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A HIGH RESOLUTION SOIL MOISTURE RADIOMETER

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This report covers a design study (ref. 1) for an advanced L-Band High Resolution Soil Moisture Radiometer - HRSMR - for the late 1980 time period conducted by General Electric for NASA Goddard Space Flight Center over the period from June to November 1978. The selected system is a planar slotted waveguide array at L-band frequencies as shown in figure 1. The square aperture is 74.75 m by 74.75 m subdivided into 8 tilted sub-arrays The system has a 290 km circular orbit and provides a spatial resolution of 1 km. The aperture forms 230 simultaneous beams in a cross-track pattern which covers a swath 420 km wide. A revisit time of 6 days is provided for an orbit inclination of 50°. The 1 km resolution cell allows an integration time of 1/7 second and sharing this time period sequentially between two orthogonal polarization modes can provide a temperature resolution of 0.7° K.

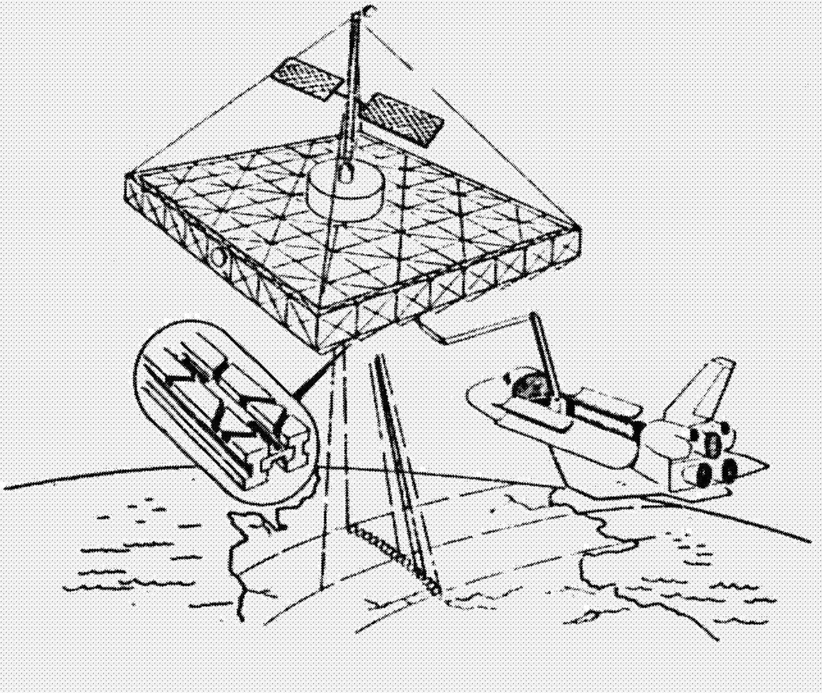


Figure 1.- HRSMR - High resolution soil moisture radiometer.

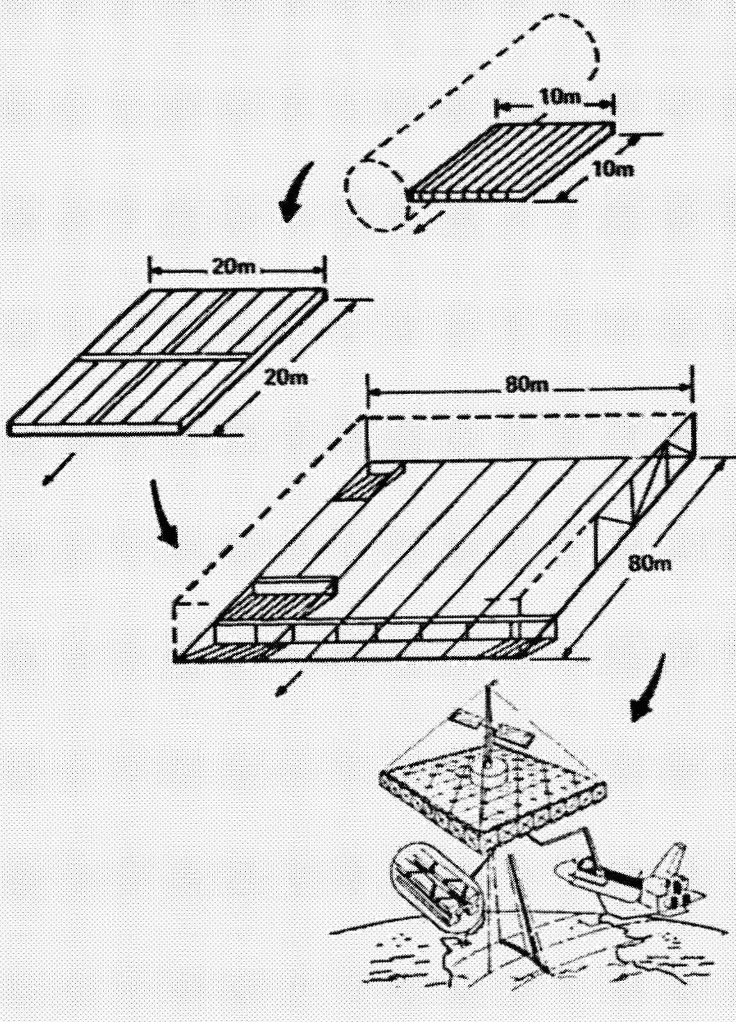
The relevent systems' parameters and performance characteristics are listed in Table 1. The antenna beam is tilted forward 20° along the satellite track to provide resolution of the two orthogonal linear polarizations.

