ARRAYS FOR SPACE APPLICATIONS*

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*Original figures not available at time of publication.

The following pictures are of concepts that were studied for application in Space Based Radar (SBR) systems. These antenna systems were for low Earth orbit and required large fields of view (FOV). They included both space-fed and corporate-fed arrays.

ARRAY FOR SPACE APPLICATION

- WHY ARRAY?

    - ELECTRONIC SCANNING - BEAM AGILITY

    - ADAPTIVE BEAM CONTROL
        - LOW SIDELOBES
        - SURFACE CORRECTIONS

    - MORE TOLERANT TO SURFACE ERRORS THAN REFLECTORS

EXISTING ARRAY CONCEPTS
LARGE FOV

- SPACE-FED ARRAYS
    - WIRE WHEEL
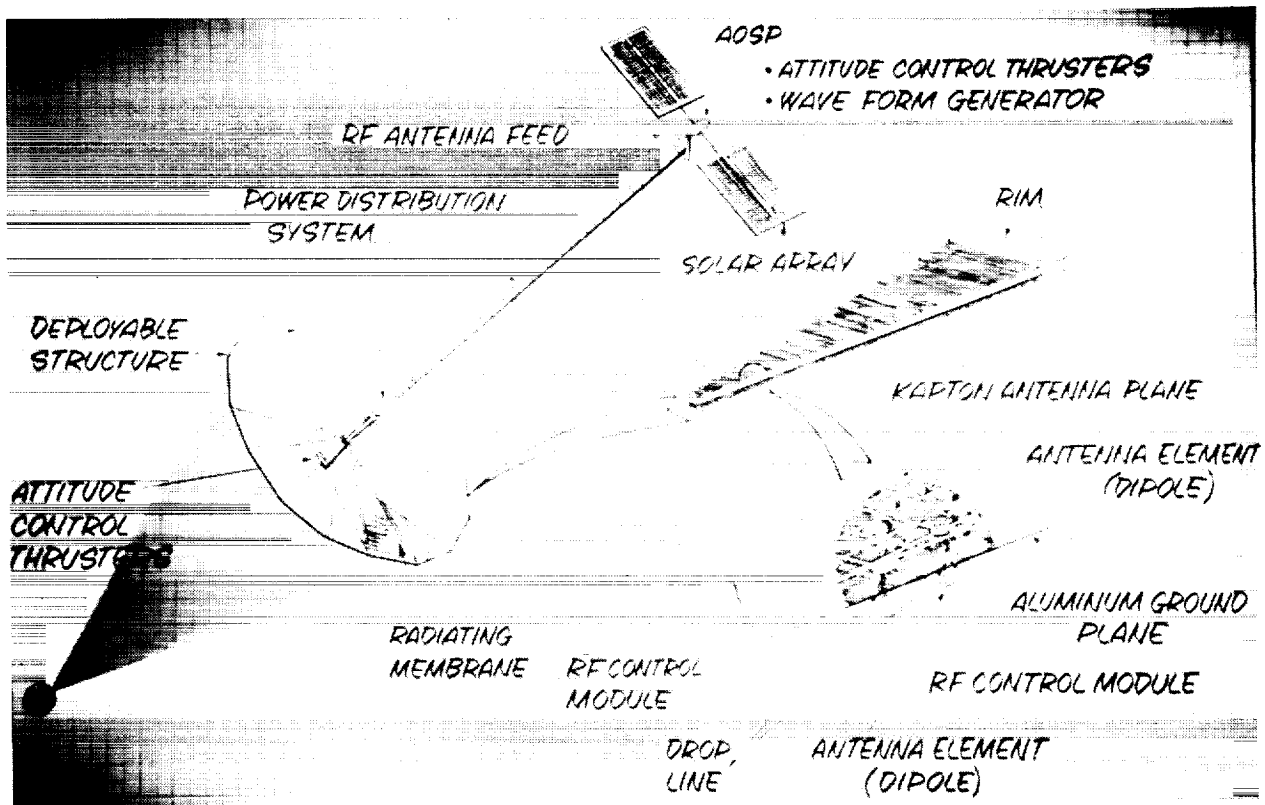   - ROLL OUT

