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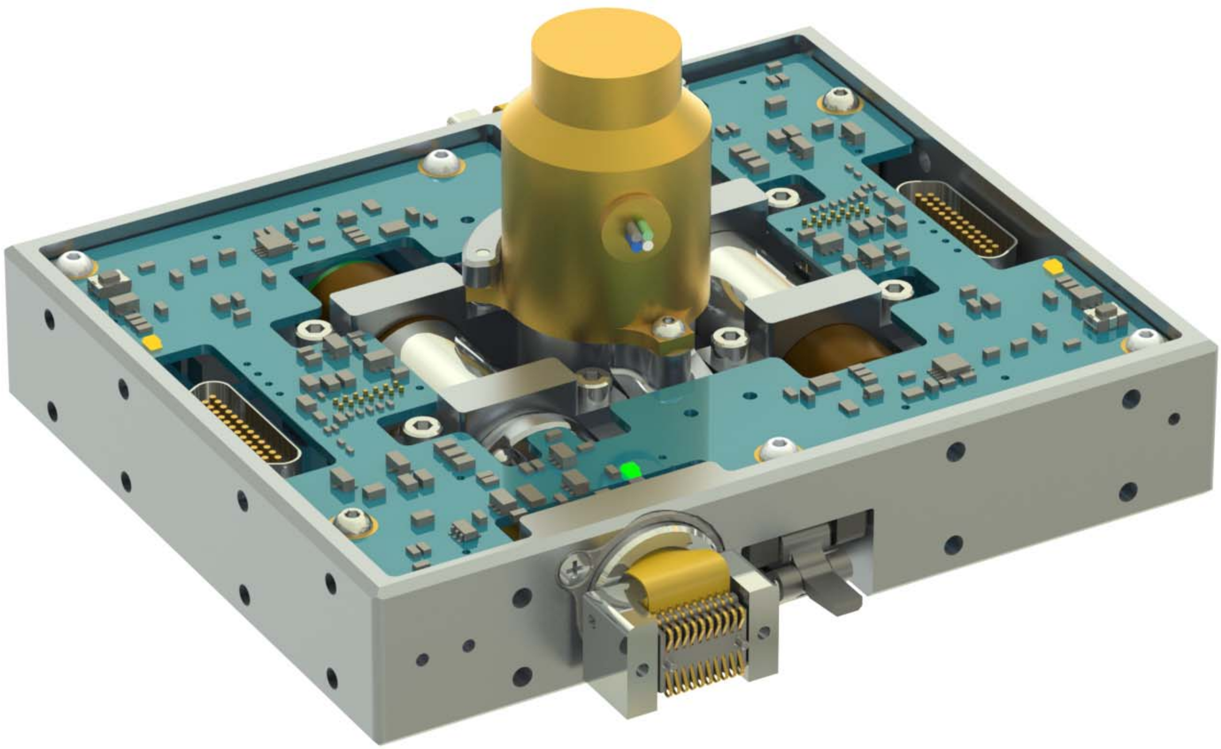
UM-33
User Manual

Deployable Articulated Solar Array (DASA) User Manual



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CHANGELOG

Rev.	Date	Author	Comments
A	20191010	AEK	Initial version.
B	20210325	AEK	Updated to reflect current revision of DASA hardware.

Overview

DASA is a low-cost, two-channel, stepper-motor-based Solar Array Drive Assembly (SADA) / Solar Array Drive Mechanism (SADM) for nanosatellites with a variety of advanced design and user features, including:

- A "dual-halves" construction with a fully independent motor/controller/sensor half for each articulated axis
- No reliance on slip rings or discrete wires in each articulated axis
- Three independent channels of solar array power and four independent channels of sensors for each articulated axis
- Three solar string power pass-through channels per articulated axis
- NASA GSFC-designed rad-hard half-bridges with JANS-rated devices
- Space-proven precision stepper motors with 50:1 reduction planetary gearboxes for high torque
- Direct control or commanded control of each stepper motor
- A full command-based interface over I2C for stepper motor control and telemetry with multiple operating modes
- Full- and half-step fast stepping, +/- 200º rotation, positive end stops
- Hall-effect sensor to enable homing
- Low-power, simple +12Vdc and +5Vdc interface
- Pin-puller mechanism to release from stowed position
- Small size housing & simple installation

Brief Specifications

- 0.15º — Minimum step size
- 0.15º/day to 25º/sec — Rate of motion
- +/- 200º — Range of motion
- <3º — Backlash (TBC)
- 2A & 80V — Rating per solar string passthrough
- 150x100x20mm — Volume (not incl. pin puller) (TBC)
- 2.4W peak — Power per active stepper motor
- <300mW — Command/telemetry power per half
- +12Vdc — H-bridge supply rail
- +5Vdc — Electronics supply rail
- 300mNm — Motor output & holding torque

- I2C Command interface (SCPI-like)
- TRL Undergoing testing Q1 2021

Dual Halves Construction

The DASA motor block consists of two completely identical halves, plus a single pin-puller-based release mechanism, all mounted inside a single enclosure. Each half has its own SupMCU controller, status LED, H-bridge, stepper motor, temperature sensors interface, Hall effect sensor, commands, telemetry, and I2C address. Each half can also fire the pin puller, and provide pin puller telemetry.

