Comments on Improvements to the Y+ Configuration Set

Excellent imaging is a key driver for ALMA specifications and requirements. A key driver for imaging quality is the configuration set.

The second of the scientific goals defined for ALMA in the Bilateral Agreement requires excellent imaging at highest resolutions, as it seeks to image few-AU structures at distances of ~150 pc: *The ability to image the gas kinematics in protostars and protoplanetary disks around young Sun-like stars at a distance of 150 pc (roughly the distance of the star forming clouds in Ophiuchus or Corona Australis), enabling one to study their physical, chemical and magnetic field structures and to detect the tidal gaps created by planets undergoing formation in the disks.*

The third of the scientific goals defined for ALMA in the Bilateral Agreement is concerned with imaging quality; ALMA shall have: *The ability to provide precise images at an angular resolution of 0."1. Here the term precise image means representing within the noise level the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This requirement applies to all sources visible to ALMA that transit at an elevation greater than 20 degrees.* A driver for achievement of this goal is the design of the configurations which produce angular resolutions of 0".1, which is achieved for baselines exceeding 1km at 650 GHz and for the most extended configurations for 35 GHz.

During rebaselining, the number of antennas in ALMA was decreased from 64 to 50. Both internal (ASAC) and external (Blandford Committee) recognized that this would decrease imaging quality. New configurations, accommodating either 64 or 50 antennas, were proposed for the inner (<4km) ALMA. For the extended configurations, only 50 antenna configurations have been designed. It behooves us to ensure that they can provide the best imaging possible to meet the science goals.

A design for the outer configurations of ALMA, tentatively numbered 21-29, was presented in ALMA-90.02.00.00-008-A-DSN. The design approach was to optimize the most extended configuration, then to fill in the intermediate configurations down to the largest of the inner configurations as specified in ALMA-90.02.00.00-006-A-SPE. This resulted in a jump in sidelobe levels from the outermost of the ALMA-90.02.00.00-006-A-SPE arrays ('Configuration 20') to the innermost of the ALMA-90.02.00.00-008-A-DSN arrays ('Configuration 21'). In a Nov 2007 memo, Hills noted that the sidelobes, found by subtracting a best fitting Gaussian and then dividing the map into three regions – near-in for less than 1.5 beams from the centre, inner for 1.5 to 10 beams and outer for beyond 10 beams, were disturbingly large for intermediate extended configurations. His results are shown in Figure 1.

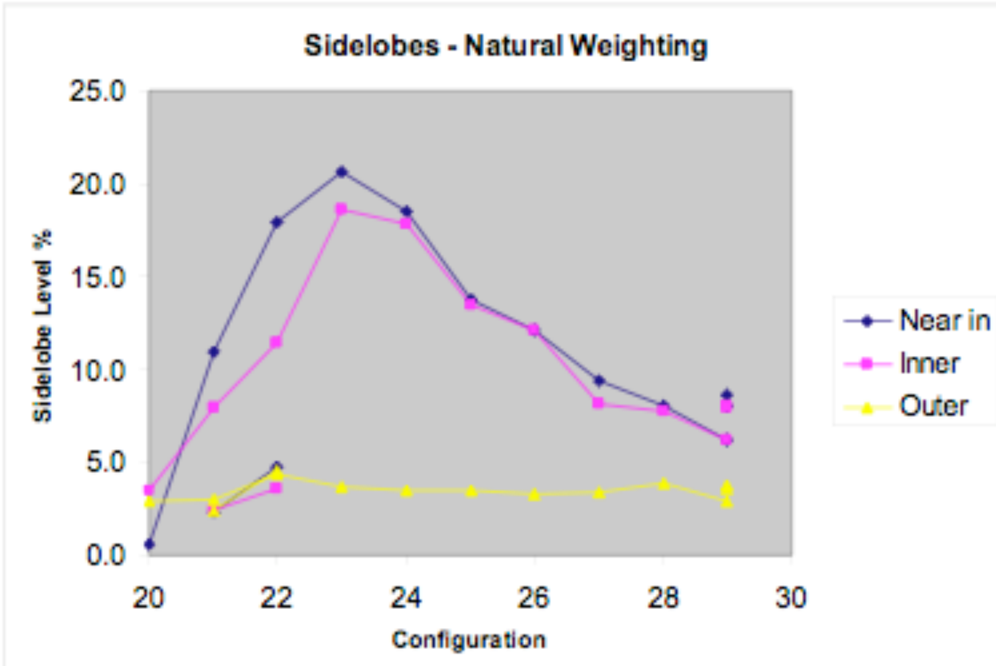

Figure 1 Naturally weighted beam sidelobe levels from configuration 20 through configuration 29, natural weighting.

