08.12.2020

Some parameters of the old Arecibo telescope platform and dish:

Platform weight **before** Gregorian upgrade: 550 tons
Platform weight **after** Gregorian upgrade: 900 tons

Dish diameter: 305 m
Height of ground screen: 15 m
Diameter of illuminated surface: 213 m (L-band)
Dish depth (from vertex to rim level): 50 m
Dish radius of curvature: 265 m
Dish panel dimensions: 1 mm thick, about 3 x 6 ft (the latter seems too large)
Idealized focal length (1/2 radius of curvature for spherical reflector): 133 m
Length over which focus actually occurs, due to spherical aberration: 30 m (length of line feed)
Length of azimuth arm: 100 m
Diameter of Gregorian secondary: 22 m

Tower heights: 111 m, 80 m, 80 m (31 storeys, 23 storeys)

FAST telescope:

Cabin weight: 30 tons

Largest ball bearing in use (alternative platform design?):

Diameter: 3.7 m
Weight: 23 tons

The max. chance of Arecibo getting rebuilt is if the redesign keeps as much as possible of the existing structure and improves on the rest. This can be achieved by keeping the fixed spherical primary, building an active secondary, extending the azimuth arm, and having the receivers and transmitters on the ground at the vertex of the dish. The supports required for this design should be significantly lower than the old towers - at least 20 m lower, and possibly more. That would decrease the height of the required towers by at least 20-25%.

The main question: How large does the secondary need to be? This would determine the weight of the platform. For the same cable tension as before, a lighter platform will sag less, which means the required height of the supports can be decreased further.

The old Gregorian secondary in the dome was 22 m across. However, that sat above the idealized geometric focus, where reflected rays already diverge. The line of focus is represented by the old line feed (30 m); **its top end is at the geometric focus**. **Its bottom end is defined by where marginal rays cross** (rays reflected by the edges of the illuminated surface). The optimal placement of a secondary is at the **circle of least confusion**, the narrowest part of the envelope along the line of focus defined by all reflected rays. To calculate its radius, I looked at equations from two papers:

Silva-Ortigoza et al. (2001): “Exact calculation of the circle of least confusion of a rotationally symmetric mirror. II”
Hosken (2007): “Circle of least confusion of a spherical reflector” (This paper specifically mentions Arecibo)

This paper I did not use, found the notation hard to follow, but apparently it was written specifically to work out designs for Arecibo line feeds:
Spencer (1968): “Focal region of a spherical reflector - circle of least confusion”

Radius of the circle of least confusion:

- Hosken: Rc = ⅛ * r * theta^3, where r is the radius of curvature, and theta is the incidence angle of marginal rays on the spherical primary; theta in rad. This is the lowest-order approximation.
- Silva-Ortigoza: Eqn. 37 (3rd order approximation)
- For theta = 30 deg (illuminating the whole dish when looking at zenith), Rc ~ 9 m (Silva-Ortigoza)
- **For theta = 24 deg (for actual illuminated surface radius at L-band), Rc ~ 3 m (Silva-Ortigoza; maybe I messed up calculating it, that is tiny!) --> a circle with radius 3 m made of aluminum 1 mm thick would weigh 77 kg. Even if the back frame plus actuators brings it to 10x that much, it’s less than a ton total!**

Location of the circle of least confusion:

- About two-thirds the length of the line of focus from the geometric focus in the direction towards the primary. **For Arecibo, that should be around 20 m down from the top of the line feed.** (This spot was too far down to be accessible from the old platform, so the upgrade in the 1990s had to use a larger and heavier Gregorian).
- Hosken: z_c = r/2 + 3/16 * r * theta^2 (coordinate system origin is at the center of curvature of the primary). This is the lowest-order approximation.
- Silva-Ortigoza: Eqn. 32 (3rd order approximation)

Active secondary advantage:

- Adjust the size and shape of the illuminated area depending on AZ,ZA. In the extreme case, it would deform so that the entire dish is illuminated no matter what AZ,ZA is. Not sure if this is possible without increasing the size of the secondary significantly. FAST does a bit of this at higher ZA by tilting the receiver such that a larger part of the dish is illuminated than if the horn were pointed perpendicular to the dish surface. This also avoids spillover.