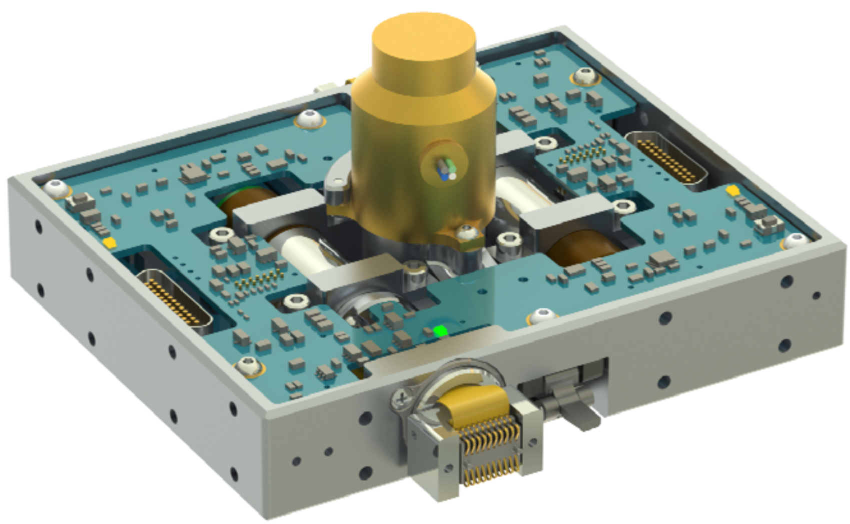


Figure 1: Underside view of DASA motor block assembly with pin puller attached. Solar panels are unconnected / not shown

Since the two halves are identical but independent, each half can perform operations independent of the other. For example, while the array on one side rotates at a predetermined rate, the array on the other side can be re-homed.

Note Since the two halves are identical, and because one stepper motor is oriented 180º from the other, take care to understand the direction of the array rotation you desire. For example, in a "GEO-like configuration" where the arrays on each side are to track the sun and remain in the same plane, command one stepper motor to rotate in the CW direction and command the other to rotate in the CCW direction at the same speed.

Note To distinguish between the two halves of a DASA when commanding it or obtaining telemetry from it, the only difference will be the I2C address used when communicating with it. The command syntax for each half will be exactly the same.

Connectors

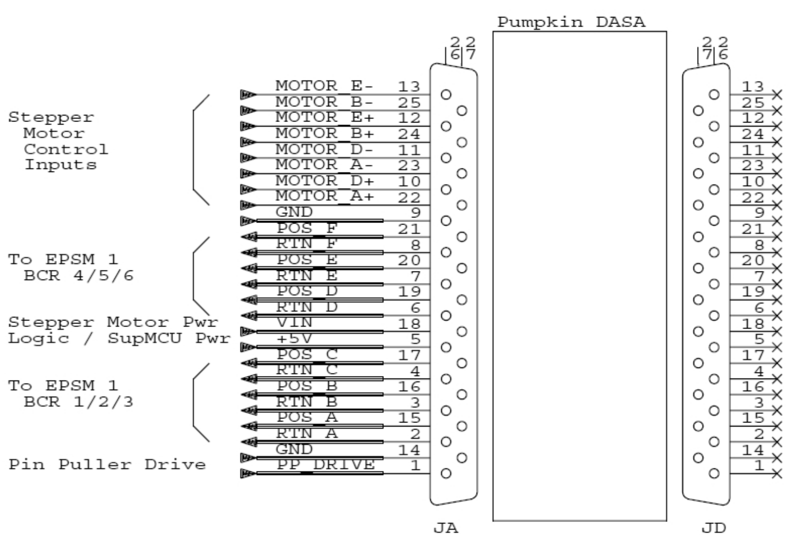
DASA can be configured at the factory with one of four connector configurations; they are shown below. Each connector JA and JD is an MDM-25 female connector; the mate is a male MDM-25 connector. Standard jacknuts are provided.

Power and ground (return), I2C communications, system -RESET and OFF_VCC, discrete half-bridge control inputs, solar string power and return, and pin puller drive signals are provided on the connectors.

The configurations vary in how the various DASA inputs and outputs are mapped to the outside world. Configuration 'C' is the most commonly-requested configuration.

Configuration 'A'

Connector Configuration 'A'



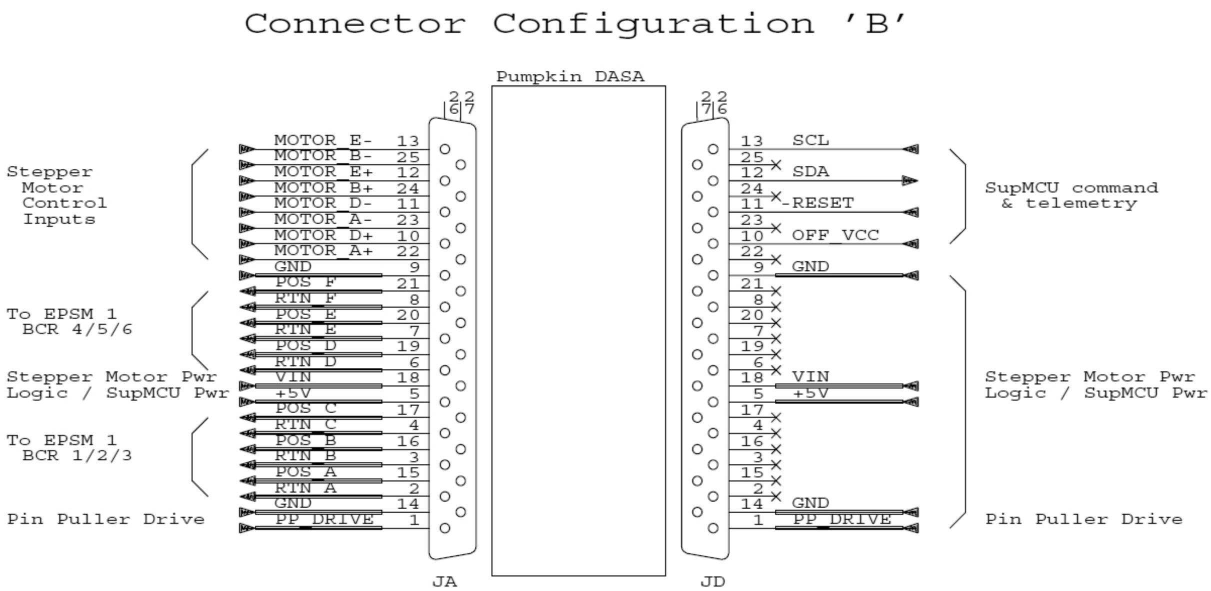
In this configuration, a single harness connects to DASA, with the following features:

