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DOCUMENT

Solar Orbiter Roll Scheduling Strategy TN

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APPROVAL

Title	
Issue 0	**Revision** 3
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SOC Development Manager	

CHANGE LOG

Reason for change	Issue	Revision	Date
FD discussions.	0	3	Nov 2019
Minor cosmetic changes	0	2	Sept 2018
First draft issue	0	1	Mar 2017

CHANGE RECORD

Issue 0	**Revision** 3		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Redefinition of the roll reference is now largely a historic discussion. Change to past tense.			1.2.1
Bring MAG calibration roll into line with NECP approach - 13 full rotations (such that >=12 at coast) - Incorporate timeline			2.1
Detail PTEL and EFECS events approach for consistency with other calibration TNs			2.1, 2.2, 3.5

Issue 0	**Revision** 2		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Cosmetic changes only - Explicitly embed fonts - Enforce field updates in footers etc.			

Table of contents:

1 INTRODUCTION

For Solar Orbiter the roll part of attitude is established early in the planning cycles (within the MOC LTP cycle that leads to the FECS planning skeleton). There is a baseline roll orientation, but this can be modified by

- Scientific calibration requirements on roll
- Occasional need to roll to avoid HGA communication blockages. Here there are different possible strategies with scientific trade-off.

Currently it is not proposed to implement an electronic interface for SOC to request particular roll angles at particular times. Rather the idea is that SOC would produce written input prior to each MOC LTP cycle detailing rough periods of time, and the strategy or calibration to apply in each. Flight dynamics would subsequently turn this written input into a specific roll profile within the MOC LTP, consistent with the pass times and WOL events.

This is analogous to the way in which SOC will provide input to the twice-yearly station scheduling exercise.

1.1 Margins for off-pointing

It is assumed that, on top of other margins, when FD define the roll profile within the MOC LTP they will include margin for the effect of possible later off-pointings (<= 1 deg in combined pitch/yaw) on comms blockages.

1.2 Not addressed by this ICD

1.2.1 Roll reference

Airbus baseline for the roll reference / baseline roll orientation is the orbit normal. However other possible roll references were under discussion (solar north and ecliptic north). These typically achieve some reduction in comms rolls, and there are scientific trade-offs as well. For the purpose of this note it does not matter how the "zero roll angle" is defined as long as a definition is in place.

1.2.2 How SOC obtain advanced knowledge of blockages

Prior to producing their written input to LTP, SOC will need to have an indication of angles at which blockages occur over time in order to trade off the different strategies. Ideally this information would be given over the whole trajectory (even if imperfectly known beyond future GAMs) because the overall mission-level scheduling of particular science goals is dependent in some cases on rolls near to the reference angle.
N.b. it is insufficient to provide simply the minimum absolute roll angle over time, because this is not enough information to assess the roll-and-stay strategy.
How this information is conveyed is not addressed in this document.

1.2.3 RPW auroral calibration rolls

RPW wants to calibrate its antenna patterns using Earth auroral emissions around E-GAMs (and LEOP/ early NECP if possible). Requirements are detailed in their EID-B. However, most likely any implemented auroral calibration rolls will be done by rolling round SC+X whilst sun-pointing. If this can be done on multiple occasions then the variation in the SSCE angle gives some possibility to calibrate a reasonable amount of solid angle round the antennas, depending on trajectory.
They are considered special operations and not discussed further here.

2 CALIBRATION ROLLS

All calibrations rolls are assumed to be performed at the highest roll rate allowed (assumed approx. 0.1 deg/sec). In the case of the MAG calibration roll this is for the quality of the calibration (i.e. to minimise temporal changes in the solar wind field that occur whilst the calibration is ongoing) whilst in other cases this is about minimising disturbance/wasted time.

All calibration rolls are assumed to be scheduled outside of comms passes to avoid interruption of comms.

None of the calibrations rolls care about the absolute roll angle from which the calibration begins. The diagrams show the rolls starting from, and coming back to, the roll reference; but this is not required. This might be relevant if a period of calibration rolls were to be superimposed with a period of comms rolls.

2.1 MAG calibration rolls

Mag calibrations rolls are unique in that the interesting period is the coast phase of the roll, and not a stable period at a specific roll angle.