It was thought that these should be improved, an opinion shared by the ASAC in its 2008 April report to the ALMA Board. In the Response to the ASAC Report on 11 May 2008, Hills responded: 'The re-examination of the intermediate-resolution configurations has produced a scheme with substantially better sidelobe levels. This does however require the construction of a number of additional pads. The work of quantifying the improvement to the final maps so that we can provide a meaningful estimate of the benefits to set against the benefits of this change is continuing.' The present document is an effort to define the costs and benefits of the improvement proposed in a draft document '**Investigating Improvements to the Y+ Configuration Se**t' by M. Holdaway (see *http://tinyurl.com/5c3jc3*).

In the improvements document, the philosophy was to optimize an intermediate array first, then to optimize a largest array and a smaller array in such a way as to more harmoniously follow from Configuration 20 of ALMA-90.02.00.00-006-A-SPE. This process resulted in the definition of sixteen antenna pad locations that are not included in ALMA-90.02.00.00-008-A-DSN. Six pad positions defined in that document are not used in the new design. In this document we will consider the scientific benefits of the new design along with a preliminary discussion of the costs involved in its construction.

The sixteen new pads are listed in the following table, numbered according to an arbitrary scheme. In the second table are listed the six pads, numbered according to the 2007 July 17th numbering scheme proposed by T. Beasley, which are not included in any of the new extended configurations. The net change in number of pads is ten. In the rightmost column is a reference number corresponding to those given in a table in Holdaway's recent study.

Holdaway PAD NAMING SCHEME - April 1st 2008		New road
All positions in PSAD-56. zone K19 UTM coordinates		Min length

Pad Name	**UTM-X**	**UTM-Y**		***"padpos" tab ID***	
MA16	630365.10	7448430.80	4805.1	*Y-C5 24 50*	0
MA15	631778.70	7458902.70	4843.9	*Y-B5 47*	0
MA14	630645.70	7454376.10	4904.2	*Y-B5 46*	1
MA13	624082.00	7455048.00	4916.4	*Y-B5 43*	0
MA12	630780.00	7453750.00	4917.7	*Y-B5 42*	2
MA11	630358.70	7454983.40	4910.4	*Y-B5 41*	See MA14
MA10	632280.00	7447663.00	4761.1	*Y-B5 40*	0
MA9	629734.60	7453889.70	4948.7	*Y-A14 50*	1
MA8	630940.00	7453180.00	4931	*Y-A14 49; B5 44*	0.6
MA7	628707.20	7454952.20	4988.3	*Y-A14 48*	0.7
MA6	628092.60	7455140.10	5021.8	*Y-A14 47*	0
MA5	629623.70	7452088.10	5028.7	*Y-A14 46*	0.5
MA4	627583.80	7451083.30	5002.9	*Y-A14 45*	0.4
MA3	629707.60	7452399.00	5006.4	*Y-A14 44*	0.3
MA2	627050.00	7456280.00	5048	*Y-A14 41*	1.2
MA1	630240.00	7454330.00	4928.1	*Y-A14 40; B5 45*	0

FINAL CONFIGURATION PAD NAMING SCHEME - July 17th 2007					
All positions in PSAD-56. zone K19 UTM coordinates					
Pads not needed in Holdaway Scheme					
Pad Name	**UTM-X**	**UTM-Y**		***"padpos" tab ID***	
W209	626159.90	7457081.80		*Y41*	26159.90
W206	624771.00	7455153.00		*Y44*	24771.00
S308	633155.00	7447659.00			
P408	631980.10	7456899.00		*Y22*	31980.10
P405	631631.20	7455746.80		*Y19*	31631.20
P402	631521.00	7455321.00		*Y18*	31521.00

In imaging tests with these arrays, the sidelobe levels shown in Fig 1 are brought beneath 10% in all configurations, at all distances from the center of the primary beam. The resolution of the newly defined arrays is comparable to those previously obtained, as is beam circularity.

