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Calibration and testing of the MEXART antenna using solar transits

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Abstract

The Mexican Array Radio Telescope (MEXART) is intended primarily for making observations of interplanetary scintillations (IPS). It consists of a 64×64 array of full-wave dipoles, operating at 139.65 MHz. The dimensions of the array are 69 m × 139 m. This array is being built in the state of Michoacan, located 350 km north-west from Mexico city (lat. 19°48′N, long. 101°41′W and 1964 m above sea level). We describe the initial tests of the antenna pattern by measuring the solar transits during the epoch (June–July 2004) that the Sun passed very close to the observatory's zenith. Observations made using different east–west rows (64 dipoles) agrees with the predicted theoretical beam pattern. The differences in the gain measurements provide important information to correct some problems with the dipole assembly, baluns and amplification system.

Keywords: Interplanetary scintillation; Instruments and techniques; Radiotelescopes; Space weather

1. Introduction

The phenomenon called interplanetary scintillation (IPS) is the random intensity variation of a cosmic radio source of small diameter caused by the diffraction of the wave front as it propagates through random fluctuations in the refractive index of the turbulent interplanetary medium. These phase distortions of the radio wave front are related to the small scale electron density inhomogeneities (ΔN_e) in the interplanetary plasma that produce a diffraction pattern in the plane of the observer and create intensity fluctuations (scintillations) as the pattern is convected across the antenna by the solar wind (Ananthakrishnan et al., 1980). The IPS technique assumes that these electron density fluctuations (ΔN_e) are proportional to density variations in the solar wind. In general, IPS events are associated with increments in solar wind density related to two general types of large-scale solar wind disturbances: (1) the region around a stream interface between a fast solar wind stream overtaking a slow stream (corotating interaction region) and (2) the density enhancement associated with solar transient events such as ICMEs and interplanetary shocks (Hewish and Bravo, 1986). IPS observations are important because they provide information on the large-scale shape and velocity of solar wind disturbances within a range in the interplanetary medium where no other technique is available to do it They can contribute to have a better understanding of ICMEs propagation and to space weather predictions.

In 2001, we began the construction of an IPS array in Mexico operating at 140 MHz called Mexican Array Radio Telescope (MEXART). Fig. 1 shows a recent picture of the MEXART from its south–west corner showing the antenna array, control room, laboratories and cubicles (under construction). Details of the prototype and selection of the final array site can be found in González-Esparza et al. (2004) (hereafter paper 1). The site is within a small farm

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Fig. 1. Picture of the MEXART observatory (see text).

community located about 330 km northwest from Mexico city. We present the initial calibration tests of the antenna array measuring the radio emissions at solar transits in the epoch that the sun passed near by the zenith.

2. Description of the array

The MEXART antenna has the same characteristics as the prototype, but covers a larger area (paper 1). The basic element of the array is the full-wave dipole ($\lambda = 2.15$ m) polarized along the East–West direction. Fig. 1 shows the array of dipoles and transmission lines (made of copper cable 14 AWG) with PVC spacers to keep the impedance constant. The dipoles and transmission lines are supported by wood poles and nylon cords. The antenna has a reflection screen $\lambda/4$ below the dipoles. The array has 64 parallel E–W rows and each row has 64 dipoles grouped in four sections (2 east and 2 west) of 16 dipoles. In total the array has $64 \times 64 = 4096$ elements occupying 9591 square meters.

Fig. 2 shows a diagram of the antenna. Each E–W row is separated about $\lambda/2$ along the North–South direction from the next row. The signal of each 16-dipole section