Each SOC request will specify:

- Integer number of full rotations[1]
- Approximate time to schedule the calibration (+/- 1 day)

Expectation is:

- Each calibration typically consists of 13 rotations
    - Implies ~13 hours duration for 0.1 deg/sec
    - 13 rotations is selected to
        - Ensure at least 12 rotations occur at coast rate, once ramp-up and ramp-down is accounted
        - Bring the default calibration into line with the approach during NECP
- Performed once in NECP and thereafter once per orbit

Because of the relatively long duration SOC will need to take care to request the MAG calibrations rolls away from periods of heavy extra-pass request. This should not be a problem, based on the expectation of 0.1 deg/s roll speed.

[1] Of course the achieved cal roll doesn't perfectly match a whole number of inertial full rotations at coast, because i) small fraction of the first and last rotation is ramp-up/ramp-down rather than coast, ii) in inertial frame, the roll reference may change slightly over time. This is understood.

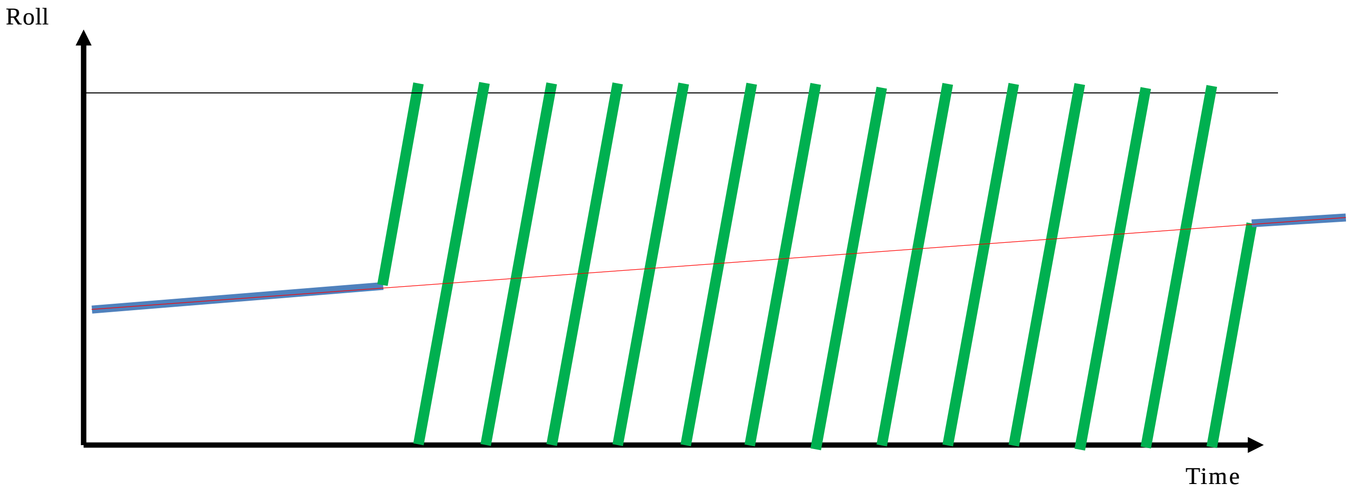

Figure 1, crude diagram of MAG calibration roll

Figure 1 shows a crude representation of the MAG calibration roll. Green represents the desired activity, blue represents stable periods outside the desired activity.
Red represents the roll reference, which is shown here drifting slightly over time, as a reminder that for some definitions of the roll reference the zero roll angle is not inertial fixed over time. The amount of drift in the figure is exaggerated.
Note that ramp-up and ramp-down periods are not represented explicitly in this figure.

2.1.1 Duration

Table 1 shows the timeline of the roll calibration for the baseline 13 rotations, taken from the equivalent NECP activity "IM-3". This timing includes pre- and post- WOLs.