* All six solar cell strings feed to EPS through one harness
* Each motor is driven independently, directly via its H-bridge, through one harness
* H-bridge is powered via VIN(x1) and GND
* Primary pin puller direct drive only
* Two GND (return) signals for H-bridge and pin puller

* NO secondary pin puller drive
* NO SupMCUs:
  * NO advanced features (e.g. commanded move, commanded pin puller activation
  * NO telemetry

This configuration has no wiring-harness redundancies.

Configuration 'B'



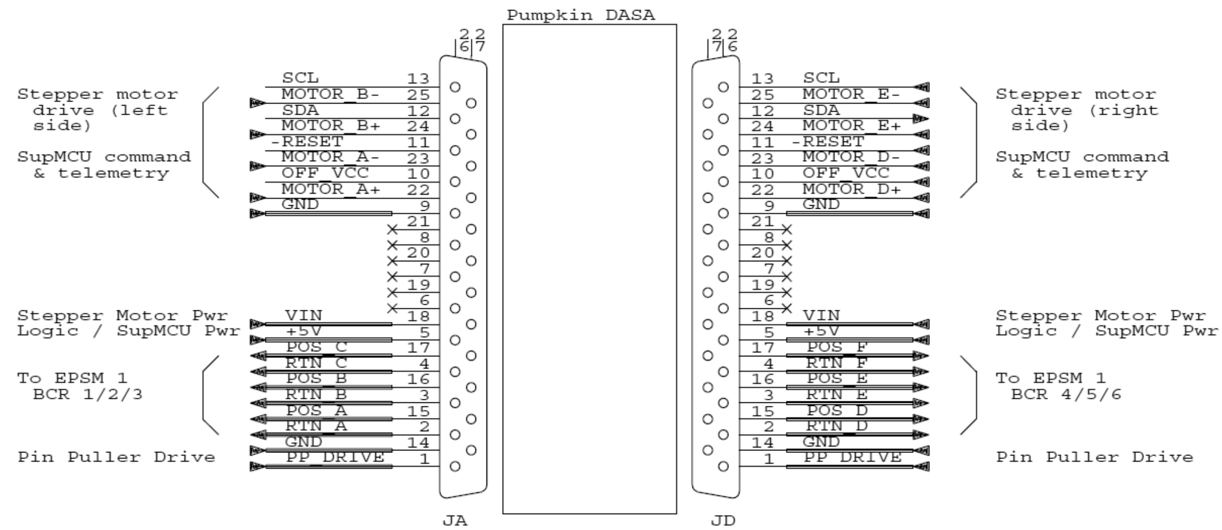
In this configuration, two harnesses connect to DASA, with the following features:

* All six solar cell strings feed to EPS through one harness
* Each motor is driven independently, directly via its H-bridge, through one harness
* H-bridge is powered via VIN(x2) and GND
* Primary and secondary pin puller direct drives on separate harnesses
* Two SupMCUs powered by +5V, on unique I2C addresses on one I2C bus:
  * Advanced features (e.g. commanded move, commanded pin puller activation)
  * Telemetry
* Four GND (return) signals for H-bridge and pin puller

This configuration only has a few wiring-harness redundancies (VIN, +5V, PP_DRIVE, GND).

Configuration 'C'

Connector Configuration 'C'



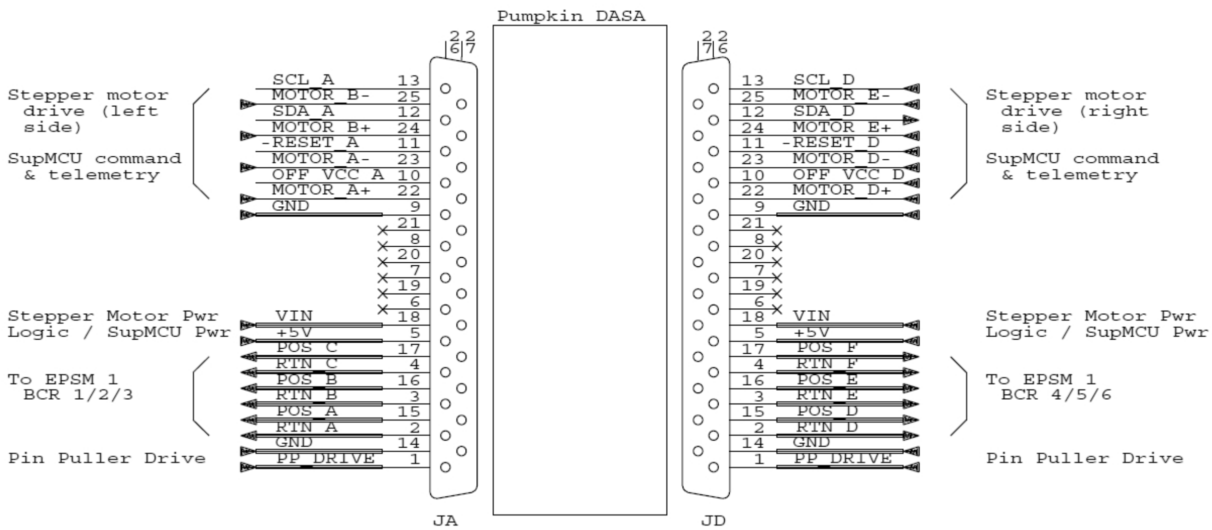
In this configuration, two harnesses connects to DASA, with the following features:

* Two groups of three solar cell strings feed to EPS, through separate harnesses
* Each motor is driven independently, directly via its H-bridge, through separate harnesses
* H-bridge is powered via VIN(x2) and GND
* Primary and secondary pin puller direct drives on separate harnesses
* Two SupMCUs powered by +5V, on unique I2C addresses on one I2C bus:
  * Advanced features (e.g. commanded move, commanded pin puller activation)
  * Telemetry
* Four GND (return) signals for H-bridge and pin puller

This configuration can fully drive one side if a harness fault occurs in the other side. I2C bus is common to both sides.

