Exposure		Pupil Registration Relative to SH and PIT
442		Take SH Exposure		
443		Take SH Exposure		Track RP on APT Relative to SH and PIT
444		Take SH Exposure		MeasureZernikes
445		Take SH Exposure		
446		Take SH Exposure		Take Multiple SH Exposures
447		Take SH Exposure		
448		Take Single Exposure		Take Single Exposure
449		Take Single Exposure		Take Single Exposure
450		Test SH With Filter and Mask and Reference Beam Combination		Perform SH Self Test
451		Throw Telescope Alignment Exception		Coarse Tilt Alignment
452		Track RP on APT Relative to SH and PIT		Track RP on APT Relative to SH and PIT
453		Turn Light Source Off		Turn Light Source Off
454		Turn Light Source On		Turn Light Source On
455		Turn the Reference Beam Off		
456		Turn the Reference Beam Off		
457		Turn the Reference Beam Off		
458		Turn the Reference Beam Off		
459		Turn the Reference Beam On		
460		Turn the Reference Beam On		
461		Turn the Reference Beam On		
462		Turn the Reference Beam On		
463		Update K mirror offset PEAS		Pupil Registration Relative to SH and PIT

#	Name	Behavior	Constrained by	Owner
464		Update K mirror offset PEAS		
465		Update K mirror offset PEAS		Perform PIT Self Test
466		Update K mirror offset PEAS		Perform PIT Self Test
467		Update K mirror offset PEAS		
468		Update K mirror offset PEAS		Track RP on APT Relative to SH and PIT
469		Update PIT Camera Params		PIT_Tracking_initialize
470		Wait for PIT to Stabilize		M3 Alignment Procedure

6 Appendix

6.1 Activity Glossary

Activity Glossary

#	Name	Documentation
1	Ack	
2	Ack	
3	Activate Stimulus	
4	Adjust Position According to Spiral Search Pattern	
5	Adjust Shear Plate PEAS	
6	Adjust Shear Plate PIT	
7	Align M3	
8	Align M3 doBehavior	
9	Analyze APT Exposures from Self Test	
10	Analyze Map	
11	Analyze PIT Images	
12	Analyze SH Image	
13	APS Actions	
14	APS Mission	
15	APS Mission Simulation	
16	APT Loop	
17	APT Loop	

#	Name	Documentation
18	APT Take Exposure	
19	Ask OP to adjustG C	
20	Ask OP to apply WH cmds	
21	Ask OP to select a Star	
22	Ask OP to Send M2 PTT	
23	Ask OP to Send Segment PTT	
24	Broad Band Phasing	
25	Broadband Phasing	
26	Broadband Phasing 30	
27	Broadband Phasing 30	
28	Broadband Phasing 100	
29	Broadband Phasing 1000	
30	Calculate Average Centroid Offsets	
31	Calculate Average M2 PTT	
32	Calculate Average Segment PTT	
33	Calculate Broadband piston commands	
34	Calculate Centroid Offset	
35	Calculate Centroid Offsets	
36	Calculate Centroid Offsets and Pupil Registration	
37	Calculate Centroid Pixel Offset	
38	Calculate Correlation Index	
39	Calculate M1 Minimize Sensor Readings	
40	Calculate M2 PTT	
41	Calculate Phasing Commands	
42	Calculate PIT Offsets	
43	Calculate Pupil Registration	
44	Calculate Pupil Registration and Image Offset	
45	Calculate RMS for M2 and Segment PTT cmds	
46	Calculate Segment Piston Tip Tilt	
47	Calculate Segment PTT	
48	Calculate Telescope Pointing Offset	
49	Calculate WH Commands	
50	Calibrate Camera Pointing Offsets	

#	Name	Documentation
51	Calibrate Single Reference Beam	
52	Calibrate Warping Harness	
53	Center Shear Plate	
54	Check for existing reference beam map	
55	Check If All Spots Present	
56	Check if Cameras Cooled Down	
57	Check Mirror is Phaseable	
58	Check Mirror Phasebility	
59	Check PIT is tracking	
60	Check Telescope Guiding	
61	Coarse Tilt Alignment	
62	Coarse Tilt Alignment	
63	Command TCS to Stop Guiding	
64	Command TCS to Stop Guiding	
65	Command Telescope Offset from PIT	
66	Command Telescope Offset in ADApparent	
67	Command Telescope Offset in Pixel	
68	Configure APS for SH Test	
69	Configure APT Subsystem	
70	Configure APT Subsystem PEAS	
71	Configure PIT	
72	Correct PIT tracking	
73	Create Zero Vector	
74	Deactivate Stimulus	
75	Determine APS Bench Mass	
76	Determine Next Search Circle Location	
77	Display Average Centroid Offsets	
78	Display cmd and RMS	
79	Display Results to APS Operator	
80	Do PIT Tracking	
81	Do Reference Beam Collection	
82	doMoveTip Tilt	
83	doMoveTip Tilt	