	Start time within calibration (hh:mm:ss)	**Duration (hh:mm:ss)**	**End time within calibration (hh:mm:ss)**
WOL	**00:00:00**	**03:00:00**	**03:00:00**
Ramp up to coast rate	**03:00:00**	**00:16:40**	**03:16:40**
Coast for 12 rotations	**03:16:40**	**12:00:00**	**15:16:40**
Continue coast to obtain correct phase angle	**15:16:40**	**00:43:20**	**16:00:00**
Ramp down	**16:00:00**	**00:16:40**	**16: 16:40**
WOL	**16:16:40**	**03:00:00**	**19:16:40**
END	***19:16:40***	**-**	

Table 1, timeline for MAG calibration roll

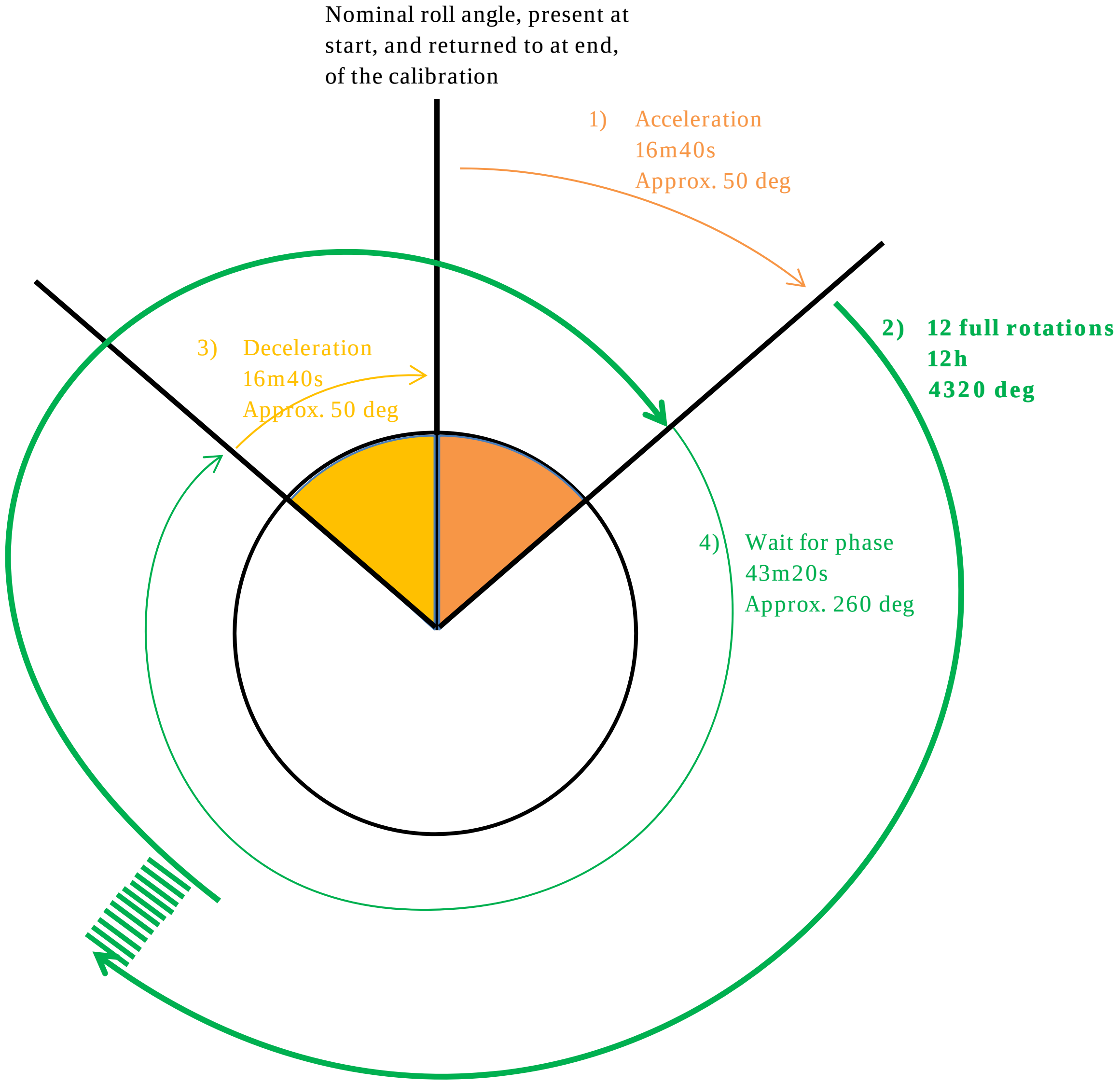

Figure 2, Phase representation of MAG calibration roll timeline (excluding WOLs)

Note that

- More than exactly 12 rotations at coast are achieved, because of the "wait for phase" segment, which add about 0.7 of a rotation at coast (based on the timeline).
- Because some conservatism in the acceleration and deceleration is expected, the start of coast phase can be regarded as a guaranteed "not later than" time[2].

