Geodesic Parabolic Reflector Antenna

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I have developed a novel antenna structure titled the "Geodesic Parabolic Antenna." This design reevaluates the conventional frame structure of parabolic reflectors, allowing for the realization of an approximate paraboloid surface simply by assembling ribs without the need for complex bending or forming processes. This article introduces the conceptual process behind this invention. Due to space constraints, please refer to my website (listed at the end) for detailed construction methods.

The Beginning: The "Umbrella-antenna"

In 2001, motivated by the desire to access the AO-40 amateur radio satellite, I faced the challenge of living in an apartment complex where permanent antenna installations were restricted. I sought a solution in portable operations. My first project was a parabolic antenna for the S-band downlink. To facilitate both transportation and storage, I conceived a foldable design inspired by the umbrella-type antennas used in Inmarsat portable stations, which I dubbed the "Umbrella-antenna."

The Umbrella-antenna can be classified as a type of stressed dish. It utilizes the mechanical principle that when stress is applied to one end of a rod while the other is fixed, the resulting deformation approximates a parabolic curve within a small range of displacement. My design philosophy was not to maximize surface accuracy at any cost, but rather to perform a trade-off: defining an acceptable surface tolerance and simplifying the structure accordingly.

Since the underlying principle is an approximation, there are inherent limitations. While the ribs follow a parabolic curve, the surface formed between adjacent ribs is naturally a flat plane. Assuming a maximum allowable deviation from the ideal paraboloid of λ/10 (where λ is the wavelength), calculations showed that a 1m diameter dish would require at least 16 ribs. To keep the rib deformation within a linear range, I opted for a shallow dish with an f･D ratio of 0.5.

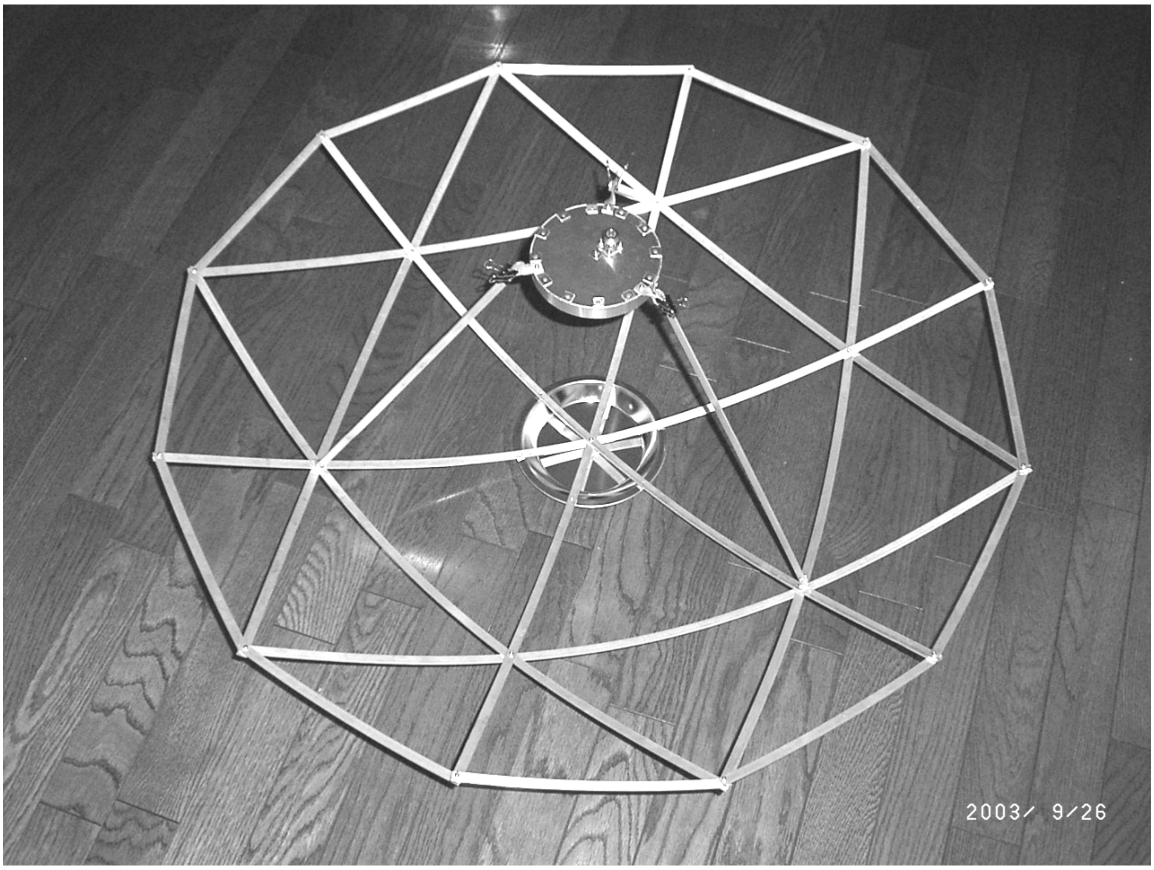
Lessons Learned from the Umbrella-antenna

When I attempted to skin the frame with aluminized plastic sheets, I encountered significant difficulties. Dividing the sheet into 16 segments to minimize wrinkles caused 16 layers to converge at the center, creating a messy, wrinkled finish. Reducing the number of segments resulted in wrinkles elsewhere due to the difference in Gaussian curvature between the center and the periphery.