- CORPORATE-FED ARRAYS
    - FOLD-OUT

This figure is of a wire-wheel configuration with a diameter of 70 meters and a focal length/diameter (F/D) of 1.5. The cutaway view of the lens shows the dipoles on either side of a T/R* module. This concept was proposed by Grumman Aerospace Corporation.
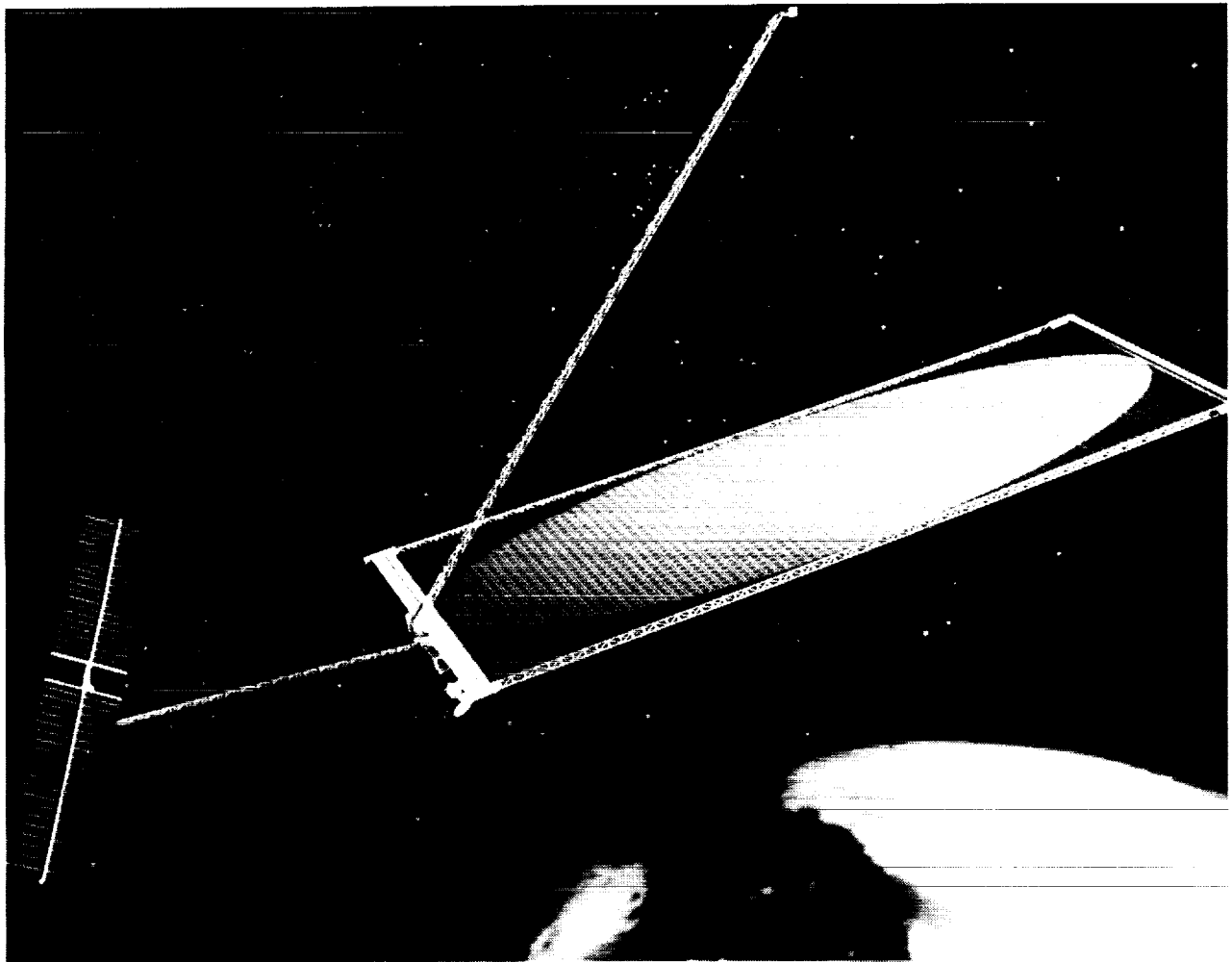
*T/R, transmit and receive