[2] Greater acceleration/deceleration performance in practise also advances the end time of the overall calibration, but the quality of the period of 12 rotations at coast would still be guaranteed (albeit occurring at slightly different absolute roll angles). The end of the "wait for phase" segment would be expected to occur more-or-less at the same time (i.e. approximately unchanged by conservatism).

2.1.2 As reported in PTEL

PTEL is the planning skeleton that comes to SOC from Flight Dynamics.

Naming of this calibration event is CALIB_ROLL_MAG
The calibration event in the PTEL would start at the start of the acceleration phase, and end at the end of the deceleration phase. WOL parts would be separate events. There is no need to report the number of rotations (where different from 13) because it is obvious from the duration.

2.1.3 As reported in SOOP Kitchen and EFECS pointing enumerations

SOC products to instrument teams will keep just the FD events above.

2.1.4 EMC requirements

Since the purpose here is calibration of the MAG instrument:

- Prior to each MAG calibration roll a bias with minimal projection in SC YZ (i.e. inertial bias either zero or aligned with SC X axis) shall be established. The objective is to minimise the momentum transfer between the wheels occurring during the coast phase of the roll. TBD whether a post-WOL quiescence period is needed before rolling.
- Mechanism movement under the control of FD shall be avoided during the calibration roll. I.e. no solar array repositioning, no HGA repositioning, no MGA repositioning.

2.2 RS-calibration rolls

For these, the interesting part is the dwell at a particular angle, and not the act of roll-slewing between.

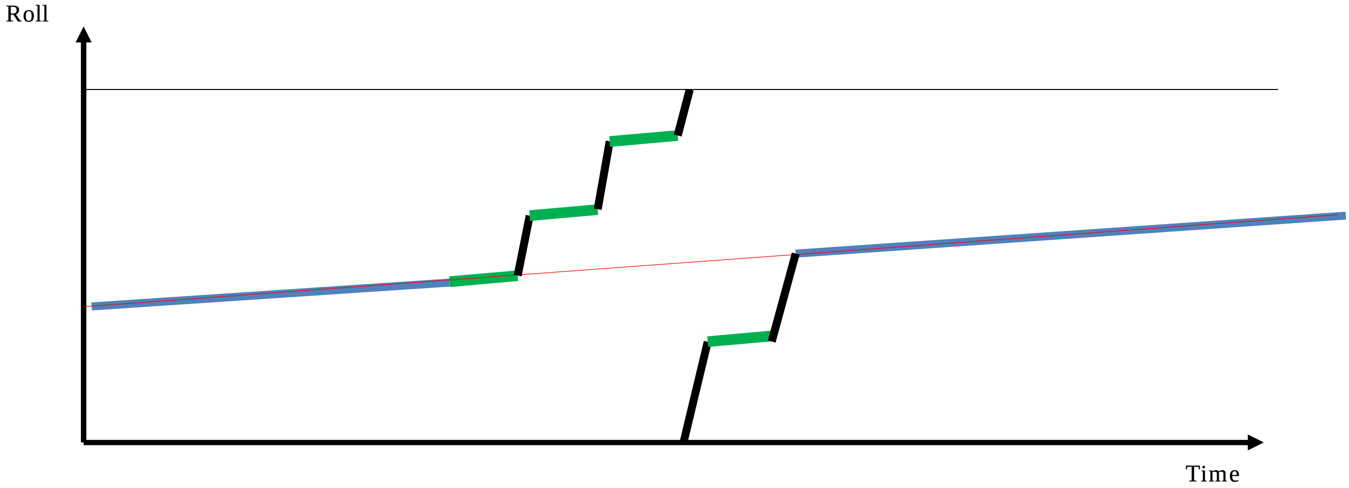

Figure 3, crude example diagram of RS-calibration rolls

Figure 3 shows a crude representation of the RS-calibration rolls. Green represents the desired activity, blue represents stable periods outside the desired activity. Black represents slews between the desired positions. Red represents the roll reference.