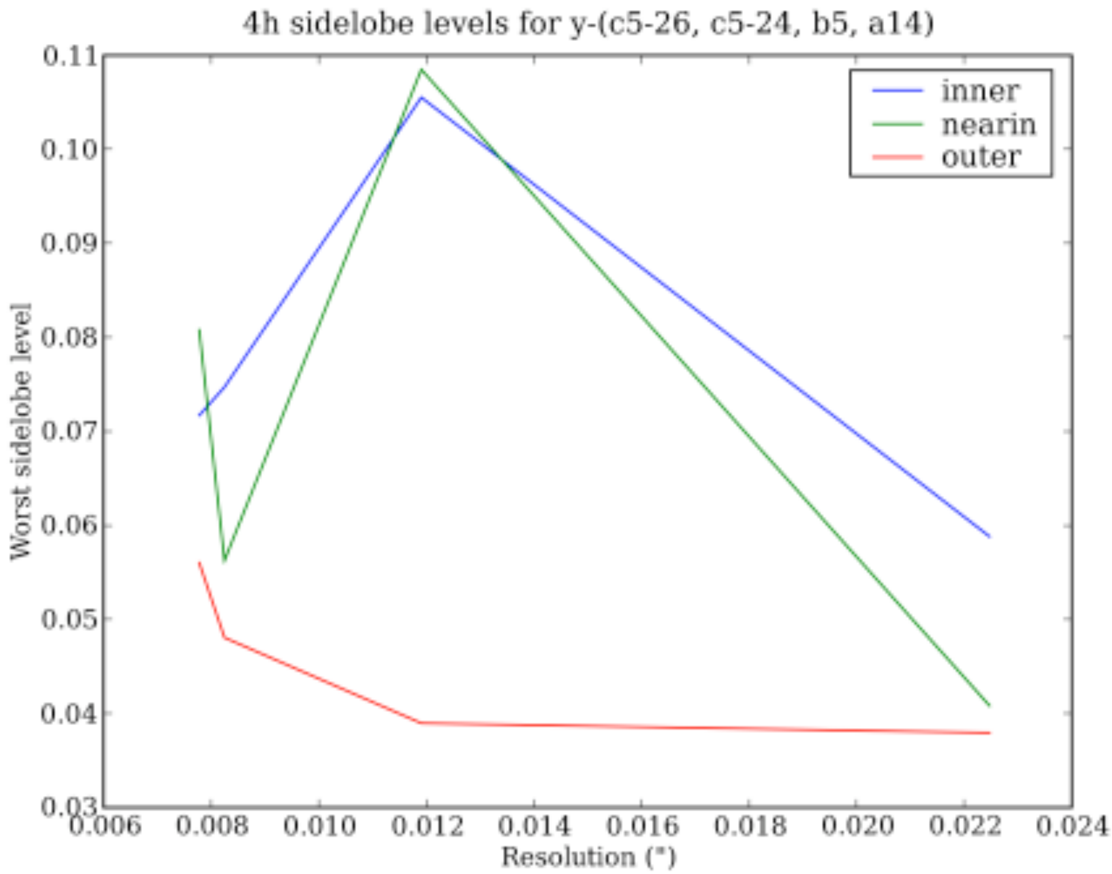

Figure 2 Sidelobe levels in the redesigned outer configurations fall below 10%, up to half those found in the configurations proposed in ALMA-90.02.00.00-008-A-DSN.

Imaging quality is not necessarily directly controlled by sidelobe levels. Two independent imaging studies were done, by Reid and by Knee, using different sets of images. In those studies, the imaging differences between the configurations proposed in ALMA-90.02.00.00-008-A-DSN and the newly proposed configurations were slight. In a 2008 June 1 report, Reid presented the evidence for improved imaging with the new configurations. An example is shown in Figure 3.