SPACE-FED PHASED ARRAY-SBR ANTENNA

WINDOW SHADE CONCEPT

This figure shows a window shade concept of a space-fed array that is 60 meters by 40 meters and has a focal distance of 40 meters. This configuration has no center mast aperture blocking. This concept was proposed by Grumman Aerospace Corporation.
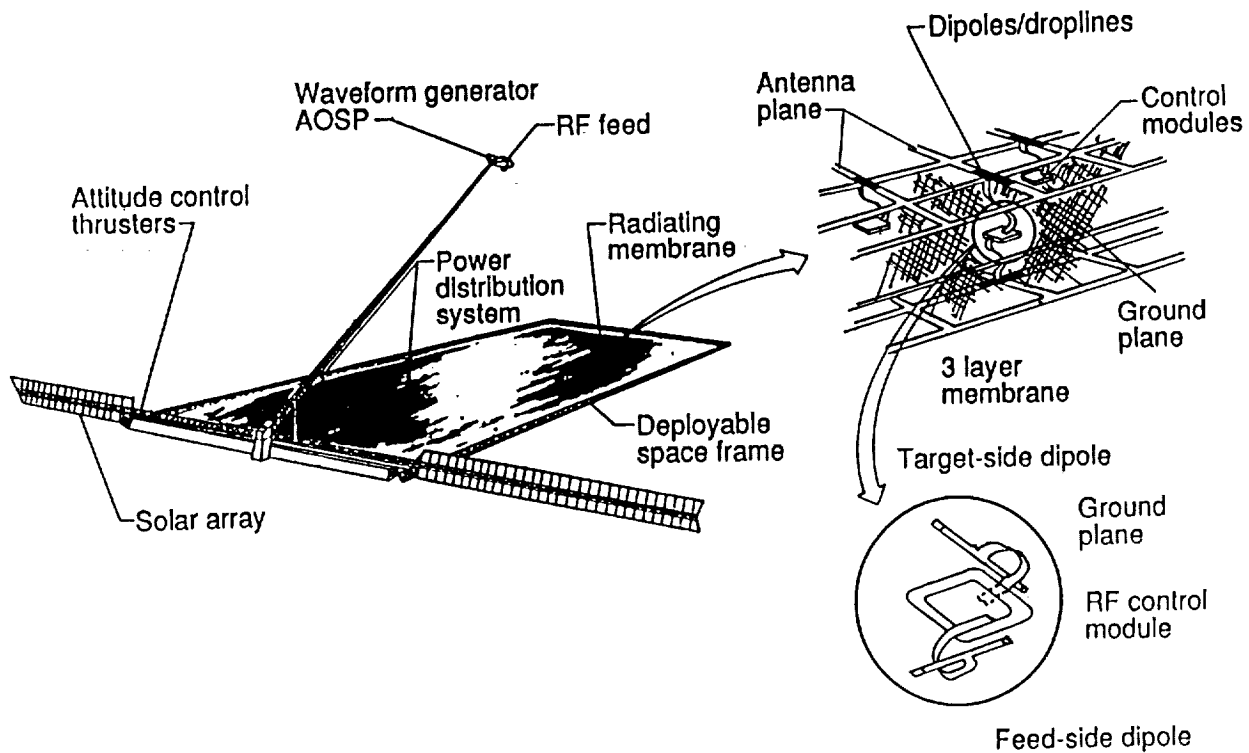
WINDOW SHADE CUTAWAY VIEW