#	Name	Documentation
84	doPIT_ Tracking	
85	Extract Data from Lookup Table Entry	
86	Extract Filter and Mask from Table Entry	
87	Find and identify	
88	Forward_Ack	
89	Forward_Ack	
90	Full power cycle	
91	GenerateListForSHFilter Step	
92	GenerateListTest Data	
93	Get CCD Temperature	
94	Get Centroid Map	
95	Get K mirror Position	
96	Get PIT Reference	
97	Get Segment WH Pos	
98	Get SH Self Test Integration Time	
99	Get Shear Plate Position	
100	Get_Installed _Segment	
101	GetSHFilterBy Index	
102	High-level Acquisition sequence	
103	Home All Mechanisms	
104	Home Mechanisms	
105	Home Mechanisms	
106	Initialize Model for Sensor Calibration	
107	InitializePEA S	
108	Is Within Tolerance	
109	Load Averaged SH Images	
110	Load Averaged SH Images	
111	Load M1CS Configuration	
112	Load the existing reference beam map	
113	M3 Alignment Procedure	
114	M3 Alignment Procedure	
115	M3 Alignment Procedure	
116	M3 Alignment Procedure	

#	Name	Documentation
117	Measure WH Influence Function	
118	Measure WH Influence Function	
119	Measure Zernikes	
120	MeasureZernikes Loop	
121	MeasureZernikes Loop	
122	MeasureZernikes Loop	
123	Move All nth WH Motors	
124	Move Arm Into Light Path	
125	Move Arm Into Light Path	
126	Move Arm Out of Light Path	
127	Move Arm Out of Light Path	
128	Move Fore- Optics Beam Splitter Assembly	
129	Move to Previous M1CS Configuration	
130	Narrow Band Phasing	
131	Narrow Band Phasing	
132	Narrowband Phasing	
133	Narrowband Phasing	
134	Notify to PEAS	
135	Offload Sensor Offsets	
136	Offset Pupil Location with M3	
137	Perform APT Self Test	
138	Perform APT Self Test	
139	Perform PIT Self Test	
140	Perform PIT Self Test	
141	Perform SH Self Test	
142	Perform SH Self Test	
143	Perform WH Influence Function Analysis	
144	PIT_Tracking _initialize	
145	PrepareForOff Axis	
146	Proceed	
147	process Activity	
148	process Exposure	
149	process Filter	

#	Name	Documentation
150	processMask	
151	Publish Pixel Data	
152	Publish_CC D_temperature	
153	Publish_CC D_temperature	
154	Pupil Registration Relative to SH and PIT	
155	Pupil Registration Relative to SH and PIT	
156	Query M2 Position	
157	Read from Data Base	
158	Read Reference Centroid Map from Database	
159	Reference Beam Collection	
160	Reference Beam Collection	
161	Request APT Exposure	
162	Request APT Exposure PEAS	
163	Request Single APT Exposure	
164	Reset Strain Gauges	
165	Reset Strain Gauges	
166	RestoreM2M3AxisBSS Positions	
167	Restore Positions	
168	Retrieve Filter and SH Mask Combinations from Lookup Table	
169	Retrieve Filter and SH Mask Combinations from Lookup Table for Pha sing Test	
170	Retrieve Reference Beam Map	
171	Rigid Body and Segment Figure correction	
172	Rigid Body and Segment Figure correction	
173	Rigid Body and Segment Figure correction	
174	Rigid Body and Segment Figure correction	
175	Rigid Body and Segment Figure correction	
176	Rigid Body and Segment Figure Correction	
177	Save Status	
178	Save to Data Base	
179	Save to PEAS Data Base	
180	SaveCurrentSensorCalib Coeff	
181	saveM2 Position	

#	Name	Documentation
182	Select Filter APT	
183	Select Filter APT PEAS	
184	Select Filter PIT	
185	Select Filter SH	
186	Select Pupil Mask PIT	
187	Select Pupil Mask SH	
188	SelectNext Target	
189	SelectNext Target	
190	Send Ack	
191	Send Ack	
192	Send Ack Stimulus Off	
193	Send Ack Stimulus On	
194	Send M2 PTT Cmd	
195	Send M3 Offset	
196	Send Segment PTT	
197	Send Segment WH Cmd	
198	Send Star Coords to ExecS W for Aquisition and Guiding	
199	send_Ack	
200	send_Ack	
201	send_Ack_Select _PM	
202	Send_Ack _Start	
203	Send_Ack _Start	
204	send_ Ack_startkm	
205	send_Ack _Status	
206	Send_Ack _Stop	
207	Send_Ack _Stop	
208	Send_Ack _Stop	
209	Send_Ack _Stop	
210	Send_Ack _Stop	
211	Send_Ack _Stop	
212	Send_ Exposure	
213	Send_ Exposure	
214	SendAck	

