MEXART: I. Sensitivity of the array and observable Inter Planetary Scintillation sources.

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1 Introduction

The minimum brightness of the source that can be observed with the telescope depends on the telescope characteristics and the random noise generated by the electronics instruments, cables etc., along the path of the signal. In addition, the contribution to the system noise by weak radio sources in the beam of the telescope (confusion limit; Condon 1974) also limit the observable sources. The expected telescope sensitivity and the confusion limit are calculated for the various configurations of Mexican Array Radio Telescope (MEXART). This can be used to test/calibrate the performance of the system. Since the primary aim of MEXART is to observe the Inter Planetary Scintillations (IPS) of radio sources, the number of sources that can be observed using IPS technique are also estimated. This helps to plan an observing strategy with the existing/future back-ends.

2 Sensitivity

The MEXART consists of an array of 64 rows of dipoles in the north-south (NS) direction. Each row consists of an east-west (EW) array of 4 modules in the east-west direction. Each module consists of an EW array of 16 dipoles in the east-west direction. The spacing between the λ dipoles at the operating frequency of 139.65 MHz, in the east west direction is λ as shown in the figure 1. The spacing between rows is $\lambda/2$. A low noise front-end amplifier of noise figure 2.9 dB is used for each module in a row. The signals from all the four modules are added together before being amplified by a similar amplifier. The rows are added together using a Butler matrix in the control room.

The effective collecting area of each λ dipole is calculated using A_{eff}=GA_0, where $A_0 = \lambda^2/4\pi$. In the final array the gain of each dipole will be affected by the coupling between dipoles. So, we estimate the 'effective gain' of a dipole by dividing the total directivity of the EW array calculated using PCAAD 5.0 (Pozar, 2002) by the total number of dipoles. The effective gain of single dipole in an EW array of 64 dipoles (single row) including the coupling effects is 7.14. So the effective area of each dipole is $2.61\mathrm{m}^2$.

The sensitivity (K/Jy) for single polarisation is $A_{eff}/2k$. The rms of the noise fluctuations (Kraus 1986),

$$\Delta T_{rms} = \frac{T_{sys}}{\sqrt{\beta\tau}}. \quad (1)$$

The system temperature, $T_{sys} = T_R + T_{sky}$. For a Noise Figure of the front end amplifier of 2.9 dB, the receiver temperature T_R=275 K. The sky background at 140MHz varies from region to region. Assuming a mean value of 200K, the $T_{sys} = 475$. For a bandwidth, β, of 2 and 1 MHz and integration time, τ, of 50 milli seconds $\sqrt{\beta\tau}$ is 316.2 and 223.6 respectively. For these values, the

