Requirements for an Artificial Source on the ALMA Site

It is proposed that we place a small low-powered millimeter-wave source on one of the mountain peaks overlooking the ALMA operations site. This will serve several purposes:

1) to provide a signal for interferometric holography measurements of the antenna surfaces
2) to provide a source of known and preferably changeable polarization so we can measure the polarization properties of the system and of the antennas
3) to provide a source with high signal-to-noise ratio to help measure things like coherence, phase stability, switching times and perhaps stability and sideband ratio.

Fortunately these different purposes produce a generally compatible set of requirements. The intention of this note is to derive the main requirements and to outline possible designs.

One important point to note is that for all the tests above it is planned that the observations will be made interferometrically. This places a requirement on the software in that it must operate correctly with two non-standard conditions:

a) the source does not move, so the fringe rate is zero and the delay does not change

b) the pointing position is different for each antenna and so is the delay value. (We will be able to calculate these values from the known positions of the antennas and the source.)

I don’t know whether these capabilities are already in place but if not I hope that it will be relatively easy to incorporate them.

Location

The obvious place to put the source is on Chajnantor peak. There will be a clear view from almost all of the pads in inner array and the elevation angle is reasonable (of order 5 degrees) from them. APEX is already operating a source up there for holography. Here is a typical view with the central cluster in the foreground.

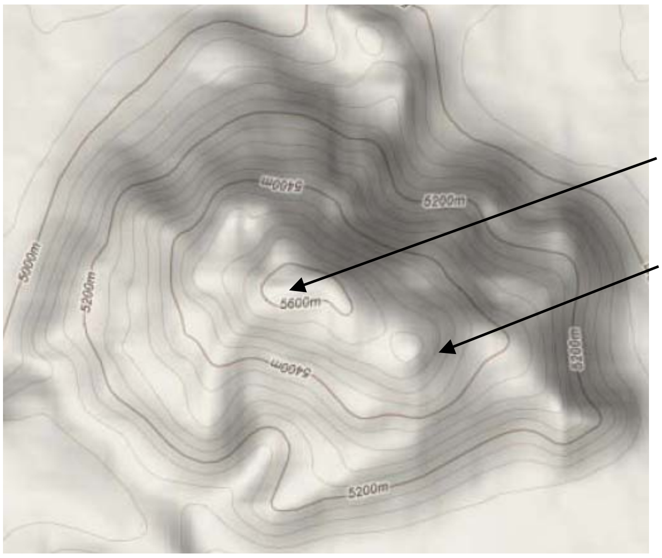
Recall that there is a Japanese IR telescope (mini-TAO) on the peak at 5640m and that they hope to install a larger telescope there soon. This is also the chosen site for CCAT. There is a (steep) road up from the Pampa la Bola side – behind the ridge on the right in this picture. This picture also serves as a reminder that the conditions on such a site will be harsh.

The source will however not be on the peak, which is at the northern end of a nearly 1km long ridge forming the crest of the mountain. Instead it would be a little below the southern end of this ridge where the ground drops away quite sharply towards the central part of the ALMA site. This would:

a) make sure that the source is well away from the TAO and CCAT sites and that there is no line of site to them. (As discussed below, the power levels will in any case be very low, but this makes it certain that there could be no interference issues.)

b) ensure that there is a direct line of site to all of the antennas in the inner array, and

c) arrange that, as seen from those locations, the source is not on the sky-line. If you put the source on the sky line you get a large change in the background signal as you scan the antenna around, which is highly undesirable for many of the these measurements. (This was pointed out to me by David Rabanus.)



Here is a contour map of the mountain.

This way is North

Chajnantor Peak

Possible site

Approx 1km

It should be reasonably easy to get access along the ridge, at least as far as the point where the ground starts to drop away.

Here is the Google Earth view from the West. ALMA array center is to the right.

This location is at about 5500 m altitude and it is about 3.5 km north of the technical building or a little more than 4km from the central cluster. The elevation angle would be about 6 degrees from there. It is important to note that there will be significant atmospheric absorption in the higher frequency bands along this sloping path and that the path fluctuations will probably be a good deal larger than when we are observing astronomical sources, especially in the daytime. WVR corrections will not be possible because of the background.