Table 1-1 HRSMR - Selected System - Major Characteristics

		Comments
Type	Dual Waveguide Array	Graphite Fiber Epoxy Technology
Frequency	1400-1407 MHz	1400-1428 MHz available astronomy band
Size	74.75 m x 74.75 m	(245 ft. x 245 ft)
Number of Subarrays	8	
Subarray Length	9.34 m	(30.6 ft)
Orbit Height	290 km, circular	(180 miles)
Footprint Resolution	1.0 km x .92 km	3 dB, 0°-scan (.62 x .57 miles)
Orbit Plane Inclination	50°	
Revisit Time	6 days	
10 dB-Beamwidth	.313°	
Number of Simultaneous Beams	230	Crosstrack
Scan Angle	±36°	Crosstrack
Swath Width	±210 km	(±130.4 miles)
Tilt Angle	20°, forward	11° electrical + 9° mechanical tilt
Polarization	Dual linear	Switched
System Temperature	600°K	
Temperature Resolution	0.7°K	Total power radiometer
Total Weight	89,200 lbs	
- Spacecraft Weight	73,100 lbs	
- Orbit Maintenance Weight	16,130 lbs	
Total Cost	322 M$	
- Development Cost	50 M$	
- Hardware Cost	110 M$	
- # of Shuttle Flights	3-4	
- Transportation Cost	162 M$	
Orbit Maintenance System	2 SEPS/0.23 lbs thrust each/4.7 KW Power required each	
Attitude Control System	Thrusters and control moment gyros/2500 lbs	
Power Supply System	Articulated roll-out solar array 279 m^2/11.4 KW/800 lbs	

The selection of an array over a reflector is based upon two factors: First, the array has the advantage of a repetitive, modular design with the inherent advantages of reduced initial design and development, reduced ground assembly and testing, reduced modular space testing and reduced complete space transportation and erection. Secondly, the symmetrical, streamlined array configuration, compared to an offset, asymmetrical parabolic torus reflector of about 3 times the aperture, has significant advantages from the viewpoint of attitude control and orbit maintenance against the disturbing forces of atmospheric drag and to a lesser degree, of solar pressure and gravity gradients effects.

With respect to systematic evolution, the array appears to lend itself well for a gradual development program based on the modular array concept, as shown schematically in Figure 2.



SINGLE, THREE SECTION, SELF DEPLOYED
10m X 10m WAVEGUIDE ARRAY OR
10m X 10m STRIPLINE ARRAY

- DESIGN AND DEVELOPMENT
- GROUND TESTING
- SINGLE SHUTTLE LAUNCH
- SHUTTLE SUPPORTED MISSION
- FREE-FLYER MISSION

SYSTEM OF 2, 3 OR 4
10m X 10m ARRAYS

- GROUND TESTING
- INDIVIDUAL SHUTTLE LAUNCH AND TEST
- EVA AND/OR MANIPULATOR ASSISTED ASSY
- SHUTTLE SUPPORTED MISSION
- FREE-FLYER MISSION

