18-Meter Antenna Optics Definition

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Change Record

Version	Date	Author	Affected Section(s)	Reason
1	2020-08-17	W. Grammer	All	Initial draft
2	2020-08-21	W. Grammer	5	Added edited content from L. Baker
3	2020-08-24	W. Grammer	5	Added more content from L. Baker; broke it into subsections for easier reading.
4	2020-08-27	W. Grammer	All	Text edits from L. Baker, R. Selina, D. Dunbar; figure edits from S. Sturgis
A	2020-08-28	A. Lear	All	Minor formatting and copy edits; prepared PDF for signatures and release
A.01	2020-09-21	R. Lehmensiek	All	Revisions based on ngVLA #7 Optics
A.02	2020-09-21	W. Grammer	All	Minor editing
A.03	2020-09-22	R. Lehmensiek	All	Minor Editing
A.04	2020-09-25	A. Lear	2.1	Added document numbers for AD03–AD05
B	2020-09-28	A. Lear	All	Merged change logs for versions A & B; prepared PDF for approvals and release

Table of Contents

1 Introduction

1.1 Purpose

This document provides a detailed description and specifications for the 18-meter antenna optics. It covers the optical system geometry, coordinate systems, ray trace description, mapping function description, and associated CAD files and formats for import. This document will form part of the Antenna Request for Proposal (RFP) documentation package.

1.2 Scope

The scope of this document covers the description of the 18-meter antenna optics, as part of the 18-meter Antenna RFP documentation package. It does not cover design aspects of the reflector system or antenna feeds, nor include any analysis results of the described optical system coupled with ideal or actual feed horns.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents may not be directly referenced herein, but provide necessary context or supporting material.

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA Antenna Technical Requirements	020.25.00.00.00-0001-REQ
AD02	Antenna Coordinate Systems	020.10.30.00.00-0001-SPE
AD03	18m Antenna Optical Sketch - ngVLA #7	020.25.01.00.00-0009-DWG
AD04	ngVLA Antenna: 18M Optical Surfaces – ZIP file	020.25.01.00.00-0010-DSN
AD05	ngVLA Antenna: 18M GRASP Input Files – ZIP file	020.25.01.00.00-0011-DSN

2.2 Reference Documents

The following documents are referenced within this text:

Ref. No.	Document Title	Rev/Doc. No.
RD01	Analysis of ngVLA Design #6 with ideal and actual feed	020.25.01.00.00-0001-REP
RD02	Offset Dual Reflector Antenna	Y. Mizugutch et al., *Proc. IEEE Antennas Propag. Soc. Int. Symp. Dig.*, Oct. 1976, pp. 2–5

3 Optics Definition Overview

The ngVLA main antenna will be implemented as a dual-offset Gregorian optical configuration, similar to the one given in [RD01], with an unblocked primary aperture of 18 meters, a secondary reflector chord length of approximately 3.33 meters, and a subtended half-angle at the secondary focus of 55 degrees. Optical shaping of both reflector surfaces is used for increasing the antenna forward gain, with acceptable trades in sidelobe levels and offset tolerances (scan loss, pointing error). The appropriate choice of primary and secondary offset angles is used for effective cancellation of the cross-polarization response introduced by the offset geometry, analogous to the Mizugutch condition [RD02] for unshaped (conic) optics. The secondary reflector is slightly oversized towards the bottom end to shield the feed horns from ground emission, thus reducing the antenna temperature.

The mapping function used for shaping the optical system was derived by an exhaustive parametric study of a parameterized aperture field distribution using an actual feed horn radiation pattern. The main objective was to maximize the system's receiving sensitivity.

4 Optical Parameter Definition

Figure 1 (taken from [AD03]) shows the key dimensions and angles in the dual-offset optical geometry. The main view is a cross-section of the optical surfaces, cut along the elevation plane of symmetry at a single azimuth angle, as shown in the inset figure. The Main Reflector (MR) coordinate frame is used in this drawing. Also shown are the 'local' coordinate frames for the primary, secondary, and secondary extension reflectors. The y-axis is orthogonal to this plane, with direction defined by the right-hand (RH) rule (i.e., into the page).

