Atacama
Large
Millimeter
Array

Long Baseline (Y+) Array Configuration: Specifications and Requirements

ALMA-90.02.00.00-002-A-SPE
Version: A

Status: *Released*

2003-06-30

Prepared By:	**Organization**	**Date**
M. A. Holdaway	National Radio Astronomy Observatory	2003-06-30
IPT Leader Approvals:	**Organization**	**Date**
	National Radio Astronomy Observatory European Southern Observatory	
System Engineering Approvals:	**Organization**	**Date**
	National Radio Astronomy Observatory European Southern Observatory	
Configuration Control Board Approval:	**Organization**	**Date**
	ALMA Configuration Control Board Secretary, signing for the Control Board	
JAO Director Release Authorization:	**Organization**	**Date**
	Joint ALMA Office Project Director	

Change Record

Version	**Date**	**Affected Section(s)**	**Change Request #**	**Reason/Initiation/Remarks**
A	2003-06-30	All		First Release

Table of Contents

1 Introduction

The original design for the NRAO's Millimeter Array (MMA) called for multiple array configurations with a maximum baseline of 3 km. ESO's Large Southern Array was envisioned to have baselines of up to 10 km. Some early proponents of high resolution sought even longer baselines (Hjellming, 1995).

In recent years, many configuration designers have assumed that a uniform (u,v) coverage was desirable (Cornwell, 1986; Keto, 1997), and designs for ring or Reuleaux triangles proliferated. Uniform coverage results in the highest ratio of average baseline to maximum baseline, or the highest resolution given the size of the array. However, uniform coverage also produces very large near-in side-lobes (15%) that do not average down with earth synthesis (Holdaway, 1996a). Furthermore, uniform-type coverages do not have great imaging properties – and when they outperform other coverages, it is because of their very short spacing excess coverage! Kogan and coworkers advanced the Donut, or double-ringed arrays, which realized some flexibility in reconfiguring, permitting a new configuration to be made by moving half the antennas. The Donut array was a compromise between the ring and more centrally condensed designs.

In the end, though, it was the logistical simplicity of the self-similar and ever-expanding spiral configuration plan (Conway, 1998, 1999, 2000a, 2000b, 2001, 2002) that swayed people to its clever design. A new configuration can be created in a single day (with luck and short moves, in a single morning before the wind starts to pick up), and the desired resolution could be dialed in with minimum sensitivity loss if tapering was needed to make an exact resolution for multi-frequency comparisons. Of course, the low side-lobe levels, the nearly-Gaussian beams, and the superior imaging quality (Heddle, 2001) all aided in the acceptance of the Conway configuration plan.

Through a compromise with individuals who desired higher resolution, a 27 station Reuleaux triangle of 4.5km diameter was added to the spiral design to achieve the higher resolution. If we were somehow constrained to have a maximum baseline of 4.5 km, this would be a reasonable approach. However, a higher resolution array with 14 km baselines was designed to ring the Chascon volcano (Holdaway, 1996b; Conway, 2002, Kogan, 2000). This 14 km configuration shared only a few antenna pads with the 4.5 configuration, hybrid arrays with intermediate resolution were difficult, and the half circumference of the 14 km ring was 22 km, implying something like a 25 km maximum cable run.

In early 2002, Angel Otarola and I officially proposed an alternative configuration design for the highest resolution array named the "Y+" configuration (Otarola and Holdaway, 2002). Our configuration design has been named "Y+" because it is a departure from a strict linear "Y" design such as the VLA. In order to match the resolution of the 14 km ring, we had to extend the maximum baselines out to 18.5 km. The coverage results in a basically Gaussian (u,v) coverage synthesized beam. This array configuration offered a number of advantages:

- The philosophy of the Y+ arrays is similar to much of the philosophy behind the spiral arrays, and observations with the Y+ will result in similar (u,v) distributions. This means that the processes of making and interpreting images should be very similar for every ALMA configuration longer than the most compact array.
- Hybrid configurations with the entire possible range of resolutions result naturally.
- Just as with the spiral array, the logistics of reconfiguring four antennas per incremental array configuration is very attractive.
- The maximum cable run in the Y+ configuration should be about 15 km, much shorter than the Chascon ring array.
- A substantial savings in the number of pads (and the number of antenna moves) can be achieved, as the 27 station Reuleaux triangle at 4.5 km becomes superfluous. Also, the Y+ array is able to share a few more antenna stations with Conway's configurations.
- Even though the Y+ array has problems with inner side lobes at 7.5%, they are significantly better than the ring array's 15% side lobes. And these inner side lobes do not form a continuous ring, so they do average down somewhat with earth rotation synthesis.

For most observations, the Y+ configuration will probably produce superior image quality.

The Y+ array does have its disadvantages. It is sometimes considered a disadvantage that the Y+ doesn't have the same resolution as an 18.5 km ring array. Of course, we can't fit an 18 km ring on the site. Even though the Y+ array has the same resolution as the 14 km ring, the Y+ array has inferior resolving power: the ring array has more long baselines than a Gaussian coverage would have, so its synthesized beam is highly non-Gaussian, dropping to the first null much faster than a Gaussian. This results in an improved ability to resolve close source pairs. While we don't match the 14 km ring array's abilities, we did improve our Y+ design to be more competitive with the ring array.

While we do present a complete design for the Y+ array configuration, this is probably not the last word on the Y+. A number of locations for antenna pads may not be possible because of excessive depth to bedrock or loose bedrock beneath the site. We will continue work on these problems and will make revisions to this document as we are required to do so. Also, issues such as the optimal reconfiguration scheme may change in the future. However, many of the details of the Y+ array and its general shape and maximum baseline length are pretty well set and can be used to design other aspects of ALMA.

2 Related Documents

The design for the inner 172 antenna station positions is presented in document ALMA-90.02.00.00-001-F-SPE. This includes the compact array for baselines up to about 200 m, extending via a more-or-less self-similar set of spiral configurations out to baselines of 4500 m.

In the future, if funding for the ACA is obtained, there will be another document that specifies the positions of the antenna stations of the ACA.

3 General Design Assumptions

Even though ALMA is designed to have 64 12 m radio antennas, the charge for the array configuration design was to determine locations for 60 antennas, leaving four antennas to perform total power measurements. As the ACA will likely be funded, this will free up the last four antennas to participate in interferometery with the other 60 antennas.

3.1 Array Philosophy

Beyond the inner 78 antenna stations that are arranged in a compact configuration, Conway’s stations are governed by a three-armed logarithmic spiral. The resolution is increased in increments of about 15% as four antennas are moved from one configuration to the next. The Chajnantor site permits this spiral configuration out to baselines of 4500 m. The outer 44 stations continue this general philosophy of incremental reconfiguration, but the three arms cannot continue in a spiral due to the mountains, so the three arms straighten out in a rough “Y” shape. A Y shaped array with straight arms and regular antenna placement produces poor snapshot (u,v) coverage and high side lobes in the point spread function (PSF), so our “Y” arms are actually 5 or 6 km wide at their ends. To maximize the resolution, antennas are placed as far apart as the land concession permits.