FULL SIZE ARRAY
WITH BACKSTRUCTURE AND
TILTED SUBARRAY FRAME

- GROUND TESTING OF INDIVIDUAL ARRAYS (10m X 10m)
- MULTIPLE SHUTTLE LAUNCH OF LIMITED NUMBER OF 10m ARRAYS AND EVA AND/OR MANIPULATOR ASSISTED ASSEMBLY
- SHUTTLE SUPPORTED MISSION
- FREE-FLYER MISSION

FULL SIZE ARRAY

- GROUND TESTING OF INDIVIDUAL ARRAYS (10m X 10m)
- MULTIPLE SHUTTLE LAUNCH AND EVA AND MANIPULATOR ASSISTED ERECTION OF ALL SUBARRAYS
- FREE-FLYER MISSION

Figure 2.- HRSMR - evolution of array technology.

Considerable iterative effort was expended on the assessment of drag effects as a function of altitude and corresponding aperture size for constant footprint resolution. It was realized that this trade-off was most critical to the determination of the optimum antenna type as well as the optimum aperture size and orbit altitude in terms of overall mission cost. The characteristic cost minima for various candidate systems are shown in Figure 3.

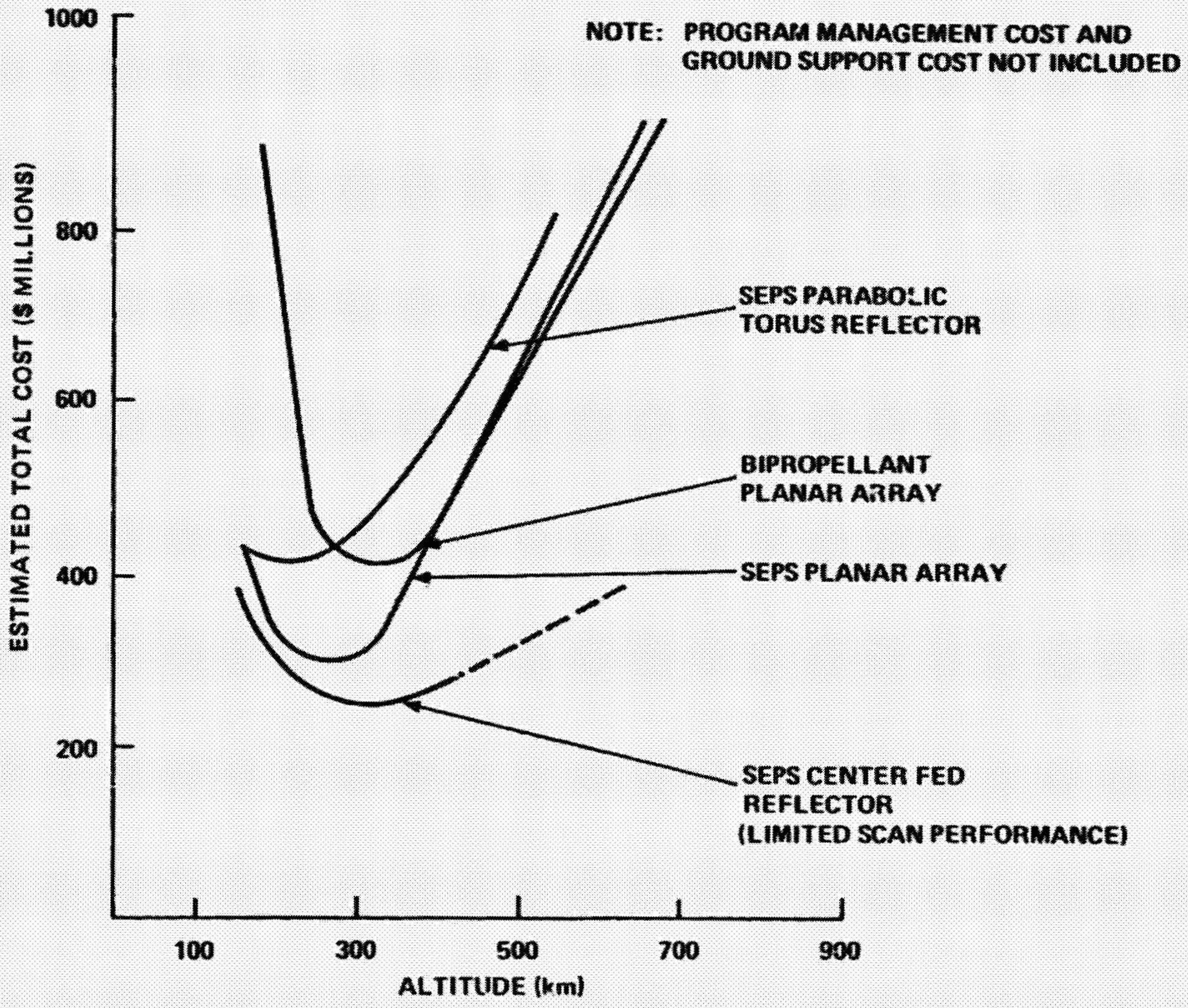


Figure 3.- HRSMR - Cost vs orbit altitude.