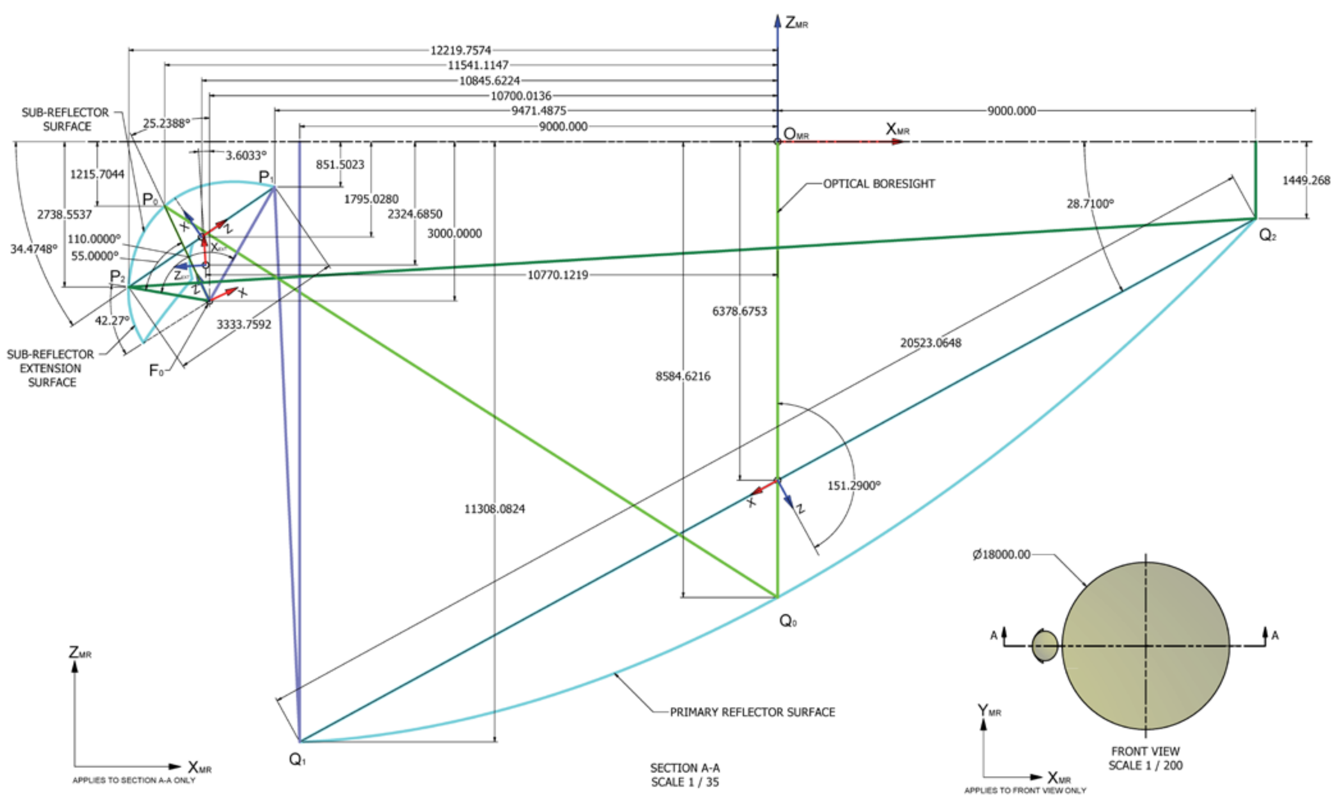

Figure 1 – 18-meter antenna optical system critical dimensions.

The table below defines the coordinate points in the symmetry plane (*y* = 0 mm), as shown in Figure 1, of the secondary focus (F_0), and points (center and edges) on the primary (Q_0, Q_1, Q_2) and secondary (P_0, P_1, P_2) reflectors.

	x [mm]	*z* [mm]
F_0	–10 700.0136	–3 000.0000
P_0	–11 541.1147	–1 215.7044
P_1	–9 471.4875	–851.5023
P_2	–12 219.7574	–2 738.5537
Q_0	0.0000	–8 584.6216
Q_1	–9 000.0000	–11 308.0824
Q_2	9 000.0000	–1 449.2682

5 Optical Surfaces Description

Figure 2 shows the same cross-sectional view of the reflector surfaces as defined in Figure 1, but with an optical ray trace overlay based on the mapping function used for optical shaping. Optical rays from the secondary focus towards the extension of the secondary reflector will reflect towards the cold sky (above the primary reflector) and in front of the secondary focus, as shown in Figure 3 (next page). The rays clearly show the regions in the vicinity of the focus where antenna structural elements and/or equipment can be placed without obstructing the beam.

The effect of optical shaping is evident at the aperture plane formed by the *x*–*y* axes: ray spacing is non-uniform, with closer spacing toward the edges. This effectively broadens a Gaussian amplitude distribution at the secondary reflector to something resembling a uniform distribution at the primary.

