A PROPOSED CORRELATOR BACK-END FOR THE CULGOORA RADIOHELIOGRAPH

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(Lecture presented by N.R. Labrum.)

1. INTRODUCTION

The original design of the Culgoora radioheliograph (Wild, 1967; Sheridan et al., 1973) incorporated a number of features, such as high time resolution and limited declination coverage, which were particularly suited to its primary function of observing the Sun. Although some of these features are disadvantageous for cosmic work, the instrument has nevertheless proved useful for a variety of non-solar studies as well.

At the present time design work has begun on a new correlator back-end for the Culgoora array which, it is hoped, will enhance the power of the instrument in both its solar and its cosmic roles. The array consists of 96 aerials equally spaced around a circle 3 km in diameter. The new plan is to correlate the signals coming from each pair of aerials and then to process all the measured correlations so as to synthesize an image of an extended field; for solar work, this synthesis will have to be done in real time.

For 96 aerials there are 4560 different pairs of aerials, although almost half the aerial spacings occur twice; if we do not attempt to record redundant spacings we will need a minimum of 2304 correlators. To limit the cost and complexity of such a large project we have chosen to build these as one-bit (or possibly 1½-bit) digital correlators and to do much of the processing digitally (delays, correlators, image synthesis).

2. ADVANTAGES

The advantages which we expect from this undertaking differ for the two cases of solar and cosmic observations.

For solar observations one important advantage is improved time resolution; in its present form the radioheliograph takes one second

C. van Schooneveld (ed.), Image Formation from Coherence Functions in Astronomy, 159–164.

to form a pair of images in two states of circular polarization at one frequency. Originally, the heliograph operated at only one frequency, 80 MHz; now however the available time is shared between three frequencies (soon four) and the time resolution at any one frequency (3 s) is poor compared with the fastest time scales for bursts (<1 s). With the new back-end the image rate will be increased to 8 or 10 per second - sufficient for one image per second in each state of polarization at each of the four frequencies. Although an even higher image rate would be desirable in some cases, we have accepted this limitation both because of the embarrassingly high data rate and because we need about 0.1 s integration to ensure a good dynamic range.

A second major advantage for solar observations is the possibility of using the considerable redundancy of the array, particularly at close spacings, to determine a much more accurate phase calibration. (The principles of this technique are discussed briefly later.) An accurate phase calibration is important for solar observations because it permits a synthesized beam with lower sidelobes, providing a larger dynamic range for observations of bursts and a more accurate image of the quiet Sun. The large dynamic range is required at the time of major solar events, when interesting weak activity (e.g. moving type IV bursts) may be confused by the sidelobes of much stronger sources. In the case of the quiet Sun, the need for a low sidelobe level is evident from the following example: if the r.m.s. sidelobe level were 1% of the main beam then with about 100 beam areas on the Sun, the r.m.s. uncertainty of the measurements of the quiet Sun would be about $\sqrt{100} \times 1 = 10\%$ of the mean brightness!

A third advantage for solar observations is that we will also obtain a modest gain in sensitivity compared with the present scanning system. Although sensitivity has not been a major problem in studies of the quiet Sun (because integration times can be long) or for bursts (because of their high intensity) the extra sensitivity will become necessary in studies of weak features that will be visible with reduced sidelobe levels. A search for wave phenomena on the quiet Sun is an example of an application where increased sensitivity is paramount.

For cosmic observations of known sources we expect a modest gain in sensitivity of about six times, made up of a factor of two, because the source will be observed all the time rather than 25% of the time as with the existing system, and a factor of about three, because it will no longer be necessary to use J^2-synthesis for beam forming.

For cosmic observations of weak sources the new back-end will open up the possibility of earth-rotation synthesis. The primary beam of the aerials of the array is large - about 34° diameter to the 10 dB level at 80 MHz, half that at 160 MHz and half again at 327 MHz. The spacing of the aerials, 100 m, ensures that the grating lobes fall outside a 2° field suitable for solar observations. In a short observation of weak cosmic sources the grating lobes associated with other sources will limit our ability to discern the source. Earth-rotation synthesis can reduce this confusion limit: Swenson and Mathur (1967) have shown that, with the limited hour-angle coverage of the existing aerials, ±2.4 h, the grating-lobes will be significantly reduced, although not eliminated (better results would be obtained with ±4 h coverage). For the study of weaker sources then it will be valuable to synthesize the full field of the primary aerial beam so that residual grating-lobes due to strong nearby sources can be recognized and possibly cleaned. Further, with the possibility of synthesizing such a large field in five hours' observations it becomes feasible to survey all the sky within the declination range of the aerials (roughly $-30° < \delta < 30°$).

3. PHASE CALIBRATION METHOD

Figure 1 shows the UV plane coverage for a circular array similar to the radioheliograph, but for 48 rather than 96 aerials. For a strong source such as the Sun we can assume that all the flux recorded originates within a limited field, and consequently we need only sample the UV plane at a moderate density; the density of sampled points about half way from the centre to the edge of Figure 1 is sufficient for a 2° field. Both at the centre and the outer edge of the figure the UV plane is heavily oversampled and this oversampling can be used in much the same way that the redundancy of an equispaced linear array can be used to correct phase errors (Jennison, 1958; Ishiguro, 1971; McLean, 1973). In practice, in solar work only the correlations from the inner few circles of spacings will be strong enough to be useful. The simplest way to use these is to compare the individual correlations with the running mean of about 16 complex correlations taken around the inner ring. The errors so determined can be assigned successively to the individual aerial channels. Because of the way the errors grow during this process the major question is whether the phases of the longer base lines will be improved; the preliminary study suggests that they will. If so, then new observations incorporating the first set of corrections can be used to refine the corrections, and repeated applications of this process will then converge to an accurate calibration.

