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Phase calibration scheme for a "T" array

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Abstract. A calibration scheme based on closure and redundancy techniques is described for correcting the phase errors in the complex visibilities observed with a T-shaped radio interferometer array. Practical details of the scheme are illustrated with reference to the Gauribidanur radioheliograph (GRH).

Key words: radio telescopes — interferometry — calibration — data analysis

1. Introduction

It is well known that the phase and amplitude errors in the complex visibilities observed with a radio interferometer array can be effectively removed making use of closure techniques (Jennison 1958; Rogers et al. 1974; Readhead & Wilkinson 1978) and redundancy in the length and orientation of baseline vectors (Ishiguro 1974; Noordam & de Bruyn 1982; Wieringa 1992; Nakajima et al. 1994). These techniques make use of the fact that most of the errors can be ascribed to individual antennas (see Pearson & Readhead 1984 for the details). In this paper a scheme based on these techniques is described for eliminating the phase errors in a T-shaped interferometer array particularly those in which the tilting of the antenna beam is done through introduction of phase/delay gradients across the array.

2. Need for the scheme

It is well known that the phase and amplitude errors inferred from observations of a calibrator source may not apply to a source observed at a different time and in a different part of the sky because of the phase errors due to propagation effects. Also in the case of a dipole antenna array like the GRH (Ramesh et al. 1998) where one has to introduce phase/delay gradients across the array to tilt the antenna beam, the instrumental phase errors do not remain constant. Apart from this external calibration scheme, the other method by which one can obtain the correction terms independant of knowledge about the sky brightness distribution is by the use of a calibration scheme based purely on redundancy in the length and orientation of the baseline vectors. But there are some practical difficulties in using this scheme for a dipole array.

In an array like the GRH, the phases of the different antenna groups along either arm of the "T" can be found by using the redundant baselines along the respective arms. These phases can then be used to correct the observed visibilities on the cross baselines (E-W $\times$ S or E-W $\times$ N) since in a T-shaped interferometer array only the visibilities corresponding to the multiplication between the antennas in either arm are necessary for making a 2D map. But the phase/delay shifter settings for tilting the antenna beam will be different for the two arms of a "T" array and in general it will not be possible to compensate exactly the path length differences between the individual elements in a group for different source locations. Due to these, the visibilities on the cross baselines will have residual phase errors. In view of the above, we present a hybrid imaging scheme based on closure and redundancy techniques to get the position of the structures in the source and then use the self-calibration for a proper treatment of the noise (Cornwell & Fomalont 1989). According to Perley (1989), self-calibration reduces the noise in regions of no known structure and increases the source brightness. It is well known that self-calibration converges quickly particularly for complex fields if the initial model closely approximates the actual source brightness distribution (Cotton 1979; Wieringa 1992) and also it fits the closure phases well (Pearson & Readhead 1984).

3. The scheme

The present scheme is described with reference to the array configuration of the GRH which has 16 antenna groups along a E-W arm and another 16 along a South arm. The redundant shortest baseline in the E-W arm is used along

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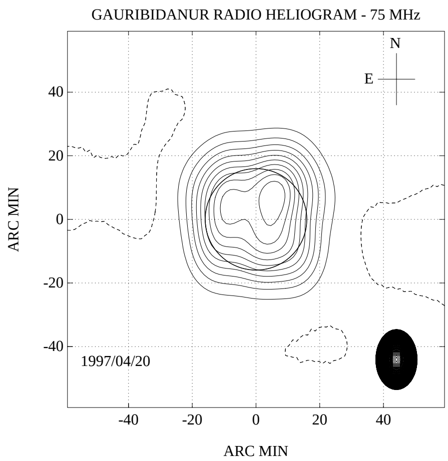

Fig. 1. Radio map of the Sun at 75 MHz made by elimination of phase errors using redundancy and closure techniques. The open circle at the centre is the optical Sun and the filled circle at the bottom right is the beam of the instrument. The peak brightness in the map is $\sim 1.5\ 10^6$ K and the rms noise is $\sim 2.5\ 10^4$ K

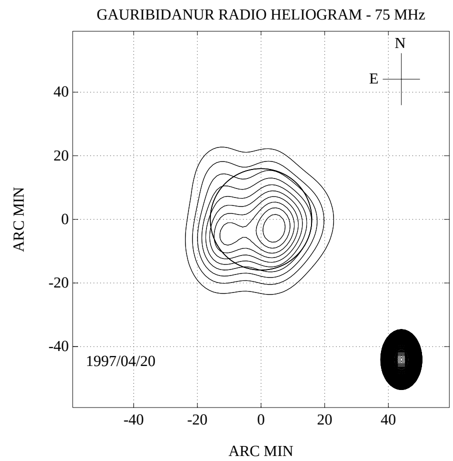

Fig. 2. Radio map of the Sun obtained on the same day as in Fig. 1 but using the external calibration method with the radio source Virgo A as the calibrator

