MMA Memo 183: A Suggested Receiver Layout for the MMA Antenna

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Abstract

This memo suggests an optical arrangement for the Millimeter Array antennas in which stationary receivers are located near the Cassegrain focal plane, with each feed slightly off the antenna optical axis. This is one of the four schemes proposed in MMA Memo 163. No movable optical elements are required; switching frequency bands is accomplished by offsetting the antenna pointing slightly. We propose enlarging the subreflector diameter to 28 inches, which decreases the telescope effective focal length to 1156.9 inches. With all feeds located less than 6 inches off axis, the resulting coma produces a negligible loss of gain and negligible distortion of the primary beam (see also MMA Memo 175, in which Bill Shillue shows that for off axis distances of greater than 4 inches gain losses due to astigmatism are larger than coma losses; for a 6 inch off axis distance, the total loss is still less than 1%). The off axis illumination results in a rearward spillover loss of up to 0.65 K and a loss of forward gain of up to 0.21%. We suggest the possibility of placing the receivers in two dewars rather than a single dewar in order to possibly improve maintainability and reliability.

1 Introduction

Memo 163 from the Antenna Group describes a strawman optics layout which places the receivers at the Cassagrain focus of the conventional antenna. It is important that the receiver group consider that proposal to see whether it leads to a workable receiver arrangement. The memo suggests four possible schemes for the receiver placement: (1) off-axis feeds, (2) Movable dewar, (3) cooled rotating beam director, and (4) rotating asymmetric subreflector. To get our discussion going, we suggest a scheme that follows the first option.

2 The Receiver Layout

In the suggested arrangement, the receivers are all situated in two stationary dewars, which are located close to the antenna axis, and each receiver illuminates the secondary from a slightly off-axis position. The basic layout is shown in Figure 1. Each feed horn is located at a tertiary focus behind the Cassagrain focal plane.

The dewar positions are fixed, and switching from one band to another just requires re-pointing the antennas.

The larger dewar operates at 12 K and contains three HEMT receivers whose bands (and ratio of high/low frequency) are 30 – 48 Ghz (1.6), 67 – 95 Ghz (1.42), and 94 – 133 Ghz (1.42). There is also provision for a 132 – 187 Ghz (1.42) HEMT receiver, but more likely this slot will be filled with a HEMT or Schottky radiometer to measure the opacity of the 187 GHz water line. The 150 Ghz capability is a small, but plausible, extrapolation in the high frequency properties of HEMTs. These bands are similar to those of Bob Brown's memo. The maximum single-mode bandwidth of a corrugated feed is 1.68, which limits the coverage of the lowest frequency band. The higher frequency bands can cover 67 to 187 GHz with 3 bands of fractional bandwidths of 1.4.

The receivers for the higher frequency bands are expected to use SIS mixers and are in the smaller 4K dewar. Seven receivers with fractional bandwidths of 1.3 (or possibly six with fractional bandwidths of 1.4) will cover the 132 – 187 Ghz band plus the bands with centers near 210 Ghz, 270 Ghz, 350 Ghz, 450 Ghz, 660 Ghz, and 800 GHz, again following Bob's memo.

Each feed horn is located at a tertiary focus behind the Cassagrain focal plane. The refocusing elements are mostly lenses and are in the dewar at low temperature to avoid warm losses; they also serve as windows in the radiation shields to block infrared radiation. For the 40 Ghz band, the re-imaging elements could be mirrors of about 10" diameter, which would fold the relatively long optical path. Both mirrors could be cooled to low temperature in the dewar as shown in Figure 1. The one close to the center is behind the largest dewar window, and the other is further offset, sitting above the 40 GHz receiver in the dewar.

One advantage of the proposed receiver design is that each band has its own optics, which can be optimized over a typical fractional bandwidth of 1.4. In contrast, if a single dewar window were used for many bands, it should be very large to accomodate the lowest frequency, thin to be low loss at the highest frequency, and have small reflection loss everywhere. A second advantage of having separate re-imaging optics for each band is that it allows the greatest flexibility for frequency multiplexing, by placing additional optics in front of the dewar.

