SOLAR OBSERVATIONS WITH THE VERY LARGE ARRAY

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ABSTRACT

Currently planned modifications to the Very Large Array to facilitate solar observations are described. The performance characteristics of the instrument in this observing mode are outlined.

1. INTRODUCTION

The Very Large Array[1,2] is a large, high sensitivity Fourier synthesis radio telescope currently being constructed by the National Radio Astronomy Observatory, under contract to the National Science Foundation. The array has been designed to produce very high resolution brightness maps of galactic and extragalactic radio sources. However, it cannot operate optimally in its present form when observing sources such as the Sun, where the system temperature due to the incident flux exceeds the intrinsic receiver temperature by several orders of magnitude. Modifications to the receivers are planned which will, to a large extent, overcome this difficulty. Such changes must, nevertheless, represent a compromise solution because of the highly variable intensity of the solar radio emissions.

2. RECEIVER MODIFICATIONS

Observations with the VLA are possible in any of four frequency bands - 20 cm, 6 cm, 2 cm, and 1.3 cm. The spectral distribution of the solar radio emission is such that, even for the quiet sun, the expected intensity changes by an order of magnitude across this frequency range[3]. Without modifications, the receivers could saturate, when observing the quiet sun, at 20 cm or 6 cm and could saturate,

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when active regions are present in the beam, at 2 cm or 1.3 cm. This problem may be overcome by reducing the gain of the receiving system by an appropriate factor when observing the sun. Such a gain reduction, however, introduces a further problem in that it is, in general, no longer possible to conveniently observe radio calibration sources. Significant uncertainties in the synthesized source brightness distribution result, as the absolute fringe phase is not well determined.

The planned solution to these difficulties is to introduce a constant-phase, switched attenuator into the receiving system, which will facilitate solar observing while allowing accurate phase calibration using normal radio source calibrators. The optimum value for the introduced attenuation is determined by a number of factors. Kundu and Rao[4] have provided compromise design values, based on physical considerations, for the VLA antenna temperatures in each of the four observing bands when observing the sun. These values are typically 5 dB above the nominal quiet sun antenna temperatures. It should be stressed that significant departures from these values of solar flux may be expected.

An ALC loop is employed in each receiver to hold its output signal level constant. With the addition of the switched attenuators, the leveling system will be able to control amplifier saturation for incident flux densities of up to 25 dB above the quiet sun flux. However, the ALC attenuator introduces a phase shift, which varies with its insertion loss, and hence, the incident signal strength. The PIN diode attenuators used are state-of-the-art devices, designed to minimize this effect over as large a dynamic range as possible. Furthermore, the attenuation introduced for solar observing has been chosen so that when the array is observing a source which results in the antenna temperatures given by Kundu and Rao, the phase errors induced by a change in ALC operating point are minimized[3]. Typical uncertainties are less than 2°. Two values of attenuation may be selected. The first is optimum for 20-cm and 6-cm observations and the second, lower value is suitable for 2-cm and 1.3-cm operation.

When the antenna beams contain a strong active region with flux several orders of magnitude greater than the quiet sun, phase errors of up to 15° can be introduced relative to the calibrator observing mode. Interferometer phase calibration will therefore possess uncertainties of similar magnitude. Similarly, when observing the quiet sun, phase errors of typically 4° can be expected and, in addition, the output of some of the receivers in the array may no longer be adequately leveled. It is important to bear in mind these restrictions when planning solar observations with the VLA.

Gain calibration of the VLA receivers is performed using a noise added technique. The additional injected noise for normal observing is typically set to be equivalent to 10% of the nominal system temperature and, hence, lies in the range 4 K to 30 K, depending upon the observing band. When observing the sun, injected noise at this level cannot be accurately detected since the system temperature is increased by several orders of magnitude. For this reason, high temperature noise calibration systems will be installed on two antennas. The added noise for solar observing will be approximately 10% of the quiet sun antenna temperature, restricting the range of signal strengths over which accurate absolute brightness temperature calibration is practical to about 13 dB above the quiet sun level. The injected noise cannot be set at a higher level relative to the minimum expected system temperature without causing possible errors in the operation of the correlator, especially when observing a source such as the sun for which relatively high cross-correlation coefficients may occur at the shorter antenna spacings. Calibration transfer requires the assumption that all system temperatures are equal and that the contribution to the system temperature by the receiver itself is negligible. In general, these assumptions are valid except when observing near the solar limb. In that case, pointing variations may cause significant transfer errors.

3. OTHER CONSIDERATIONS

Certain software limitations restrict the applicability of the VLA to solar observations. The measured visibilities are stored with real and imaginary parts each occupying a sixteen bit, fixed point computer word. The binary point location must be specified in advance and is forced to be the same for all data of a given observation. However, the sun can exhibit a very large dynamic range of visibility in the spatial frequency domain and with the wide range of antenna spacings of the VLA it is difficult to choose the optimum scaling to avoid overflow at short spacings and underflow at long spacings.

