A RANGE COMPENSATING FEED MOTION CONCEPT FOR SPACEBORNE RADAR

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Introduction - NEXRAD in Space: Tropical cyclones can cause major loss of both life and property, so that improvements in forecasting motion, intensity, and rainfall are needed. Such forecasting requires accurate measurements of the current state of the cyclone. Ground-based Doppler radars have long been used as an effective means of monitoring severe precipitating storms. Because of the oceanic nature of tropical cyclones, remote monitoring from space is desirable. Recently, the Precipitation Radar (PR) [1] aboard the Tropical Rainfall Measuring Mission (TRMM) [2] satellite has demonstrated an unprecedented capacity for 3-D imaging of precipitating storms. Nonetheless, due to the relatively long TRMM return cycle (less than once per day) the value of PR data has primarily been limited to the understanding of climatological properties of tropical cyclones [3]. The return cycle can be substantially reduced by sensing from a geostationary platform. In pursuit of this goal, we are currently developing radar technologies for the NEXRAD-In-Space (NIS) instrument [4], which is intended to be a science observatory for detailed tropical cyclone monitoring from a geostationary orbit. The acquired measurements would provide continuous, 3-dimensional information on the evolution of rainfall systems and their dynamics.

The design of the NIS radar includes pulse compression and onboard processing. However, the most innovative feature is the antenna, a large deployable reflector at 35 GHz for sufficient spatial resolution (12 km). Scanning is accomplished by moving the feed, rather than the entire antenna. The antenna is a spherical reflector instead of the conventional parabolic reflector design to allow large angular scan without performance degradation. Two antenna feeds, one for signal transmission and the other for echo reception, are used. The separation between feeds is chosen so that the receive-feed moves into the correct position to capture the received signal after the roundtrip to the earth surface. This allows the scan mechanism to move continuously, providing one full-disk scan image (at 5200-km surface diameter) every hour without requiring rotations by the antenna reflector or the spacecraft.

Array Compensated Spherical Reflector Antenna: While the most attractive feature of a spherical reflector is its wide angle scan capability, the major drawback is the excessive gain loss due to the spherical phase aberration. In order to overcome the effect of spherical aberration, several correcting methods have been investigated previously. The method which has been adopted in the present work is to use a planar array located in the focal region of a spherical reflector [5, 6]. An advantage of a fast moving small planar array on a prescribed path enables us to scan the beam and achieve the required coverage in a desired time period. To achieve the desired gain and beamwidth, the size of the illuminated aperture should be ~28 meters. However, an oversize reflector antenna with a diameter of 35.5 meter is used to cover the desired angular scanning range by using subapertures for various beam look angles. Recent parametric studies [6] have shown that a 271-element, rotating, fixed feed array with complex fixed excitation coefficients can compensate for phase aberration and improve the performance of spherical reflector significantly. The size of the array is about 14 cm in diameter. The radius of the sphere was set to 56 meters based on the reflector aperture dimension and its caustic region at the optimal feed location. The array has a hexagonal configuration with element spacing of 0.9 wavelengths at 35 GHz.

Feed Motion Concept: The feed arrays, designed to compensate for the spherical aberration of the reflector, must be moved on a spherical surface centered on the center of the main reflector sphere in such a manner as to produce a scanning beam which covers a large circular area on the earth. The synchronous orbit geometry is illustrated in Figure 1.

As the transmit array moves, it sends a series of radar pulses to the earth which upon reflection are to be intercepted by the receive array that moves on the same trajectory as the transmit array but slightly behind thus allowing for the range delay. Note that at the extremes of the angle θ (4°) the range R is considerably larger than the height, h (synchronous orbit altitude). This implies that the round trip travel time of the radar pulses will be longer at the extremes of angle. The normalized range variation as a function of angle can be expressed in the form,

$$g(\theta) = \frac{R(\theta)}{h} = (1+\frac{r}{h})\cos\theta - \sqrt{\left[(1+\frac{r}{h})\cos\theta\right]^2 - \left(1+2\frac{r}{h}\right)}$$

This variation in range delay must be accommodated in the feed motion. The proposed concept is shown in Figure 2. Here the feed arrays follow each other on a path determined by the rotation of two support arms about two rotation axes as shown.