The use of the tertiary focus is discussed by Padman, Murphy, and Hills (19xx). One of its features is an effective collecting area which is approximately constant across each band (and a primary beam size proportional to wavelength). With an illumination taper of about -10.2 db at the edge of the primary, the expected aperture efficiency is about 84%, including the taper, central blockage and spillover. When feed leg blockage, gaps between panels and panel adjustment screws are included, an aperture efficiency close to 78% may be expected, not including the surface roughness efficiency. The efficiency due to a 25 micron rms surface roughness ranges from greater than .99 at frequencies less than 95 GHz to .45 at 850 GHz. See also Welch et al(1996) and Lugten (1994).

Following last year's discussion, we suppose that each receiver will have dual linear polarization. For the moment, we suppose that there is no sideband separation, beyond what is provided by first LO phase switching. In last year's memo, we pointed out that with the low background of the atmosphere in Chile, most of the noise will arise from the receiver, even at noise temperatures of $2h\nu/k$, so that there is little improvement in SSB system temperature with hardware separation of the sidebands. This point deserves further discussion, but note that sideband separation in the RF circuit doubles the number of receivers and associated RF and IF components, and we have already a very large number of receivers for our 40 antennas.

2.1 Size of the Vertex Hole

The vertex hole diameter is 18.9 inches in the strawman design. To allow the 40 GHz beam, and the others, to be off axis, we propose that the vertex hole be enlarged to a clear diameter of 26 inches (and the subreflector to a diameter of 28 inches). This would increase the geometrical blockage from .0044 to .0079.

The enlarged subreflector and vertex hole decreases the telescope effective focal length to 1956.9 inches (f/6.21) and produces smaller beam waists in the Cassegrain focal plane, allowing the feeds to be packed more closely together. All feeds (up to 11 total) can be placed no more than about 6 inches off axis. At the lowest frequency, 30 GHz, the vertex hole transmits over .995. The higher frequency feeds transmit even more.

2.2 Phase Errors

The first order phase effect of the offset is a linear phase term, which is just a pointing change. The next term is cubic, usually called coma. The gain loss which results from coma associated with a feed displacement of x from the axis in the focal plane is given by

$1 - [(x/\lambda)/(43F^3)]^2$

where λ is the operating wavelength and F is the focal ratio. For a 1% gain loss,

$x/\lambda = 4.3F^3$

For the proposed design with a 28 inch subreflector, F=6.21, so that a displacement of about 1000 wavelengths makes only a 1% loss in gain. Even at .35mm wavelength, that is about 35 cm (14 in). The largest feed offset for the receiver concept in Figure 1 is 6 inches.

2.3 Spillover due to Off-axis Illumination

One of the least desirable aspects of the proposed design is the fact that the off axis illumination results in some rearward spillover past the primary mirror. This rearward spillover is likely to terminate at 300 K, at least for part of the antenna elevation range. The maximum distance a feed is located from the telescope axis is about 6 inches which results in crescent shaped spillover past the edge of the primary which extends 180 degrees around the primary and reaches a maximum width of about 5.4 inches. Including the -10.2 db illumination taper, this results in a contribution of up to .65 K to the system noise. For comparison, the likely noise contribution of a single mirror at 100 GHz due to ohmic loss and a small amount of spillover (terminated at 300 K) is about 1 K. The off axis illumination also produces a loss of gain in the forward main beam of about 0.21 %.

One possibility for reducing this noise contribution is to add a skirt around the dish perimeter. This skirt can be added only to the top part of the dish without increasing the minimum close packing distance of antennas.

However, it may well reduce the antenna noise contribution at least for some of the (lower frequency) bands with the most sensitive receivers.

2.4 Other Devices in the Focal Plane

Because the receivers are actually at the tertiary focus, there is a beam waist region in front of the receiver dewars. This is therefore an excellent place for the calibration optics. One or two temperature regulated loads can be placed here and can be moved in front of each receiver. Accurate location in the focal plane of each receiver is not critical for these. Polarizers to convert the two linear polarizations to circular may also be put here for temporary use.