Configuration 'D'

Connector Configuration 'D'



In this configuration, two harnesses connect to DASA, with the following features:

* Two groups of three solar cell strings feed to EPS, through separate harnesses
* Each motor is driven independently, directly via its H-bridge, through separate harnesses
* H-bridge is powered via VIN(x2) and GND
* Primary and secondary pin puller direct drives on separate harnesses
* Two SupMCUs powered by +5V, on unique I2C addresses on separate I2C buses:
  * Advanced features (e.g. commanded move, commanded pin puller activation)
  * Telemetry
* Four GND (return) signals for H-bridge and pin puller

In this configuration, the left and right sides are completely independent of each other.

Resolution, Stops and Range

DASA utilizes a 24-pole permanent magnet stepper motor with a multi-stage 50-1 planetary reduction gearbox. 0.15 degrees of rotation is equivalent to a single half-step of the stepper motor, the smallest possible commandable rotation. 90 degrees of rotation is equivalent to 600 steps of rotation, and so on.

Each DASA stepper motor employs a hard mechanical stop at approximately ±200 degrees. When the motor encounters this hard stop, it will stall without damage. The stop prevents damage to the internal electrical routing of the solar cell strings and temperatures sensors on the attached solar panels. Customer drive algorithms for DASA should seek to limit overall rotation to less than ±200 degrees from the home position. In order to rotate the attached array "full circle", stop DASA before it reaches a hard stop, and reverse direction. DASA's wide speed range for commanded rotations is a great benefit in this case.

DASA can rotate its array through a range of approximately ±200 degrees, or ±1333 half steps.

Positional Knowledge

The DASA stepper motor operates in an open-loop mode, without an encoder to provide absolute or closed-loop positional feedback. Based on commanded stepper motor moves, DASA keeps track of the current position of the array via positive or negative position and angle values that are available as telemetry. The position and angle values can be redefined via the **`DRIVE:SET POS`** and **`DRIVE:SET ANGLE`** commands.

Note At power-up, the position is always (re-)defined to be 0. This may or may not be the actual home position, and should not be assumed to be home. See *Homing* for DASA's emergency and autonomous homing functions.

Note Because of the lack of an absolute encoder, position knowledge is lost whenever the stepper motor stalls against the hard stops, and whenever the SupMCU restarts. See *Homing* for DASA's emergency and autonomous homing functions.

Drive Modes

Enabled vs. Disabled

The DASA stepper motor is initially disabled, i.e. unpowered and not capable of accepting rotation commands. In order to command it to rotate, it must be enabled via a **`DRIVE ENABLE`** command. It can be re-disabled via a **`DRIVE DISABLE`** command.

Warning DASA's drive must be disabled via **`DRIVE DISABLE`** (or, DASA can be depowered) when using external discrete H-bridge inputs; see *Rotation*.

Hold vs. Release

The DASA stepper motor can be operated in two modes as regards its H-bridge: HOLD and RELEASE modes. The mode is specified via the **`DRIVE {HOLD|RELEASE}`** command.

In HOLD mode, the H-bridge remains energized in the last state associated with the stepper motor's most recent rotation; this means that one or both stepper motor phases (A and/or B) may be conducting current after a move is complete. When in HOLD mode, the stepper motor remains energized in most conditions, and this helps resist backdriving the stepper motor through the mass of the connected array, which in turn may help maintain DASA's open-loop position knowledge. Running in HOLD mode consumes stepper motor current at all times.

In RELEASE mode, the H-bridge is completely de-energized after each commanded move. Without any drive current, the stepper motor cannot resist any backdriving through the mass of the connected array – it depends solely on the reduction gear ratio to prevent uncommanded rotation of the array. Running in RELEASE mode consumes stepper motor current only when the stepper motor is turning the array.

The mode can be changed at any time.

Commanded Rotation

Absolute vs. Relative Rotation

DASA can be commanded to rotate to an absolute step count / angular position, or to rotate by a number of steps / angle from the current position. This is specified in the first argument to the **`STEP`** and **`ROT`** commands, **`ABS`** or **`REL`**.

Half-stepping vs. Full-stepping

DASA's control of its H-bridge driver permits half and full steps of rotation; microstepping is not supported. When half stepping, the phase transitions for the two stepper motor phases A and B can overlap as the stepper motor rotates. When full stepping, the two phases A and B will never be on at the same time. This is specified in the second argument to the **STEP** and **ROT** commands, **HALF** or **FULL**.

All commanded rotations are in units of half steps; one **FULL** step is equivalent to two **HALF** steps. Degree arguments (see below) are automatically converted to the corresponding number of half steps. Rotating in half-step mode affords the finest resolution.

Speed

The speed of a DASA rotation is given either in half steps/sec, or in degrees/sec. This is specified as the third argument to the **STEP** and **ROT** commands, in integer or floating-point format. Speed is always positive.

Tip Since speed is specified in half steps (and 0.15º/sec), a **STEP FULL** command will result in twice the rotational speed specified than a **STEP HALF** command. Similarly, a **ROT FULL** command will result in the array turning at twice the speed of a **ROT HALF** command.