This figure shows a cutaway view of the lens with dipoles, ground screen, and T/R modules. This concept was also proposed by Grumman Aerospace Corporation.
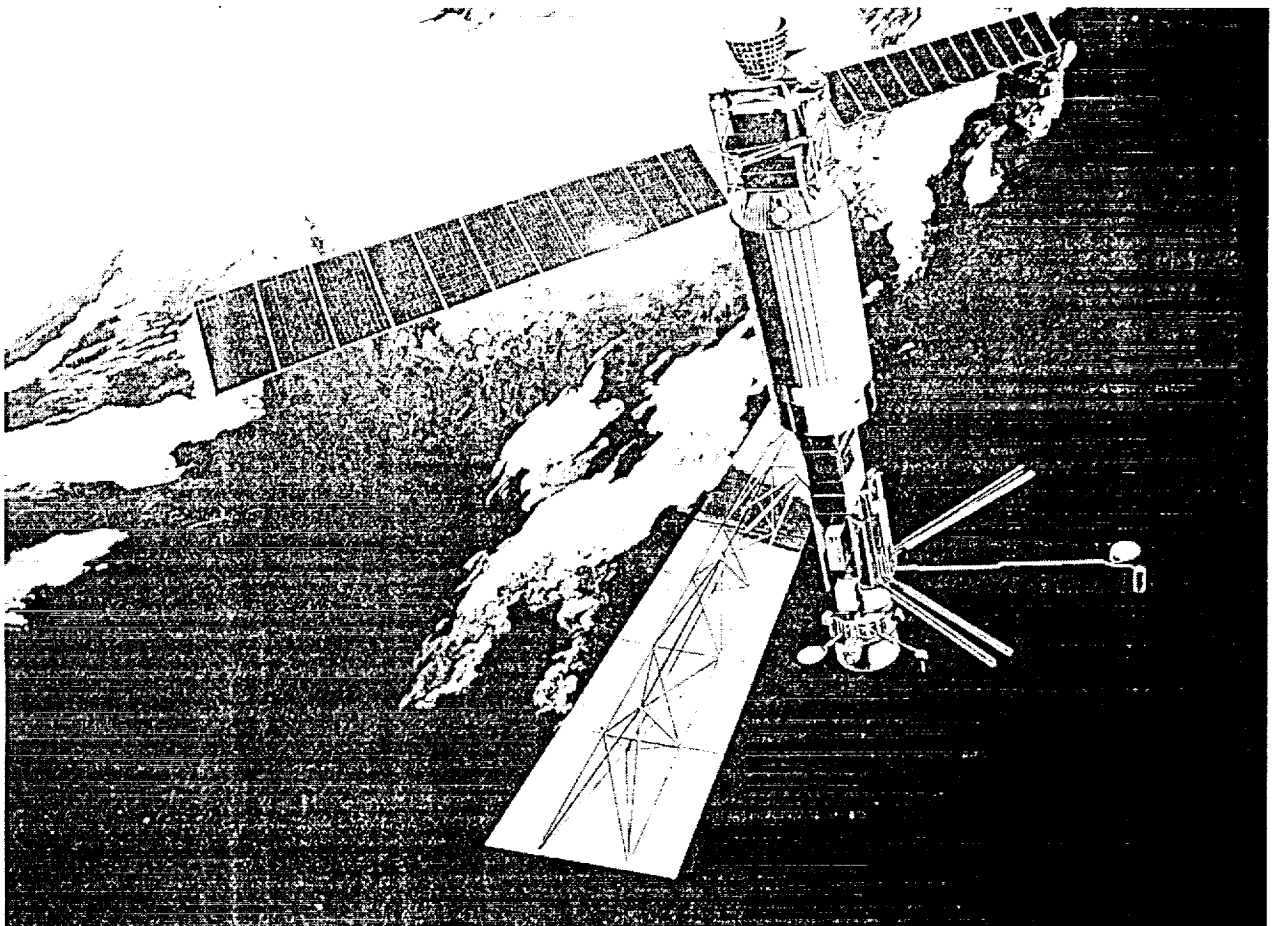
SPACE-FED PHASED ARRAY-SBR ANTENNA