3.2 Mask Considerations

A large variety of optimization methods can operate on a binary mask that indicates the geographical locations that permit or preclude building antenna foundations. The generation of the mask is one of the most important steps in determining an appropriate array configuration. The mask used to generate our Y+ array configuration is shown in Figure 1.

The mask has a number of logical layers, including the political land concession, topographical shadowing, proximity to the natural gas pipeline, and a maximum local gradient. In addition to these more precise masking conditions, we also masked subject to accessibility to the land. Finally, earlier simulations indicated that there was not a great deal of difference in the imaging quality of “tight Y” configurations verses “wide Y” configurations. The cost of roads and cabling on a “wide” Y would be more than the “narrow Y”. After initial attempts at optimization using the entire concession produced arrays that under-utilized the concession, we further restricted the mask by removing some of the northern parts of the western arm and some of the eastern parts of the north arm on Pampa la Bola.

3.2.1 A Few Notes on Coordinates

The digital elevation model (DEM) of the Chajnantor site is in UTM coordinates referenced to the SAM 56 datum. This DEM was made by McLain Aerial from aerial photographs without ground control, and could have substantial errors. Cross-correlation with a more recent high quality DEM of the inner portion of the Chajnantor site indicated that coordinate offset errors of 50-100 m were present. However, surveying the 44 Y+ antenna locations with simple GPS indicated that the features on the old DEM used for the Y+ work had coordinates which were generally accurate to 20-30 m, occasionally with worse accuracy.

In order to maintain sufficient numerical accuracy in a single-precision FLOAT, as used in several software systems, we removed some of the most significant digits in the coordinates of the DEM and of the antenna coordinates. While those digits have been added back in for the UTM coordinates in the tables, the figures are not referenced to the absolute UTM coordinates.

3.2.2 Land Concession

The coordinates of the concession that we have used are actually different from the coordinates of the actual concession. However, no antenna stations lie outside the current concession. The coordinates of the concession are not available in any official ALMA document, and it is outside the scope of this document to reproduce them here.

3.2.3 Maximum Local Gradient

The maximum gradient at each 10m pixel on the site was calculated via the methods of Butler (2001) from a DEM of the site (Holdaway et al, 1996c; Radford Site Web Site). The accuracy of the DEM greatly influences the accuracy of the mask image in that an error in the coordinates of a topographical feature result in a translation of the acceptable or unacceptable locations in the mask.

The transporter and road have strict gradient requirements, but those requirements do not translate directly into a requirement of the topographical terrain's gradient, as there will always be a way to build a flat road on a steep slope by directing the road perpendicular to the topographical gradient. However, it is reasonable and economical to desire the array be sited on the flattest terrain that permits an array design which does not compromise the astronomical goals of the array. For the inner configurations, a maximum gradient of 5% resulted in a minimal compromising of the astronomical capabilities of the array.

The terrain that is found in the concession required to build the Y+ configurations would not permit a viable high resolution array with a 5% maximum gradient, but by extending inclusion in the mask up to a 7.5% maximum gradient, enough real estate opened up to permit a high resolution array. At the 7.5% gradient limit, all of the mountains and the sides of the arroyos were excluded.

In 2002, a high resolution DEM was made for the inner 5 x 5 km of the Chajnantor site. This DEM proved far superior to the old DEM that covered the rest of the site, so it was quickly used for the Conway configurations. We have inserted this mask into the center of our mask.

3.2.4 Topographical Shadowing

We had a goal of no shadowing from topographical features above 10 degrees. There are a number of stations on Pampa la Bola and near the cinder cones at the southern end of the array which have shadowing in some directions as high as 15 or 16 degrees, but not towards the north.

3.2.5 Gas Pipeline

We precluded any antenna station being sited within 50 m of the gas pipeline. UTM coordinates for the gas pipeline were taken from http://www.tuc.nrao.edu/mma/sites/Chajnantor/maps/coordinates.html

3.2.6 Accessibility Issues

Locations that showed no access because of being isolated by a combination of terrain and the gas pipeline were eliminated. Locations at the bottom of arroyos that were otherwise permitted were eliminated.

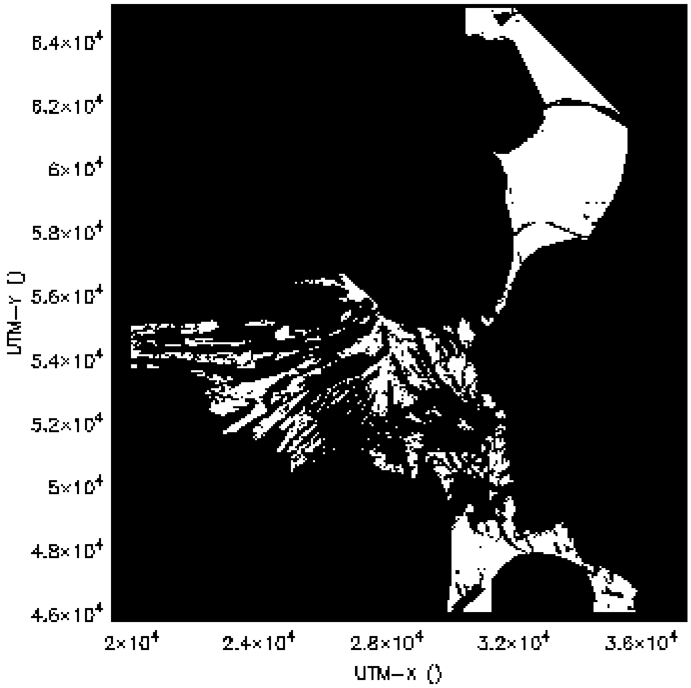

Figure 1: The mask image used for antenna placement on Chajnantor. White pixels are acceptable antenna locations, black pixels have been masked out to reflect the land concession, shadowing of astronomical sources by mountains, proximity to the gas pipeline, excessive local gradient, access considerations, and other ad hoc reasons.

3.3 Design Criteria

3.3.1 Optimize for Long Tracks

Unlike the compact array and the spiral configurations that were optimized for a snapshot, the Y+ configuration is optimized for long tracks. The beam is so small that it is thought that most observations will require long integrations to get sufficient sensitivity. After only an hour or two of earth synthesis rotation, the outer side lobes are greatly diminished, typically by a factor of about 10, as they move among the PSF’s pixels. However, the side lobes which are within a few beam widths of the main lobe of the PSF are hardly reduced at all for a one or two hour synthesis, and perhaps by a factor of only 2 after a full six hour synthesis. This indicates that a great deal of attention must be paid to the inner side lobes of the PSF, as they are likely to dominate the image quality of images made from long integrations using the Y+ configuration. Similarly, we should discriminate against configurations which produce high inner side lobes. A "Y" shaped array will naturally produce a snapshot with a six-pointed star pattern in the inner side lobes, so reducing these side lobes by the detailed placement of antennas has become a major effort in the Y+ design.