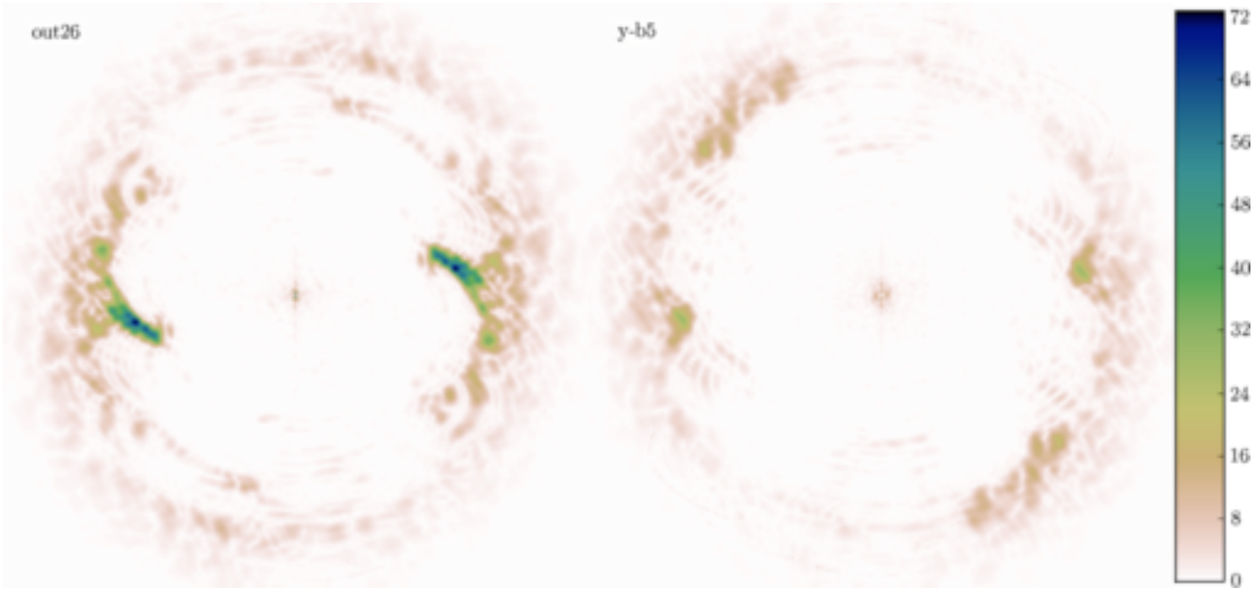

Figure 3 ***uv*** **error amplitudes after cleaning a simulated noiseless 4 hour observation of an M31 H II region using the largest ALMA arrays. Left: previous array configuration 26; R: optimized array with similar configuration. Note the decreased error amplitudes in the redesigned configuration.**

From this brief review, we note two advantages of the redesigned configurations:

1) Much lower inner sidelobe levels
2) Modestly lower *uv* error amplitudes for at least some imaging examples.

Disadvantages include:

I. Ten additional antenna pads, increasing the total number from 192 to 202, or 5%.
II. Changes in a network of roads and fiber whose design has already advanced considerably.

The cost of additional pads is fairly easily determined; the cost of changing of the road design is less easy to calculate, especially since I was unable to locate machine-readable files of road locations. In the last column of the first table, I put my WAG of the minimum amount of new road required to reach an antenna pad. If the pad lies near an existing road and a pad not needed in the new scheme (second table) or if it is enroute to a more distant pad, '0' is entered.

Given the importance of excellent imaging, required to meet two of the three highest level science goals of ALMA, I believe the newer design should be adopted.

Appendix
Detailed discussion of pad locations (incomplete)

Examine in detail the relation of the proposed new pads to existing pads.
Pad MA-16 lies on the Western arm between pad locations W208 and W210 (numbers correspond to those proposed 2007 July 17 by T. Beasley). As pad W209 is not required, the only change is to reposition the access road by a short distance in relatively benign terrain.

Pad MA-15 is used in the intermediate array and is located in the far northeast, along the road connecting P410 and P411. Along this arm, neither P402, P405 nor P408 are needed; I propose that the infrastructure associated with P408 be reassigned to MA-15.
Pad MA-14 lies 1km SE of P401 just across the pipeline crossing. MA-11 lies along the line connecting these two pads. This terrain needs investigation; a new ~1km road could be required to service MA-14 and MA-11.