The length of the arms and the ratio of the angular velocities are fixed by the desired field of view. As the arms revolve, the feed arrays cover the area of the sphere shown by the large circle and, moreover, the linear velocities imparted to the feeds by the two rotations subtract at the edge of coverage resulting in compensation of the range delay if the design parameters are chosen appropriately. A more detailed diagram of the mechanism geometry defining the design parameters is shown in Figure 3.

In terms of these parameters, one can express the linear velocity of the feeds relative to that at the center of coverage. The reciprocal of this ratio can be expressed in the form,

$$f(\theta) = \frac{-q\sin\alpha}{\sqrt{\left(1+2q\cos\alpha+q^2\sin^2\alpha\right)-2q\cos\alpha\cos\theta-\cos^2\theta}}$$

where,

$$q = \frac{\omega_1}{\omega_0}$$

ω_1 is assumed to be negative and much larger in magnitude than ω_0. Thus, the function f gives the time between the arrival of the transmit and receive arrays at a given point relative to that at the center of the field of view and this time must accommodate the variation in range given by the function g.

To illustrate the compensation, we choose an example with the following design parameters:

$$r = 6.38\times10^6 \text{ meters} \qquad h= 35.8\times10^6 \text{ meters} \qquad \theta_{max} = 4 \text{ degrees}$$

From these one may derive that $\alpha = 2$ degrees and $q = -118.117$. Figure 4 shows a plot of the two function f and g for this example. Also shown is a curve of the difference between f and g; i.e., the compensation error. From this it is clear that the compensation error can be made very small. Of course, in retrospect one may recognize that the angles involved are small so that the two functions f and g can be expanded in Taylor series about the center of coverage. Upon doing this we find that both functions are approximately parabolic in the angle and can therefore be made to coincide quite closely with proper choice of design parameters.

Conclusion: A feed motion concept has been presented that permits a pair of aberration compensating feed arrays, one transmit and one receive, to cover a circular region of the scan sphere of a spherical reflector radar antenna in such a manner as to compensate via changes in linear velocity for the difference in range from synchronous orbit to the earth's surface across the coverage area. The proposed mechanism requires only a single constant speed drive motor rotating at ω_1. The slower angular velocity is derived from this using a large circular interior ring gear engaging a mating gear on the higher speed axis; i.e., the fast axis "rolls" around the perimeter of the large interior gear ring.

Acknowledgement: This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA under contract with the National Aeronautics and Space Administration.

References:

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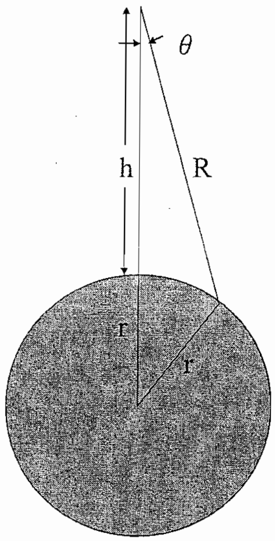

Figure 1. Orbiter and the earth.

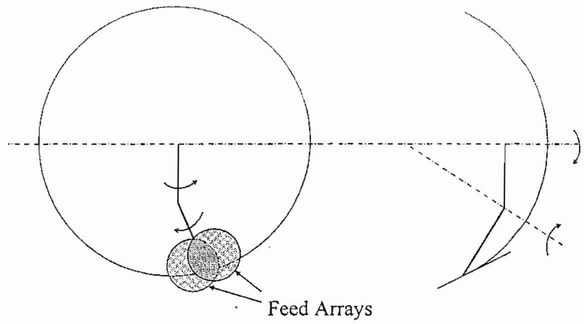

Figure 2. Feed motion concept.

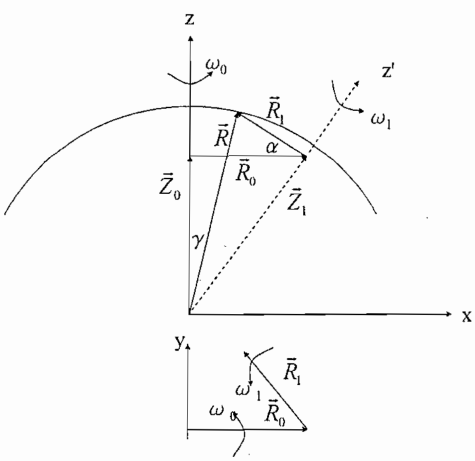

Figure 3. Design parameters of the mechanism.