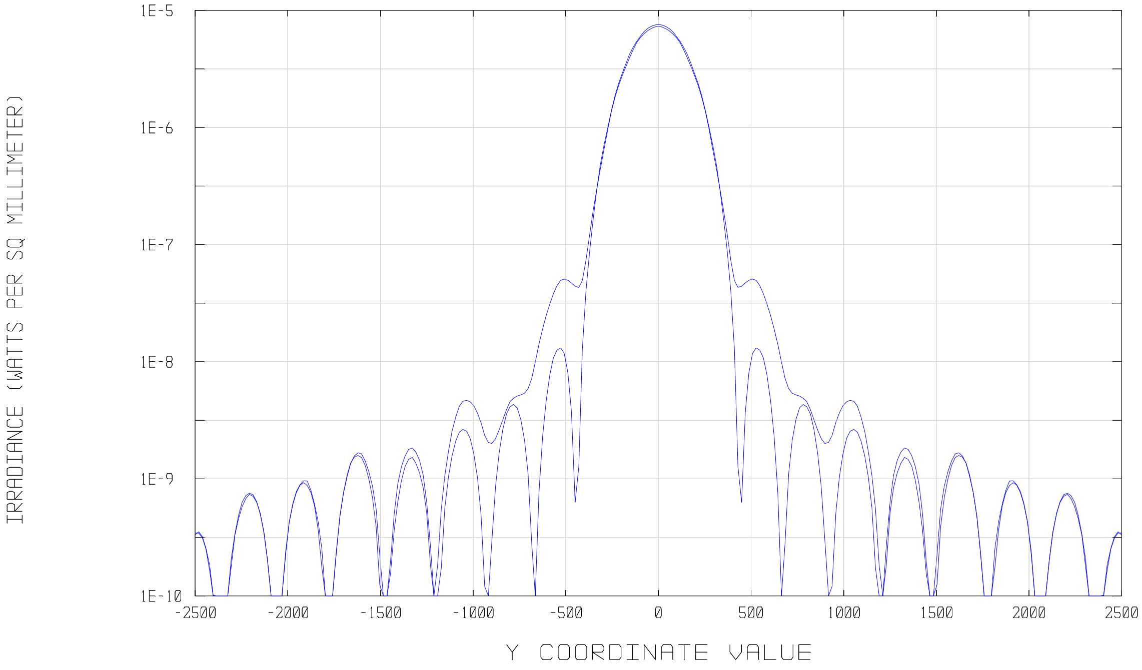
Obviously the final location will need to be decided after more detailed investigations of access and lines of site. The issues of if and how to provide power and communications will of course be key ones as well.

Distance to Source

One important point to check is that source would be sufficiently distant for our purposes. Since we are going to use the astronomical receivers we cannot do what is done for the tower holography where the feed is deliberately displaced outwards (by about 90mm, I believe) to be closer to the actual focus. Instead we have only the nominal 10mm of axial motion of the subreflector. With luck we should get a little more because we will be operating at one end of the range of gravitational corrections.

The paraxial focus position is f ', where 1/f ' = 1/f – 1/D, so the defocus f ' – f = +5.8mm for a focal length f = 4.8 m and a source distance D = 4km. Because of main reflector has such a fast f-ratio (f/0.4) there are however higher-order terms and the focus that minimizes the wavefront error is actually at about +7.8mm. The rms half-path residuals are then about 50 microns, which means that we will still get a pretty good beam pattern at one millimeter wavelength.

In fact for the holography measurements we have no problem correcting for these near-field effects. This is already included in the reduction software. When we are doing the measurements of the polarization primary beam, however, it will be much more convenient if we are actually measuring a good replica of the far-field pattern. Here is a simulation for 345 GHz of the case of D = 4km and refocus of +7mm, which seems to give the best result.



The lower curve is the far field pattern (obviously this assumes a perfect dish) and the upper curve is the result for a distance of 4km but with refocusing. This is power on a log scale. Obviously the inner sidelobes have come up a bit, but this still looks acceptable to me.

It would be worth doing some further checks, including polarization effects, in particular to find out whether it will be possible to do these measurements when the antennas are closer to the base of the mountain. My impression is that 3km will still be OK but below that we may have problems and in any case we are likely to reach the limit of axial focus adjustment on the subreflector. Since we will be measuring polarized phase and amplitude rather than just power we can in theory reconstruct the aperture fields and thence the far-field patterns. This would however be a complication in the data analysis.

A final point to note is that the physical width of the antenna beam will be roughly λD/d where d is the 12m (or 7m) dish diameter. For D = 4km this is about 300mm at 345GHz (as seen in the plot above). This means that from the point of view of the single dish beams, any reasonable size of source – e.g. a millimeter-wave horn – will be a point source. For the interferometer fringe, however, this is not so. In an extreme case we might be using antennas say two kilometers or more apart, in which case an object 2λ across would be completely resolved by the fringes. This is of course just another way of saying that we will need to use a small horn to illuminate the entire plateau. More on that later, but the point to note here is that we could easily get significant phase effects, e.g. phase changes as a function of frequency, if we try to make measurements using pairs of antennas that are far apart. Fortunately this will hardly ever be necessary for any of the tests described above.