Steps vs. Degrees

The number of half steps, or number of degrees for a DASA rotation, is the fourth argument to the **STEP** and **ROT** commands, respectively, in integer or floating-point format. Positive values denote CW rotation, whereas negative values denote CCW rotation -- See Figure 2.

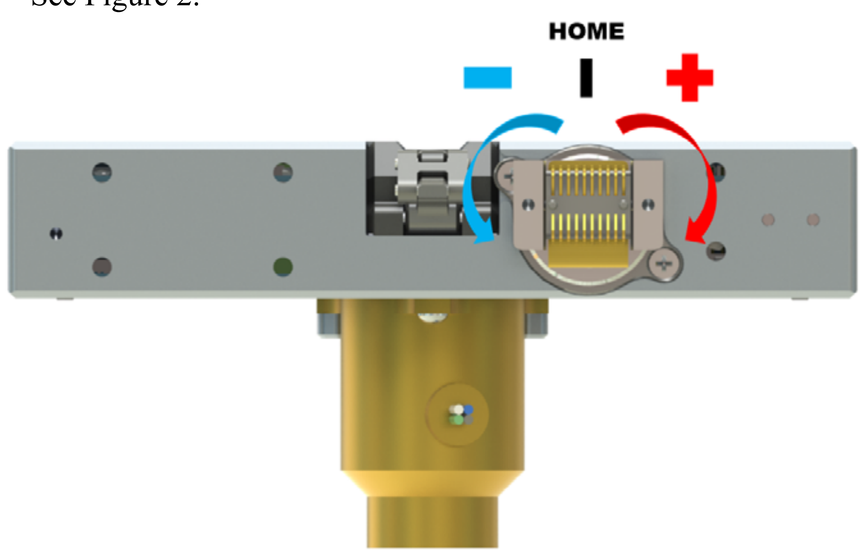


Figure 2: Home position and sense of rotation

Examples

Command	Result
DASA:STEP ABS,FULL,10,+477	Rotate to 477 half-steps CW from home, at 10 full steps/sec (20 half steps/sec)
DASA:STEP ABS,FULL,5,0	Rotate home at 5 full steps/sec
DASA:STEP REL,HALF,12.2,-37.3	Rotate 37.3° CCW at 12.2°/sec, half-stepping
DASA:STEP ABS,FULL,0.1,90	Rotate to 90° CW from home at 0.2°/sec, full-stepping

Table 1: Examples of Rotation Commands

Rotation via External Inputs

External Inputs to H-Bridge

DASA incorporates external inputs that can drive the H-bridges for each motor. These external inputs **BUS_A+**/**BUS_A-**/**BUS_B+**/**BUS_B-** are effectively OR'd with DASA's internal H-bridge drive signals. The external inputs all feed the bases of NPN transistors in the H-bridge, making these active high control signals.

Warning "Shoot-through" and permanent damage to the H-bridges is possible if the external inputs to an H-bridge are active and complementary to DASA's internal/commanded inputs in response to a rotation command. Therefore it's imperative to issue a **DRIVE DISABLE** command to DASA or to disable DASA's 5V power whenever the external H-bridge inputs are used.

Note Nothing inside DASA can prevent the external inputs from driving the H-bridge. As long as +12Vdc is applied to DASA to power the H-bridge, the external inputs can drive the bridge, and hence, the stepper motor. External inputs are active at all times, including if/when the DASA SupMCUs are unpowered, booting or fully operational.

Driving the Stepper Motor via External Inputs

Each DASA stepper motor employs the common four-lead, bipolar wiring scheme. Inside DASA, the two "A" leads are connected to the "A" H-bridge, and the two "B" leads to the "B" H-bridge. Each H-bridge is provided with two control signals ("+" and "-"), to force current in opposite directions in the connected winding.

The usual stepper motor control schemes like full stepping, half stepping, micro stepping and use of PWM methods are all possible with the external inputs.

Note the following about the H-bridges:

- The positive rail is +12Vdc.
- Flyback diodes are employed throughout.
- There is no inherent current limiting beyond a sub-1Ω current sense resistor through which all H-bridge current flows.
- The "+" and "-" control signals for a given phase of the H-bridge can be applied simultaneously; doing so is likely to induce "shoot-through" and may permanently damage the H-bridge if the +12Vdc supply is not sufficiently current-limited.

Hall-Effect Sensor

DASA incorporates a Hall-effect sensor (HES) that senses a small magnet attached to the stepper motor shaft at its home position. The HES is normally off (to protect it against radiation damage), and is normally only used by the automatic homing function (see below).

It can be enabled or disabled via the **`HES {ENABLE|DISABLE}`** command, and its output is available as DASA telemetry.

Homing

DASA's home position is defined as the rotational position of the main shaft, when the array is in the stowed position. By convention, this is represented by a position value of 0, and the corresponding angle value of 0º. See Figure 2.

Emergency Homing

A brute-force way to home the DASA array is to implement the following algorithm:

1. Rotate DASA far enough to guarantee reaching a hard stop

2. Knowing a priori how many steps will fully span the complete range of DASA's motion, rotate back in the opposite direction by half this value
3. Use **`STEP SET,0`** to redefine the current position to be the home position

This method has the advantage of not requiring any sensors, and can be accomplished either by driving the DASA H-bridge directly without any DASA SupMCU intervention, or via commands to DASA and its SupMCU. It capitalizes on the facts that motor stalls at the extremes of rotation will not damage the stepper motor, and that the range of rotation is limited equally in both directions by the hard stops.

Autonomous Homing

DASA provides an autonomous "home finding" function. The customer can specify the speed and step mode for the homing operation. A minimum number of steps or degrees to be rotated is required for the home-finding algorithm to work.