with those formed by the multiplications between the antenna groups in the E-W and South arm. Consider the multiplications between the groups $G_1,\ G_2,\ G_3\ \ldots\ G_{16}$ in the E-W arm and G_{17} in the South arm. The possible closure equations are,

$$\theta_{1,2,17} = \phi_{1,2}^{\text{obs}} + \phi_{2,17}^{\text{obs}} - \phi_{1,17}^{\text{obs}} \quad (1)$$

$$\theta_{2,3,17} = \phi_{2,3}^{\text{obs}} + \phi_{3,17}^{\text{obs}} - \phi_{2,17}^{\text{obs}} \quad (2)$$

$$\vdots$$

$$\theta_{15,16,17} = \phi_{15,16}^{\text{obs}} + \phi_{16,17}^{\text{obs}} - \phi_{15,17}^{\text{obs}}. \quad (15)$$

These 15 equations can be solved for the 16 unknowns using the standard singular value decomposition technique (Press et al. 1992). The method gives the best possible solution in the least squares sense. It can be shown that the error due to the number of equations being one less than the number of unknowns is only 6% (Ramesh 1999). The above process is repeated 16 times corresponding to each one of the 16 groups in the South arm. In each step, a set of 16 phases are determined and thus at the end of 16^{th} step, we have all the 256 true visibility phases that correspond to the E-W $\times$ S multiplications. It is to be noted that in the above set of equations, the visibility phases $(\phi_{1,2}^{\text{obs}}, \phi_{2,3}^{\text{obs}}\ \ldots\ \phi_{15,16}^{\text{obs}})$ corresponding to the redundant shortest baseline in the E-W arm is assumed to be zero, since the baseline length is small to resolve a source like Sun in our frequency range ($40 - 150$ MHz) of observation.

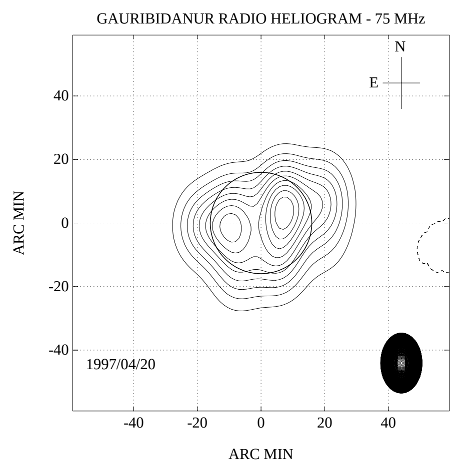

Fig. 3. Radio map of the Sun at 75 MHz made using self-calibration technique in AIPS with the map in Fig. 1 as the starting model. The peak brightness in the map is $\sim 1.6\ 10^6$ K and the rms noise is $\sim 10^4$ K

Figure 1 shows the radio map of the solar corona at 75 MHz obtained with the GRH on April 20, 1997 using the above method. The map made using the external calibration method i.e., by correcting for the instrumental errors using the observations of radio source Virgo A (which is a point source for the GRH and happens to be close to the Sun's declination during the month of April) is shown in Fig. 2. The similarity between the two maps is good. A map obtained using the self-calibration technique with the map in Fig. 1 as the starting model, is shown in Fig. 3. One can notice that the features in the self-calibrated map are seen more clearly with improvement in the signal to noise ratio. We also found that our method is quite successful in extracting weak and diffuse features particularly during times when Sun is active and is dominated by emission from strong and localised

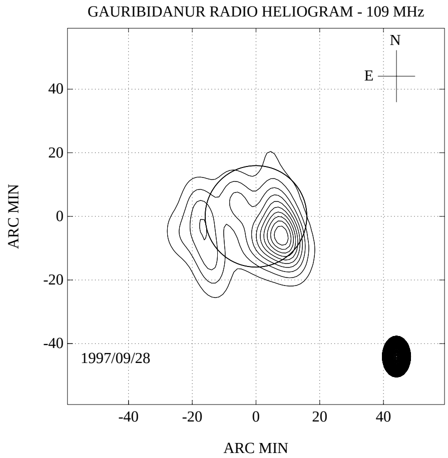

Fig. 4. Radio map of the Sun at 109 MHz obtained using our method. The brightness temperature of the bright source close to the limb in the S-W quadrant is $\sim 8\ 10^7$ K and that of the source close to the east limb is $\sim 10^6$ K

radio emitting discrete source(s). Figure 4 shows one such map obtained on September 28, 1997. Although the map is dominated by the strong source close to the limb in the S-W quadrant, the presence of weak, diffuse features close to the east limb can be seen clearly. A comparison of the GRH maps shown above with those obtained with the Nancay radioheliograph at 164 MHz indicates that our method works reasonably well.

4. Conclusion

A phase calibration scheme applicable to a "T" array is presented using closure and redundancy techniques. When combined with self-calibration, this method is particularly suitable for obtaining radio maps of the Sun with good positional accuracy and signal-to-noise ratio, since it is generally difficult to obtain an adequate initial model for self-calibrating a source like Sun which can be highly complex at times.

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