- Looks like it can be really small and light, which would allow for a small and light platform with a long azimuth arm.

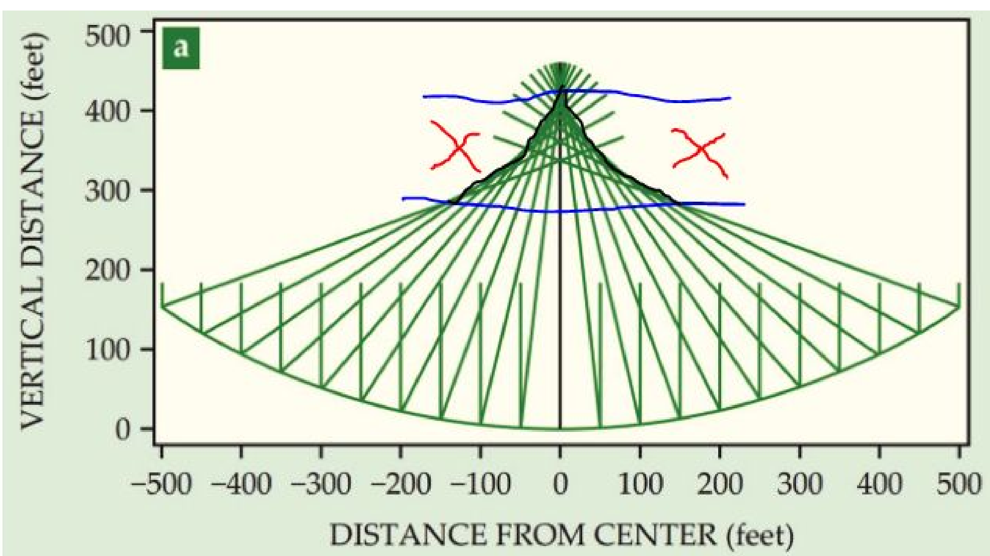
Active secondary disadvantage:

- Since the receivers and transmitters will be at the dish vertex (or even below it, on the ground), the receiver will have to tilt so that the horn always illuminates the secondary. It will have to move continuously to track the secondary as the secondary is moving to track a source.
- Receivers will have to be covered (with a radio-transparent material) since the horn will be pointing up and otherwise exposed to rain. Think a Radome at the dish vertex. Not sure if that would work for transmitters or would have to retract.

03.01.2021

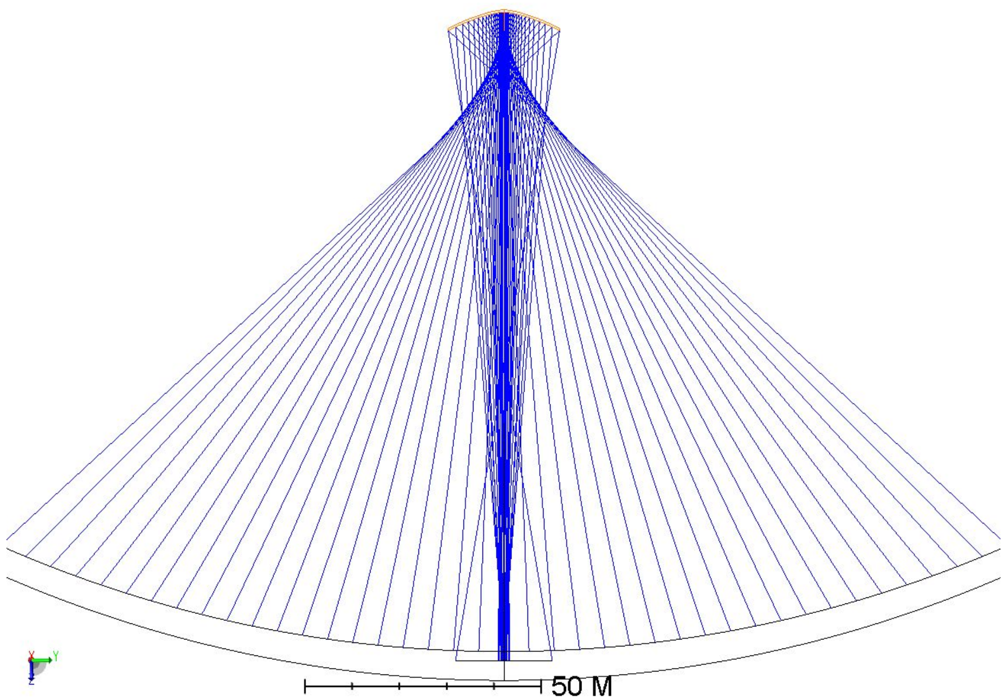
Notes from Dan Flickinger (Janelia optics expert):