The algorithm rotates the array and monitors the HES for stable minimum and maximum values; these indicate that the magnet is far from the HES, and that the stepper motor shaft is aligned with the HES at the home position. The algorithm transitions through four states in its search for these stable min/max HES values. Depending on where the array is when commanded homing begins, the algorithm must be permitted to rotate long enough to find the desired min/max.

Commanding DASA to perform an autonomous home-finding operation is just like a **`STEP`** or **`ROT`** command, but with **`HOME`** as the first argument. Additionally, the number of steps or degrees serves as a limit for how far the autonomous homing is allowed to rotate.

Examples

From 90º CCW

As shown below, a **`ROT HOME,FULL,15,100`** command applied when the array was at -90º resulted in home being found within roughly 90º (out of the 100º allowed) at 15º/sec, full-stepping.

Tip The fact that the total change in degrees over the homing operation (90º) matches the distance to the original position (90º CCW) shows that the system was already properly homed when commanded to find home (again).

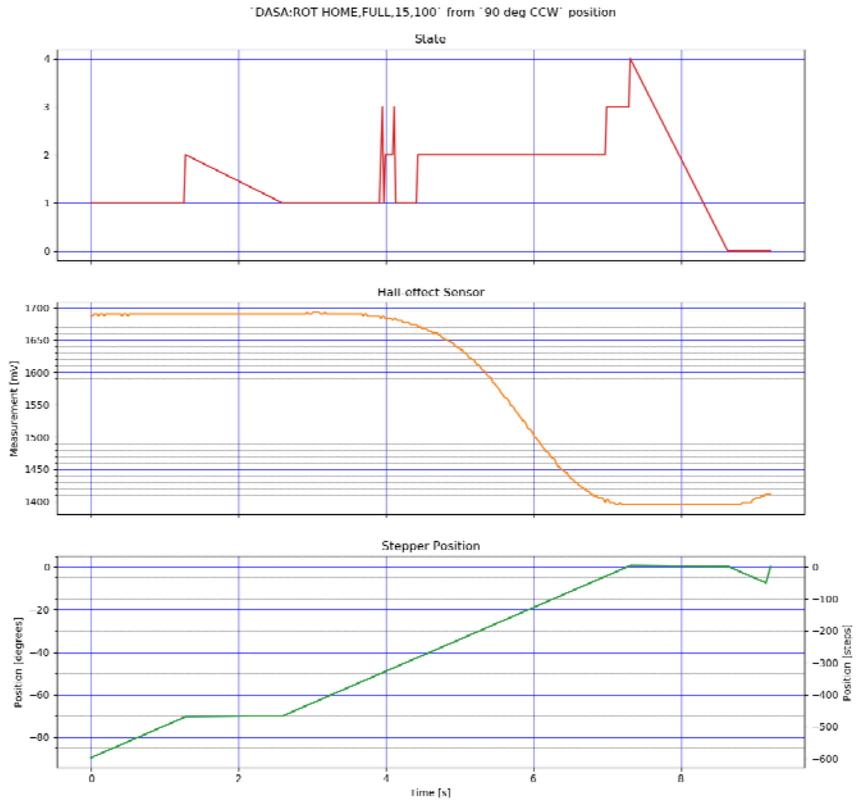


Figure 3: Homing action from 90º CCW

From 40º CCW

As shown below, a **`ROT HOME,HALF,15,-100`** command applied when the array was at -40º resulted in home being found after roughly 31º further CCW rotation, and then 79º CW (out of the 100º allowed) rotation at 15º/sec, half-stepping. The homing algorithm reversed direction at around 5s at a local min/max, to eventually find the min/max point that represents home.

Tip The final jump of 20º in the position value when homing was achieved indicates that the previous position knowledge was off by 20º; this is confirmed by having started at an indicated 60º CCW, which from observation was closer to 40º CCW.

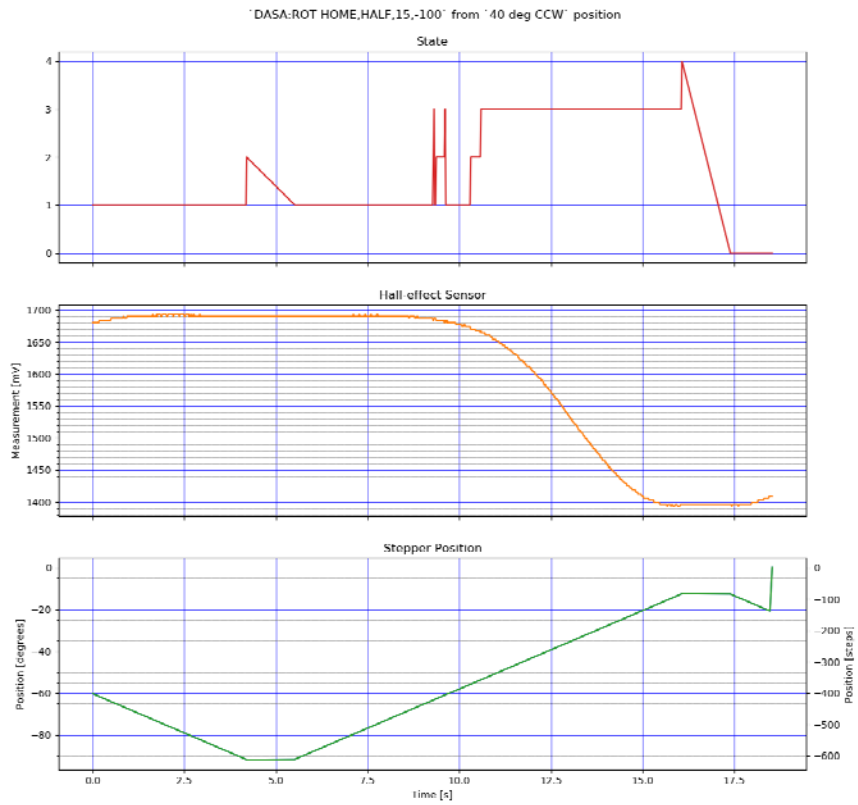


Figure 4: Homing action from 40º CCW

From Home

As shown below, a **`ROT HOME,FULL,15,100`** command applied when the array was already homed resulted in home being found after roughly 70º further CW rotation, and then 78º CCW (out of the 100º allowed) rotation at 15º/sec, full-stepping, and finally a 8º CW rotation to land at home. The homing algorithm automatically reversed direction at around 5s, to eventually find the min/max point.