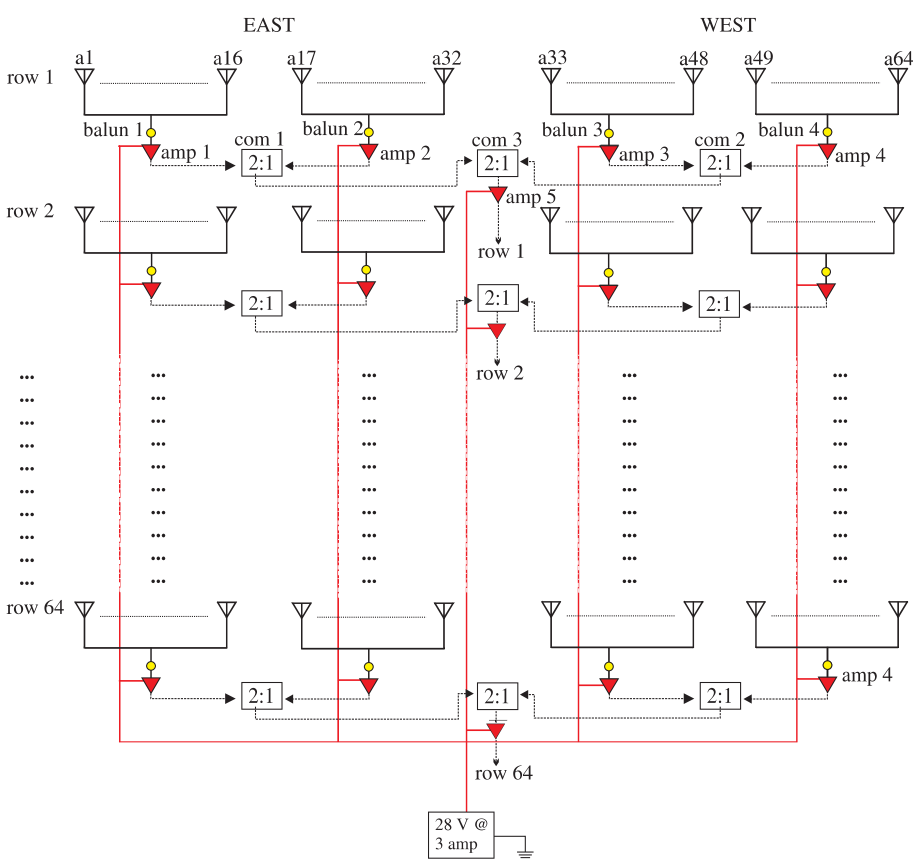

Fig. 2. Diagram of the MEXART antenna. The amplification system is underground below the dipoles and the combination system uses a tree configuration.

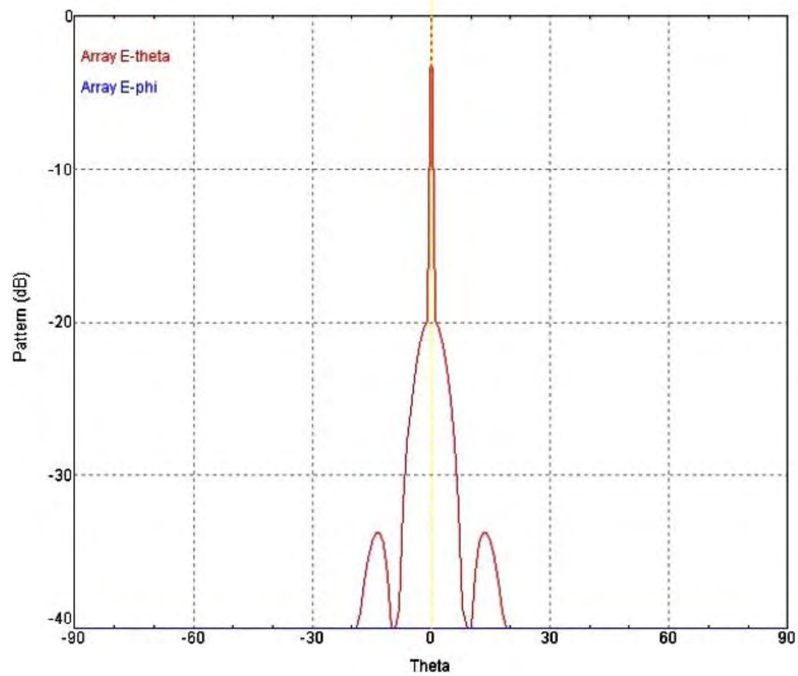

Fig. 3. Theoretical E–W (theta plane) antenna beam pattern of a 64 polarized dipoles array in rectangular coordinates and decibel power scale. The pattern was obtained by the program CAAD 5.0.

is amplified (amp 1–4 in Fig. 2) with an increment of about 28 dB and the signals of the two eastern (western) adjacent sections are added by a 2:1 power combiner (com 1–2 in Fig. 2). Finally, these resulting signals from the east and west wings are combined and amplified at the central channel sending this signal to the back-end (com 3 and amp 5 in Fig. 2). More details of the ensemble dipoles and technical characteristics of the components can be found in paper 1.