The conclusion here is that the location on Chajnantor appears to be a good compromise between being too close, which places the source too much into the near field, and too far, which puts more atmosphere in the path.

Frequency Coverage

The holography measurements will be made with the astronomical receivers – the technique resembles “astro-holography” more closely than “tower holography”. In principle we can do this in any of the ALMA bands, but it would be good to make sure that we include the standard 86 GHz. This sets the lower limit of frequency coverage required. In general it will be better to use higher frequencies for the holography since this reduces the effects of diffraction at the subreflector and the smearing of the shadows of the legs. The maps needed are also smaller in angular extent so can perhaps be done slightly faster. On the other hand, at higher frequencies the pointing accuracy required goes up and atmospheric fluctuations become more important so it is unlikely that we would go above 300 GHz for this.

For the polarization, Band 7 is regarded as the most critical but clearly we would like to be able to make measurements in all bands. Bands 8 to 10 will be getting difficult because of atmospheric absorption, but might be possible under very good conditions.

Most of the other tests mentioned would probably be satisfied by being able to measure at one or two frequencies per band. Measurements at an arbitrary frequency or being able to scan a band more or less continuously would be nice but not essential.

So the minimum requirement is to cover roughly 85GHz to 350GHz with a spacing of say 30GHz, but if it is easy to provide more frequency coverage then we should do so and it would certainly be good to extend the polarization measurements to the higher bands.

It is important to note that there is no tight requirement on frequency stability or accuracy. The reason for this is that we will be making all the measurements (at least everything that I can think of) with the full ALMA system, which is of course designed to work with incoherent sources – e.g. the delay is set so that there is no first-order phase change due to any frequency drift in the source. One might like to be able to place the line nicely in the middle of one of the frequency channels of the correlator, but even that isn’t essential. If we use TDM mode this means that an accuracy / stability of about 1MHz would be fine. If we are using the ACA correlator or if we want to use higher spectral resolution to get better signal-to-noise then better frequency control would be needed, but it is hard to think of a reason to try for better than 1kHz. So the lets set the requirement at 1MHz, with 1kHz as "nice to have".

Darrel Emerson has pointed out that it may be even simpler to use a completely broad-band noise source. A possible way of doing this is to drive a photo-mixer with incoherent light – e.g. a high-power LED – and he said that some experiments on this have already been done. If enough RF power can be generated then this appears to be (almost[1]) the simplest possible way of doing what need. I'll come back to this in the next section.

Power Required

The most demanding requirement is probably the holography, since we will be measuring the far out sidelobe patterns and we would like to do so relatively quickly. Even so we know that we are talking about very weak signals since we can already do this with astronomical sources with really rather good sensitivity and resolution. We have for example been using Saturn which has a flux of about 200 Jy at 86GHz. This means that the power density when we are using in a 2GHz bandwidth and one polarization is 2×10^{-15} W/m^2. To get the same power from a source at distance D requires $4\pi D^2/G$ times this, where G is the gain of the horn that we use to transmit. With G = 10dB which is about the lowest feasible gain – e.g. an open-ended waveguide – this means we need 40nW. (Yes, nanowatts!) So long as we have a narrow-band source and we can use the resolution of the correlator, we could actually manage with even less than this. The signal-to-noise <u>improves</u> as the square root of bandwidth in this case, so we will gain a factor of 16 here if we are using the 256-channel TDM mode. One point that goes against us however is the fact that we will be looking at the mountain, so the system temperature will be perhaps 350K at band 3 and rather more at the highest frequencies.

From the above it is clear that we do not need a lot of power. In fact anything above a few microwatts would become a problem in starting to cause saturation and the like. Doing the calculation rather more explicitly, let's take a total power radiated of P = 100nW or -40dBm. Then the power received is $P\,G\,A_e / 4\,\pi\,D^2$ where A_e is the effective aperture, $A_e = \eta_A\,\pi\,d^2 / 4$. With d = 12m, $\eta_A = 0.7$, $A_e = 79\text{m}^2$ and taking G = 10 and D = 4km as before, we have a total link gain of 4×10^{-6} or -54dB. So the power received when we are pointed at the source and refocused is 4×10^{-13} W or -94dBm. This is a factor of 10 above the noise in a 7MHz wide spectral channel. This may not seem much, but we are of course using coherent integrations rather than just doing an instantaneous measurement. One has to be a little careful here because we have a c.w. signal and random noise rather than the usual coherent and incoherent noise, but I think that in the cases of interest – e.g. one antenna pointed at the source and other being scanned so that it is measuring the weak signals out in the sidelobes – we still gain the usual factor of sqrt(bandwidth×integration time), which is a further factor of ~500 for an integration time of 48msec. This already gives plenty of signal-to-noise for all the applications suggested above. For many of them we could in fact use much longer integration times than the 48 msec assumed here.