Each SOC request will specify:

- A list of roll angles (deltas relative to the starting roll angle) at which to dwell
- The dwell time at each angle. (We assume the same dwell time value applies for all angles in a request)
- Approximate time at which to schedule the calibration (+/- 12 hours)

Expectation is:

- Typical dwell time of the order of 5 to 30 mins
- Typical angle lists of
  - 0, 45, 90, 135 deg — METIS
  - 0, 90, 180, 270 deg — Cardinal directions for EUI, SOLO-HI
  - 0, 90 deg — Simplified cardinal directions
  - 0, 45, 90, 135, 180, 270 deg — Combined METIS and cardinal directions

2.2.1 As reported in PTEL

PTEL is the planning skeleton that comes to SOC from Flight Dynamics.

Naming of this calibration event is CALIB_ROLL_RS

The calibration event in the PTEL would start at the start of the first roll acceleration of the calibration from the nominal roll angle, and end at the end of the last roll deceleration phase returning to the nominal roll angle. WOL events before or after would be separate events.

Flight dynamics will provide a roll time formula to SOC (in the FD ICD). This will:

- Allow SOC to determine the timeline of the individual rolls from the CALIB_ROLL_RS event start time.
- Drive the SC commanding of the implemented calibration, such that the two remain in sync.

2.2.2 As reported in SOOP Kitchen and EFECS pointing enumerations

SOC products to instrument teams will add explicit ROLL events for each roll within each calibration, such that the timing of the roll dwells (between the roll events) is clear.

3 COMMUNICATION ROLLS

All communication rolls are assumed to be performed at the highest roll rate allowed (assumed approx. 0.1 deg/sec). This is to minimise the disturbed/wasted time.

On top of other margins in roll planning, it will be necessary to extend the constraints (by ~1 deg) to allow for the effect of off-pointing that can come in a later planning cycle.

For each comm roll period the SOC will specify:

- The time period
  - To identify which comms obstruction events are covered
  - For certain strategies (roll-and-stay) the effect of the strategy can extend beyond the obstruction events.
- The strategy to use over this time period

In principle a single period of comms obstruction (i.e. multiple days/weeks over which comms rolls are always necessary) may be divided into sub-periods where different strategies apply.

Where no strategy is defined by SOC, the daily minimum absolute roll strategy will be assumed.

3.1 "Daily minimum absolute roll"

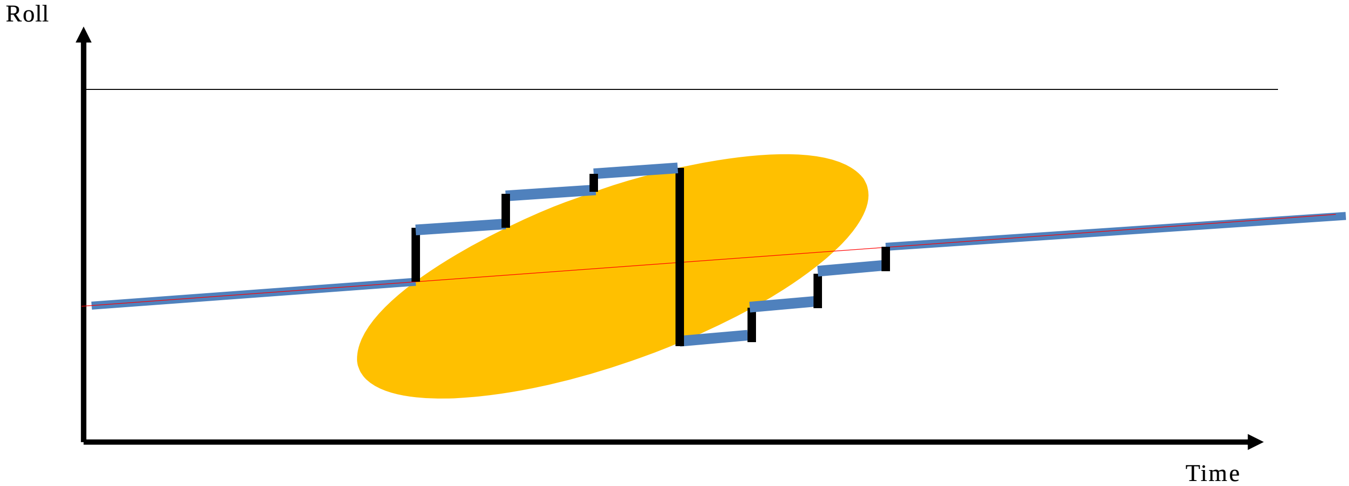

Figure 4, crude example diagram of comms rolls for daily minimum absolute roll

Figure 4 shows a crude representation of this approach to comms rolls. Blue represents stable periods and black represents slews between. Red represents the roll reference. The yellow shape represents HGA comms blockages from the SC body (and equivalently thruster impingement constraints and HGA mechanism constraints) that prevent the roll reference being used for passes.