- “The caustic is the surface where the reflected rays cross each other at the edge and there’s always a ray that’s tangent to it—I drew black lines over these curves. Any reflector placed in this region will have points where rays from two or more, far-away places on the primary impinge at once (this is anywhere you see rays cross in your drawing). A simple reflector surface can’t possibly treat these rays differently, and so it can’t send them all to a single secondary focus.” --> **This means the secondary can’t be at or near the circle of least confusion. It also means the secondary can’t be as small as the circle of least confusion.**

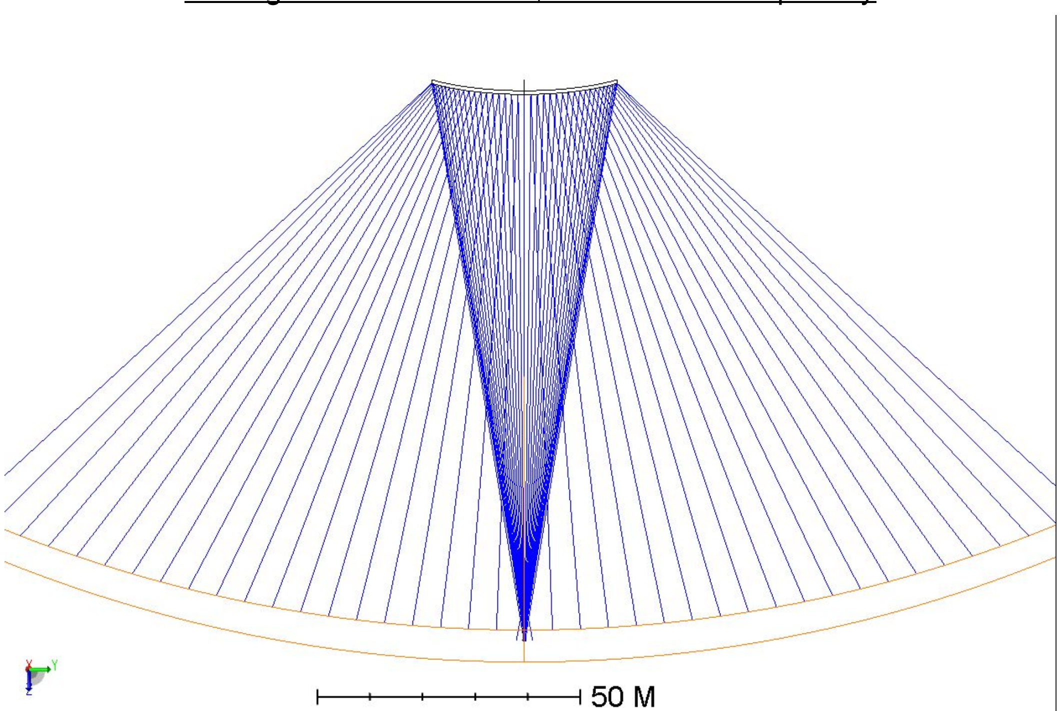


- The smallest a secondary can be is 22 m across, 132 m above the primary (Gregorian--above the caustic zone); or 32 m across, 102 m above the primary (Cassegrain--below the caustic zone).