The conclusion is that 0.1 microwatts will be plenty of power for the CW case. In general one could probably make do with less at the lower frequencies, but ideally one would have at least this level at the higher frequencies, where the noise is higher and the antenna efficiency is lower. Obviously this is good because it means that either harmonic mixers or photo-mixers should be able to provide sufficient power.

---

[1] In theory some other form of electronic device that generates broad-band RF directly – instead of making light and then down-converting it – would be even better. For lower frequencies this is of course just a noise diode. One would have thought that it ought to be possible to generate broad-band mm-wave signals directly but the fact that nothing of this type is available already obviously means that it is hard and there are presumably good physical reasons for this.

Turning to the case of the broad-band source proposed by Darrel, one can see from the above that one needs a power density of perhaps 10^{-18} W/Hz in the source to give the same signal-to-noise ratio that we have on Saturn at 86GHz (allowing for the higher background). Obviously we should aim for more than this, by say a factor of 10 (but note that this means that you will be saturating the receivers at the lower frequencies!).

Now an ideal photo-mixer would take incoherent light with a bandwidth B and convert it into a range of RF signals with frequencies extending from DC up to 2B. As I understand it, if the photon occupation number is large then a photo-mixer behaves like a square-law detector with a noise signal as input, i.e. the total power in the fluctuations on the output of the photo-mixer (integrated across the RF bandwidth) would be equal to the DC power detected. For normal light of course the photon noise would dominate, but I suppose that for narrow-band LED's, and certainly for Laser Diode sources, the occupation number is high (i.e. the brightness temperature greatly exceeds $h\nu/k$) so the mixing products should dominate.

In any case it is clear that we should use a light source with a bandwidth that is comparable to the RF frequencies that we want to produce, i.e. a few hundred GHz. This means that we want a light source with a fractional bandwidth of something like 0.1%. I imagine that these are easily available, although obviously it isn't just your basic LED. A power density of say 10^{-17} W/Hz with a total bandwidth of 1 THz means 10 microwatts of total RF power. If we can put a few mW of light into the photo-mixer, then this does not seem completely unreasonable – i.e. efficiency of a few tenths of a percent. Presumably the lower frequencies will be much easier, both because of the smaller effect of parasitics in the device and because one could use a narrower frequency-width for the light and so concentrate the output power at lower frequencies. As an embellishment I note if, for example, we make a device to cover a particular waveguide band, then we might be able to use a light source that generates two or more peaks with a separation that matches the RF band required. That should boost the RF output in the band of interest.

So the preliminary conclusion seems to be that further experiments on this would definitely be worthwhile. I note that practical tests with a receiver are rather easy – one would simply put the source at the distance where the receiver beam has spread to the same dimensions as the refocused antenna beam will have at 4km – i.e. where the beam is about 1m wide if this is done at 100 GHz – and measures the change in total power. If you can drive it into saturation you are doing well, and can move on to higher frequencies!

An important consequence of the fact that we are using signals at levels comparable to those from astronomical sources is that the issue of interference with other facilities on the mountain is not likely to arise.

This is certainly true in the broad-band case: we all radiate this sort of power across the ALMA bands ourselves, just by being warm! The fact that we are making polarized signals, however, and that there are experiments on the mountain doing the most extraordinarily sensitive measurements of CMB polarization, means that we would need to do a check with the QUIET and ACT people that they cannot see it – neither in theory or in practice.

For the CW case, where our signal would look like a spectral line, Darrel points out that with the rough power numbers I calculated above we would be just about at the limit set by the ITU for interference on radio astronomy sites and that we have a legal agreement with SUBTEL that is intended to enforce this on the ALMA site for our protection. This could put us in a difficult position. As an absolute minimum we have to be very careful to keep calling it an "artificial source" and never use the words like "transmit". I am confident that in reality there would be no problems for either our own single-dish work or that of APEX, except possibly when they were observing a source just above the ridge of the mountain, but again we should do theoretical and experimental checks. Scattering off the feed legs and perhaps the edge of the subreflector are probably the main things to check.