This is the simplest comms roll approach. The roll of the spacecraft follows the shape of the comms constraint, albeit in discrete steps once-per-day (or per pass). The movement to allow comms is always in the direction that minimises the movement away from the reference. This can change during a particular constraint period, as shown in the figure where the roll switches from one side of the constraint to the other.

In the Figure 4 the diagram shows the comms constraint being avoided at all times (blue lines completely outside the yellow). This simplifies the diagram, and would be acceptable implementation, even though strictly-speaking the constraint has to be avoided only during passes.

3.2 "There-and-back" per pass

This approach is like the former but adapted to apply only during the pass itself. Outside the pass the SC rolls back to the reference angle.

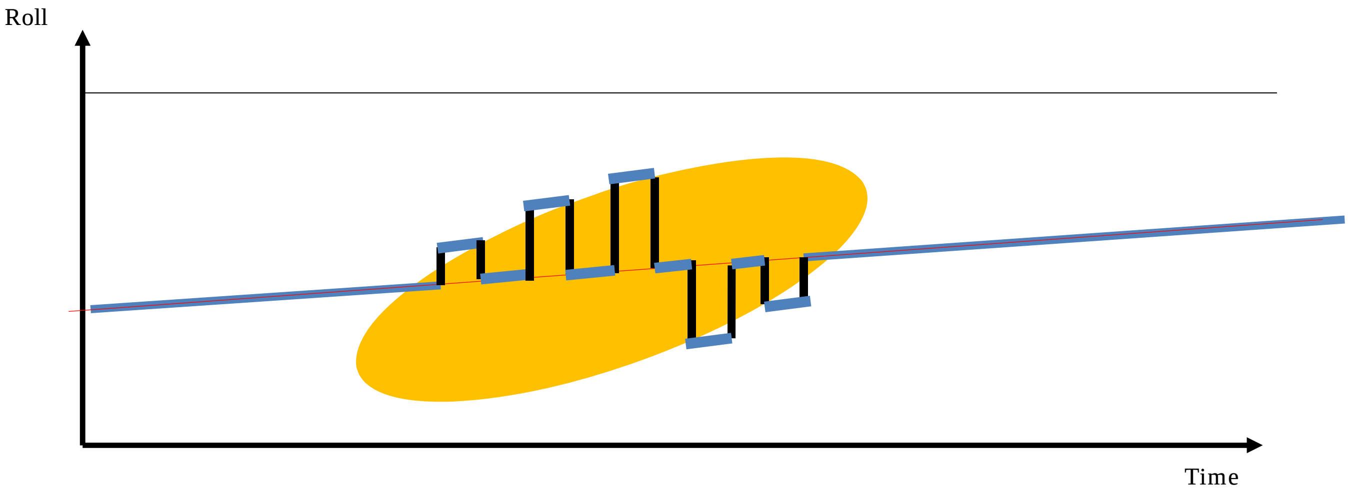

Figure 5, crude example diagram of comms rolls for "there and back" per pass

3.3 "Roll-and-stay"