3.3.2 16 Y+ Stations Use Conway's Pads

This is not a primary design criterion, but is a secondary criterion that is a compromise between pressures to minimize the total number of pads and pressures to minimize the inner side lobes. When more than 16 Conway pads were used, the inner side lobes became too large.

3.3.3 Two Short Baselines for Calibration

Conway's configurations always maintain at least three baselines of 40 m or less to detect large objects like planets that are useful for flux calibration. In Conway's largest configuration, those three baselines are accomplished with three pairs of antennas (each pair of close antennas is widely separated, six antennas are involved in obtaining these three short baselines). The Y+ configuration keeps two pairs of these close antennas to ensure that there are always a couple of short baselines for calibration purposes.

3.3.4 11 Incremental Configurations

This is not a primary design criterion, but follows from the philosophy of reconfiguring four antennas at a time and sharing 16 pads with the Conway configurations. Hence, optimizing for 60 antennas, there will be 44 pads that are used only for the Y+ configurations, or 11 different incremental configurations. The configuration that uses all 44 Y+ pads is called the full resolution Y+ array, and the other incremental configurations are sometimes referred to as the intermediate Y+ arrays. We refer to the individual Y+ configurations by name as Y0, Y1, Y2…. Y11, where Y11 is the full resolution Y+ array, Y0 is Conway's 4.5 km array, and Y1 is made by moving the first four antennas out of Y0, etc.

3.3.5 The Y+ Array is Optimized for Full Resolution

The full resolution Y+ array received primary attention in the optimization, as is explained below.

3.3.6 Nearly Circular Beam Over All Sky

Foster (1994) studied the problem of obtaining a nearly circular beam with an array that observed in long tracks, and found that a 10% N-S elongation results in optimal circularity. We have achieved a 10% N-S elongation in the beam by optimizing for the declination of $\delta = -48$ degrees: $1/\cos(\text{lat} - \delta) = 1.10$ for lat = -23 degrees. Optimizing for this declination does not adversely affect operation at other declinations.

3.3.7 14 mas Resolution at 300 GHz

The Y+ configuration achieves a resolution of 14 milli-arcseconds (mas) at 300 GHz. The Project Book mentioned maximum baselines of 14 km and a resolution of 10 mas at 700 GHz. The maximum baselines of the Y+ array are about 18.5 km, and the resolution at 700 GHz would be 6 mas, exceeding the specification in the project book.

Even so, there was extreme pressure to design a higher resolution Y+ configuration. While a smaller beam would be possible given the masked region we were working with, such an array would require more Y+ pads or would compromise the inner (u,v) coverage (ie, 2-8 km), and would result in higher inner side lobes.

3.4 Optimization Methods

After attempting several different optimization methods, we settled on a modified version of Kogan's CONFI algorithm in Classic AIPS to generate the Y+ configuration. We chose this algorithm after we identified that the large inner side lobes were the most problematic aspect of the Y+ array optimization. Kogan's is the only algorithm that explicitly minimizes side lobes, and Leonia Kogan made several modifications to his code that helped us to attack the inner side lobes, which can easily be confused with the main lobe of the beam.

We had several options for how to proceed with the array optimization. We could have sought to optimize all 11 incremental Y+ configurations simultaneously, we could have optimized each incremental configuration (i.e., Y1, Y2,…Y11) one after the other, or we could have optimized the full resolution Y+ array (Y11) and then picked the best intermediate Y configurations subject to those positions. Simultaneously optimizing all 11 incremental configurations was not technically feasible with any of the software packages we tried working with. Optimizing the incremental Y+ configurations sequentially worked fine out to about Y5, but the inner side lobes got worse and worse. Apparently, with only four antennas free to move, there are not enough degrees of freedom to fix those side lobes. Optimizing the full resolution array and then finding the best way to make the remaining 10 intermediate Y+ configurations produced arrays which were as good as the individually optimized arrays out to Y5, and superior to the individually optimized arrays between Y6 and Y11. As it is anticipated that the full resolution Y+ array will have more observing time than all the intermediate configurations combined, this approach is a good one.

In April 2003, Simon Radford and I traveled to the site to verify that these positions were reasonable. We made a number of minor modifications in the proposed antenna locations. The cumulative effect of these small changes was to degrade the quality of the configuration and the PSF. We sought to regain the inner side lobe level we had obtained earlier by moving just a few antennas, but Kogan's algorithm did not produce good results with moving only a few antennas. We wrote a simple algorithm that is similar to simulated annealing at the GLISH level of the AIPS++ package and accomplished the improvement we sought in the PSF by moving six antennas. These six antennas pads, 173 D, 174 D, 175 D, 178 D, 186 D, and 211 D, still need to be resurveyed to verify that they are viable antenna sites.

4 Pad Numbers and Positions

We include both the 16 Conway pad numbers and the 44 pads that are unique to the Y+ configuration in Tables 1 and 2 below. The elevation has been taken from the digital elevation model, but the elevation is not a specification.

For the inner 172 antenna stations whose positions are given in the specifications and requirements document ALMA-90.02.00.00-001-D-SPE, we are required to build the antennas of that position with some accuracy. For the 44 station positions specified here (173 – 216), we turn the problem around backwards. For these outer stations, we were often concerned with the accuracy of the digital elevation model and the mask image, as well as the accuracy of the GPS measurements. Hence, instead of regarding the positions mentioned in this document as binding, we consider that the stakes in the ground are the primary specification, and accurate surveying of these stake positions should replace the coordinates given in this document at a later date. Contrary to this scheme, there are six pads that have been moved in software and in this document since the stakes have been driven into the ground, and these positions (pads 173 D, 174 D, 175 D, 178 D, 186 D, and 211 D) must be re-staked and surveyed, with the new and accurate survey positions reported in a revision document.

We have used UTM coordinates, rather than array-center based or "Master 0" based coordinates. The Y+ stations can be surveyed onto the construction grid at a later time.

Plots of the pad locations for the 44 Y+ stations and the 16 Conway stations which are included in the full resolution Y+ array are shown in Figures 2-5.

Table 1: Locations of 16 Conway pads that were used in optimizing the Y+ configuration.

Pad	UTM-E [m]	UTM-N [m]	Elevation [m]
115	627996	7453400	5023.6
124	627243	7453289	5026.9
141	627598	7452078	5026.4
155	628942	7451991	5044.4
158	629386	7453037	4968.5
160	626770	7451509	4964.1
161	629374	7454165	4971.6
162	626577	7454180	5021.0
164	628479	7455020	5004.8
165	626100	7452930	4996.5
166	628922	7451126	5075.0
167	627426	7455315	5034.1
168	621145	7451458	4927.2
169	629628	7452186	5024.6
170	628031	7453412	5023.4
172	627233	7453318	5027.3

Table 2: Locations of pads unique to the Y+ configuration.