The MEXART is designed as a transit instrument and the first step in the calibration is to test the beam pattern in broadside configuration for each individual E–W row. The operation of the radio telescope requires that the signals coming from all the E–W rows arrive at the back-end with the same phase (±1°) and amplitude (±1 dB), so we need to check the beam pattern for each row. Every E–W row can be considered as a uniform linear array of 64 elements with the same amplitude and phase having a length of 64λ. Since we do not apply any weighting to different dipoles, all the signals are added equally resulting a narrow main lobe. The main lobe points toward the zenith, the half power beam width (HPBW) along the E–W is about $57°/64 = 0.9°$ and the N–S HPBW > 130° (Kraus, 1966). Fig. 3 shows the theoretical beam pattern in the E–W plane (theta plane in the figure) assuming isotropic dipoles without mutual coupling and considering that the array has a reflection screen at $\lambda/4$. The resulting main beam has a 3 dB beam width of about 0.3° with two minor lobes at about 10° from the main axis. This E–W beam pattern can be tested measuring the transit of a strong radio source passing near the array's zenith and the Sun is a good source for this purpose.

3. Solar transit measurements

At the MEXART's latitude (19°48′N) the Sun passes though the zenith twice during the summer (18 May and 23 July) and passes acceptably close between those dates. Table 1 shows the altitude of the solar transits at MEXART in this interval, providing an excellent opportunity for testing the beam pattern of individual E–W rows in broadside configuration. Fig. 4 shows some solar transit measurements by different E–W rows at different dates in 2004. The data points correspond to gain measurements taken every 30 s. For these measurements we used as a receiver a power spectrum analyzer (HP 8596E) with a 40 MHz bandwidth. The temporal durations of the solar transit through the main lobe were about 6 min in good agreement with what was expected. The observations show similar patterns of the main and the two minor lobes for all the rows, but there were other minor lobes in some measurements. The gain differences in the row measurements (before/after the main lobe) were related to some problems with the coupling of the transmission lines and the baluns,

Table 1
Date, local time and altitude of the solar transit at MEXART

Date (yr/month/day)	Time (h:m)	Altitude
2004/05/01	12:43	85°33′
2004/05/15	13:43	89°16′
2004/06/01	13:44	87°37′
2004/06/15	13:46	86°27′
2004/07/01	13:53	86°50′
2004/07/15	13:55	88°35′
2004/08/01	13:55	87°44′
2004/08/15	13:53	83°39′

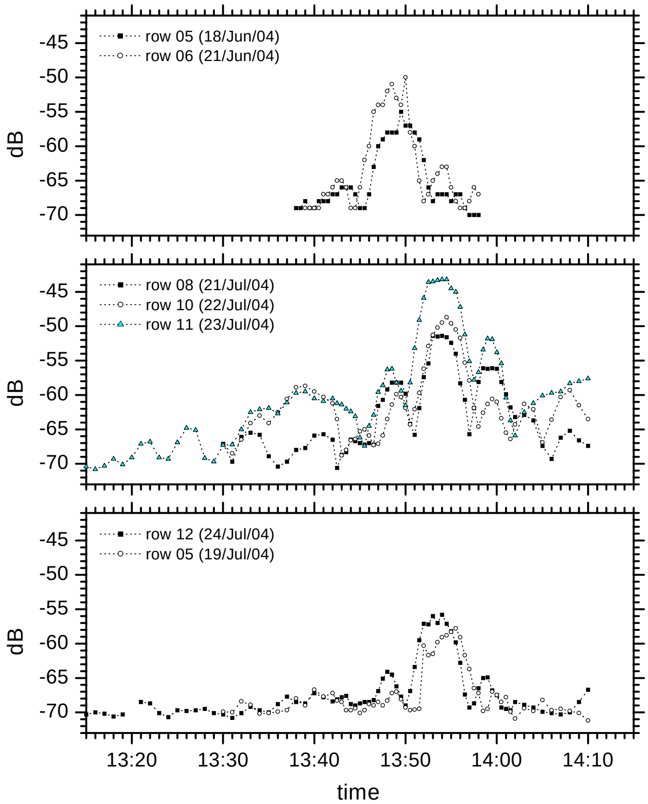

Fig. 4. Solar transit measurements of different E–W rows in broadside configuration in decibel power scale.

and differences in the amplification gains causing that the beam patterns were not symmetric. In other cases, the differences in the plots were related to IRF and solar transients. These measurements provide information to correct problems with the dipole assembly, baluns and amplification system that will be reported elsewhere.

4. Summary

We present the advances in the construction and calibration of the MEXART. At the moment of writing we are operating with about 1/4 of the total antenna array (16 E–W dipoles). The initial tests of the antenna pattern of individual E–W rows in broadside configuration agrees well with the theoretical predictions. The equality in the gain and phase of the signals coming from all the E–W rows to the back-end is an important requirement for the final operation of the IPS array.

Acknowledgments

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