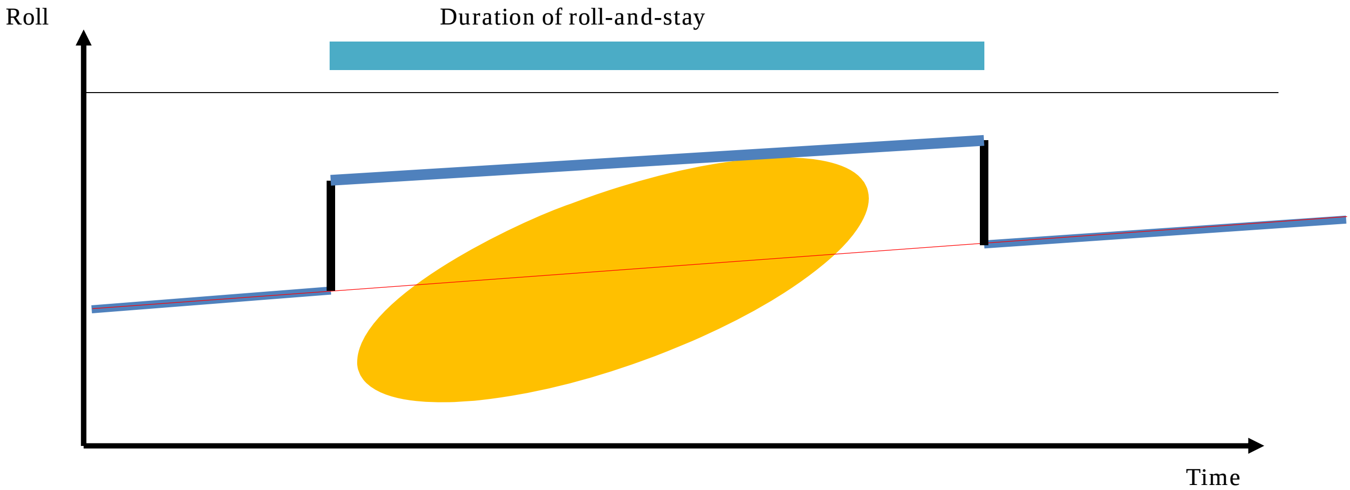

Figure 6, crude example diagram of comms rolls for simple "roll and stay"

In this case the scientific goals prefer roll stability over maximising the time spent at the roll reference. Thus a particular roll angle enveloping the constraint over the entire time period is used.

Note that, for "roll-and-stay" the duration of the non-reference roll angle can exceed the period directly affected by the constraint.

This strategy could apply for example to particular RSWs where stability more important than IS data quality.

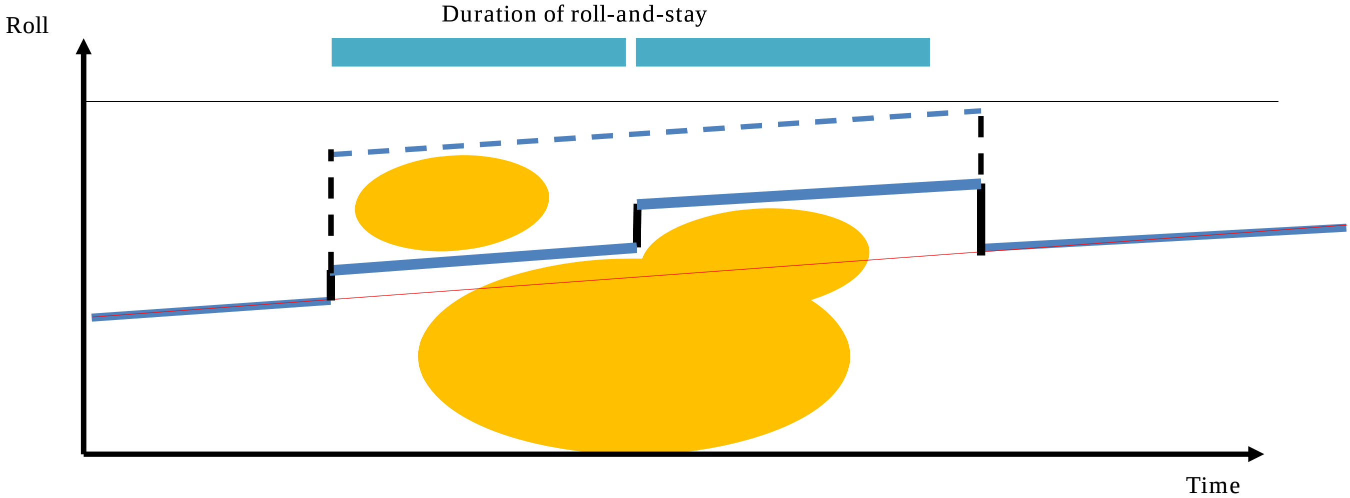

Figure 7, crude example diagram of comms rolls for complicated "roll and stay"

Figure 7 shows a situation where is advantageous to break the roll-and-stay into two discrete periods. The dotted lines show the more extreme profile that would result from treating the entire period as a single roll-and-stay.

