Optical Design Parameters of BIMA's TIW Antennas

John B. Lugten

Radio Astronomy Lab
University of California
Berkeley, CA 94720

ABSTRACT

This memo describes the optical design chosen for the new BIMA antennas (those manufactured by TIW). The coma due to the off-axis feed locations is calculated and the shape of the primary beam is calculated.

Optical Design Parameters

In order to best take advantage of the large receiver cabins on the new BIMA antennas and to provide easy access to the receivers, the Cassegrain focus has been located 24 inches aft of the vertex of the primary mirror (for comparison, the old antennas, 1 and 3, have the Cassegrain focus located 19 inches forward of the primary mirror vertex). The resulting effective focal length is 1185.9 inches and the telescope focal ratio is F/4.94 for the new telescopes. The plate scale at the Cassegrain focus is 1 arcsec = 0.00575 inches. The parameters of the optical design are given in Table 1.

Coma due to Off-axis Feeds

The feed horn for each frequency band is located off axis by a distance of 2.5456 inches at the Cassegrain focal plane corresponding to 7.379 arcsec on the sky. The angular tangential coma, ATC, due to this off-axis illumination of the telescope is given by,

$$ATC = \frac{3\theta D^2}{16 f^2}$$

where D is the telescope diameter, f is the effective focal length, and θ is the off axis angle. The r.m.s. phase error in the wavefront, Φ_{rms}, due to this distortion is given by

$$\Phi_{rms} = \frac{D \cdot ATC}{18\sqrt{8}}$$

For the design parameters of our TIW telescopes, $ATC = 1.649 \times 10^{-5}$ radians and Φ_{rms} is 2.0 μm which is less than $\lambda/550$ even at 270 GHz. The deviation from a circular primary beam due to this coma is insignificant.

Primary Beam Shape

The receiver/telescope optics form an image of the primary mirror at the aperture of the feed horn. This provides frequency-independent coupling of the feed horn to the dish, very high aperture efficiency, and a primary beam diameter which scales with wavelength. Using GEEBEAMS, a Gaussian mode analysis package written by Jerry Hudson, the electric field pattern was propagated from the feed horn aperture to the sky, including the effects of truncation of the field at all finite-sized apertures along the optical path. The electric field pattern of the primary beam is well approximated (to an accuracy of about a percent of the peak) by

$$|E| = (1.0 + .3982s - .0453s^2 + .0633s^3 - .0346s^4)e^{-s}$$

where,

$$s = \left(\frac{\Theta(arcsec)}{26.50\lambda(mm)}\right)^2$$

The simpler function,

$$|E| = (1.0 - .093s^2)e^{-0.598s}$$

is an equally good fit inside the half power point and also gives approximately the correct radius for the first null. Truncation of the E field by finite-sized apertures (lenses, windows, etc.) is more severe at low frequency, but the shape of the primary beam is not substantially affected. The direction of E is very nearly vertical over the primary beam.

The size of the primary beam scales with wavelength following the relation $\theta_{\mathrm{FWHP}} = 1.14\lambda/D$ which gives for our 6.096 m dish diameter θ_{FWHP}(arcsec)= 38.7λ(mm). The angular radius to the first null is $\theta_{\mathrm{radius\ 1st\ null}} = 1.40\lambda/D$, which is $\theta_{\mathrm{radius\ 1st\ null}}$(arcsec)= 47.9λ(mm) for the BIMA antennas.