Obviously we will turn off the source when we are not using it and, if necessary, we could coordinate our tests with the other experiments to make sure we are not using the same frequencies as they are.

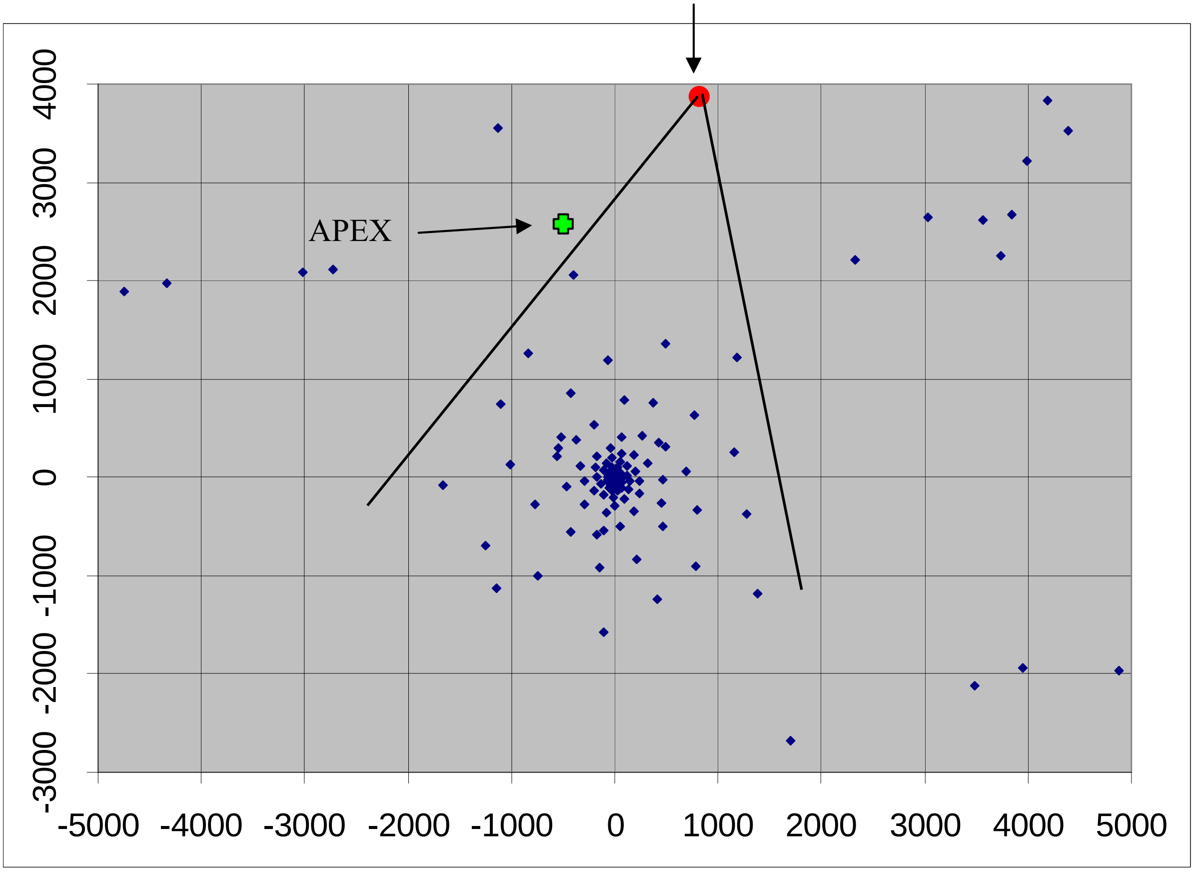
In the case of APEX we could probably choose the location so there is no line of sight to them but in practice they would probably want to use the source too – e.g. for polarization calibration and perhaps holography, so the question would more likely be the opposite – can we find a location where they can see it and we still get good coverage of the ALMA area?

Beam Pattern

As already indicated, I am assuming that we may want to do these sorts of measurements at times when the antennas are not in the central cluster. If we cannot then this will make a pretty strong restriction because on the current plans some of the antennas will only visit the central pads one a year or perhaps even less frequently. We therefore want quite a wide pattern to make sure that we get signals at antennas in at least all of the inner part of the array. It could in principle be much narrower in elevation, which would of course increase the gain of the horn and therefore reduce the power requirement further. For some of the designs discussed below, however, we need to turn the feed, in which case we would want to make the pattern as circular as possible.

Here is a plan to show the sort of angle required.

The position for the source suggested above is about here.



