Beam Aberration Correction Technique for a BWG Antenna

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Abstract: A technique for a real-time beam aberration correction scheme for deep space uplink and downlink communications is presented. This technique provides a closed-form relationship between the beam aberration angles and the corresponding feed displacement for a reflector antenna with a beam waveguide (BWG) or multiple reflector system. This algorithm will enable one to accurately predict the movement of the feed in real time for a known beam deviation while the antenna is tracking a spacecraft. It is also useful to determine the feed offset position needed to correct for the beam deviation due to an imperfect antenna mechanical structure, and subreflector and mirror misalignments for a complex multiple reflector system.

Introduction: The aberration effect arises whenever a spacecraft is not moving along the line of sight as seen from an antenna on earth. In such a case, the spacecraft has a cross-velocity component, which is normal to the line-of-sight direction. In order to obtain optimum two-way communication, the uplink and downlink beams must be pointed differently for simultaneous uplink and downlink communications. At any instant of time, the downlink (or receive, Rx) beam must be pointed at a position where the spacecraft was 1/2-round-trip light time (RTLT) ago, and the uplink (or transmit, Tx) beam must be pointed where the spacecraft will be in 1/2-RTLT (Figure 1). For a spacecraft at Saturn, the RTLT is about 160 minutes with a maximum beam separation of about 20 mdeg. Without a proper aberration correction, the uplink pointing loss will exceed 5 dB for more than 30% of the time for a 34m antenna at Ka-band, where the uplink half-power beamwidth is about 16 mdeg. For a BWG antenna as shown in Figure 1, the separation of Rx and Tx beams can be achieved by having the Tx feed move while the Rx feed is fixed. The purpose of this paper is to present a technique that will provide a closed-form relationship between the feed movement and the aberration value or beam deviation. This algorithm will enable one to accurately predict the feed movement in real time for a known beam aberration angles while the antenna is tracking. It is also useful to quickly determine the feed offset position needed in order to correct for beam misalignment due to an imperfect antenna mechanical structure or mirror/subreflector misalignment.

Analysis Method: The aberration effect, or the separation between the Rx and Tx beams is defined by aberration values (α, β) where α is a separation distance (typically 0–20 mdeg) and β is a clock angle from 0 to 360 degrees (Figure 2). Assume that the Rx feed is fixed at the 0,0 position with the Rx beam coincident with the antenna axis. From Figure 1, the Tx feed is positioned on an X/Y table, and has to move from position 1 to position 2 in order to produce the two-beam separation and orientation (α, β). The main issue is to find a closed-form relationship between the feed position (ρ, ϕ) and the beam movement (α, β). The complexity of this problem is due to the fact that α and β vary with time and the BWG mirrors rotate with the azimuth (AZ) and elevation (EL) pointing of the antenna. Also, the beam position depends on the angle between the azimuth pointing of the antenna and the position of the feed on the floor of the antenna pedestal room.

The approach to this problem is to recognize that the separation distance α depends entirely on the feed movement in the ρ direction, if the antenna optics is circularly symmetric in ϕ. The asymmetric case will be discussed later. The relationship between α and ρ could be determined by several techniques, such as ray tracing, or a more accurate rigorous technique using a scattering program. In this approach, a spherical wave expansion (SWE) is used for the feedhorn representation, physical optics scattering is used for all mirrors and the subreflector, and the Jacobi-Bessel technique is used for the main reflector analysis in order to obtain the beam offset (α) and peak gain loss due to feed displacement ρ. The analysis was performed on the 34m BWG antenna (DSS-25) of the NASA/JPL Deep Space Network (DSN) at Goldstone, California. The result is shown in Figure 3. The best-fit polynomial to this curve, which will be used for real time correction on the antenna is

$$\rho = 0.087\,\alpha + 0.00065\,\alpha^2 \qquad (1)$$

where ρ = radial feed movement in inches and α = beam separation in millidegrees. The above relationship depends on the optics configuration of each antenna. The ϕ dependency for an asymmetric antenna can be obtained (if needed) by analyzing ρ vs. α in different plane cuts and performing a two-dimensional curve fit.

