Structural Dynamic Performance of a Geostationary Microwave Radiometer

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Abstract

THIS synoptic addresses the on-orbit structural performance of a low-frequency microwave radiometer (LFMR) for Earth science applications. The LFMR is an instrument aboard a geostationary platform as part of the proposed program Mission to Planet Earth. The present study[1] quantifies the ability of the LFMR structure to retain its design shape subject to a representative onboard disturbance. It includes a description of the LFMR concept, the structural model, the assumed on-orbit disturbances, and the analyses performed to quantify the antenna's resulting root mean squared (rms) surface roughness, pointing error, and defocus. These errors are measured based on the locations of the nodes of the distorted antenna relative to the ideal (error-free) antenna node positions. The electromagnetic performance of an antenna can be adversely affected by numerous factors, among which is the geometric displacement of the antenna's various structural components from their optimum positions. Minimizing the overall surface roughness, pointing error, and defocus is of extreme importance for high-precision reflector antennas such as the LFMR. Reference 1 describes in detail a sequential approach for assessing the ability of an antenna structure to retain its geometric shape subject to a dynamic disturbance.

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The Mission to Planet Earth is a proposed NASA program to monitor and study the Earth's hydrologic, biogeochemical, and climate cycles on a global scale. In support of this effort, NASA is proposing technology development programs to produce the sensors to perform the necessary observations and the spacecraft and data handling technologies to support these instruments. The complement of spacecraft needed to support these types of observations will consist of low-inclination and polar low-Earth-orbit and geosynchronous-Earth-orbit platforms, each carrying a payload of instruments and sensors. The geostationary platform concept[2] used in this study is illustrated in Fig. 1.

The 15-m-diam LFMR is a significant part of the platform's structural configuration because of its large aperture and focal length, which make it susceptible to electromagnetic performance degradation caused by dynamic disturbances. The LFMR must operate at frequencies of 6, 10, 18, 21, and 37 GHz to satisfy the science requirements.[3] The instrument used in this study is an offset-fed cassegrain antenna with an effective focal-length-to-diameter ratio of 1.5. The antenna system consists of a paraboloidal primary reflector and an extended feed mast that supports a subreflector and a feed system. The LFMR finite element model (FEM) was generated using the Tetrahedral Truss Structure Synthesizer (TTSS), part of the Large Advanced Space Structures (LASS) software package,[4] and Supertab, part of the I-DEAS software package.[5,6]

The LFMR is assumed to be error free in its undistorted state. The primary reflector of the LFMR is a 15-m-diam offset-fed paraboloid, with its edge offset from the vertex of its parent parabola by 3.0 m. It consists of a 0.5-mil-thick aluminized Kapton membrane reflector surface supported by a General Dynamics GEOTRUSS[7] 12-bay tetrahedral truss (strongback). Tie cords are assumed to be used between the connection points, eliminating pillowing of the membrane surface. The primary reflector is represented in detail in the FEM by beam elements for the truss tubes and by lumped masses for both the joint masses and the membrane-distributed mass. The feed mast is represented in the FEM as an equivalent beam model based on the Minimast truss.[8] It is 19.5 m long and is composed of 18 beam elements and 19 lumped mass elements. The feed mast is connected to the reflector strongback at one end, supports the subreflector at the other end, and supports the feed system 2.0 m below the subreflector. The connections are made via rigid element attachments. The subreflector is 2.35 m in diameter, is located 19.5 m above the vertex of the parent paraboloid of the primary reflector, and is assumed to be constructed of solid panels supported by a tetrahedral truss strongback, similar to those under current study in the precision segmented reflector (PSR) program.[9] The resulting subreflector has a mass of 52 kg and an inertia of 18 kg-m^2. It is represented in the FEM as a lumped mass element concentrated at a single node and attached to the feed beam by a rigid connector. Since the details of the feed system design are not yet known, its mass is approximated by estimating based on that of a scanning feed array of a single aperture Earth-sensing radiometer,[10] yielding a feed mass of 443 kg. The feed mass is included in the FEM as a lumped mass at a single node, rigidly connected to the feed mast.