Pad	UTM-E [m]	UTM-N [m]	Elevation [m]
173D	626812	7456473	5040.3
174D	626680	7456620	5032.2
175D	631413	7452589	4897.8
176D	625182	7450592	4830.8
177	628873	7450253	5087.1
178D	630762	7454610	4903.8
179	625597	7456320	5003.6
180	623980	7455030	4909.9
181	625167	7456304	4992.4
182	624002	7451852	4917.9
183	623904	7451397	4910.8
184	630161	7448769	4837.4
185	631668	7451342	4936.2
186 D	631538	7455367	4870.9
187	632165	7456751	4833.5
188	631830	7449428	4848.0
189	623164	7451766	4900.0
190	631817	7450521	4971.5
191	630158	7448160	4795.8
192	631883	7458453	4838.9
193	631412	7455517	4881.9
194	622619	7455000	4813.8
195	630038	7447028	4755.0

Table 2: Locations of pads unique to the Y+ configuration (cont).

Pad	UTM-E [m]	UTM-N [m]	Elevation [m]
196	631744	7459213	4858.8
197	631969	7456046	4848.2
198	622691	7452275	4960.0
199	633388	7448436	4777.4
200	632138	7460131	4857.5
201	632630	7457447	4792.4
202	621495	7454015	4707.0
203	633409	7448770	4790.7
204	631155	7446205	4796.2
205	632449	7457145	4798.4
206	631994	7457601	4836.0
207	630043	7446432	4720.3
208	634310	7457870	4724.8
209	620680	7453662	4630.9
210	620048	7454159	4558.9
211D	634521	7446779	4798.4
212	632696	7463148	4836.9
213	631494	7460186	4902.8
214	634970	7446006	4717.7
215	635856	7446468	4735.4
216	631931	7464220	4852.8

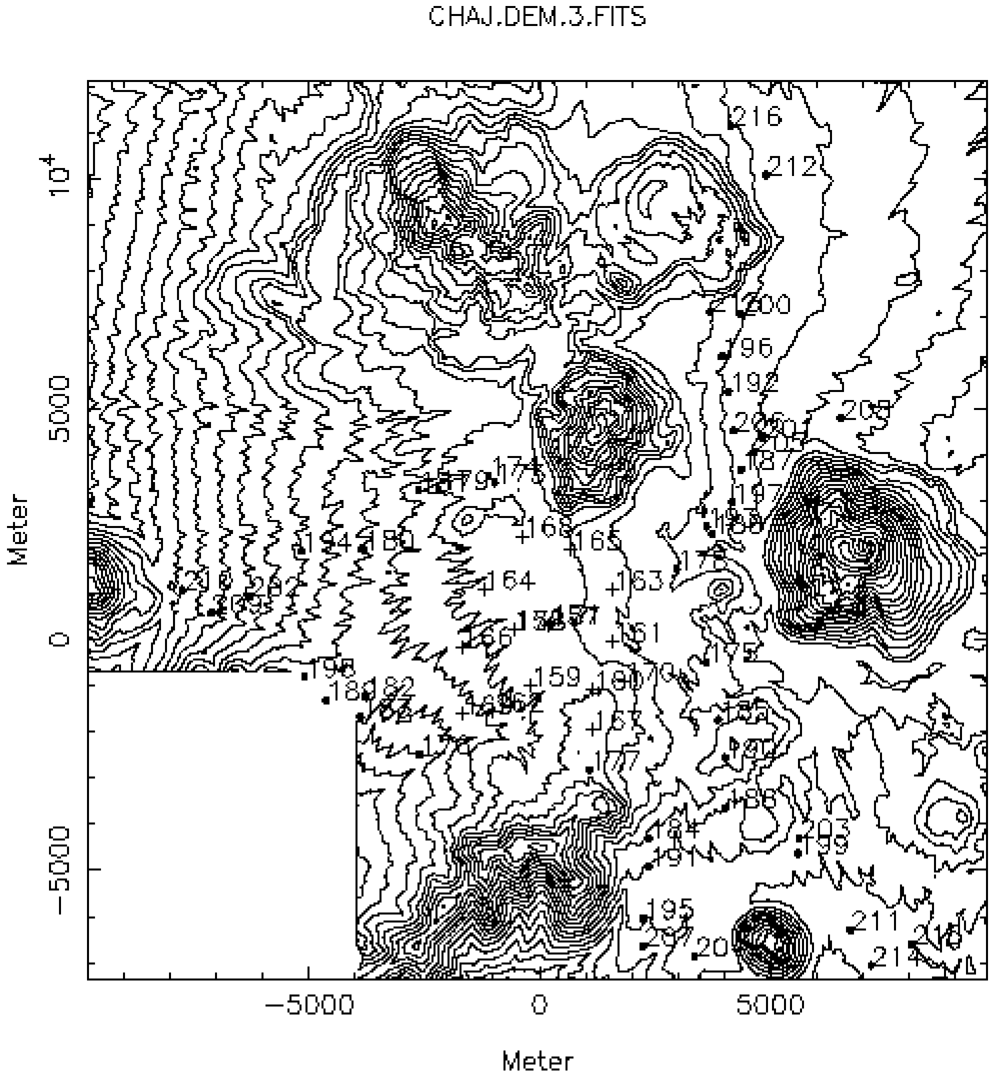

Figure 2: The Chajnantor site with 50 m contours and the Y+ station locations.

