NATIONAL RADIO ASTRONOMY OBSERVATORY

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VLA SCIENTIFIC MEMORANDUM #6

SIDE LOBES OF THE VLA--ATMOSPHERIC EFFECTS

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A memorandum on side lobes of the VLA was presented at the last VLA Design Group Meeting (VLA Scientific Memo #1). It was decided then to produce a summary of it with main emphasis on spurious side lobes coming from atmospheric effects or imperfect calibration.

Moreover, some new information about the phase variation has been provided in the past few days by the 3 element interferometer, presently in operation at Green Bank, and the need for further information will be discussed.

Diffraction Side Lobes need no new comment, as it is a classical question.

Hole Side Lobes studies have been summarized by D. Hogg in VLA Scientific Memo #2; if no systematic optimization process has been found, it appears that a few configurations give holes side lobes with RMS between 25 and 30 db everywhere and peak values of 20 - 22 db almost everywhere but around 0° declination where the peaks may reach 15 db. This is in good agreement with the assumptions given in the preceding memo. Complementary antennas studied by N. Mathur may be used to reduce unwanted hole side lobes in some regions, mainly close to zero declination. Peak value better than 25 db are probably feasible with a set of two observations with two different configurations.

Dish Side Lobes due to surface inaccuracy must be reduced to at least 50 db for the non random part of it, i.e. common to all dishes. This has been given at length in our first memo.

Array far Side Lobe were seen to be not a critical question. More generally, it appeared that outside the dish main lobe, with proper care of diffraction effects, no side lobe problem was difficult to solve. On the contrary, inside the dish main lobes, the dynamic range is not only limited by the effect of holes, but two other causes of side lobes exists. The imperfect calibration of the system gives array side lobes random, but not varying with time, whereas the differential variations of optical paths through the atmosphere give array side lobes which are essentially variable.

Let us examine the phase variations due to the atmosphere: They have two aspects: Their size distribution, and their spectrum, and both effects must be taken into account for the calibration of the array and for the choice of the site.

A preliminary estimate of their size is possible from the diagram obtained by D. Hogg from the three-antenna interferometer at Green Bank (Fig 1). If this diagram represents an average value, this value is ≤ 6° for 50% of the time, ≤ 12° for 80% of the time, at about 2 km. We know very little about the variation of these phase errors with time, but we can make some estimates; on the high frequency side, a visual inspection of the records shows clearly that variation with a time scale shorter than a few minutes is rare. On the low frequency side it is improbable that variations slower than about one hour exist. This would imply different atmospheric conditions above two antennas, and at the same time a low wind, which is an unlikely situation. Winds are rarely under a few km per hour, and if they are lower, the atmosphere is probably horizontally homogeneous. So we will take two assumptions about the time scale of phase variations: 10 min. and 1 hour.

For size values at distances larger than 2 km, we know nothing yet, and we can make three possible hypotheses: same size as at 2 km; larger than at 2 km, but under 45° most of the time; larger than 45°.

From the formulas given in Memo #1, some characteristic figures may be derived:

(1) Observations with 2.1 km configuration:

(a) Time scale of atmospheric phase effect ≈ 10 mn; the side lobes given by these phase variations have rms values around 30 db. They are negligible compared to "calibration" side lobes. The latter depend upon the time spent for calibration and on the ultimate stability of the interferometer itself. If we take 1° for this limit, 100 periods of 10 minutes, or about one full day are necessary to average the rms atmospheric phase variation from 10°, to 1°, and to achieve a proper calibration giving rms side lobes of 27 db, quite compatible with hole side lobe values of 25 db as seen earlier. With a two hour calibration the rms side lobes would be 23 db and will be the limiting factor for large dynamic range observation.

(b) If the time scale of atmospheric phase effects is ≈ 1 hour, the side lobes given by phase variation would be ≈ 27 db rms. To achieve comparable values for calibration side lobes, one would have to spend four full days. If a few hours only are available for calibration, then side lobes around 20 db rms are to be expected.

(2) Observations with 20 km configuration:

(a) If phase variations are of the same order as that of 2 km side lobes effects will be as above.

(b) If phase variations are less than 45° most of the time and time scale of atmospheric phase variations is 10 min., side lobes cannot be better than 24 db rms with a calibration of at least three full days. With two hours calibration the limit is 16 db.

(c) If phase variations are less than 45° most of the time with a time scale of 1 hour, side lobes cannot be better than 20 db in one observation with a calibration of at least two full days. With two hours calibration, the side lobe level is 13 db rms.

(d) If phase variations may be larger than 45° an appreciable part of the time; i.e., with some peaks of 90°, observations will be very difficult in average conditions, and "good days" are probably to be selected. We will not dare to put any figures here.

Of course, it is possible to achieve lower side lobes than above for a peculiar observation by averaging calibration or observations, whichever is the cause of the high side lobes. From the preceding figures it is quite clear that side lobes, and hence dynamic range, are extremely sensitive to the time scale of variable phase atmospheric effects, and of course to the amplitude of these phase variations.

So it is important to achieve two groups of preliminary measurements:

(a) Spectrum of the phase variations, mainly at distances of the order of 2 km, with the present Green Bank interferometer.

(b) Amplitude of these variations at 2 and 20 km, during periods of at least some months; eventually, some observations at 20 km in the selected site are needed to be certain that case 2(d) is avoided.

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RMS OF A 15-SEC OBSERVATION, ABOUT THE MEAN PHASE OVER 20 MIN.