Note also the lack of a well-defined focal point for the primary mirror, unlike in an unshaped system with purely conic surfaces.

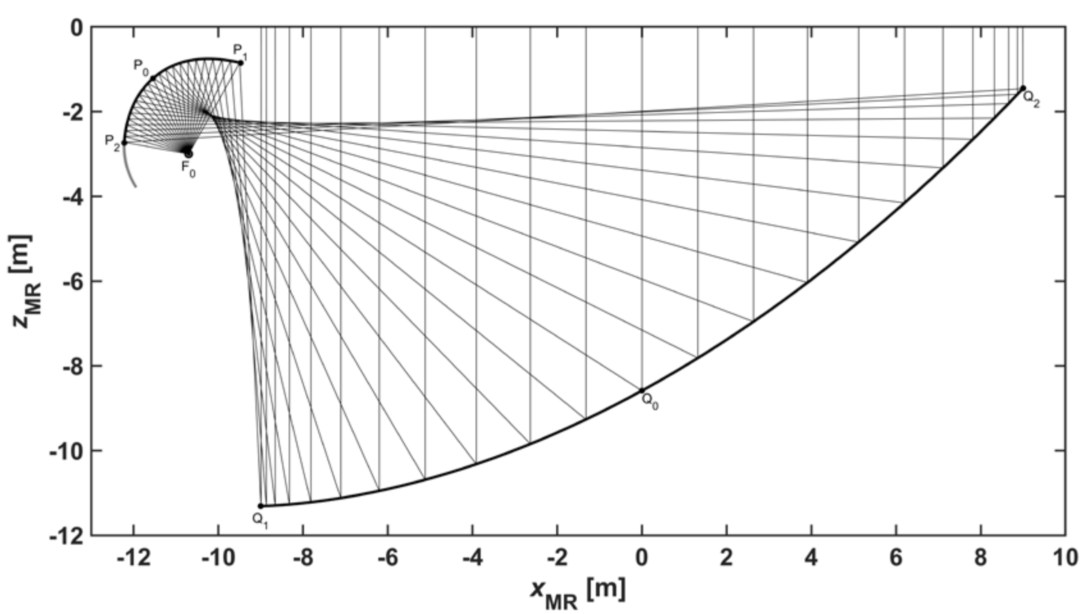

Figure 2 – ngVLA 18-meter reflector system with an optical ray trace overlay.

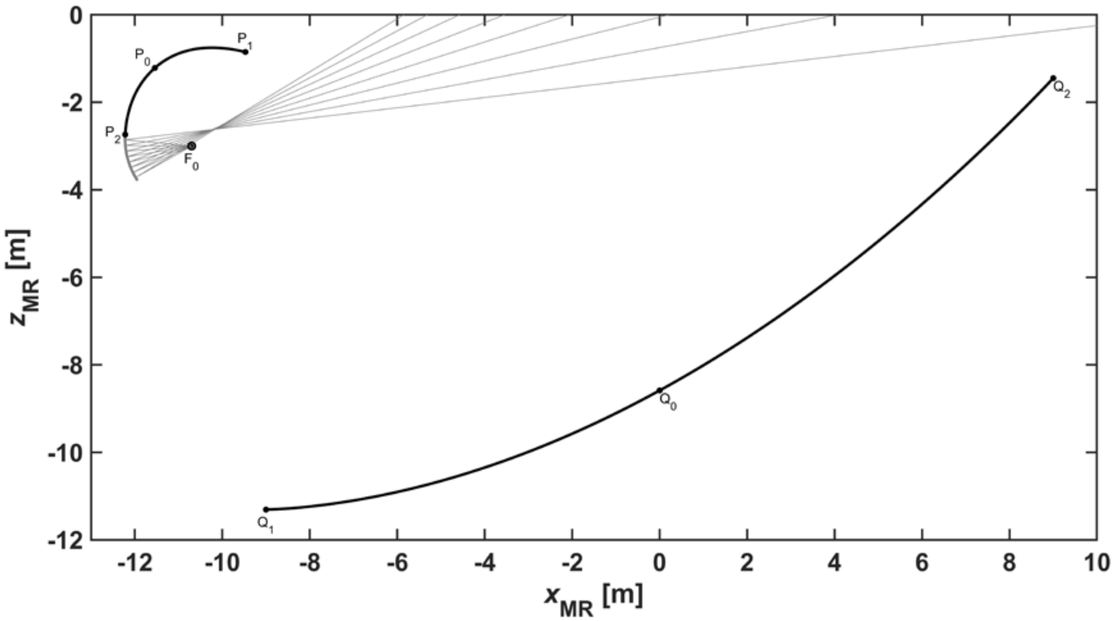

Figure 3 – ngVLA 18-meter reflector system with the ray trace overlay of rays from the secondary extension.