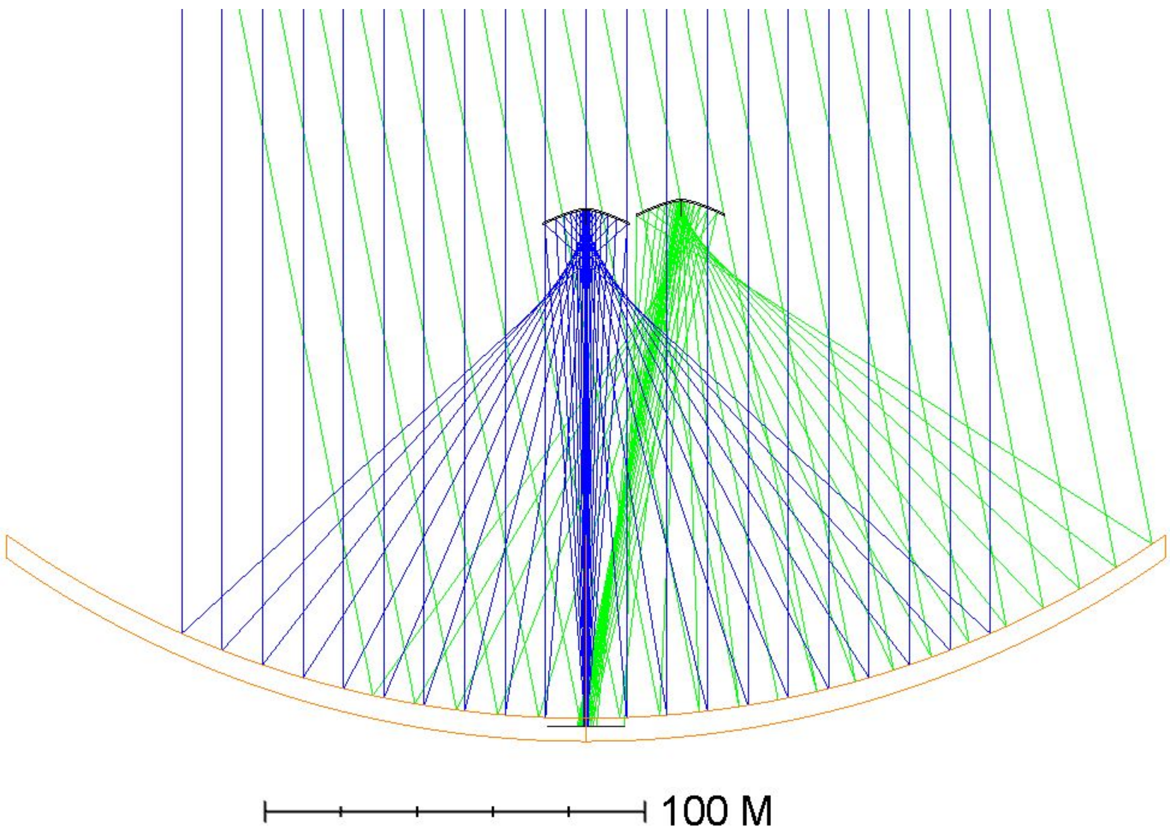
Gregorian: 22 m diameter, 132 m above the primary