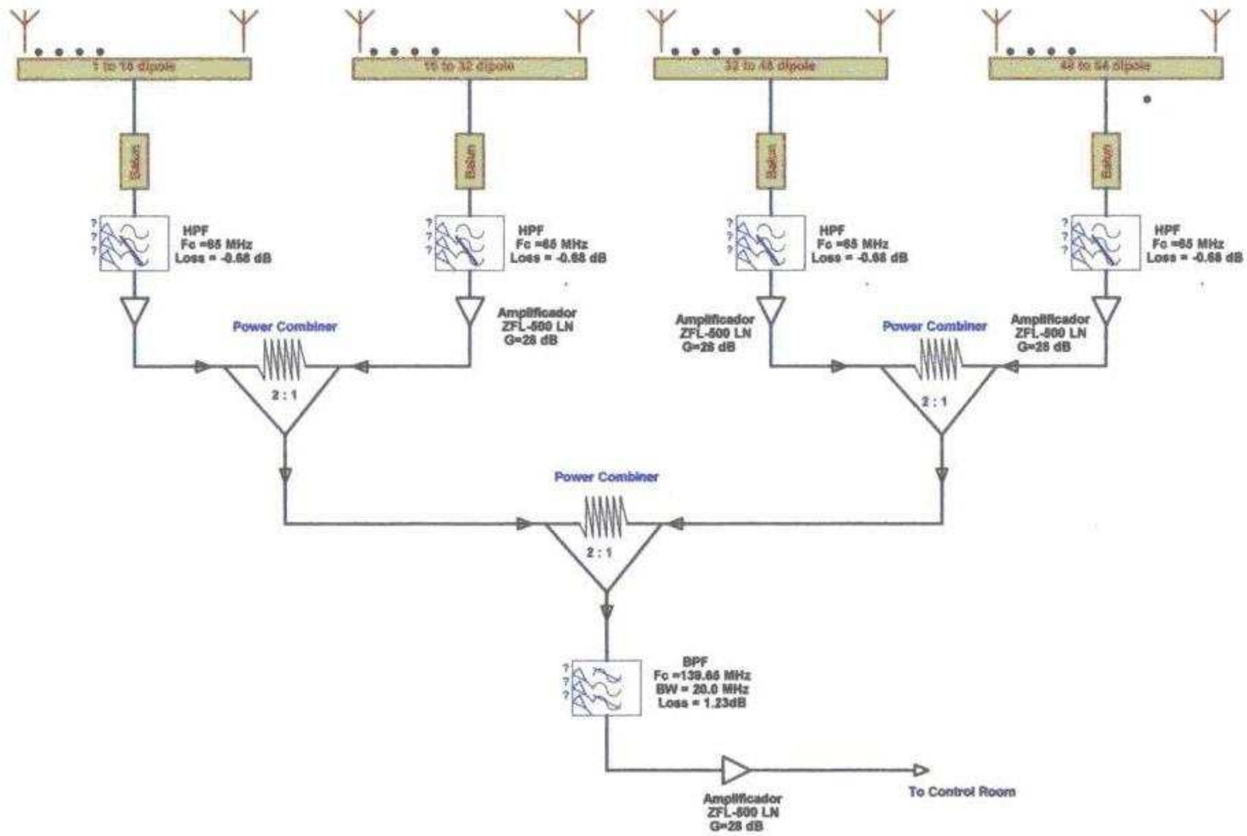

Figure 1: The block diagram of MEXART EW array of dipoles

rms noise, ΔT_{rms} and minimum detectable flux density $\Delta S_{rms} = (2k/A_{eff})\Delta T_{rms}$ are estimated (see Table 1)

The coupling between NS elements will influence the aperture efficiency. This factor is not known, so we use a value of 0.7 measured using Crab nebula as the aperture efficiency. This value is used for the calculation of the effective area using the physical area, for the NS array of rows.

3 Confusion limit

The confusion noise due to faint radio sources within the beam depends on the beam size and the frequency. The confusion limit is defined as (Condon 1974),

$$S_c = \left(\frac{q^{3-\gamma}}{3-\gamma}\right)^{\frac{1}{1-\gamma}} (n_0\Omega_b)^{\frac{1}{1-\gamma}}, \tag{2}$$

where γ and n_0 are defined as, $n(s)ds = n_0 s^{\gamma} ds$. Here $n(s)$ is the differential source count. The effective telescope beam,

$$\Omega_b = \frac{\pi}{4}\frac{\theta_1\theta_2}{(\gamma-1)ln(2)}$$

Table 1: Expected telescope sensitivity and confusion limit for various configurations

Configuration	Area m^2	Sensitivity K/Jy	ΔS_{rms} Jy (β=2MHz)	ΔS_{rms} Jy (β=1MHz)	Confusion limit Jy
1 module	41.7	0.0151	99	140	397
1 row	167.86	0.0608	25	35	137
2 rows	205⋆	0.074	20	29	133
4 rows	411⋆	0.149	10	14	57
16 rows	1644⋆	0.595	2.5	3.6	16.5
Full array	6576⋆	2.38	0.6	0.9	5.43

⋆ Calculated by assuming an efficiency factor of 0.7.