Several candidate waveguide array systems were considered. It was found that the beam smear of the antenna due to the dispersion in the waveguide and feed network prevented the use of a full-length waveguide array. Not only would the beam smear be excessive, but the manufacturing tolerances to maintain the desired slot excitation in phase and amplitude over the length of the waveguide would be severe. This system would have the minimum number of receivers and least complexity, but the performance degradation due to beam smear and manufacturing tolerances are not acceptable.

The selected system is a planar waveguide array consisting of 8 subarrays. The 8 subarrays are necessary to prevent the beam smear discussed in the above paragraph. It was found in the trade-off studies of orbit height, drag coefficient, and orbit maintenance propellant, that a 74.75 m by 74.75 m array in a lower orbit met the 1 km resolution requirement with an increased fraction of overall weight devoted to orbit maintenance fuel. The selected system is shown in Figure 4.

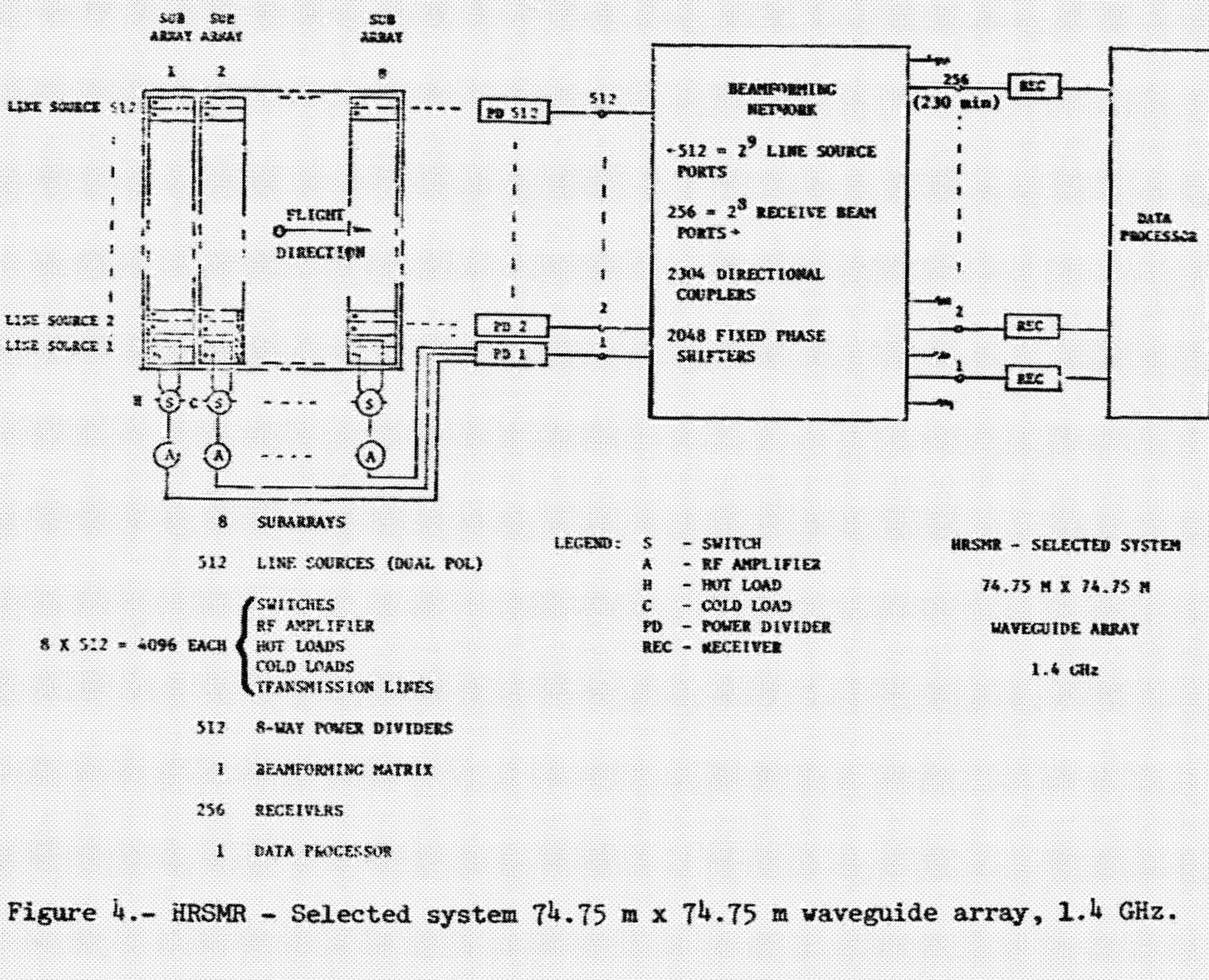


Figure 4.- HRSMR - Selected system 74.75 m x 74.75 m waveguide array, 1.4 GHz.

The antenna array consists of 512 dual line sources. To reduce dispersion and resultant beam smear to acceptable levels, the line sources are divided into eight subarrays, each approximately 9.34 m long. The line sources, oriented parallel to the flight direction, consist of dual slotted waveguides. In order to accommodate dual waveguides for orthogonal, linear polarization and at the same time to maintain a small spacing between waveguides for grating lobe suppression, it is necessary to use ridged waveguide. This results in smaller overall waveguide width and allows an interlaced geometry as shown in Figure 5. In order to tilt the beam 20° forward from nadir, the entire array must be mechanically biased by 9° from the orbit tangent. To prevent grating lobes in visible space, the beam must not be tilted more than 11° electrical. The 20° forward tilt is then accomplished by a mechanical subarray tilt of 9° and an electrical beam tilt of 11° as shown in the figure. The discontinuities in the array aperture are corrected by an electrical compensation method.