Representative onboard disturbances were modeled simulating subreflector scanning to evaluate the dynamic performance of the LFMR in space. Scanning will be performed mechanically, without momentum compensation, by rotating the subreflector about its x and y axes for north-south and east-west scanning, respectively. Subreflector rotation is one of the primary on-orbit disturbances that can degrade the electromagnetic performance of the antenna by inducing surface roughness, pointing errors, and defocus. Torque input equations were modeled for the x and y components of the scan based on the retrace time (time allowed for each Earth disk scan) and footprint (projection of the half-power beamwidth on the Earth) requirements. The scan examined consisted of a 10-km footprint with a 30-min retrace. The LFMR was assumed to employ a raster-type scan technique, which in-

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Table 1 Summary of results

Performance parameter	Assumed limit	Free flyer: Maximum	Free flyer: Contributing modes	Platform mounted: Maximum	Platform mounted: Contributing modes
RMS surface roughness, m	8.11 E-5	5.3 E-6	n/a	4.7 E-6	n/a
Pointing error, rad	6.22 E-5	1.9 E-5	2,3,5 (x axis) 1 (y axis)	4.5 E-6	2,7 (x axis) 1,3 (y axis)
Defocus, m	1.62 E-3	1.3 E-4	1	7.0 E-5	1,8

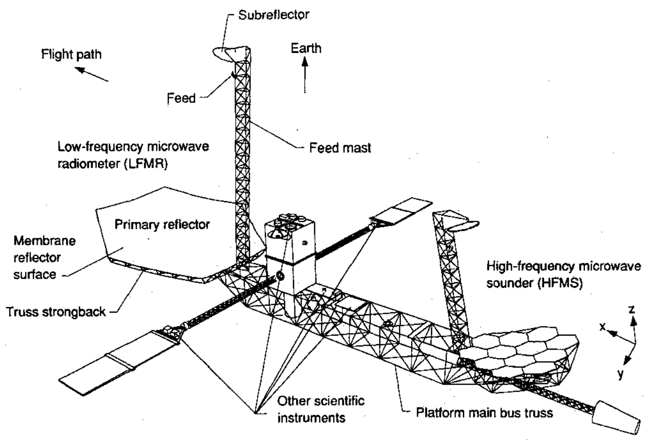

Fig. 1 Geostationary Earth science platform.

volves dividing the desired area into a grid of spots with dimensions of the required footprint and scanning back and forth across the grid line by line. The scenario assumes a line is scanned from east to west, followed by a north-to-south step to the succeeding line, which is then scanned west to east. The s pattern is repeated until the entire area is scanned.

The LFMR was analyzed in two configurations. First the antenna was analyzed as a free flyer (i.e., on a dedicated spacecraft), with the assumption that the supporting subsystem masses are negligible compared to the mass of the antenna. Next, the antenna was rigidly attached at three central nodes on the bottom of the strongback to the geostationary platform, which was represented as a lumped mass with appropriate mass properties. Each configuration was analyzed under free-free (i.e., unsupported) conditions.

The performance analysis of the LFMR consisted of using the natural frequencies and corresponding mode shapes of each configuration as determined by a modal analysis, along with the torque inputs from the subreflector scan, to perform a forced response analysis. The resulting dynamic displacements were then used to quantify the antenna geometric errors. The modal analysis was performed using I-DEAS Model Solution. The forced response analysis was performed using I-DEAS Systan, calculating dynamic distortion data in the three translational degrees of freedom for the subreflector node and for a representative set of surface nodes.

The surface node data were used in conjunction with the Utku-Schmele best-fit parabola technique[11] to quantify the antenna's errors due to the surface distortions, i.e., rms surface roughness, pointing error, and defocus. The maximum allowable rms surface roughness for an Earth-scanning radiometer system such as the LFMR is approximately 1% of wavelength,[12] yielding a limit in this case of 8.11E-5 m. The maximum allowable total pointing error and total defocus have been identified as 10% of beamwidth and 20% of wavelength, respectively.[7] For the LFMR, these limits are 6.22E-5 rad and 1.62E-3 m, respectively. These geometric performance parameters, and the various components that comprise the total pointing error and defocus, are discussed further in Ref. 1.

For both configurations, the scanning maneuver was found to have minimal impact on the electromagnetic performance of the antenna. Each performance parameter remains within its limit throughout the course of the scan. The resulting maximum errors for each case are summarized in Table 1, and plots of the results, which show the variation of each error with time, are included in Ref. 1. In general, each pointing error is induced primarily by its corresponding component of the input torque, whereas the rms error and defocus appear to be caused by some combination of both torque components. The results of this analysis indicate that the LFMR strongback and feed mast as designed are capable of maintaining their shapes within specifications for the assumed on-orbit disturbance. Care must be exercised in devising scan scenarios so as to minimize the torques that are input to the system as a result of subreflector rotation and to minimize the concurrence of torque input frequencies with the natural frequencies of the system.

The present study demonstrates the feasibility of the specified configuration subject to subreflector scanning, thus providing a baseline for this type of large-diameter antenna analysis. It is important to note, however, that various other factors must be assessed as to their impact on the antenna performance. Additionally, alternative LFMR configurations and scanning techniques must be evaluated to evolve an optimum design.

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