Tip This illustrates that the homing algorithm has to rotate the array to be "far from home" as part of normal operation. This is because of the presence of a single HES, and the nature of a sinusoidal response as the magnet on the motor shaft rotates away from the HES.

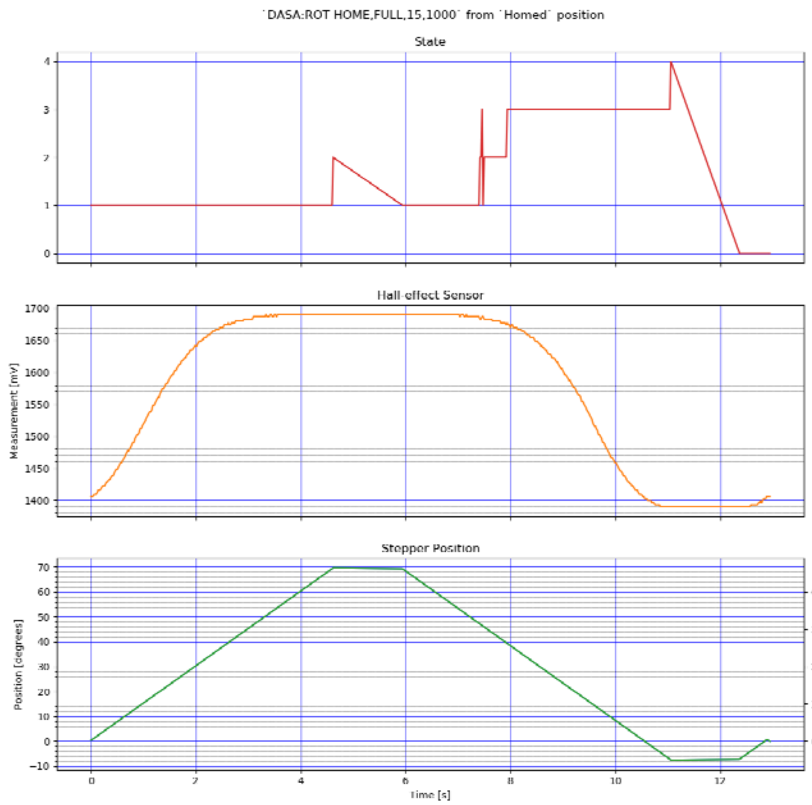


Figure 5: Homing action from home

Failed Homing

As shown below, a **`ROT HOME,HALF,15,-100`** command applied when the array at roughly 60º CW failed -- the state machine never completed. The failure to find home was due to the nature of the HES sensor reading -- a min/max for the sensor must be found, and it is typically around ±75º or further from home. Since the homing operation started at +60º, and was allowed to initially move at most -100º, it failed to move far enough to reach -75º, and the homing operation failed.

Tip From Figure 5, we see that a stable HES min/max is found around 70º from home. Hence, a rotational limit of 1000 steps or 150º in either direction is usually adequate for finding home, regardless of the initial position.

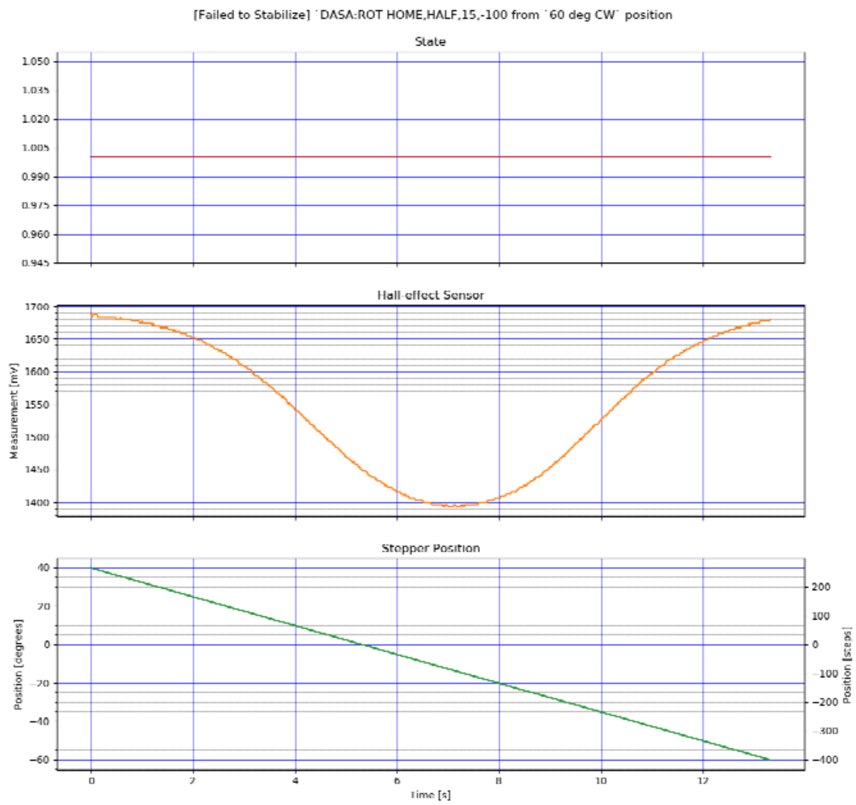


Figure 6: Failed homing

Release Mechanism

A pin puller-based release mechanism is provided, to release the two solar arrays from their stowed position. Each half of DASA – each with its own SupMCU – can be commanded to fire the pin puller. Additionally, there is a second, independent connection to the pin puller for an external source to energize.