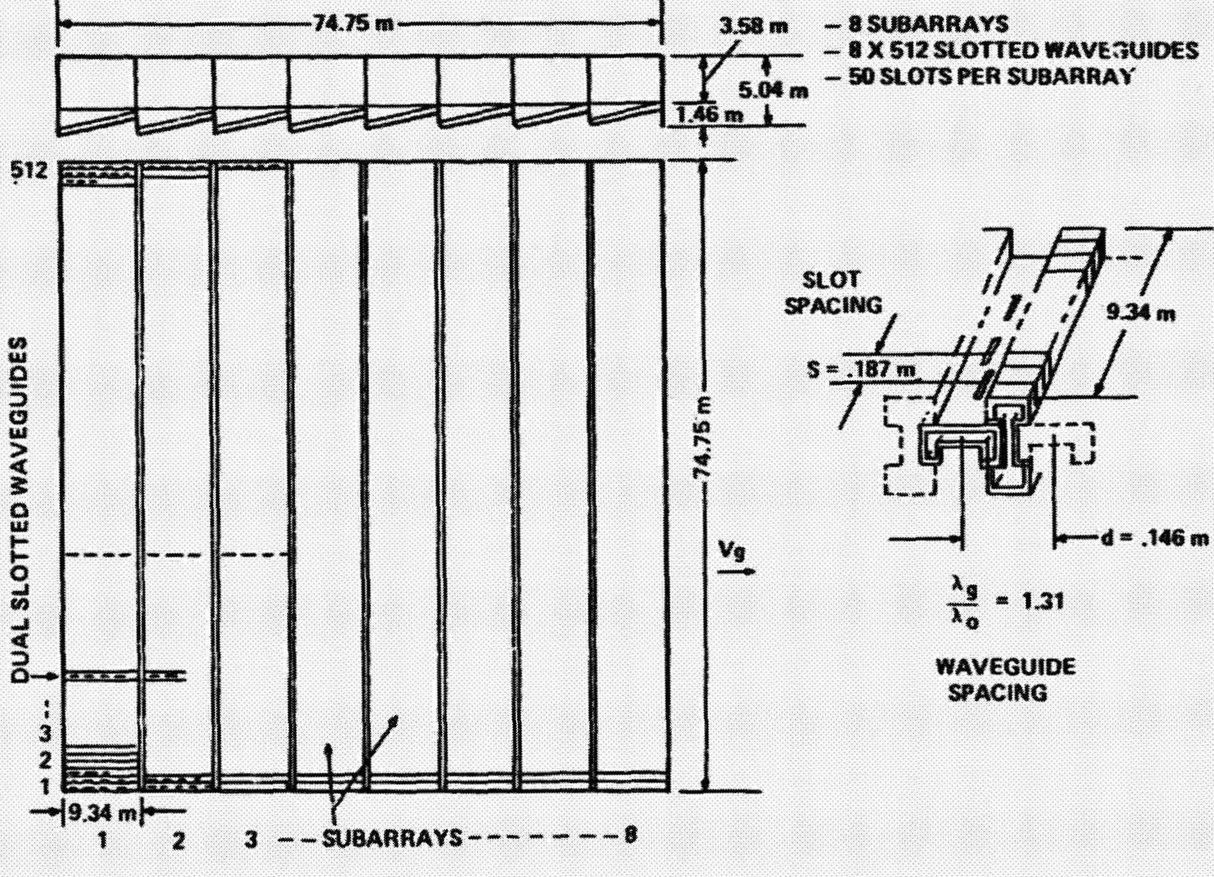


Figure 5.- HRSMR - Waveguide array, 1.4 GHz.

The success of the large aperture radiometer depends critically on a design approach and technique that will permit the maintenance of adequate dimensional tolerances. A rigorous analysis will be performed in the next phase of the study program. A preliminary analysis has been performed to define the various kinds of tolerances and their effects on performance and to determine boundaries within which the design must operate. The total tolerance can be conveniently broken up into four parts. Figure 6 shows one subarray in its deformed state. The four component parts are: (1) Δz represents the dislocation of the center of mass of the subarray from its nominal (X,Y) reference plane, (2) $\Delta\alpha$ represents the tilt angle of an ideal planar subarray, (3) dz represents a systematic bowing of the panel, and (4) σ represents the random distortion.