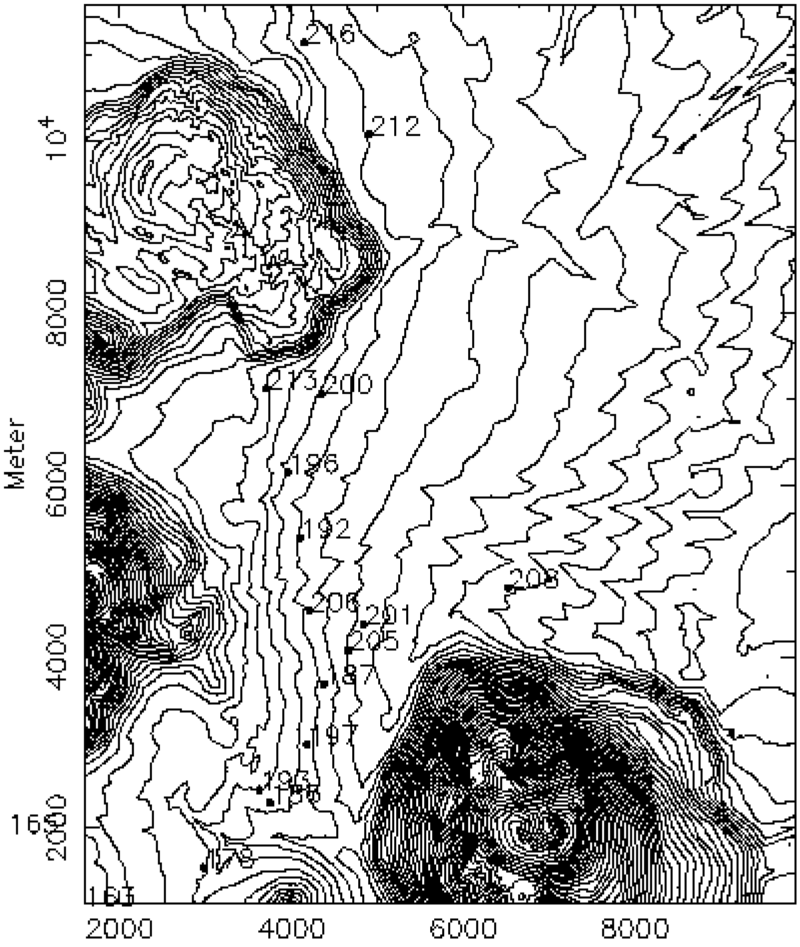

Figure 3: The north arm (Pampa la Bola) of the Y+ array with 20 m contours.

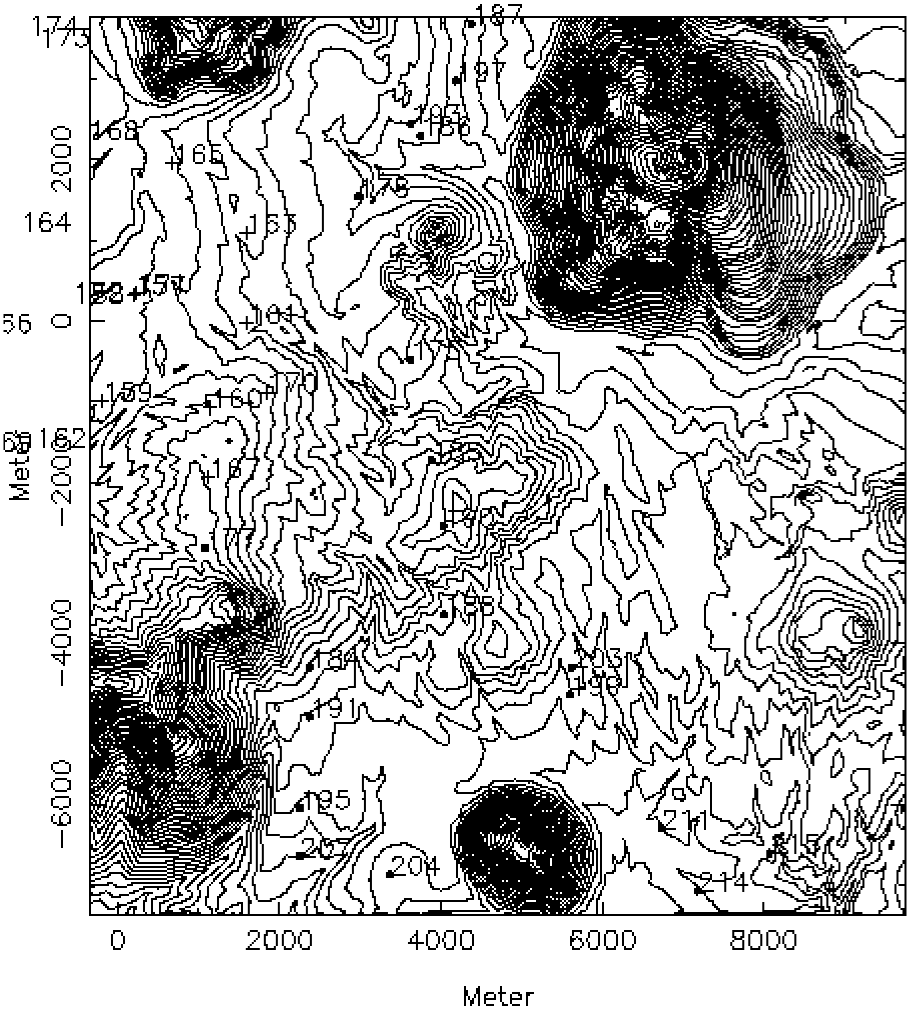

Figure 4: The south arm of the Y+ configuration with 20m contours.

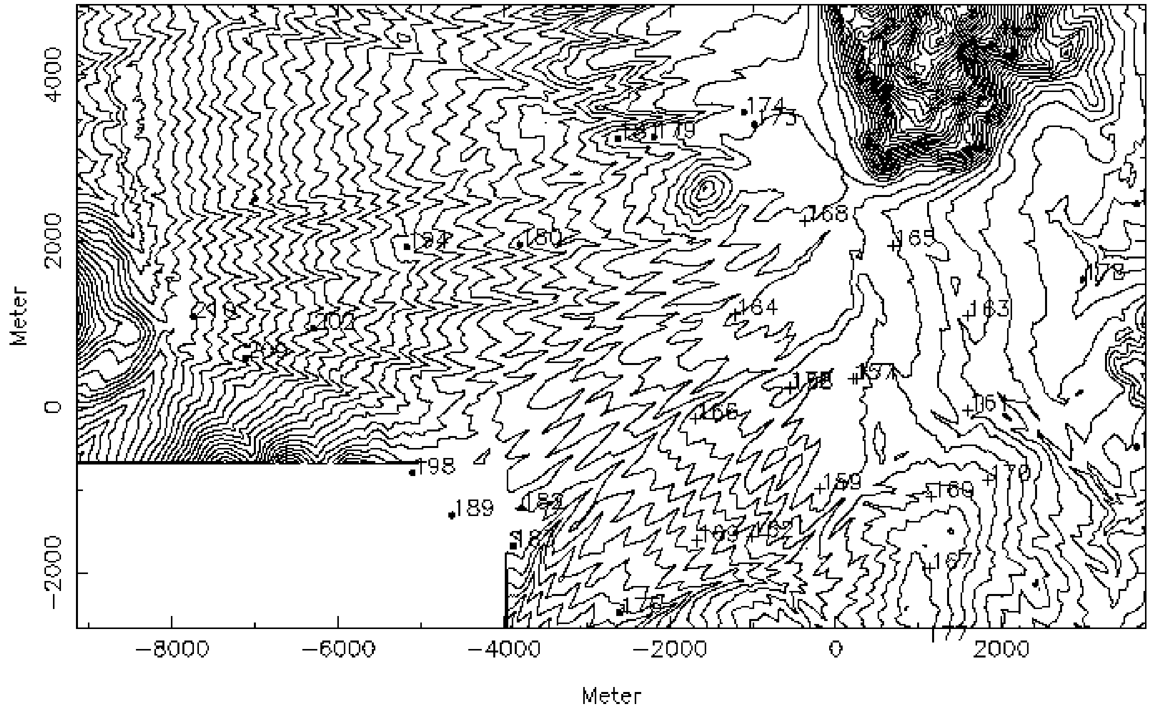

Figure 5: The western arm of the Y+ configuration with 20m contours.

