Case and Requirements for SWARM-Based Near-Field Holography

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1. Background

The current holographic measurement system at the Submillimeter Array (SMA) uses vector voltmeters (VVM) as backends with the capability to measure two antennas simultaneously (Sridharan et al., 2002, 2004). A complete measurement of the full complement of 8 antennas of the array is accomplished through multiple sessions, typically spread over 18 months. Using the correlator backend to carry out holographic measurements promises a number of benefits, described below. While the advantages were recognized early on, the lack of manpower to enable acquisition of correlator data at the required fast rates limited any measurements to small maps, or equivalently to low resolution mapping. Such low resolution maps, of size 16×16, were indeed made for celestial holography, delivering a lateral resolution of approximately one panel (Sridharan, Saito & Patel, 2014). These maps were shown to be in good agreement with high resolution VVM based maps. The lower resolution of the correlator based maps is adequate for assessing large scale structures, specifically, the gravitational deformation of the antennas, through measurements at multiple mean elevations. It falls well short of the requirements for measuring and correcting inter- and intra-panel deviations. Multiple pixels within a panel excluding the edges are required for this purpose which VVM based holography meets by delivering a resolution of ~ 8 cm, with some 256×256 pixel test maps reaching ~ 3 cm resolution.

2. Correlator Holography Advantages

The benefits of conducting holographic measurements with the SWARM correlator are: (1) The current SWARM correlator allows four beacon tones to be observed simultaneously. The 230 GHz SMA holography beacon emits a CW frequency comb with a pitch of 16.6 GHz. Thus, it is possible to capture two tones, one in each sideband of each of two receivers. Holographic mapping with multiple tones allows mitigation of multipath effects which is currently handled by averaging a series of maps obtained with multiple sub-reflector positions. (2) As many as N-1 antennas can be measured in one session (3) The aperture illumination for two receiver bands and as many as N-1 antennas can be characterized in one mapping session (4) Elimination of non-standard set up using vector voltmeter backends and holography IF switches (5) Possibility of using the set up for a science track as the wide bandwidth allows the flexibility to place the beacon tones over a wide range in the IF as opposed to the narrow 10 kHz range with the VVM based system. (6) The same VVM based quick turnaround 1-D techniques can be used with the SWARM based system for assessing optics alignment for multiple bands and N-1 antennas in a single scanning measurement.

Clearly, establishing the capability to obtain large, high resolution holography maps, with the SWARM correlator backend, will allow realization of these benefits for routine holographic measurements. This powerful new alternative would result in significant time saving and ease of use.

3. Requirements

Here we lay out the requirements for such a measurement capability. While the goals set forth here may or may not be feasible, they can be modified based on discussions to arrive at the final specifications, closing the loop. The VVM based capability should continue to be maintained for other array diagnostic purposes. In the following, we assume 232.4 GHz and 332.0 GHz as the nominal frequencies (n=14 and n=20 for the beacon comb components) for measurements with the 230/240 and 345/400 receivers.

3.1 Top Level Goal

The ability to complete a holography mapping session with N-1 antennas in half a night is set as the desirable goal, with one antenna being the reference (see section 3.2). Completion in one full night is acceptable. The more detailed requirements listed below flow from this top level goal. An *on-the-fly* (OTF) data acquisition scheme without Walsh switching is envisaged as the primary mode of operation. Data will be binned onto a regular grid offline, for further processing. The requirements are summarized in Table 1 and further discussed in more detail below.

Table 1. Requirements for SWARM Holography

Item	Goal	Acceptable	Comment
Session time	Half night (4hr)	1 night	2 maps (repeatability)
Mapping time	2hr/map	4hr/map	4 hr. with Walsh
Map size	128×128	96×96	
Mapping speed	40s per row	71s per row	
Scanning speed	106"/s		
Data sampling	36 ms/sample	64 ms/sample	w/o Walsh
		0.8 s/pixel	Walshed
Walsh switching	No Walsh	fastest doable Walsh	
Channels recorded	16 per SB per Rx		Flexible placement

3.2. Mapping Time

Goal: 2 hour per map
Current: 38 minutes for a 96×96 map

Rationale: High quality holographic measurements require good phase stability which, based on past experience, is typically obtained in the second half of the night. The antennas are also expected to have reached thermal equilibrium by the second half. Thus, it is desirable to fit a mapping session into one half night, or about 4 hours. Allowing time for two maps to estimate repeatability, one map should be completed in 2 hours.