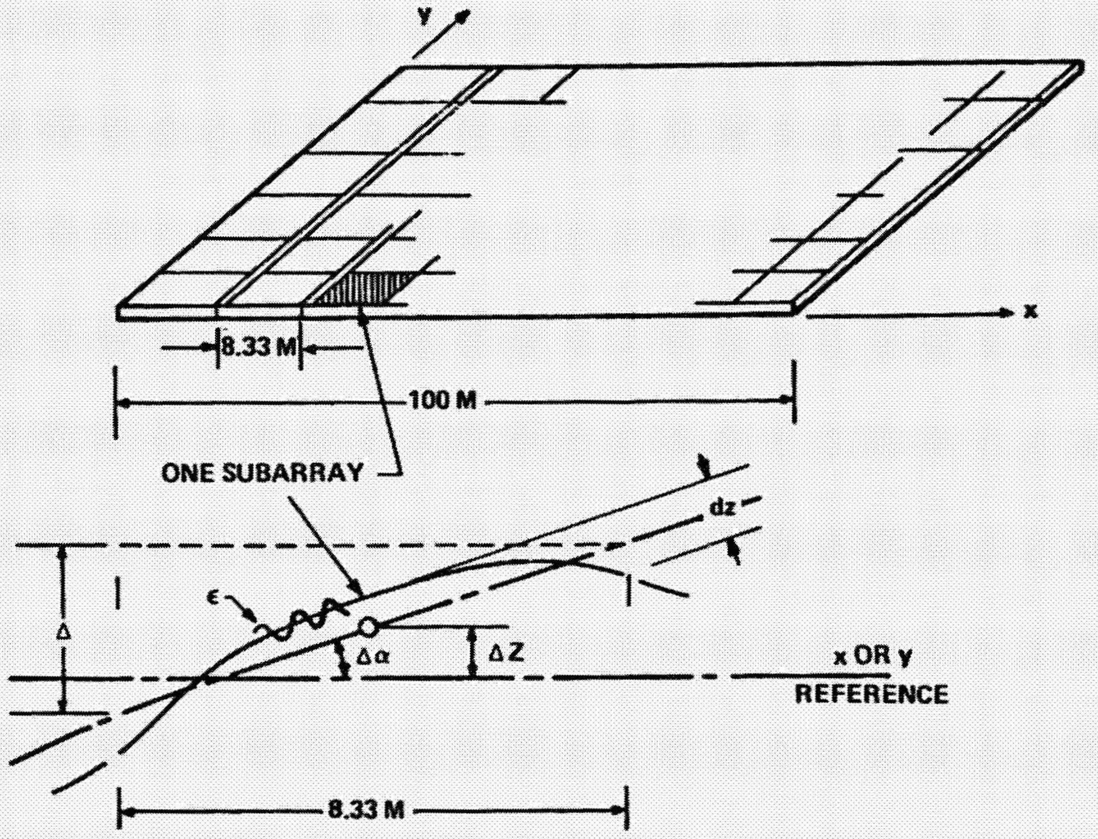


Figure 6.- HRSMR - Array tolerance definition.

Each antenna subarray is joined by bayonet joints and supported every 9.34 m by graphite-epoxy truss work to provide increased stiffness, load stability and to provide support for the auxiliary systems module and for the distributed network of R F amplifiers, switches, hot and cold loads and transmission lines. The truss work supporting the antenna is held in tension by a deployable boom (such as an Astromast) and cable system designed to control and reduce the array overall thermal distortion. Multi-layer insulation blankets cover the array for passive thermal control. The instrument is assembled from multiple