Waveform generator AOSP — RF feed

Attitude control thrusters

Power distribution system

Radiating membrane

Deployable space frame

Solar array

Dipoles/droplines

Antenna plane

Control modules

Ground plane

3 layer membrane

Target-side dipole

Ground plane

RF control module

Feed-side dipole

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SEASAT CONCEPT

This picture is a concept of SEASAT with a fixed beam corporate-fed array of microstrip antenna elements, similar to the one for the SIR-A antenna shown on the next page. This antenna is a foldout panel deployment configuration whose concept originated at Ball Aerospace Corporation.
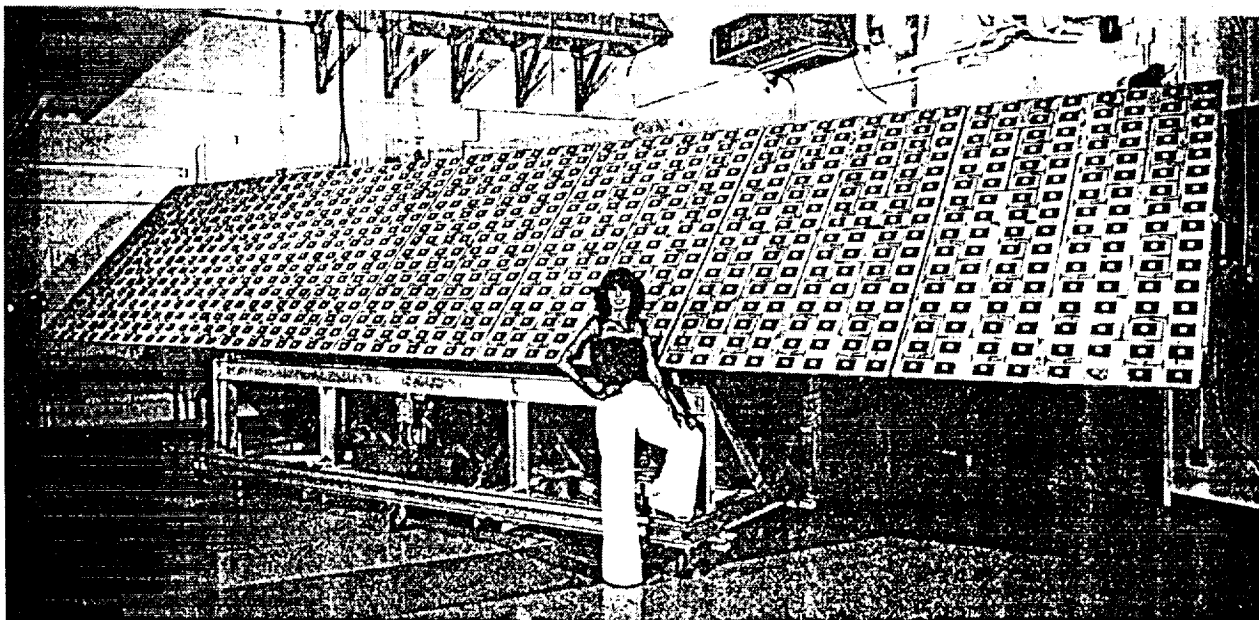
SEASAT-A

SIR-A ANTENNA

Shown below is the SIR-A antenna flown on the shuttle. This antenna is a foldup microstrip fixed-beam array.