It is seen that all of the inner array is well covered if by a beam represented by the dark lines. The full angle is about 50 degrees so this is consistent with our assumption above of a roughly one steradian solid angle, which corresponds to a gain of 4π. We would need to go a little wider to make sure that APEX is covered. The are quite a lot closer so they will get a stronger signal but they will not be making interferometric measurements so they may need more power anyway. We should discuss with them their interests and requirements as well as the interference issue.

Polarization Properties

There are two important cases to consider:

1) We want to measure the polarization properties of the array of dishes, i.e. we want to do the polarization calibration using this artificial source instead of astronomical ones. According to the bible (Thompson, Moran and Swenson) there are seven complex quantities to be measured for each baseline. These are combinations of the gains of the polarization channels and the leakages of the cross-polar components. Note that what one measures, and what one needs to correct the data, is the combination of the terms associated with the two antennas (and the associated receivers) involved in each baseline. This concept of only needing to 7 complex quantities to describe a baseline only applies to sources that are small compared to the primary beam, i.e. these are the on-axis values.

2) We want to measure the variation of the gains and leakages across the primary beam of an individual antenna, so that we can make accurate polarization maps of extended sources. This is clearly easier since one is only measuring the change in the terms as one moves the antenna around.

It seems to me that in general the second of these is the more important use of the artificial source. Several of the terms in case 1) are likely to vary as the antennas move and the electronics drifts so it is probably better to do most of this with astronomical sources[2]. Except possibly at high frequencies, we expect the variation across the primary beam to be dominated by the optics of the front end and this should be mostly independent of elevation, temperature, etc. This is also the case where we will be most pressed to get adequate signal to noise ratio on astronomical sources with reasonable observing times.

The texts say that to do these measurements properly one needs three different polarization states in the source. The ALMA receivers have two nominal linear polarization channels, Pol_0 and Pol_1 and the correlator produces four outputs XX, XY, YX, YY. A very simple-minded way of thinking about what to do it as follows: using a linearly polarized source one would align the source first with Pol_0, so you can measure the fractional leakage into Pol_1 from XY/XX and YX/XX, then align the source with Pol_1 the leakages into Pol_0 from XY/YY and YX/YY and finally put the source at 45 degrees to both of them so you can measure the relative gains and phase differences of the X and Y channels.

The receiver bands have different orientations, as follows:

Band	Orientation
1	135
2	-135
3	-80
4	80
5	-45
6	45
7	0
8	-90
9	90
10	180

These are the original values. Band 7 was altered so that in the new cartridges the angle is 37.5 degrees. For quite some time to come we will be working with a combination of the old and new cartridges.

---

[2] It is well known that unless one already has an astronomical source for which the orientation of the plane of polarization is known one cannot measure the absolute orientation of the plane of polarization of the instrument. We should therefore plan to use the source to do at least this measurement.

Clearly the only way we can do the exact process above for all these bands would be to have a source where the orientation polarization could be set to any angle. If we can't do that, then it is almost certainly true that we can measure everything we need if we have a 100% linear polarized source with three different orientations – e.g. 0 and +/– 60 degrees. What is not at all clear to me is what we would loose if we only had two orthogonal polarizations, e.g. 0 and 90 degrees (or perhaps some other values, e.g. +17.5 and -72.5 degrees, chosen to provide some offset with respect to all the bands). This would provide some saving in complexity and so it would be worth going through the analysis to see if it would give us what we need, especially in the case of the primary beam measurements.

The polarization produced should of course be a pure as is practical. In practice it should be possible to obtain at least 30 dB cross-polarization with wire grids but one has to analyze carefully what happens off-axis. Since ALMA has a 0.1% polarization requirement we certainly need to know what is being produced to this sort of level. Note however that the flow-down is not direct – I think one needs to go through the analysis of what accuracy one would get in the leakage terms and how that relates to the errors in the final Stokes parameters.

Other Requirements

Because of its location, the device obviously needs to be extremely reliable. It would also be a great help if it had very low power requirements so that it could be run from a (very robust) solar cell and a battery. In conflict with this is the fact that if it contains electronics it might be necessary to keep it warm. This implies good thermal insulation as a minimum. On the other hand it is probably not a huge problem to run a power line along the ridge from the mini-TAO. For their holography transmitter APEX use a generator at the foot of the mountain and run a line up. (I think they used solar originally but it got wiped out by an ice storm. I am not keen to be reliant on a generator but running a line all the way up is presumably also a possibility. It seems possible that a photonic solution could be devised which requires no electrical power at all – i.e. sending the very small amount of power needed to bias the photo-mixers up in the form of light in another fiber (see more below).