The feedhorn angular rotation ϕ depends on the aberration clock angle β, the antenna pointing direction (AZ, EL), the feed position on the floor (ϕ_F), and a constant ($n\pi/2$). This relationship (in degrees) can be written as

$$\phi = -\beta + EL - (AZ - \phi_F) - 90 \qquad (2)$$

Equation (2) is for JPL DSN BWG antenna (DSS-25) as shown in Figure 1. For other antennas with different optics configurations, this equation may have different signs for the various terms, and the general form of the constant will be $n\pi/2$, where n = 0, –1, 1, 2. The actual signs and value of n can be easily determined by performing tests on an actual antenna with known feed offset locations and known beam movements.

Numerical Results and Discussion: Measurements were performed on the DSS-25 34m BWG antenna to validate the findings, and the results show excellent agreement between predicted and actual beam movement. Samples of the test data will be presented. Figure 4 shows the actual aberration values (XEL and EL beam movements, $\Delta XEL = \alpha \cos[\beta], \Delta EL = \alpha \sin[\beta]$) of the Cassini spacecraft during a 7-hour period of its cruise phase in January 2000. The α value at this time (19 mdeg) was larger than will be typically seen when the spacecraft is in orbit at Saturn. The movement of the feed is almost at a constant radius because of a nearly constant value of α. However, the feed angular motion is much larger, due to the complex relationship among β, AZ, and EL during the track, as can be seen in Equation (2).

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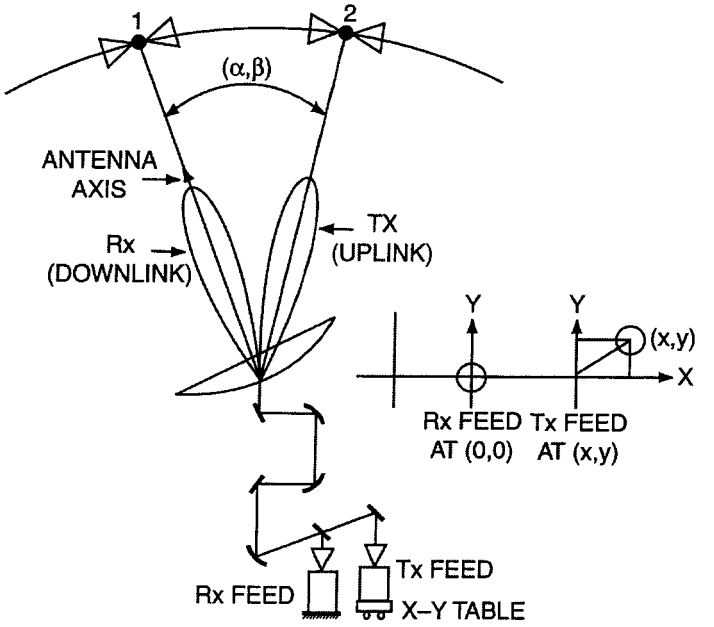


Figure 1. BWG antenna with aberration effect.

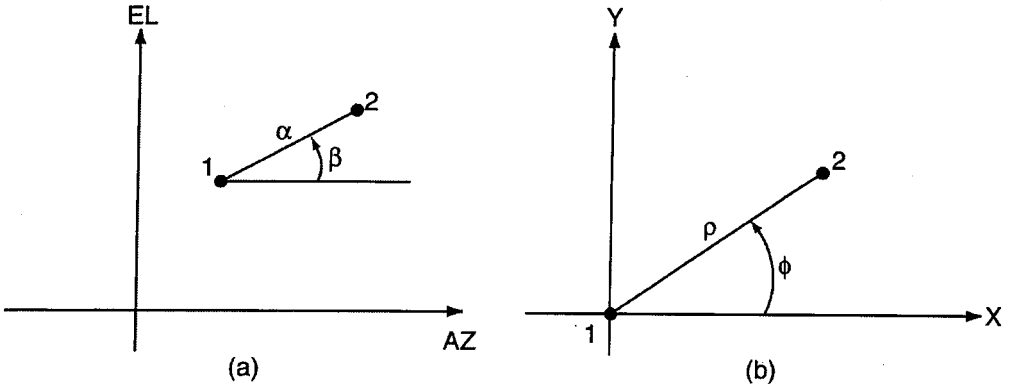


Figure 2. Configurations for (a) aberration space and (b) XY feed coordinate.

