interoffice

NATIONAL RADIO ASTRONOMY OBSERVATORY

TUCSON, ARIZONA

25 Meter - Millimeter Wave Telescope
Memo # 42

To: 25-Meter Telescope Design Committee

From: B. L. Ulich

Subject: Pattern range for the 25-meter telescope

Previous experience with existing millimeter wavelength radio telescopes has proved the value of constructing a pattern range for various antenna measurements. In fact, with the exception of the NRAO 36-foot telescope on Kitt Peak, all existing millimeter antennas in the U.S. (i.e., The University of Texas at Austin 16-foot antenna, the Aerospace Corporation 15-foot antenna, and The University of California at Berkeley 20-foot antenna) have dedicated pattern ranges with transmitters located in the far field of the telescope. Unfortunately, the 36-foot pedestal limits the observable horizon to 14° elevation, and it is therefore physically impossible to view any ground-based transmitter. This is a serious drawback in calibrating the gain, polarization, and radiation pattern of the 36-foot telescope. The absolute gain calibration must therefore depend on independent, absolute measurements with other large antennas. These data are currently scarce and sometimes unreliable. The purpose of this memo is to point out the advisability and the feasibility of a pattern range for the 25-meter telescope.

A stable transmitter in the Fraunhofer (far) zone of an antenna is a necessity for making precise absolute gain measurements (generally by comparison with a standard gain horn). It is also very useful for precisely measuring the residual instrumental polarization. The radiation pattern can be measured more quickly and to a lower level than will be possible using only celestial sources such as quasars or interstellar masers. Various reflector aberrations such as coma, curvature of field, and astigmatism could be quickly diagnosed and corrected. It should also be pointed out that when the telescope initially becomes available for testing, much work must still be done before a celestial source can be tracked within a fraction of the half power beamwidth. The transmitter obviates this difficulty and immediately provides a strong accessible signal with which to initially align the antenna subreflector, and feed. In addition, the effects of individual panel adjustments could be quickly measured, perhaps in an iterative fashion, to tune up the antenna for maximum performance. For these reasons a pattern range will not only be a convenience, but it is almost a necessity for accurately adjusting and calibrating the telescope.

The transition from the Fresnel (near) zone of an antenna to the Fraunhofer (far) zone is gradual. The usual minimum range criterion for simulating far zone patterns is $2D^2/\lambda$ (D is the antenna diameter and λ is the wavelength). However, it has been shown analytically that far zone patterns can be simulated at much smaller ranges by appropriately defocusing the feed (or subreflector) away from the primary mirror. If the range R is equal to nD^2/λ the focal length increase Δf is given by

$$\frac{\Delta f}{\lambda} = \frac{1}{n}\left[\left(\frac{f}{D}\right)^2 + \left(\frac{1}{4}\right)^2\right]$$

where f is the far zone focal length of the primary reflector. Defocusing introduces phase errors across the aperture which (in an average sense) cancel out the spherical error due to the finite range of the transmitter. After refocusing, measurements as close as $0.25D^2/\lambda$ will reliably reproduce the far zone gain and radiation pattern, and this is probably the minimum desirable range.

Regardless of which of the proposed sites is chosen for the 25-meter telescope, it should be possible to construct an adequate pattern range. I have considered in some detail where transmitters could be located if the telescope were built on Mauna Kea or on Mt. Lemmon, and the results of some calculations are shown in Table I. All the sites listed are currently accessible by road and electrical power is available. From Mauna Kea the most desirable range is to Red Hill on Maui, a distance of 128 km at an elevation angle of -1.09°. From Mt. Lemmon the best pattern range is to Kitt Peak (93 km away at -0.86° elevation). Of course, if the 25-meter telescope were built on Kitt Peak, a transmitter could be located either on Mt. Lemmon or on Mt. Hopkins. As shown in Table I the Mauna Kea - Red Hill and Mt. Lemmon-Kitt Peak ranges are adequately long, although at 1 mm wavelength they become somewhat marginal. A rough calculation of atmospheric attenuation in the 9 mm, 3 mm, and 2 mm wavelength windows indicates losses of about -10 dB to -20 dB. In itself this is not a major problem, but it should be pointed out that the stability of the attenuation over ranges on the order of 100 km is unknown and at times turbulent fluctuations along the line of sight might limit the usefulness of the pattern range. This possible limitation could be investigated using portable equipment, and this should be done before any permanent installation is considered.

The transmitter power required is extremely small due to the fact that narrow receiver bandwidths can be used when the local oscillator is phase-locked to a stable reference source. Using current receivers and a 36-foot Cassegrain feed horn as a transmitting antenna, only about 3 microwatts of CW power is required to achieve a signal to noise ratio of 60 dB in 1 second. This miniscule power requirement permits a variety of possible transmitter designs. It should be possible to drive a harmonic generator with a klystron or solid state oscillator at 30 GHz to generate a comb of transmitter frequencies at harmonics of 30 GHz. This would be a simple economical method of producing stable signals in the atmospheric windows at 30, 90, 150, and 240 GHz.

I point out the advantages of a pattern range now because it has some impact on the detailed telescope and radome design and precise site selection. For "complete" radiation patterns the telescope should have an unobstructed view toward the transmitter down to at least -3^o elevation and preferable down to -5^o elevation. The current specification which is given in the 25-meter telescope proposal is 0^o elevation, which is inadequate for any pattern range.

Recent observations with the 36-foot telescope through the astrodome wall indicate that the incoming wavefront is considerably distorted over the telescope aperture by the dielectric fabric. The physical asymmetry of the dome with respect to the telescope produces a large linear phase error which shifts the telescope boresite by as much as 15 arc seconds. Second order phase errors are also introduced which result in curvature of field and astigmatism. The curvature of field can be corrected by refocusing the antenna, but the astigmatism results in a broadened, elliptical main beam. This asymmetric aberration cannot easily be corrected and might prove to be quite troublesome for the 25-meter telescope in a radome. The point I want to make is that both the boresite shift and the astigmatism caused by the radome fabric can be minimized by choosing the radome (or astrodome door) shape so that it is symmetrical with respect to the electrical axis of the telescope.

TABLE I

SUGGESTED PATTERN RANGES FOR 25-METER TELESCOPE

FROM	TO	Range, R (km)	Azimuth (°)	Elevation (°)	$n = \frac{R}{D^2/\lambda}$, λ = 9.55 mm	λ = 1.2 mm
Mauna Kea	Red Hill	128	320.69	-1.09	1.96	0.25
Mauna Kea	Mauna Loa	41	200.11	-0.24	0.63	0.08
Mt. Lemmon	Kitt Peak	93	235.23	-0.86	1.43	0.18
Mt. Lemmon	Mt. Hopkins	85	185.71	-0.66	1.30	0.16