Obviously an ideal solution would be one that has no control requirements. This again seems a possibility with the all-photonic system. If not, and we do put in a power line, then running a simple line along-side the power (or even putting it on the wire as a modulation) is presumably not too difficult. APEX use radio control which is I suppose not difficult to do but in theory I guess it violates our radio-quite zone code.

Straw-man Designs

There are three stages, A) generating the RF signal, B) coupling it out to form a beam of suitable width and C) making the different polarization states:

A) Generating low powered signals over a wide range of millimeter wavelengths:

1) Conventional.

I suggest that all we need is a YIG (or multiplied DRO) source in the 20 to 30 GHz band and a harmonic generator. To meet the minimum requirement the source would be fix-tuned and perhaps locked to a crystal to be sure that we have adequate frequency stability. (A YIG by itself would probably be good enough if the temperature is controlled and a DRO certainly should be fine.) It would be tempting to use a version with a simple synthesizer but obviously this immediately requires more complicated remote control. I believe that there are plenty of either of these on the market, but we would probably need a mil-spec version to make sure it survives in low temperatures. One thing to watch is that the oscillators themselves are usually running at a lower frequency so sub-harmonics are present which come up in the multiplication. A filter after the oscillator to remove these might be worthwhile. Some amplitude control would useful so a variable gain amplifier could be included, but again control is then required.

For the harmonic generator I have had good success up to about 375 GHz just using the harmonic mixer from a spectrum analyzer and driving it at ~15GHz and at quite a high level (~ +16dBm?). I don't have any real measure of what power was being generated. The power requirement above implies that the conversion loss can be over 50 dB but of course the energy gets spread over the harmonics. To be sure of getting a known amount of power at 300 GHz and above we would probably need to talk to people like RPG, Virginia Diodes and perhaps Spacek.

2) Photonic (narrow-band)

Essentially the concept is that one does all the complicated control, signal generation and such like in the relative comfort of the AOS technical building and only puts the absolute minimum of components up on the peak. All we then need to do then is find a way of getting a few fibers up there! What I have in mind is essentially a very stripped-down version of the ALMA photonic reference distribution system: i.e. make light at two frequencies differing by the RF frequency that we want and mix them in photo-mixer that takes the place of the harmonic generator in the conventional schemes above.

For the system in the control building, I defer to the experts. I understand that designs for a suitable optical comb generator exist. Recall that no control of the RF phase is required so we don't need any expensive master lasers. As has been emphasized the RF power requirement is pretty low, but I don't know what this converts to in terms of optical power or the question of what distance the light can be sent by fiber without getting into problems with Bragg scattering, etc. If necessary I suppose that an optical amplifier could be used before the photo-mixer but I guess that this requires a good deal of bias power and probably control. If an amplifier is not needed then it appears that the only power required is that for the bias of the photo-mixer and that should be very small. I suppose that it could be generated by laser light and a few photo-diodes, is that right?

Obviously one of the larger challenges in this case is getting the fiber up the mountain. Note however that it does not have to be buried. It might be possible to just run it down the front face of the mountain and then connect it to the ALMA system where it runs round the bottom of the hill. Spare fibers have been planned in the ALMA system. The alternative would presumably be to run along the ridge to the TAO and then hook into the system that they and CCAT will no doubt be installing. That is however likely to take quite some time and it would be of order 15km total run from the AOS TB. This suggest the alternative of asking the TAO people whether we could house the optical source there and just run the fiber along the ridge, which would be more like 1km.

3) Photonic (broad-band)

This is the concept that Darrel has suggested. As discussed above it is very simple indeed – just an LED or laser diode plus a photomixer. The power consumed would presumably be a good deal more than for case 2) but still not large. We would need to have some remote control – if nothing else to be able to turn the source(s) on and off.

B) Coupling the power out and providing the required beamwidth.

If one just has a single device to cover the whole range of wavelengths, this may be a little tricky. Making a ~50 degree wide beam is of course not at all difficult for a single waveguide band (an open-ended wave-guide or a very small horn would do) but it is a little harder to find a way of doing it for a frequency range of 85GHz to at least 350GHz and preferably beyond. It is tempting to think about some of the quasi-optical tricks that people have tried –

some sort of planar antenna (Maltese Cross?) plus a lens for example. There may be suitable things that one can buy, but obviously we need to talk to people who have done this sort of thing.

Another option that would probably work would be a rather gently tapered horn, which should still work when over-moded and would give a relatively narrow beam, followed by a convex lens to spread the beam. In this case the lens could perhaps be cylindrical to give the preferred wider spread in azimuth than in elevation.