4.1 Positional Tolerances

When we performed our rough survey of the antenna locations, we often placed the stakes some tens of meters away from our initial position estimates to locate the antenna at a site with superior drainage, minimal topographical shadowing, or better access. When it comes time to actually build foundations, some of these foundations may need to be moved again to get better drainage or better (i.e., closer to the surface or more solid) bedrock. These small movements will affect the synthesized beam. We specify that a movement of up to 30 m away from the staked antenna locations (i.e., a 30 m radius) will be permitted. If an antenna foundation must be moved by more than 30 m, there must first be a consultation with a scientist who can assess the effects of the antenna displacement on the beam properties.

4.1.1 Vertical Tolerance

While we have used the elevation from the DEM in the final step of the optimization and we report these elevations, we place **absolutely no specification** on the elevation of any antennas in the Y+ array configuration.

5 Reconfiguration Scheme

We will have two antenna transporters moving antennas at the rate of two per day, so our specification is to move four antennas between incremental Y+ configurations. The Y0 configuration is set by Conway's work, and the 44 new stations in the Y11 configuration have been determined via an optimization with 16 fixed Conway stations. Selecting the four Conway pads to evacuate and the four Y11 pads to populate is an optimization problem that we have addressed by performing an exhaustive search of all reasonable options. The criteria here are 1) we want to maintain a circular beam at $\delta = -48°$,
2) We want the resolution to improve smoothly by 15% in each incremental reconfiguration, and 3) we want to keep the inner side lobes as low as possible.
The resulting set of incremental Y+ configurations is summarized in Table 3.

6 Interfaces to Other Subsystems

The interfaces between the Y+ array and the other array subsystems are mainly conceptual and environmental, as there are few hardware or software interfaces.

6.1 Site and Roads

The Site IPT must design a system of roads that enables the transporter to move antennas to each antenna pad position we have specified here.

The Site IPT made a preliminary design of a road from the OSF to the Chajnantor site that also serves as access to pads 180, 194, 202, 209, and 210. We made an agreement not to move these antenna pad positions so that the road could be nailed down. However, the stated tolerance of 30 m should not be a problem. We should check with the Site IPT for the most recent road coordinates before we move these five pads at all.

6.2 Site and Cabling

The layout of the roads will be highly affected by the transporter's maximum gradient requirements, but the trenches and cables will not have any such requirements, and will likely cover different routes than the roads. As the Y+ pad locations become fixed, the cabling design will ensue.

Table 3: Reconfiguration order for the entire set of Y+ configurations.

Pad	UTM-E	UTM-N	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
113	627385	7453085	1	1	0	0	0	0	0	0	0	0	0	0
114	627968	7452695	1	0	0	0	0	0	0	0	0	0	0	0
115	627996	7453400	1	1	1	1	1	1	1	1	1	1	1	1
116	627401	7452876	1	1	1	1	0	0	0	0	0	0	0	0
117	628223	7452982	1	1	1	0	0	0	0	0	0	0	0	0
118	627819	7453513	1	0	0	0	0	0	0	0	0	0	0	0
119	627648	7452567	1	1	1	1	0	0	0	0	0	0	0	0
120	628202	7453194	1	1	0	0	0	0	0	0	0	0	0	0
121	627513	7453512	1	1	1	1	0	0	0	0	0	0	0	0
122	627920	7452526	1	1	1	1	1	0	0	0	0	0	0	0
123	628147	7453435	1	1	0	0	0	0	0	0	0	0	0	0
124	627242	7453289	1	1	1	1	1	1	1	1	1	1	1	1
125	628269	7452668	1	1	0	0	0	0	0	0	0	0	0	0
126	627910	7453696	1	0	0	0	0	0	0	0	0	0	0	0
127	627192	7452924	1	1	1	0	0	0	0	0	0	0	0	0
128	628407	7453042	1	1	1	0	0	0	0	0	0	0	0	0
129	627522	7453656	1	1	1	1	1	0	0	0	0	0	0	0
130	627368	7452534	1	1	1	1	1	1	1	0	0	0	0	0
131	628237	7453543	1	1	1	1	0	0	0	0	0	0	0	0
132	627173	7453428	1	1	1	1	1	0	0	0	0	0	0	0
133	627796	7452382	1	0	0	0	0	0	0	0	0	0	0	0
134	628053	7453808	1	1	1	1	1	1	0	0	0	0	0	0
135	627005	7453080	1	1	1	1	1	1	1	1	0	0	0	0
136	628307	7452503	1	1	1	0	0	0	0	0	0	0	0	0
137	627607	7454133	1	1	1	1	1	0	0	0	0	0	0	0

Table 3: Reconfiguration order for the entire set of Y+ configurations (cont).

Pad	UTM-E	UTM-N	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
138	627117	7452562	1	1	1	1	1	1	0	0	0	0	0	0
139	628549	7452854	1	1	1	1	1	1	0	0	0	0	0	0
140	627352	7453476	1	1	1	1	1	1	0	0	0	0	0	0
141	627598	7452078	1	1	1	1	1	1	1	1	1	1	1	1
142	628638	7453381	1	1	1	1	1	1	1	1	1	0	0	0
143	626785	7453197	1	1	1	1	1	1	1	0	0	0	0	0
144	628747	7452479	1	1	1	1	1	1	1	1	1	1	0	0
145	628375	7454064	1	1	1	1	1	1	1	1	0	0	0	0
146	626918	7452383	1	1	1	1	1	1	1	0	0	0	0	0
147	628669	7452135	1	1	1	1	1	1	1	1	1	1	1	0
148	627790	7454368	1	1	1	1	1	1	1	1	1	1	0	0
149	627247	7451946	1	1	1	1	1	1	1	0	0	0	0	0
150	628894	7453208	1	1	1	1	1	1	1	1	1	0	0	0
151	627084	7454211	1	1	1	1	1	1	1	1	1	1	1	0
152	628241	7452097	1	1	1	1	1	1	1	1	1	1	0	0
153	628712	7454170	1	1	1	1	1	1	1	1	0	0	0	0
154	626544	7453182	1	1	1	1	1	1	1	1	1	0	0	0
155	628942	7451991	1	1	1	1	1	1	1	1	1	1	1	1
156	628092	7454880	1	1	1	1	1	1	1	1	1	1	1	0
157	626392	7452646	1	1	1	1	1	1	1	1	1	1	0	0
158	629386	7453037	1	1	1	1	1	1	1	1	1	1	1	1
159	627157	7454571	1	1	1	1	1	1	1	1	0	0	0	0
160	626770	7451509	1	1	1	1	1	1	1	1	1	1	1	1
161	629374	7454165	1	1	1	1	1	1	1	1	1	1	1	1
162	626577	7454180	1	1	1	1	1	1	1	1	1	1	1	1

Table 3: Reconfiguration order for the entire set of Y+ configurations (cont).