5.1 Mapping function

The normalized feed-to-aperture mapping function is shown in the line plot of Figure 4. For reference, the dashed line shown next to the curve is the mapping function of a conic section design. For the ngVLA mapping function, the associated feed pattern G_θ and aperture field distribution E_ρ are shown in Figure 5 (next page). The feed pattern was derived from an actual corrugated feed horn pattern averaged over the feed azimuth angles and frequency. This feed pattern closely resembles a Gaussian pattern with a 15 dB edge taper as shown by the dashed line. The optimized aperture field distribution then maximizes the receiving sensitivity.

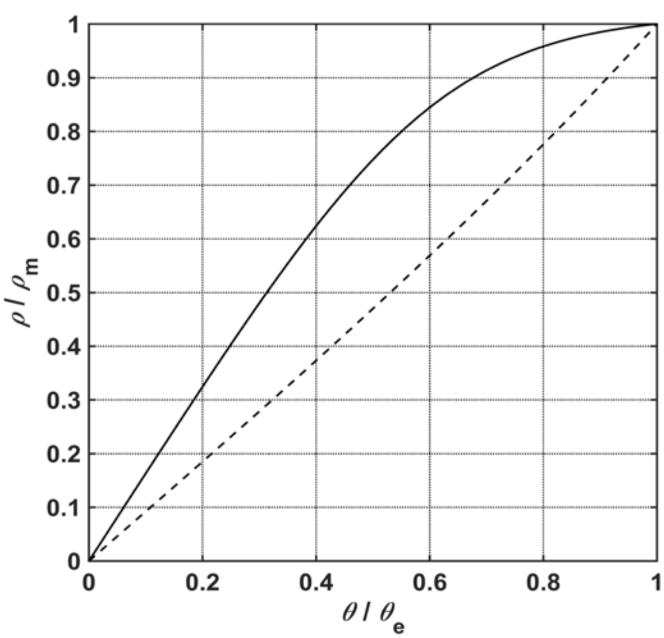

Figure 4 - The reflector system normalized feed angle-to-aperture radius mapping function.

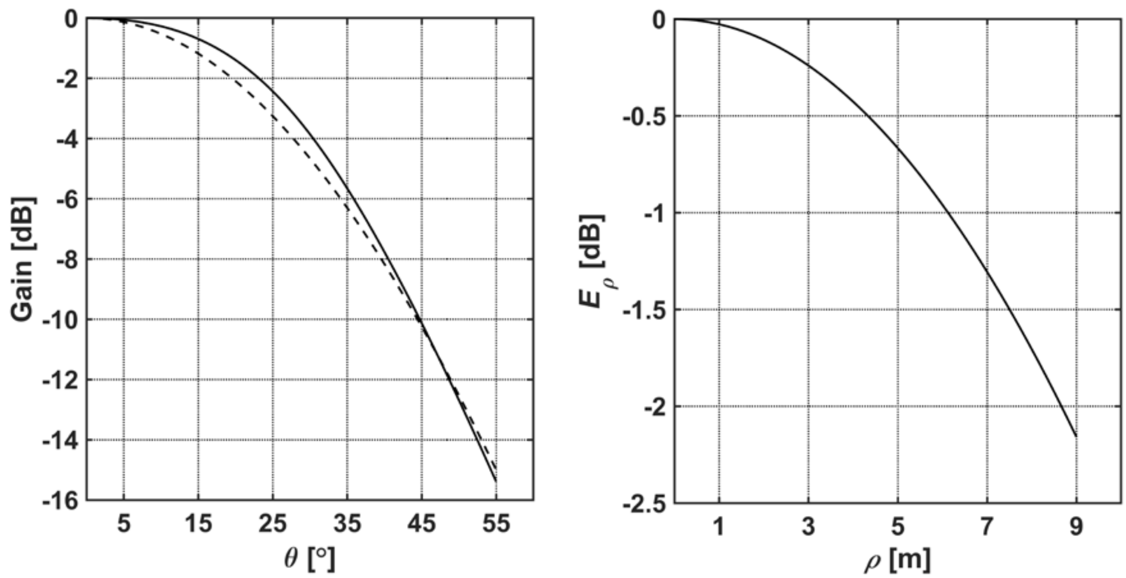

Figure 5 – The associated feed pattern and aperture field distribution of the ngVLA mapping function.