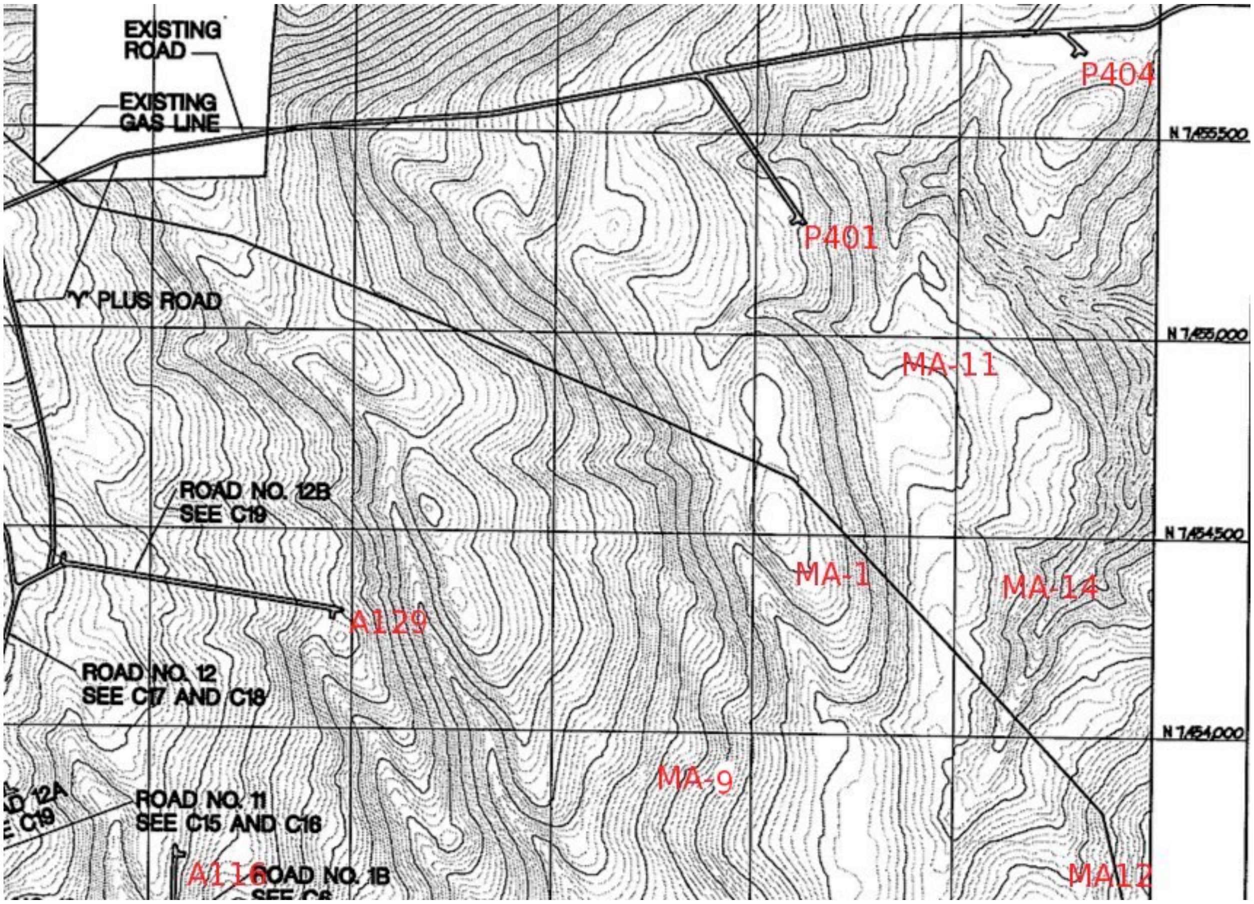

Figure 4 Approximate locations of MA-14 and MA11 are shown. It might be possible to construct an extension of the road reaching P401 to these pads.

Pad MA-13 lies ~0.6km from W206, an unused pad, along the Western arm; we propose that the infrastructure associated with W206 be reassigned to MA-13.
Pad MA-12 lies in a cluster of three new pads SSE of pipeline crossing B. This terrain needs investigation; this region is not reached by a currently planned road. MA-12 lies 1.9 km SE of pad A129 and about the same distance E of A121. See the Figure.