Pad	UTM-E	UTM-N	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
163	627502	7451786	1	1	1	1	1	1	1	1	1	0	0	0
164	628479	7455020	1	1	1	1	1	1	1	1	1	1	1	1
165	626100	7452930	1	1	1	1	1	1	1	1	1	1	1	1
166	628922	7451126	1	1	1	1	1	1	1	1	1	1	1	1
167	627426	7455315	1	1	1	1	1	1	1	1	1	1	1	1
168	626115	7451458	1	1	1	1	1	1	1	1	1	1	1	1
169	629628	7452186	1	1	1	1	1	1	1	1	1	1	1	1
170	628031	7453412	1	1	1	1	1	1	1	1	1	1	1	1
171	627959	7452660	1	1	1	1	1	1	1	1	1	1	1	0
172	627233	7453318	1	1	1	1	1	1	1	1	1	1	1	1
173D	626812	7456473	0	1	1	1	1	1	1	1	1	1	1	1
174D	626680	7456620	0	1	1	1	1	1	1	1	1	1	1	1
175D	631413	7452589	0	1	1	1	1	1	1	1	1	1	1	1
176	625182	7450592	0	1	1	1	1	1	1	1	1	1	1	1
177	628873	7450253	0	0	1	1	1	1	1	1	1	1	1	1
178D	630762	7454610	0	0	1	1	1	1	1	1	1	1	1	1
179	625597	7456359	0	0	1	1	1	1	1	1	1	1	1	1
180	623980	7455030	0	0	1	1	1	1	1	1	1	1	1	1
181	625167	7456304	0	0	0	1	1	1	1	1	1	1	1	1
182	624002	7451852	0	0	0	1	1	1	1	1	1	1	1	1
183	623904	7451397	0	0	0	1	1	1	1	1	1	1	1	1
184	630161	7448779	0	0	0	1	1	1	1	1	1	1	1	1
185	631668	7451342	0	0	0	0	1	1	1	1	1	1	1	1
186D	631538	7455367	0	0	0	0	1	1	1	1	1	1	1	1
187	632165	7456751	0	0	0	0	1	1	1	1	1	1	1	1
188	631830	7449428	0	0	0	0	1	1	1	1	1	1	1	1

Table 3: Reconfiguration order for the entire set of Y+ configurations (cont).

Pad	UTM-E	UTM-N	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
189	623164	7451766	0	0	0	0	0	1	1	1	1	1	1	1
190	631817	7450521	0	0	0	0	0	1	1	1	1	1	1	1
191	630158	7448160	0	0	0	0	0	1	1	1	1	1	1	1
192	631883	7458453	0	0	0	0	0	1	1	1	1	1	1	1
193	631412	7455517	0	0	0	0	0	0	1	1	1	1	1	1
194	622619	7455000	0	0	0	0	0	0	1	1	1	1	1	1
195	630038	7447028	0	0	0	0	0	0	1	1	1	1	1	1
196	631744	7459213	0	0	0	0	0	0	1	1	1	1	1	1
197	631969	7456046	0	0	0	0	0	0	0	1	1	1	1	1
198	622691	7452275	0	0	0	0	0	0	0	1	1	1	1	1
199	633388	7448436	0	0	0	0	0	0	0	1	1	1	1	1
200	632138	7460131	0	0	0	0	0	0	0	1	1	1	1	1
201	632630	7457447	0	0	0	0	0	0	0	0	1	1	1	1
202	621495	7454015	0	0	0	0	0	0	0	0	1	1	1	1
203	633409	7448770	0	0	0	0	0	0	0	0	1	1	1	1
204	631155	7446205	0	0	0	0	0	0	0	0	1	1	1	1
205	632449	7457145	0	0	0	0	0	0	0	0	0	1	1	1
206	631994	7457601	0	0	0	0	0	0	0	0	0	1	1	1
207	630043	7446432	0	0	0	0	0	0	0	0	0	1	1	1
208	634310	7457870	0	0	0	0	0	0	0	0	0	1	1	1
209	620680	7453662	0	0	0	0	0	0	0	0	0	0	1	1
210	620048	7454159	0	0	0	0	0	0	0	0	0	0	1	1

Table 3: Reconfiguration order for the entire set of Y+ configurations (cont).

Pad	UTM-X	UTM-Y	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
211D	634521	7446779	0	0	0	0	0	0	0	0	0	0	1	1
212	632696	7463148	0	0	0	0	0	0	0	0	0	0	1	1
213	631494	7460186	0	0	0	0	0	0	0	0	0	0	0	1
214	634970	7446006	0	0	0	0	0	0	0	0	0	0	0	1
215	635856	7446468	0	0	0	0	0	0	0	0	0	0	0	1
216	631931	7464220	0	0	0	0	0	0	0	0	0	0	0	1

6.3 Site and the ALMA Concession

It is obvious that no ALMA pad should be located outside the land concession. While this is currently true, antennas 210, 211, and 214 are located close to the concession boundary. If those pads need to be moved, we must ensure that their coordinates are still within the concession region.

6.4 Maximum fiber run for LO

There is great concern over the maximum length the fiber cables must run from the LO reference source (located in the AOS) to the antennas. Drawing straight line segments which avoid the most obvious obstacles like mountains, the cable lengths from the proposed location of the AOS to the most distant pads (216 to the north and 215 to the south) will be no less than 13 km. A full cabling design will obviously result in somewhat larger cable lengths to these extreme pads, but 15 ± 2 km is quite possible as a goal for the maximum fiber run (subject to approval by the Site IPT).

6.5 Antenna Foundations and Depth to Bedrock

A preliminary survey of the soil and rock underlying the specified Y+ antenna locations has been made. Most antenna sites had bedrock between a few tens of centimeters and 2 meters below the soil surface. However, five antenna pad sites on the Pampa la Bola site, 212, 216, 213, 206, and 201, had a depth to bedrock exceeding 2 m. The design of the antenna foundation specifies cement in contact with bedrock, and sites that have very deep bedrock will be very expensive. One rallying cry of the project manager has been “No Expensive Foundations”.

The Site IPT has been cooperating trying to find alternative locations for these five antenna pads, but snowy conditions at the site have delayed this work. Optimization work we have done indicates that just moving these five antennas will probably result in a poor configuration with high inner side lobes. Moving 10 or 12 antennas on the Pampa la Bola arm of the Y+ array will result in a good configuration.