The software also restricts the minimum integration time to ten seconds. It is possible, in theory, to synthesize separate maps of the source brightness distribution at ten-second intervals. However, computing time limitations restrict the number of ten-second interval maps that can be handled, since as the number of maps increases the time for data reduction rapidly exceeds the observing time. Furthermore, the instantaneous sampling of data points in the spatial frequency domain produced by the standard VLA configurations is not adequate for high quality image reconstruction. The completed array, with 27 antennas, produces 351 different baseline vectors. The instantaneous spatial frequency domain sampling, comprising 702 points, is always in the form of a six-pointed star, with varying distortions for different declinations and hour angles. As an example, consider a point source at $\delta = 30°$, $H = 0$. The ideal image response, synthesized with uniform weighting in the u,v plane, has a principal side lobe at 27% of the peak value.

The characteristics of the radiation patterns of the VLA antennas, which normally operate with orthogonal, circularly polarized beams, can affect the accuracy of polarization mapping of solar radio sources.

The left and right circularly polarized beams possess an angular offset equal to 6% of the 3 dB beamwidth, which results from the offset-fed Cassegrain antenna geometry[5]. The beam separation for orthogonal linear polarization is typically less than 1% of the half-power beamwidth. In general, the errors induced by the beam squint are negligible if the source is strongly circularly polarized and near the beam center. At the shorter wavelengths antenna pointing variations may give rise to significant inaccuracies in the polarization information contained in the synthesized maps.

It has been shown that altering the field distribution at the feed aperture can reduce the magnitude of the beam squint[5]. However, since the method is currently only effective over narrow bandwidths and since for most observations the beam offset introduces small errors, no hardware modifications are currently planned.

4. CONCLUSIONS

Every effort is being made to minimize the difficulties related to solar observations with the VLA, consistent with the instrument's primary function as a nonsolar Fourier synthesis array. However, observers should be aware that considerably more care is required to obtain accurate radio images of the sun than when observing other radio sources. It is likely that the instrument will never achieve the same precision for solar mapping that it promises to achieve for weak-source radio imaging.

5. ACKNOWLEDGMENTS

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REFERENCES

1. Heeschen, D. S., Sky and Telescope, Vol. 49, pp. 334-351, June, 1975.

2. Weinreb, S. et al., IEEE Trans. MTT, Vol. MTT-25, pp. 243-248, April, 1977.

3. Archer, J. W., VLA Electronics Memorandum No. 181, April, 1979.

4. Kundu, M. R. and Rao, R., Private Communication.

5. Napier, P. J. and Gustincic, J., Proc. IEEE-AP/S Symps., pp. 452-454, June, 1977.

DISCUSSION

Kundu: I have a couple of questions on the present status of the VLA for solar observations.

1) Do I understand correctly that the problem of measuring circular polarization accurately is still at the bottom of priorities?

2) What would it cost to equip all the antennas with the modified front ends rather than only two antennas as planned now? If it is only a question of money, I think one should be able to obtain the money somehow. The most important thing is that one should be able to do solar observations properly on the world's most powerful instrument.

Archer: On subject of optimum value for introduced attenuation:

i) Design principles presented in talk were based on optimum performance for quiet sun. Since the general consensus expressed today is for a compromise between quiet and active sun observations, we will use the values for nominal solar flux given in your recent communication as a basis for system design. In this case maximum calibration transfer phase errors of the order of 5° can be expected for quiet sun observations.

ii) On the reason for using only two antennas as transfer standards for absolute flux calibration:

The principal considerations of concern here are:

i) Due to the tight coupling values necessary for injection of high noise temperature calibration signals, directional couplers used have relatively high insertion loss. Hence, their insertion causes a significant increase in system temperature for normal operation of the receiving system (∿10% at 6cm). This factor prohibits installation on all antennas.

ii) Significant cost of installation on all antennas is beyond budget allocation for solar observing modifications.

Marsh: Our solar flare observations with the VLA indicate that 16-bit storage for the visibilities is inadequate to cover the dynamic range of the visibility function. One way of overcoming this would be to use different gain codes for different baselines. Would this be feasible?

Archer: To overcome this difficulty would in principle be feasible, although possibly not in the manner suggested. However, extensive changes to the visibility data handling software would be required. Due to other priorities especially the implementation of the spectral line observing program, I do not see any modifications being made,for quite some time.

Tarnstrom: Have you considered injecting a frequency comb to obtain continuous phase calibration?

Archer: The possibility of injecting a phase coherent frequency comb for continuous phase calibration has been considered in detail analytically by A.R. Thompson in an internal VLA memorandum. The method has been shown to be feasible. However, once again, priorities dictate that the implementation of this system be delayed until after the completion of the construction program in 1981.