The constraints as show in Figure 7 may appear artificial but situations like this **do** arise. For example earlier comms roll analysis has shown that there are RSWs where the simple "roll-and-stay" angle is more than twice the maximum angle that occurs when using "daily minimum absolute"

In the extreme/limit case where roll-and-stay periods are each one day long the strategy becomes almost equivalent to the daily minimum absolute roll.

3.4 “No roll, accept blockage”

Exceptionally it may be desirable to accept a comms interruption as a kind-of artificial conjunction. I.e. perform no roll away from the reference and give up any pass in the period of the blockage.

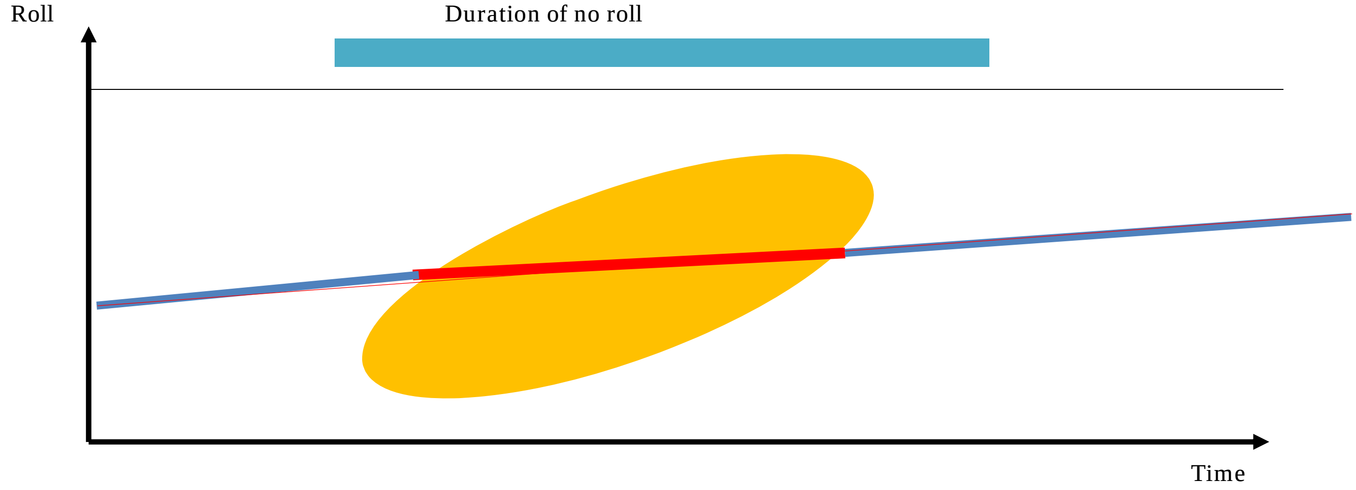

Figure 8, crude example diagram for “no roll, accept blockage”

Figure 8 shows “no roll, accept blockage” situation. Thick red represents the period over which passes are blocked.

This could be the case for (rare) campaigns where long-duration attitude stability is paramount. This is not favourable for typical science periods because visibility and the ability to react (also sometimes with VSTP PTRs) is usually more important.

It might also arise where there is potentially a short-lived but very large comms roll constraint. E.g. suppose if maximally one pass might be affected.

N.b. as for all very short-lived constraints it can happen that SOC would request a particular strategy, but that once the pass schedule is known no special action is needed (if the pass happens to fall outside the short-lived constraint). For other strategies it will be obvious to the SOC whether this has happened from the insertion of rolls that the SOC will see in the FECS (planning skeleton). However in this strategy it will not be obvious from the FECS which passes are blocked and which not. Some thought is needed on the best way to track/report the affected passes and (most likely) release them from the ground station schedule.

3.5 Reporting

3.5.1 *As reported in PTEL*

PTEL is the planning skeleton that comes to SOC from Flight Dynamics.
Comms rolls will be shown by ROLL events.

3.5.2 *As reported in SOOP Kitchen and EFECS pointing enumerations*

SOC products to instrument teams will simply maintain the ROLL events of the PTEL.