So, we are in limbo at the moment. We have an array configuration that has good astronomical properties, but has five expensive antenna foundations. We do not have enough information to create a new mask that we believe can result in an optimized array configuration that moves basically the entire Pampa la Bola arm of the array.

If the five expensive antenna foundations are found to be unacceptable, we will have to make a revised mask that precludes placing antennas on sites with deep bedrock, and we will make a new configuration and revise this document.

6.6 Operations: Scheduling and Atmospheric Sensing

The antennas in the Y+ configuration will, at times, be subject to vastly different micro-environments. Minute by minute comparisons of phase stability measurements at the NRAO Chajnantor site and the NRO Pampa la Bola site indicate that over this 10 km distance the rms phase can be up to a factor of 10 different (Holdaway et al, 1997). The same situation will hold for most of the antennas in the Y+ configuration. While it may be we will need to find ways to reliably monitor atmospheric conditions above each of the antennas in the Y+ configuration.

6.7 Calibration

At the highest resolutions, the quasars that will be used as calibration sources will begin to be resolved. We will usually be observing these sources at 90 GHz, so the resolution of the Y+ configuration at 90 GHz will be about 45 mas. This will be a marginal problem for most flat spectrum sources, as the steep spectrum jet components will generally disappear this far out from the core, and most calibrators will still have most of their flux in an unresolved component at this resolution and frequency.

However, we will also need to perform dual frequency calibration on a bright quasar, observing at both the fast switching calibrator frequency (i.e., 90 GHz) and at the target frequency, which could be as high as 900 GHz. The resolution will jump from 45 mas to 4.5 mas at the target frequency. There could be some jet components which are unresolved at 45 mas resolution, but which are resolved at 4.5 mas resolution. There are no fundamental problems with this situation, but we need to account for the structure of these objects in the calibration, and perhaps more to the point, it would benefit us to find specific bright calibrators that keep a large fraction of their flux in an unresolved component at the highest frequencies.

7 Future Extensions

7.1 64 Antennas

Our charge was to design a 60 element array configuration, but with the ACA funding likely, ALMA', main array will have 64 antennas performing interferometry. Given the incremental Y+ design, it will not be difficult to specify four more Conway pads to accommodate these extra four antennas, though their addition will probably raise the level of the near-in side lobes and reduce the resolution. We may want to specify one or more additional Y+ pads.

7.2 Depth to Bedrock

In the design of the Y+ configuration presented in this document, there are five antenna locations on Pampa la Bola that have very deep bedrock (>2m). The extreme depth of the bedrock results in a very expensive antenna foundation. Interactions with the Site IPT to identify possible alternative locations for these antennas have been slow because the site is currently covered in snow. Preliminary optimization work indicates that just moving these five antenna locations will probably result in poor inner side lobe levels in the PSF; in order to obtain lower inner side lobe levels, we will need to reposition about 10 antennas on the Pampa la Bola arm of the Y+ configuration.

7.3 Longer Baselines

The design of the Y+ configuration permits expansion to even longer baselines for higher resolution. However, given the current design for the fiber cable signal distribution system, longer baselines are unlikely. There is also an opportunity to move some of the 16 Conway stations to the far out on the Y+ arms. While this would not increase the maximum baseline length (and hence would not break the LO distribution plans), it would increase the average baseline length, and hence the resolution.

7.4 Other Reconfiguration Schemes

Alternative reconfiguration schemes may be chosen which optimize on a different quantity or to other boundary conditions (such as a different number of antenna moves per reconfiguration).

7.5 Other Shared Conway Stations

The sixteen Conway stations which form the inner part of the Y+ configuration were chosen to provide two very short (40 m) baselines, sparse but reasonable coverage on baselines out to 4 km, and low inner side lobes of the PSF in the full resolution Y+ configuration. While the outer 44 antenna locations have been selected subject to the constraint of the positions of those inner 16 antennas, in the future we may find a reason to select a different set of 16

Conway antennas. Such a change would need to be made within the framework of the specified Y+ antenna positions. A new reconfiguration scheme would also need to be provided.

8 References

Butler, Bryan J., “An Antenna Location Mask for Configuration Designs for ALMA”, ALMA Memo 364, 2001.

Conway, John, “Self-Similar Spiral Geometries for the LSA/MMA”, ALMA Memo 216, 1998.

Conway, John, “A Comparison of Zoom Arrays with Circular and Spiral Symmetry”, ALMA Memo 260, 1999.

Conway, John, “First Simulations of Imaging Performance of a Spiral Zoom Array: Comparisons with a Single Ring Array”, ALMA Memo 291, 2000.

Conway, John, “A Possible Layout for a Spiral Zoom Array Incorporating Terrain Constraints”, ALMA Memo 292, 2000.

Conway, John, “A Preliminary ALMA Zoom Array Design for the Chajnantor Site”, ALMA Memo 348, 2001.

Conway, John, “Antenna Configurations—Specifications and Requirements”, ALMA-90.02.00.00-001-F-SPE, 2003.

Cornwell, “Crystalline Antenna Arrays”, ALMA Memo 38, 1986.

Foster, S.M. “The Optimal Elongation of the MMA A Array”, ALMA Memo 119, 1994.

Heddle, Steven, unpublished imaging simulation results, 2001.

Hjellming, R.M., “Outrigger Stations for the MMA”, ALMA Memo 140, 1995.

Holdaway, M.A., “What Fourier Plane Coverage is Right for the MMA?”, ALMA Memo 156, 1996a.

Holdaway, M.A., “Fitting a 12 km configuration on the Chajnantor Site”, ALMA Memo 153, 1996b.

Holdaway, M.A., et al, “Digital Elevation Models for the Chajnantor Site”, ALMA Memo 160, 1996c.

Holdaway, M.A., Matsushita, Satoki, and Saito. M., “Preliminary Phase Stability Comparison of the Chajnantor and Pampa la Bola Sites”, ALMA Memo 176, 1997.

Keto, E., “The Shapes of Cross-Correlation Interferometers”, ApJ 475, 843-852, 1997.

Kogan, L., “Optimization of an Array Configuration Minimizing Side Lobes”, ALMA Memo 171, 1997.

Kogan, “A, B, C, and D configurations in the shape of concentric circles with fixed pads at the common circumferences”, ALMA Memo 226, 1998.

Kogan, “The Imaging Characteristics of an Array with Minimum Side Lobes”, ALMA Memo 247, 1999.

Kogan, L., “Fitting of the Largest Configuration (10 km) into the terrain at the Chajnantor Site”, ALMA Memo 296, 2000.

Otarola, Angel, and Holdaway, M.A., “The Y+ Long-Baseline Configuration To Achieve High Resolution With ALMA”, ALMA Memo 419, 2002.

Radford, S. The Chajnantor Site Studies web page: http://www.tuc.nrao.edu/mma/sites/sites.html

Yun, M., and Kogan, L., “Strawperson Donut/Doubling-Ring Configurations”, ALMA Memo 320, 2000.