4. PROBLEMS

We are currently studying a number of problems which might limit the success of this project.

(a) The limited sky coverage of the aerials of the array has already been mentioned as a major limitation of synthesis observations. Modification of the aerial mounts may be possible at some future time.

(b) Coupling between the open wire transmission lines and possibly radiative coupling between aerials will introduce spurious correlations between pairs of signals. Although the level of coupling is low it will become serious when we seek to process individual correlation measurements to extract phase calibration data. We believe that we can eliminate the effects of coupling using synchronous switching techniques.

(c) A third problem is caused by the complexity of the system that we are proposing and the large number of correlators required. Furthermore, the large rate of flow of data means a heavy, on-line, computing load. With a minimum of 2304 correlators, each recording two numbers each 0.1 s, we must process some 40,000 numbers per second. For solar observations we need images in real time and so we must have sufficient computer power to cope with this rate of data and to reduce it to an amount that can be recorded and stored.

(d) Although preliminary evaluation of the phase calibration system described above suggests that the process converges, if slowly, a more thorough evaluation has yet to be made to confirm this.

5. CONCLUSION

The Culgoora radioheliograph is already a powerful instrument (it is, as yet, the only fast imaging radio telescope in the world), and with the new back-end described here its usefulness will be further extended. Operating in the metre and decimetre bands at 43, 80, 160 and 327 MHz, with resolution in two dimensions ranging from about 7'.5 arc at 43 MHz down to about 50" arc at 327 MHz, it will be capable of studies of solar bursts and the quiet Sun with high time resolution and large dynamic range. It will also be capable of extensive studies of galactic and extragalactic objects with a sensitivity at 80, 160 and 327 MHz of about 0.1 Jy.

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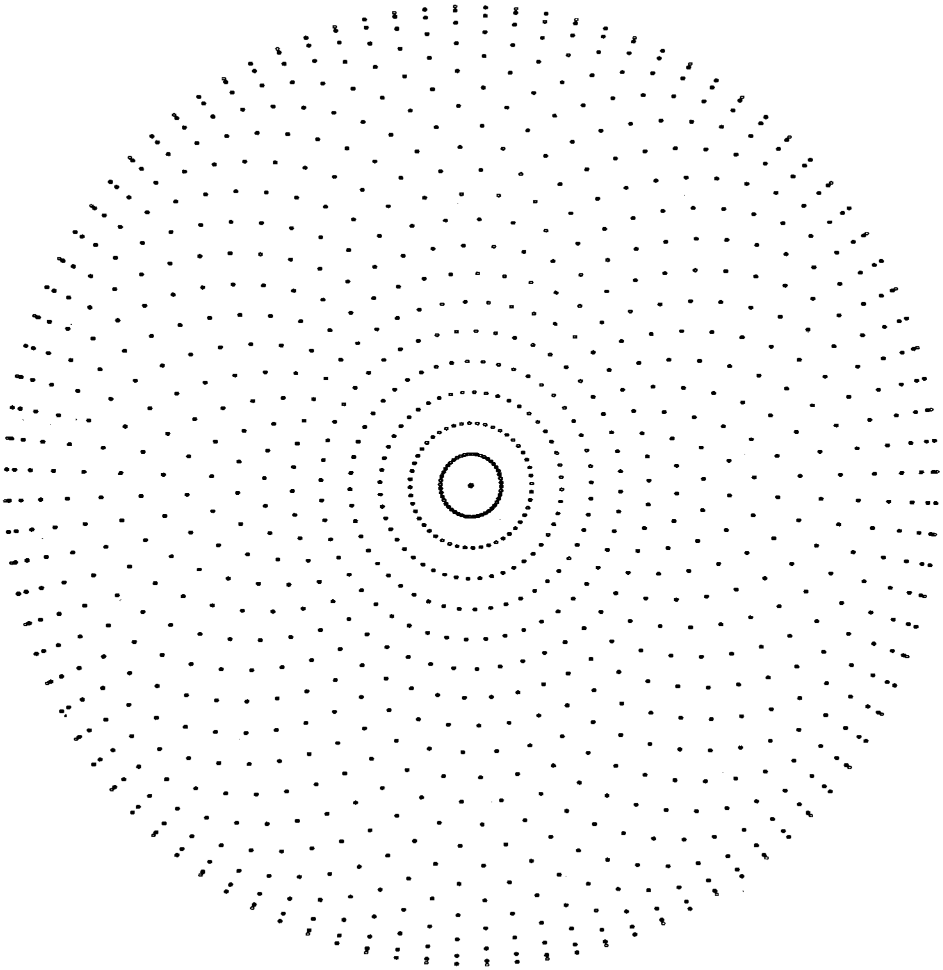

Figure 1. The UV plane for a circular array like the Culgoora radioheliograph. Each point represents the direction and spacing between a pair of aerials of the array. To simplify the diagram an array of 48 aerials has been represented, rather than the actual 96.

DISCUSSION

Comment W.M. GOSS
What are the representative sensitivities and resolutions for the correlation mode of the radioheliograph? Is the sensitivity limited by confusion?

Reply N.R. LABRUM
Beamwidth at zenith ranges from $7'.5$ at 43 MHz to $0'.9$ at 327 MHz. Sensitivity at 80, 160 and 327 MHz will be about 0.1 Jy. Rough calculations indicate that the confusion limit will be less than 0.1 Jy at all these three frequencies.