The beam widths in two perpendicular directions are denoted by θ_1 and θ_2. The factor q is usually taken to be 5. The source count at 178 MHz from the Cambridge survey provides $\gamma = 2.3$ and $n_0 = 1.0 \times 10^3$ $sources/sr$. Since the operating frequency of MEXART is closer to this frequency, the source count at 178MHz are used for the calculations. Using these values,

$$S_c = 4.1454(\theta_1''\theta_2'')^{1/1.3} \text{ Jy}. \quad (3)$$

The confusion limit for different configurations are also listed in table 1.

4 Observable sources

For detection at 3σ level with 2MHz bandwidth, the detection limit is about 1.8 Jy. For a spectral index of 0.75, this detection limit at 178 MHz is smaller by factor of 1.137. This yields a detection limit of 1.6 Jy at 178MHz. The number of sources brighter than 1.6 Jy at 178MHz is 4900 (obtained using NED). Limiting the observations to elongation angles less than 45 degrees limits the declination to ±68.5 degrees, and the number of sources observable within this range are about 4600. Restricting the scintillation targets to elongation angles between 45 and 15 degrees, the fraction of sky covered is about 0.108. Thus the number of sources that can be easily detected using IPS technique in a day are about 460 (see also next section).

5 IPS of radio sources

At the telescope operating frequency of 139.65 MHz, the angular size of the source that will scintillate is about 1 arcsec. In case of extended sources, the compact components that are smaller than 1 arcsec will scintillate. The scintillation index, $m = \Delta S_{rms}/S_T$, where ΔS_{rms} is the scintillating flux and S_T is the total flux of the source. For sources detected at N σ level the lower limit to the scintillation index, m, is 1/N. For example, for a 5σ detection, scintillation index greater than 0.2 is measurable.

The scintillation index of a point source decreases as the elongation angle (ϵ), the angle subtended by the lines of sights to the source and the Sun from the observer, increases. The

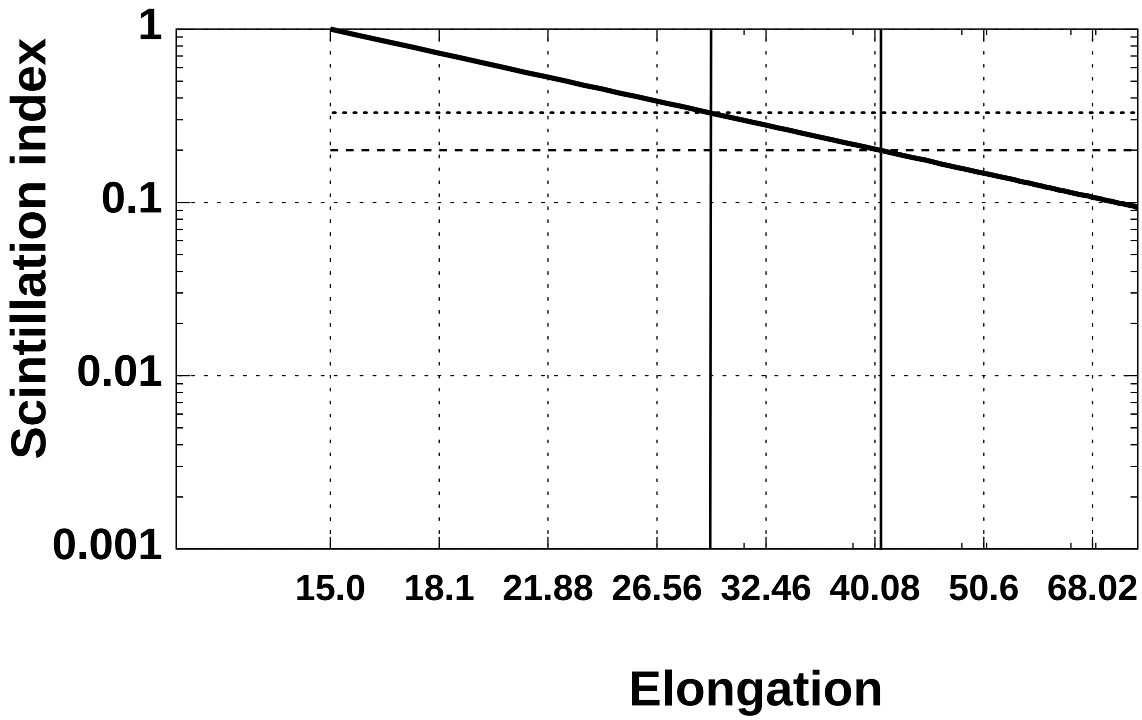

Figure 2: Variation of scintillation index with solar elongation angle.