Commanding the Release Mechanism

Either or both halves of DASA can be commanded to fire the pin puller release mechanism. Both halves provide voltage and current telemetry of the pin puller drive.

The release mechanism must receive a tightly-defined series of commands to fire. They are, in order:

1. **`REL ENABLE`** to enable the release mechanism
2. **`REL ARM`** to arm the release mechanism

3. **`REL FIRE,NN`** to fire the pin puller for **`NN`** seconds

The pin puller can be re-enabled, re-armed and re-fired at will, as long as the above sequence is observed.

Note DASA cannot rearm the release mechanism once DASA has fired it. The release mechanism can be rearmed manually using a special tool after it has been fired.

DASA does not provide any telemetry per se on the success of the release event. Depending on the model of pin puller employed, it may be possible to discern a difference in the pin puller current, pre- and post-release. Customers should infer the success of the release event by analyzing the performance of the solar arrays before and after the release event. It should be simple to ascertain if the two arrays are in the same plane, post-release, whereas they opposed each other in DASA's pre-release, stowed position.

Temperature Sensors

Each DASA half supports up to four temperature sensors on its solar array. The default configuration is to support three independent LM335 absolute-Kelvin temperature sensors, in telemetry channels Temp Sensor 2 – Temp Sensor 4.

To utilize the temperature sensors in this configuration, DASA's Negative Power Rail (NPR) must be first enabled. The NPR extends the temperature range of the LM335s by roughly 180K. This enables DASA to read temperatures up to and including 380K, a typical upper value of the solar panel operating temperature range.

To obtain valid temperature sensor telemetry, issue the **`NPR ENABLE`** command, wait at least 1s for the NPR to stabilize, and then request temperature telemetry for temperature sensors 2-4. The NPR can be disabled via a **`NPR DISABLE`** command if/when temperature telemetry is not needed.

Note Alternate methods of acquiring temperature data (e.g., via remote I2C temperature sensors, one-wire temperature sensors, or other methods) may be supported in future DASA release.

H-Bridge Telemetry

The current in each winding of the stepper motor is available as telemetry.

Note The sampling rate of the stepper motor currents is relatively low. The full- and half-stepping modes used to drive the stepper motor phases mean that the reported current typically takes on only two values – either nothing when the winding is not driven, or (12V/phase winding resistance in Ω) when it is driven. Therefore, this telemetry is most useful mainly to verify that current is flowing in the two windings of the stepper motor.

Attached Arrays

DASA normally operates with an array attached to each motor block. The array is hinged such that it is kept in the stowed position by DASA's release mechanism. Once released, each DASA motor is free to rotate its attached array.

Warning Do not issue rotation commands to DASA before the release mechanism has been enabled, armed and fired. To do otherwise will likely result in damage to DASA and/or its attached array.

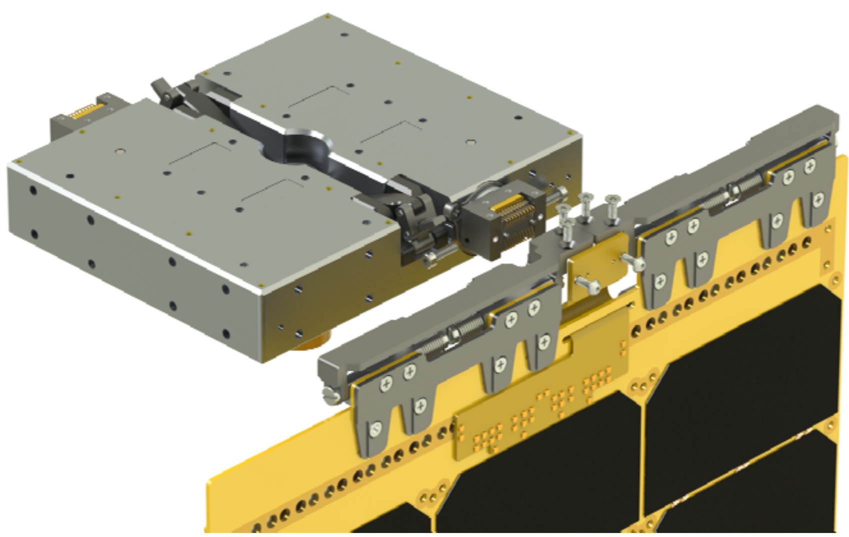


Figure 7: Array detached from DASA motor block

Each array attaches to its side of the DASA motor block via eight screws. Six screws secure the 90-degree hinge assembly to the motor shaft. The two remaining screws secure the flex connector that feeds solar array power and telemetry into the DASA motor block.

Array Power & Signals

Each side of DASA is can handle three independent solar cell strings, and four telemetry signals from its attached array. The telemetry signals are sampled by DASA and are provided as DASA telemetry. The solar cell strings are passed from the array, through DASA's rotating mechanism and out its main connector, to the system's EPS. Series diodes are present in-line with each solar string array, inside of DASA.

Note There are no electrical connections between the solar cell strings that pass through DASA, and DASA itself.

Note While DASA provides telemetry from the four telemetry channels per array, it cannot provide any telemetry on the array's strings. They pass through DASA on their way to a connected EPS.