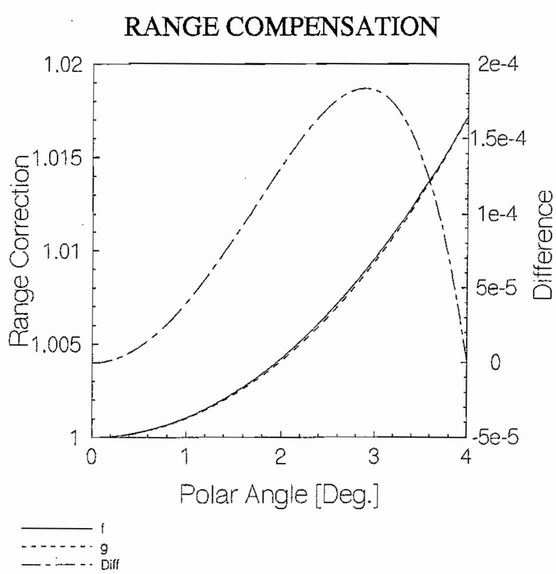

Figure 4. Range compensation.

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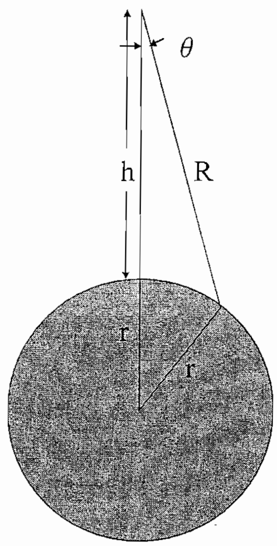

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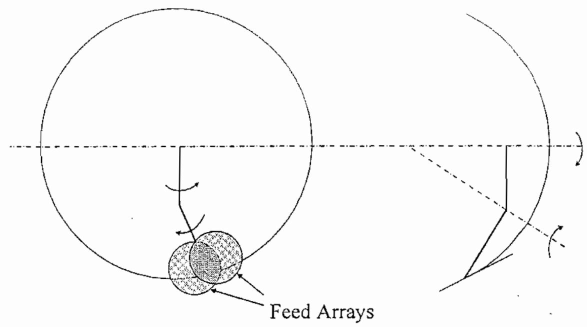

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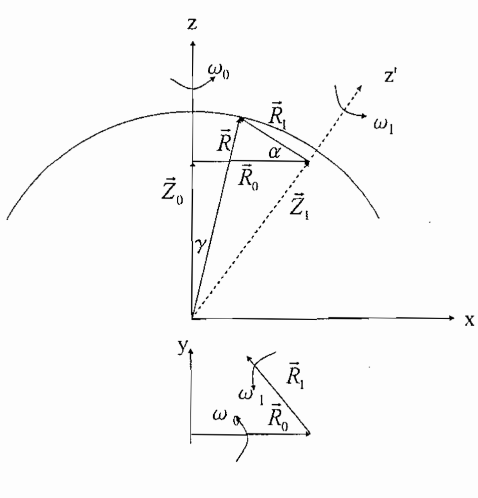

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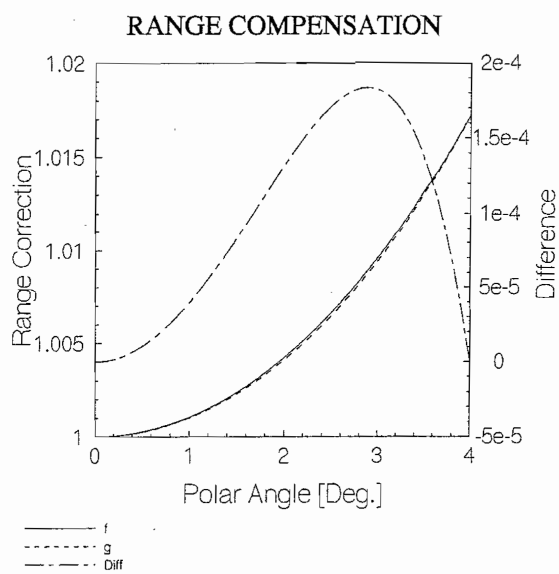

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