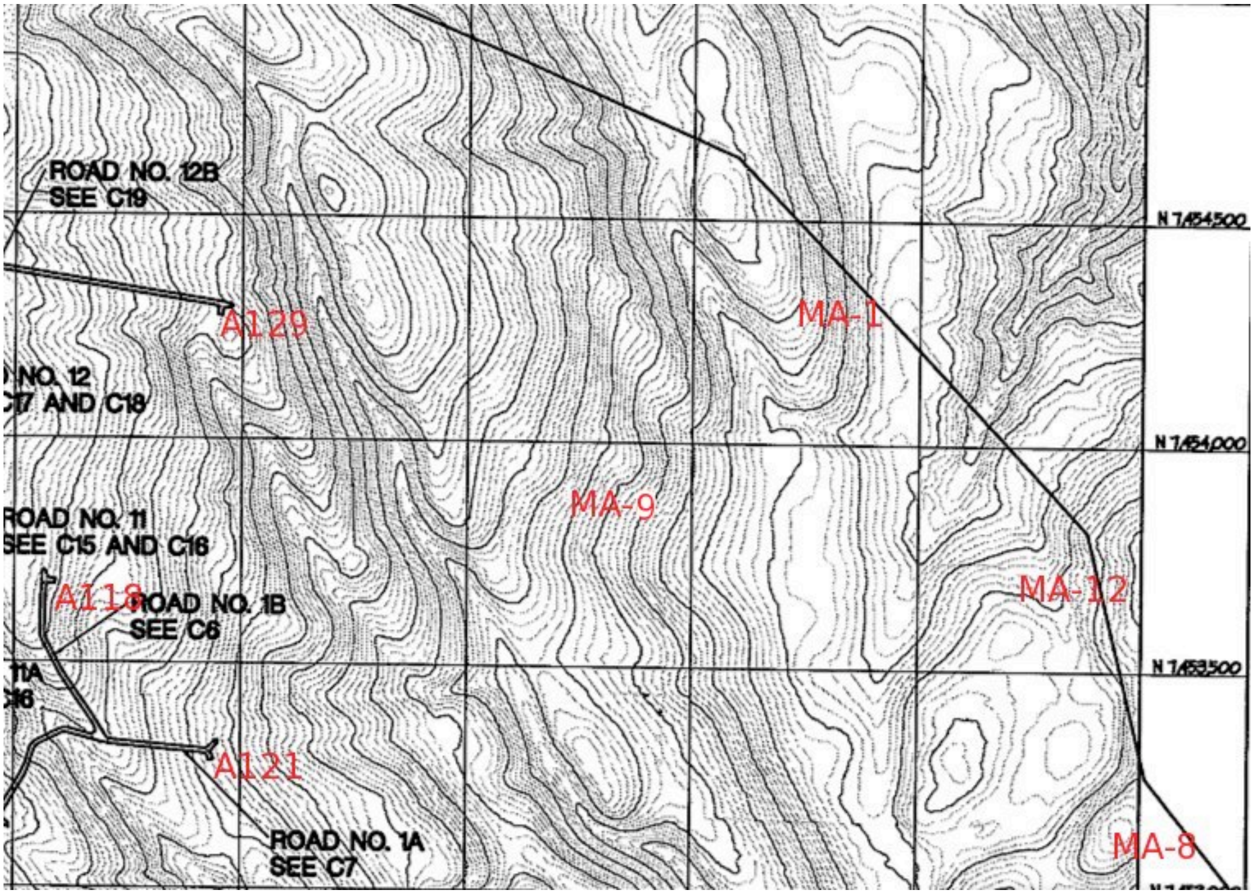

Figure 5 Four new pads lie between the A121-A129 region and the pipeline in a region where no roads are planned. Approximate locations only are shown. Three locations lie near the pipeline access road.

Pad MA-11 was discussed above in conjunction with Pad MA-14; it lies about 0.6km SE of P401.
Pad MA-10 lies on the S arm, between S303 and S308. As S308 would not be built, it would trade the infrastructure of that pad. The terrain should be examined.
Pad MA-09 lies ESE of A129 and ENE of A121 in between the cluster of pads discussed in MA-12 above and the main array; it could lie along a road postulated to follow the pipeline S on its W side which would connect MA-9, MA-12, MA-8 and MA-1.
Pad MA-8 lies 0.6 km SSE of Pad MA-12 and would need to be connected to a road reaching MA-12 from MA-1.
Pad MA-7 lies 0.7 km NW of A129 and 0.7km NE of A124 on the S side of the pipeline.
Pad MA-6 lies 0.6 km WNW of MA-7, also just S of the pipeline in the vicinity of Crossing A.
Pad MA-5 lies 0.5 km ENE of A131, just WSW of Pad MA-3.
Pad MA-4 lies 0.4 km S of A128. Road 1 might be extended.