shuttle payload deliveries to 290 km altitude. The first flight will bring the system module and solar array, thus providing a controlled assembly platform. Subsequent shuttle loads contain the array, structure, and SEPS hardware. The structure (truss work) is of a collapsible type with attachment joints permitting EVA-assisted RMS deployment and attachment including harness connection. The antenna arrays are stacked in the cargo bay as shown in Figure 7.

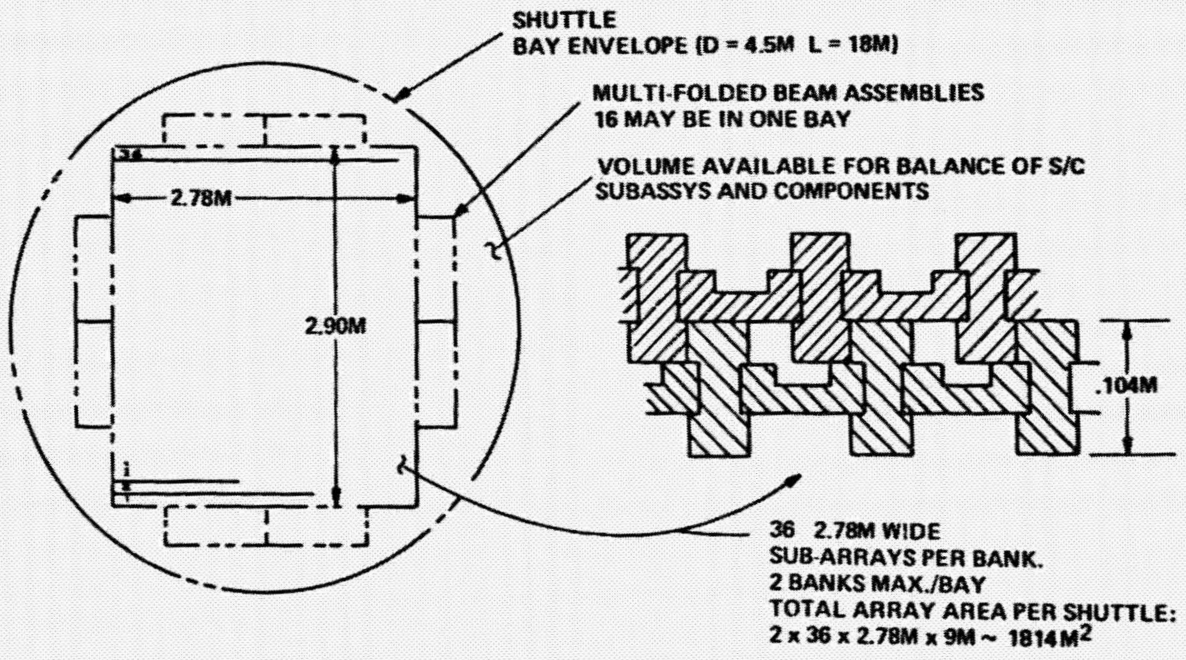


Figure 7.- HRSMR - Packaging concept for dual waveguide planar array.

Reference

1. A Design Study for a High Resolution Soil Moisture Radiometer. General Electric Company Final Report 78SD4241, November 1978.