#	Name	Documentation
215	SendAck	
216	SendAck_ Exposure	
217	SendAck_ Exposure	
218	SendAck_ Filter	
219	SendAck_ Filter	
220	SendAck_ Filter	
221	SendAck_ Filter	
222	SendAck_ Filter	
223	SendAck_get Pos	
224	SendAck_get Pos	
225	SendAck_Pupil Mask	
226	SendAck_Pupil Mask	
227	SendAck_RB _Off	
228	SendAck_RB _Off	
229	SendAck_RB _On	
230	SendAck_RB _On	
231	SendAck_S _Close	
232	SendAck_S _Close	
233	SendAck_S _Open	
234	SendAck_S _Open	
235	SendAck_S_PM _Ack	
236	SendAck_StartK M	
237	SendAck_ Status	
238	SendAck_Take _Exposure	
239	SendAck_Take _Exposure	
240	SendAck_UpdateK M	
241	SendAck_UpdateK M	
242	Set APT Integration Time	
243	Set APT ROI	
244	Set WH Strain	
245	SetPosition	
246	Setup APS, Acquire and Start Guiding	
247	Setup APS, Acquire and Start Guiding	

#	Name	Documentation
248	Setup APS, Acquire and Start Guiding	
249	Star Shutter Close	
250	Star Shutter Open	
251	Start Kmirror	
252	Start PIT Tracking	
253	Start PIT Tracking	
254	Stimulus Arm Into Position	
255	Stimulus Arm Retract	
256	Stimulus Light Source Off	
257	Stimulus Light Source On	
258	Stimulus Off	
259	Stimulus On	
260	Stop PIT Tracking	
261	Stop PIT Tracking	
262	Subtract Zernikes	
263	Subtract Zernikes	
264	Take Multiple SH Exposures	
265	Take PIT Exposure	
266	Take PIT Exposure PEAS	
267	Take PIT Exposure PIT	
268	Take SH Exposure	
269	Take Single Exposure	
270	Take Single Exposure	
271	Take Single Exposure	
272	Take Single Exposure	
273	Template Activity	
274	Test PIT With Filter and Mask and Reference Beam and Integration Time Combinations	
275	Test SH and PIT with Filter and Mask Combinations for Specific Reference Beam	
276	Test SH With Filter and Mask and Reference Beam Combination	
277	TestList Functions	
278	TestNB_SH Filter	

#	Name	Documentation
279	Throw Telescope Alignment Exception	
280	Track RP on APT Relative to SH and PIT	
281	Track RP on APT Relative to SH and PIT	
282	Trigger_CTA	
283	Trigger_FTA	
284	Trigger_GetR Beam	
285	Turn Light Source Off	
286	Turn Light Source Off	
287	Turn Light Source On	
288	Turn Light Source On	
289	Turn the Reference Beam Off	
290	Turn the Reference Beam On	
291	Turn Warping Harnesses Off	
292	Turn Warping Harnesses On	
293	Update APT Camera Parameters	
294	Update K mirror offset PEAS	
295	Update K mirror offset PIT	
296	Update PIT Camera Params	
297	UpdateParams	
298	Wait for Acquisition or Guding	
299	Wait for PIT to Stabilize	
300	Zeroing Sensor Readings	

6.2 Algorithms Used by APS

Algorithms used by APS

#	Name	Documentation
1	Calculate Average Centroid Offsets	
2	Calculate Average M2 PTT	
3	Calculate Average Segment PTT	
4	Calculate Broadband piston commands	
5	Calculate Centroid Offset	
6	Calculate Centroid Offsets	

#	Name	Documentation
7	Calculate Correlation Index	
8	Calculate M1 Minimize Sensor Readings	
9	Calculate M2 PTT	
10	Calculate Phasing Commands	
11	Calculate Pupil Registration and Image Offset	
12	Calculate RMS for M2 and Segment PTT cmds	
13	Calculate Segment Piston Tip Tilt	
14	Calculate Segment PTT	
15	Calculate Telescope Pointing Offset	
16	Calculate WH Commands	
17	Check Mirror Phasebility	
18	Check PIT is tracking	
19	Correct PIT tracking	
20	Find and identify	
21	Load the existing reference beam map	
22	Notify to PEAS	
23	Publish Pixel Data	
24	Read from Data Base	
25	Save Status	
26	Save to Data Base	
27	Save to PEAS Data Base	
28	Set APT Integration Time	
29	Set APT ROI	
30	Start PIT Tracking	
31	Stop PIT Tracking	
32	Throw Telescope Alignment Exception	
33	Update APT Camera Parameters	
34	Wait for Acquisition or Guding	
35	Wait for PIT to Stabilize	