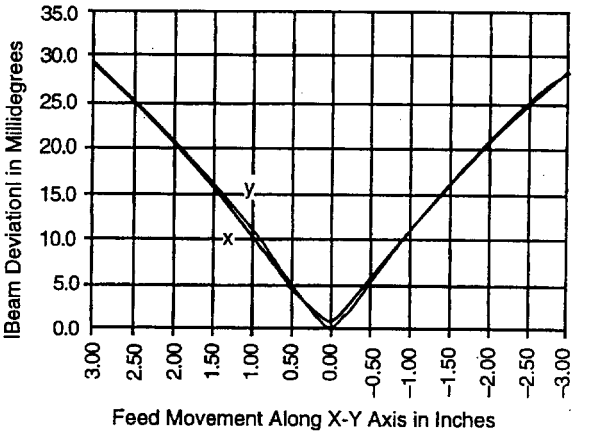
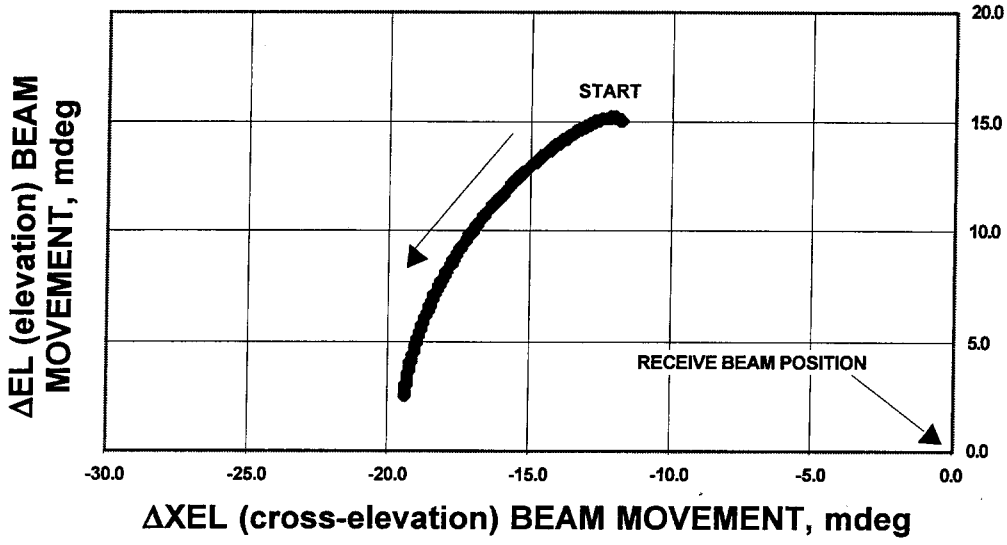
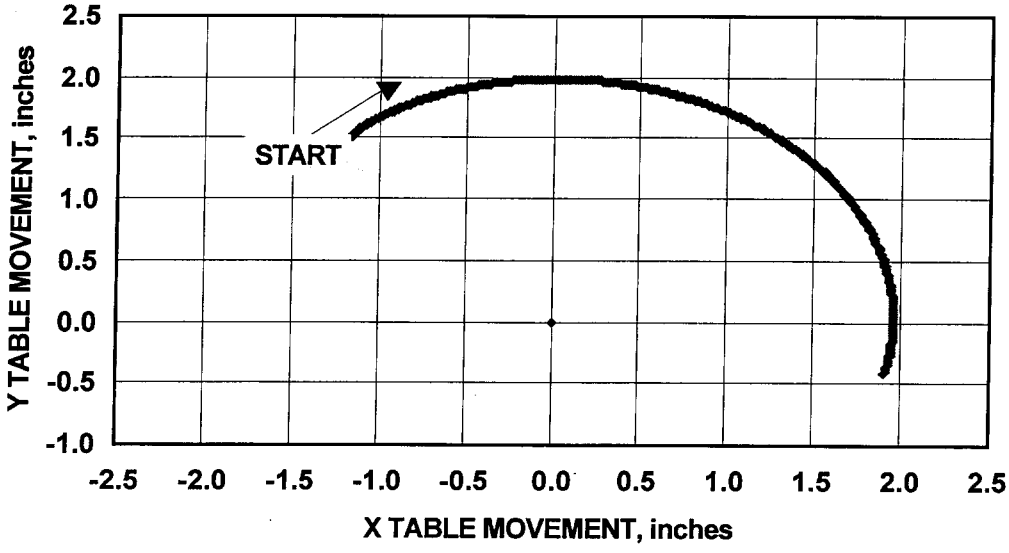


Figure 3. Beam deviation vs. feed movement for DSS-25.



(a)



(b)

Figure 4. (a) Actual aberration values, and (b) the movement of the feed.