Dichroic beam splitters for dual band operation may also be located here. In last year's discussion, we noted that from the point of view of sensitivity it may be just as well to observe different bands in turn. The loss in sensitivity due to the time sharing may well be equivalent to the loss in sensitivity associated with the additional optics.

3 Key Questions

Is it a good idea to divide the receivers between two dewars (up to 8 in the 12 K dewar and up to 14 in the 4 K dewar)? Is 14 receivers per dewar a managable number?

Is it reasonable to expect that HEMT receivers will have comparable sensitivity to SIS receivers up to 130 GHz? Is it foolish to preclude the possibility of using SIS receivers below 130 GHz by not having space in a 4 K dewar?

Is a 0.65 K contribution to system noise due to the off axis receivers a reasonable compromise? Should options to eliminate this contribution, such as a tilting or rotating subreflector, or movable dewars be considered?

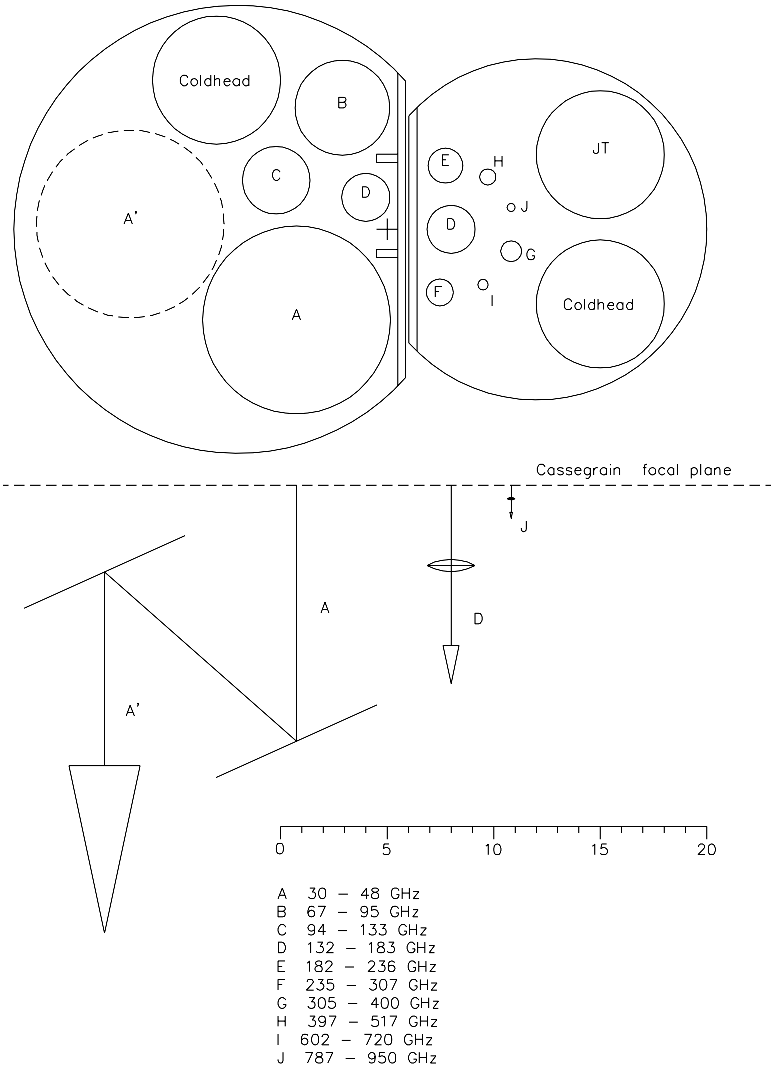

Figure 1: (top) A possible scheme for placing receivers for 10 frequency bands in 2 dewars: a 12 K dewar for low frequency (30 to 133 GHz) HEMT front ends and a 4 K dewar for SIS (133 to 950 GHz) front ends. (bottom) The optical paths for the 30 - 48 GHz, 132 - 183 GHz, and 787 - 950 GHz bands are shown from the Cassegrain focal plane to the horns. The lowest frequency band uses a pair of mirrors to re-image the telescope aperture at the horn aperture; the higher frequency bands are shown with re-imaging lenses which can also serve as radiation shields.