scintillation index, m, is related to ϵ as $m \propto sin(\epsilon)^{-1.75}$ (Manoharan et al., 1995) as shown in figure 2. A lower limit on the scintillation index sets an upper limit on the elongation angle up to which scintillations can be measured. The lower-limit to the m and the corresponding upper-limit to the ϵ are given in the table 2, for different detection limits.

6 Scintillation map and observing strategy

The region set by the ϵ limit above are shown in figure 3. For an integration time of 50 ms, the minimum detectable flux is 0.6 Jy. Assuming that most of the sources are close to the detection limit, the number of sources that would fall within each zone are given in the table 2. This is calculated assuming that the lines of sights with elongation angles less than 15° are not observed due to strong scattering. Since the telescope is a transit instrument, the above elongation angles correspond to a transit time (see the table 2). During the transit time the observations can be carried out. For a source the ON source time is about 5 mins. Assuming 10 mins of observing time for each source including the OFF source observations, the total data-time is about 31 hours for 5σ and 34 hours for 10σ detection. To acquire the data within the transit time of the IPS-zone the required receivers are 6 for 5 σ detection and 3 for 10 σ detection. The number of sources that can be observed with elongation angles less than about 75 degree are about 650. These sources can be observed using 7 receivers over a transit time of 10 hours.

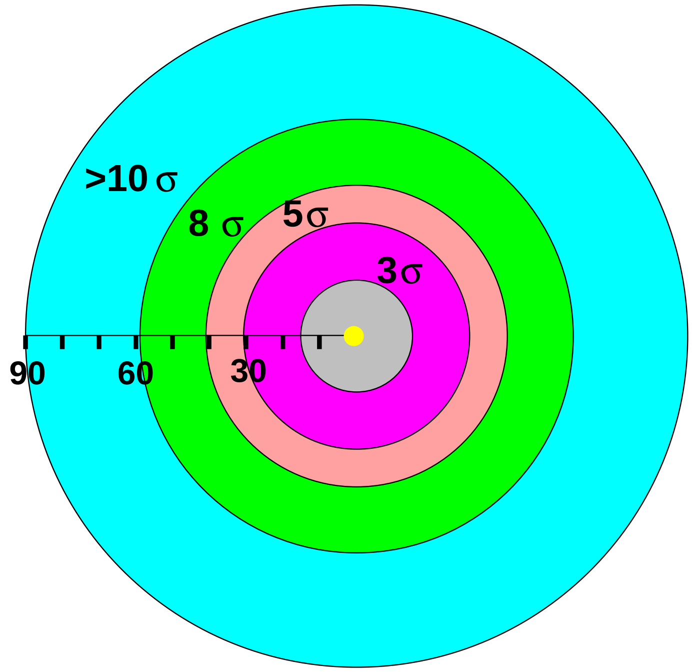

Figure 3: Region of the sky with the detection/scintillation index limit.

Table 2: Table of IPS-zone and the number of sources.

Observing limit	m-limit	ϵ-limit degree	Number of sources Total	IPS-zone	Transit Time (Hour)
1.8 Jy (3σ)	0.33	29	4900	230	3.87
3.0 Jy (5σ)	0.2	40	3000	310	5.3
6.0 Jy (10σ)	0.1	75	826	340	10.0

7 Conclusion

The sensitivity and the confusion limit of the radio array, MEXART are estimated. These values are tabulated for various configurations of the array, so that comparison can be made with observations aimed at calibrating the array. Based on the sensitivity estimates, an observing strategy is formulated for the observations of scintillating sources.

8 References

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