6 CAD File Formats and Importing

6.1 *GRASP File Import*

For importing an optical reflector into GRASP, three (text readable) data files are required. The first file defines the local coordinate frame of the reflector and has the extension *.*cor*. The second file with extension *.*sfc* defines the surface points consisting of rows of (*x*, *y*, *z*) coordinates mapping the reflector surface in the local coordinate frame. The distribution of *x*, *y* values is an irregular grid and GRASP uses quintic pseudospline interpolation to define the surface. The third file with extension *.*rim* defines the reflector extent or rim and has the same basic file format as the *.*sfc* file and is again defined in the local coordinate frame on the plane z = 0. Thus, for the ngVLA optics, a total of nine data files are required for the three reflectors, i.e. primary (*MR.**), secondary (*SR.**), and secondary extension (*SRext.**).

The *Feed.cor* file defines the feed coordinate system.

The object repository file (*ngVLA_7.tor*) sets up the base location and orientation of each reflector with respect to its own internal or global coordinate system, and the location and orientation of the feed coordinate system. A user would specify the feed pattern, analysis frequencies, and required primary antenna pattern in this file.

The command input file (*ngVLA_7.tci*) contains all analysis steps to be executed by GRASP as required by the user. This file contains no design-specific data.

All the above files are found in the folder *working*, and are assembled in the project file *ngVLA_7.gxp*.

A ZIP file containing all these files for the ngVLA optics is archived [AD05].

6.2 *Mechanical Model File Import*

Three IGES files [AD04] define the primary, secondary and secondary extension reflector shapes, respectively, of the 18-meter ngVLA design. In combination with the cross-section plot in Figure 1, these are used to import and integrate the antenna optical surfaces into an overall mechanical model of the antenna.

Each reflector surface is defined according to its own local Cartesian coordinate frame with the origin in the plane of symmetry. For the primary reflector, its local origin lies at the point where the rim-to-rim chord (Q1–Q2) intersects the optical boresight line along the z-axis in the MR coordinate frame. For the secondary reflector, its local origin lies on the rim-to-rim chord (P1–P2). The local *y*-axis on both reflectors is parallel to and in the same direction as the *y*-axis in the MR coordinate frame, while the local z-axis for the primary and secondary reflectors is orthogonal to the rim-to-rim chord and pointing toward the reflector. The local *x*-axis is coincident with the rim-to-rim chord and in the direction shown, as defined by the RH rule at the origin. The origin of the secondary extension reflector lies near the rim-to-rim chord of the secondary plus extension reflectors.

Transforming the IGES data into the coordinate system shown in the cross-section plot (MR coordinates) requires first a translation followed by a rotation of the local coordinate frame. Rotation is performed about the *y*-axis, with the direction of positive rotation determined by the RH rule. The required translation and rotation values for each reflector are given in the following subsections.

It should be noted that the reflector shapes defined in the IGES files for the primary and the secondary reflectors extend beyond the nominal aperture sizes defined in Figure 1. The reason was to accommodate possible use of panelized reflectors by the antenna designer that may not precisely terminate at the nominal aperture boundaries. Cutting the surface in the local *x*–*y* plane (local *z*=0) yields the actual useable aperture surface, and gives a flat rim. The precise rim shape of a shaped reflector system is non-planar by only a small fraction of a mm, so this is a negligible error. The secondary extension surface is defined only to the rim.

6.2.1 Primary Reflector Coordinate Transformation

The required translation (*x*, *y*, *z*) and rotation about the *y*-axis to convert from the local to the common MR reference frame are

(0, 0, –6.3786752986) meters
+151.2899535168065 degrees

6.2.2 Secondary Reflector Coordinate Transformation

The required translation (*x*, *y*, *z*) and rotation about the *y*-axis to convert from the local to the common MR reference frame are

(–10.845622426, 0, –1.7950279785) meters
–34.474758206973732 degrees

6.2.3 Secondary Reflector Extension Coordinate Transformation

The required translation (*x*, *y*, *z*) and rotation about the *y*-axis to convert from the local to the common MR reference frame are

(–10.770121949, 0, –2.3246850438) meters
–93.603301706926786 degrees

7 Appendix

7.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
CAD	Computer Aided Design
GRASP	[Physical optics analysis software, for computing aperture efficiency of optical systems combined with an input feed horn radiation pattern]
MR	Main Reflector
IGES	Initial Graphics Exchange Specification
ngVLA	Next Generation VLA
RD	Reference Document
RFP	Request For Proposal
RH	Right-Hand