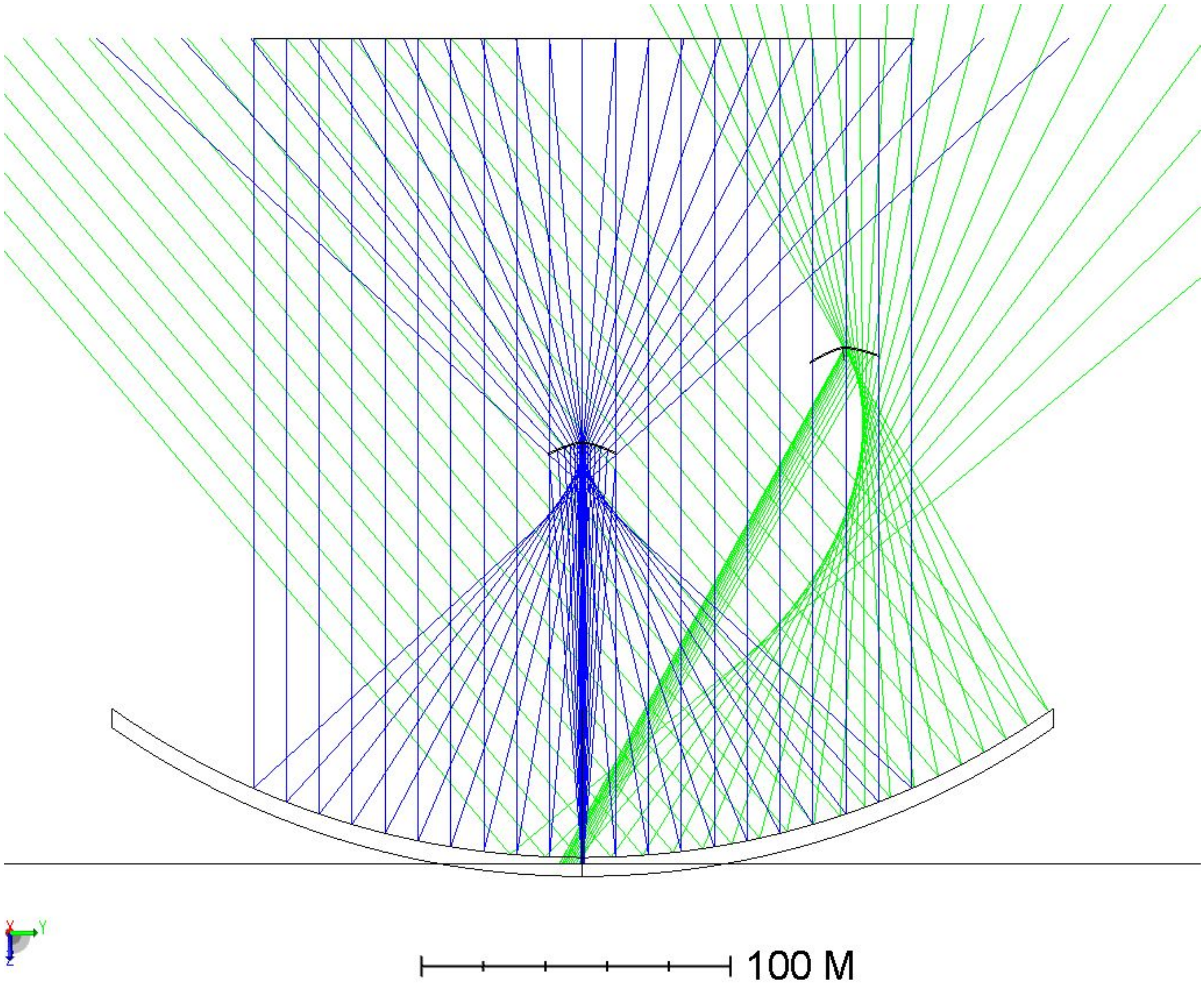
Cassegrain: 32 m diameter, 102 m above the primary



- “Here’s an image of how it looks with the simplest thing done at 11 deg. I just moved the secondary along an arc centered at the primary reflector center. The secondary shape hasn’t changed. It’s pretty close to working right. On axis everything is very well diffraction limited. Off axis it’s not quite there. There are a couple waves of coma (at λ=6 cm) and a couple waves of defocus. That will be very easily corrected by changing the shape of the secondary (maximum movements on the edges will be about a couple waves ~= 12cm). Long story short this will definitely definitely work, but it would take a little bit more time to get the design right.”



- “Since at 11° we’re almost at the edge of the primary reflector, there will be a lot of vignetting at 20°, let alone 40°. Out at 40°, only about 1/5th of the “light” will hit the primary reflector, I’m guessing now.… I guess the idea is to not keep the aperture centered at the center of the primary curvature? That way you could keep the full aperture out at those angles, but you’ll lose the symmetry that minimizes the spherical aberration of the primary reflector. I just tried this out for 40 deg, and it won’t work unless the secondary gets over 50m in size (this is the second image below). So either way it seems like 40° won’t work... Any compromise that ends up decentering the aperture (necessary to avoid losing sensitivity past 11 deg zenith angle) will make the secondary grow fast.”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