Conventional umbrellas remain taut because the fabric is elastic. In my case, radial tension alone was insufficient; a perpendicular (circumferential) force was required. I realized that wrinkles can only be eliminated by a vector sum of these forces—tension in a diagonal direction.

The key lessons learned were:

- Increasing radial rib density is not a fundamental solution, as the density varies between the center and periphery.
- Removing wrinkles from a reflective sheet or mesh requires simultaneous longitudinal and transverse tension.
- A frame of radial and concentric ribs forms trapezoids, which are structurally unstable. Triangulation is necessary.
- Tension-based wrinkle removal is feasible on convex surfaces; it is extremely difficult on concave surfaces.
- The stressed-dish principle is attractive as it eliminates rib pre-bending, but shallow dishes tend to be "top-heavy" and poorly balanced.



Three Key Concepts

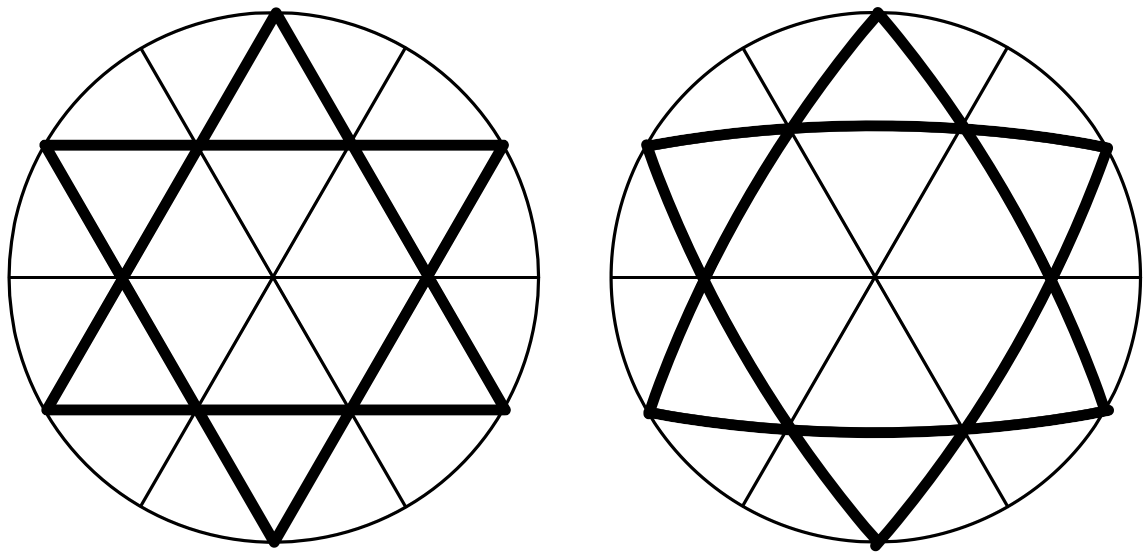
After a year of contemplation, I identified three keywords to evolve the design:

- Approximation of a curved surface using flat facets.
- A frame structure with uniform density.
- Skinning mesh over a convex surface.

The most renowned structure that achieves a tessellation of flat facets within a uniform-density frame is Buckminster Fuller’s Geodesic Dome. While I arrived at this similar structure independently—a case of "reinventing the wheel"—it was a logical necessity of fulfilling those three keywords.

A standard frame of radial and circular ribs forms trapezoids. Reinforcing these with diagonal members naturally leads to the adoption of a triangular facet as the basic structural unit. My initial concept used round pipes to create point-contact intersections, but I realized this would protrude too much when skinning the convex side.

The breakthrough came when I realized that a design using flat ribs required the edges to follow Geodesic Lines (the shortest path between two points on a curved surface). Once I grasped this correct projection, I could clearly visualize the design and calculation method for a frame built from flat, straight ribs.



Rational Simplification: The "Lazy" Approach

Approximating a paraboloid with flat facets and skinning the mesh over a convex surface are forms of "rational simplification." I applied this "lazy" philosophy to the fabrication process as well.

In typical antenna design, one dictates the diameter first. Instead, I designed the frame based on the standard commercial lengths (1m) of available materials. The final diameter was a byproduct. By simply joining these pre-cut, 1-meter ribs, the inherent mechanical properties of the structure naturally give rise to a faceted approximation of a paraboloid.

Validity of the Approximation

How much does the gain degrade when a smooth paraboloid is replaced by a collection of flat facets?

Surface tolerance is measured by the peak deviation (0-p) from the ideal paraboloid and its periodicity. Reference [1] provides gain degradation data normalized by wavelength. For example, a deviation of $\lambda/10$ with a period of λ or greater results in ~3.4 dB degradation.

In my prototype, the peak deviation is approximately 5mm (0-p) with a period of about 200mm. At 2.4 GHz (λ=125mm), these are $\lambda/25$ and 1.6λ respectively. Based on Reference [1], I estimate the degradation is well within 1 dB. Since peak deviation only occurs at the center of each triangular facet, this is a conservative estimate. To further improve accuracy, one could manually mold the mesh into a slight curve within each triangular segment.

Closing Remarks

At the time of writing, I have not yet completed full characterization of the antenna's performance. I intend to continue data acquisition and publish the results on my website: http://www.terra.dti.ne.jp/~takeyasu/

References:

[1] Evans & Jessop, VHF-UHF Manual (3rd edition), RSGB, 1976.

[2] Jay Baldwin (Auth.), “Bucky: A Guide to the World of R. Buckminster Fullere,” 1984.