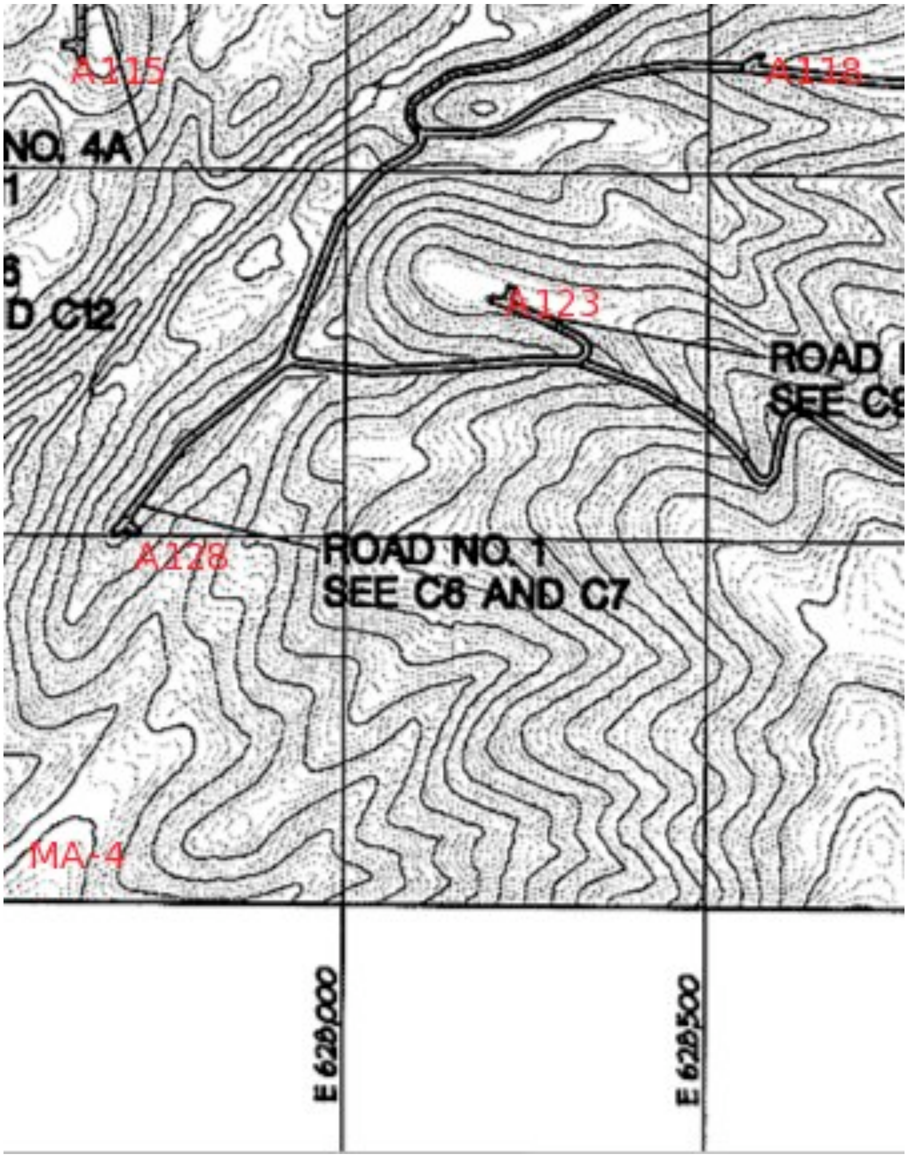

Figure 6 MA-4 in relation to A128 and roads.

Pad MA-3 lies 0.3km ENE of pad MA-5.
Pad MA-2 lies 1.2km NNW of pad A132, near the APEX antenna.
Pad MA-1 lies 0.8km NW of MA-12, the origination of the road leading to MA-12 and MA-8 perhaps.

I estimate that, at a minimum, implementation of the new Holdaway configurations might require ~7.7 km of additional roads. This is in addition to ten new sets of pad infrastructure.

Al Wootten 2008 Aug 19