3.3. Map Size

Goal: 128×128 pixels - 6 cm resolution, routine maps will be smaller.
Current: routine - 96×96 pixels, 8 cm resolution, 128×128 and 256×256 are feasible and have been made.

Rationale: A map size of 128×128 delivers 6 cm resolution, allowing high quality measurements of intra-panel deviations and ability to discard panel edges when fitting for deformations.

3.4. Mapping Speed

Goal: 40s per row
Current: 19s per row

Rationale: Sections 3.2 & 3.3 above determine the mapping speed.

Time per row: 120s/128 = 56.25s. This includes scanning a row and a retrace. In principle, alternate rows can be scanned in opposite directions but this will require the lag between acquisitions of correlation data and antenna position data to be well determined. The retrace can be done at full slew speed and will result in little loss of time while eliminating any impact of lag. This is the approach used in the current VVM based system. Allowing 10% time for retrace, time per row is 50.6s per row. Boresight visits ~ every 5 minutes to track gain drift would add 24 additional scan equivalents making this 42s. We target 40 seconds per row.

The current systems takes 19s per row, excluding retrace. A larger scan than the map extent is made to allow speed to reach steady state and the scan goes past the end of the row, before the antenna comes to a stop. Time for retrace and stopping: 5s per scan.

3.5. Scanning Speed

Goal: 106"/s
Current: 400"/s

Rationale: The spatial sampling desired is 33.3"/pixel at 232.4 GHz and 23.3"/pixel at 332 GHz (= $0.75\times\lambda/D$), translating to 4263" for 128 pixels. The required speed is 4263"/40s = 106"/s. For the higher frequency map, the required map size is smaller or equivalently, for 232/332 maps made simultaneously, the 332 maps will have more pixels.

3.6. Data Taking Speed

Goal: 36 ms/sample
Current: 16 ms/sample

Rationale: The time per pixel is 33.3"/106"s^{-1} = 315 ms for 232 GHz and 23.3"/106"s^{-1} = 220 ms for 332 GHz. We would like to get 6 samples over a pixel. If we bin samples into pixels with bin width of 33.3"/2, this would provide 3 samples per bin. The requirement is more stringent at 332 GHz, 6 samples over 23.3" or equivalently in 220 ms. The sampling rate required is 36 ms per sample.

3.7. Walsh Switching

Goal: no Walsh switching with the option to obtain Walsh switched data
Current: no Walsh switching (not applicable)

Rationale: Walsh switching is required for sideband separation and to suppress unwanted spurious effects. It will be desirable to keep the tones in the two side bands as far away from each other as possible in the IF to minimize the effects of inadequate sideband rejection. It should be possible to map without Walsh switching, as the frequency separation in the IF for the two tones alone, which can be set to be large, can isolate them. Since the signal from the beacon is strong, the integration per pixel is short, low level effects that will become limiting factors after long integrations should not be an issue. This potential ability to do away with Walsh switching is important, as it can allow fast data taking to fully exploit on-the-fly mapping. The data can be taken as fast as allowed by the rest of the system. The reliability of data without Walsh switching is yet to be established, but it can be reasonably expected to be of good quality.

The option to acquire Walsh switched data should be available which requires a scheme to synchronize OTF scanning with the Walsh cycle. With Walsh switching, the fast data rates requirement set in section 3.6. will not be feasible. In this case, we will relax the requirements to complete one map in 4hrs, or the fastest feasible with Walsh switching. For a 128 × 128 map, this would amount to 4×3600s/(128×128) = 0.879 s per pixel.

3.8. Recorded Channels

Goal: 16 channels × 4 (2 in each Rx), with flexible placement
Current: 2 channels, one for each Rx/VVM.

Rationale: Most of the power in the CW tones fit well within one 140 kHz SWARM resolution channel. The restriction of number of channels required to be recorded may help with high speed data acquisition. Ability to choose the placement of these 16 channels will allow tuning flexibility.

References

Sridharan, T. K., Saito, M., Patel, N. A., 2002, Holographic Surface Quality Measurements of the Submillimeter Array Antennas, SMA Technical Memo No. 147

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