The basic problem is essentially the same whether one is using a harmonic mixer or a phot-mixer. If however the basic device is cheap, the simplest solution may be to have a separate device and feed horn for each band. In case 2) above they could be driven by separate fibers and simply sit side-by-side in the source. Even with case 1) it might be easiest to use several harmonic generators, each in its own waveguide, and have a switch to select which one is being driven by the oscillator and any time.

C) Generating the required polarization states.

The sources described above would all generate a linearly polarized signal, but it would not be very pure. A single grid should be enough to clean it up – a well-made grid should be really quite wide-band but we should check how good the practical results are here and whether better purity is achieved in transmission or reflection.

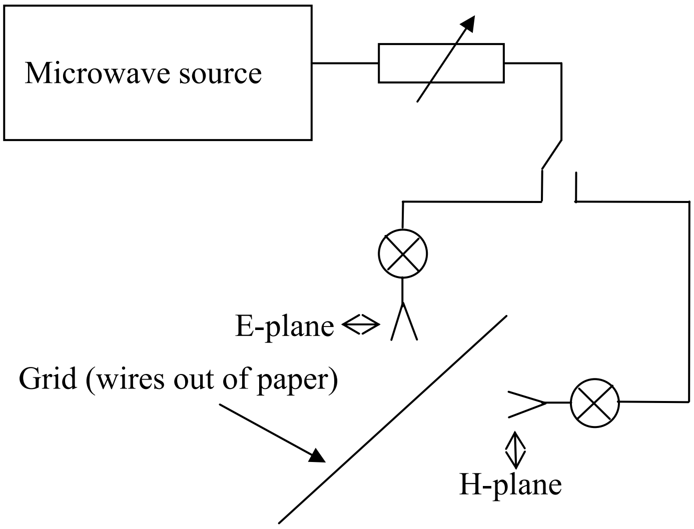
(i) The most obvious way of change the polarization is then to rotate the combination of source plus grid about the axis aligned with the peak of the beam.

(ii) Another possibility is to keep the source itself fixed and have two grids in front of it, which can both rotate – i.e. the relative orientations of the wires can be changed. This would enable one to adjust both the power level and the plane of polarization in a controlled way. I suspect the details of this would be messy given the rather wide beamwidth.

Both the above need motors and some form of encoder to do the correct positioning. There is however a no moving parts solution:

(iii) Simply make several devices and set them side by side, each looking out through its own small grid. Remember that at 4km, 20mm is only 1 arc second. One would need to take the position differences into account but one could know what they are to sufficient accuracy.

(iv) If only two polarizations are needed one could just use one grid which would reflect one polarization while transmitting the other. Here is that case for the “conventional” generation:



In this case one would build it so that the two polarizations appear to come from the same point, which would simplify the usage compared to case (iii).

Other Design Points

Naturally these components all go in a box and are surrounded by absorber. A very weather-tight window would be needed with good polarization properties. This would also require some investigation – foam might be an option.

Peter Napier has pointed out that it is essential that the unit be firmly tied to the mountain so that one can make accurate phase measurements using this source even when the wind is blowing. A suitable requirement is a stability of 0.1mm, which implies that the unit should be designed with rigidity in mind and that it should be fixed to a solid bit of rock rather than just sitting on the ground.

Commentary

The solutions suggested here span a range between A) the conventional, which one could basically go out and order tomorrow, but which would cost a fair amount, and C) the very innovative, which should be cheap to make and easy to operate but requires tests and development and might prove impractical. The intermediate case B) photonic with fibers would also require some work but will almost certainly work and we have people in the project who know how to do it. We could probably follow more than one option for a short time but we should obviously make a decision as soon as we can.

The main driver here is the requirement for calibrating the polarization so the top priority is to sort out the question of whether a continuously adjustable orientation is required, or three fixed ones, or whether just two fixed ones would be sufficient. Another question one might ask is whether it is foolish to do the polarization source right away. Should we perhaps first get something set up just for holography? I would resist this. We are not doing much on polarization right now but we really must start paying attention to it soon.

Next Steps

The plan it to circulate this discussion document within the project and to knowledgeable people outside. The two aims are:

1) to find out what has been missed from the requirements

2) to get views on which of the design options we should pursue.

We do need to get on with this, so I think we should try to conclude that stage by the 14th October.

The other obvious thing to start following up right away is the broad-band source. If we have the relevant parts in either Charlottesville or Chile then a quick test to see what sort of power levels can easily be achieved would clearly be worthwhile.

Richard Hills 21st Sept 2010