SHUTTLE BAY SAR ANTENNA (SIR-A)

- L-BAND, SAR
- EARTH RESOURCES
- FIRST SHUTTLE EXPERIMENT
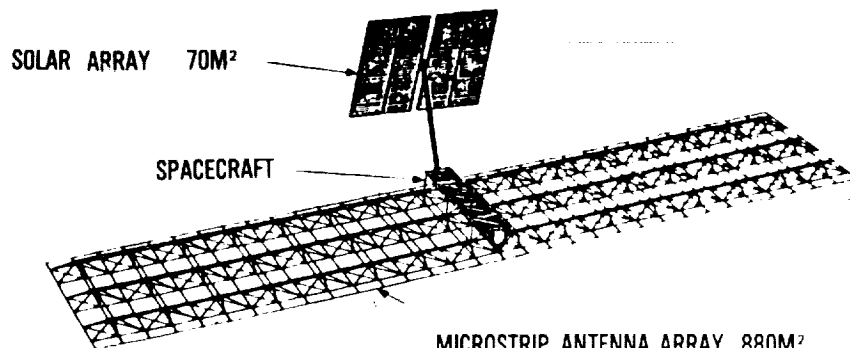- 33 DB GAIN

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE IS
OF POOR QUALITY
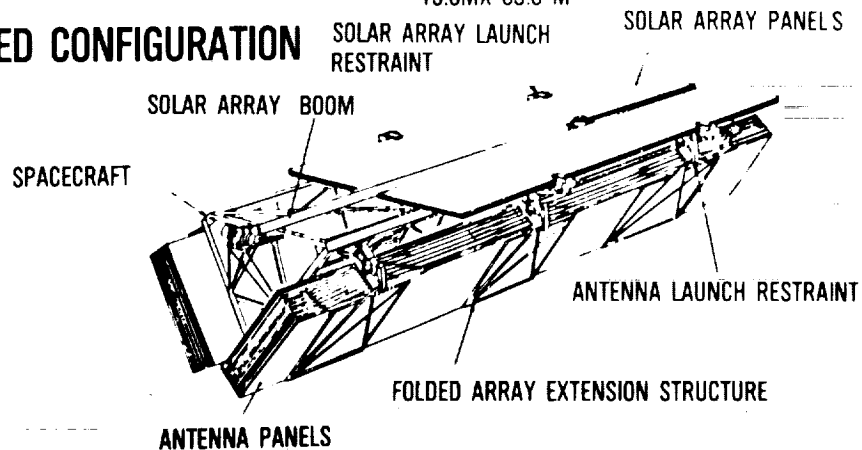
CORPORATE FED PHASED ARRAY CONCEPT

This figure shows a foldout concept of a microstrip phased array for Space Based Radar (SBR). Both the deployed and stowed configurations are shown. The array is approximately 13 meters wide by 64 meters long. This concept is proposed for SBR by Ball Aerospace Corporation.

FOLDOUT DEPLOYMENT

ORBIT CONFIGURATION

SOLAR ARRAY 70M²

SPACECRAFT

MICROSTRIP ANTENNA ARRAY 880M²
13.8MX 63.6 M

STOWED CONFIGURATION SOLAR ARRAY LAUNCH RESTRAINT   SOLAR ARRAY PANELS

SOLAR ARRAY BOOM

SPACECRAFT

ANTENNA LAUNCH RESTRAINT

FOLDED ARRAY EXTENSION STRUCTURE

ANTENNA PANELS

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Constrained Feed:

A corporate fed array uses elements of an array with each output phase adjusted for collimating the received energy from a particular direction. The output of each element is then combined through a series of power combiners as shown to a single output.
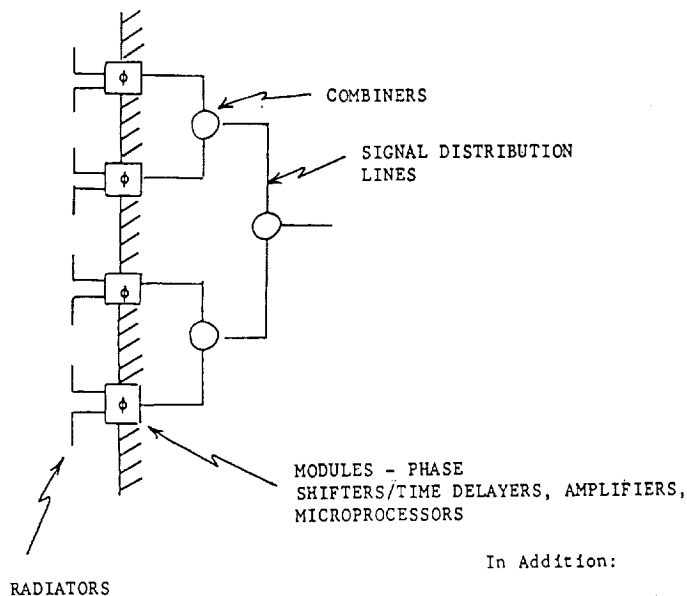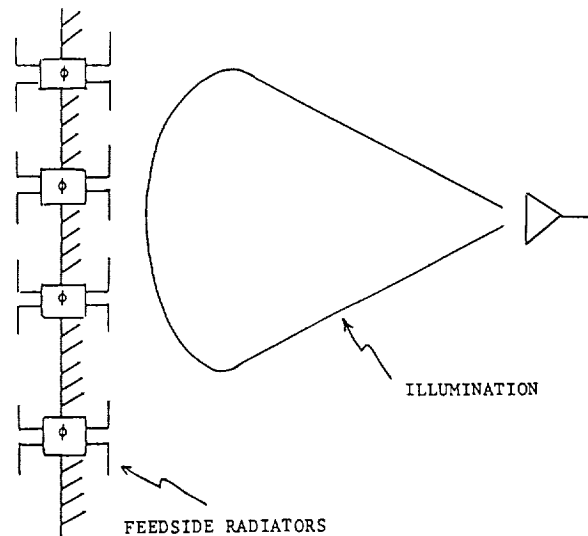
Space Feed:

A space fed array uses elements of an array with each output phase adjusted for collimating the received energy from a particular direction. The output of each element is then used to feed a corresponding element on the back side of the array (bootlaced lens array). The phase shifters in the bootlaced lens array are also used to produce a converging circular wavefront to converge at a feed for single output.

Each of these antenna system concepts requires prime power distribution to each phase shifter module. All modules require control signals from some central beam steering command center. These modules produce heat and, therefore, temperature control will be required, especially for space application. These modules could also have transmitters and or receivers in them.

CONSTRAINED FEED

COMBINERS

SIGNAL DISTRIBUTION
LINES

MODULES - PHASE
SHIFTERS/TIME DELAYERS, AMPLIFIERS,
MICROPROCESSORS

RADIATORS

SPACE FED

ILLUMINATION

FEEDSIDE RADIATORS

In Addition:

- POWER DISTRIBUTION
- TEMPERATURE CONTROL
- MODULE CONTROL

LOSS VERSUS PHYSICAL DEFORMATION

The three curves on this graph, (1) Reflector, (2) Corp-Fed Array, and (3) Space-Fed Array show the loss in gain as a function of edge deflection in wavelengths and in centimeters for each respective frequency from 5 to 200 GHz as shown. The curves clearly show that the surface of a corporate fed array is twice as tolerant as a reflector antenna system and the space-fed array is 10 times more tolerant than the corporate fed array. The reason for this is that in the space-fed array, any deformation of the array in the plane normal to the array causes a delay or advance of phase with respect to a plane wave and on the opposite side a corresponding advance or delay is naturally created. Hence, the deformation is automatically compensated for with deformations up to about one wavelength for 0.5 dB loss in gain. Also, the flat surface of a lens would be much easier to maintain flat than to maintain a reflector surface parabolic.
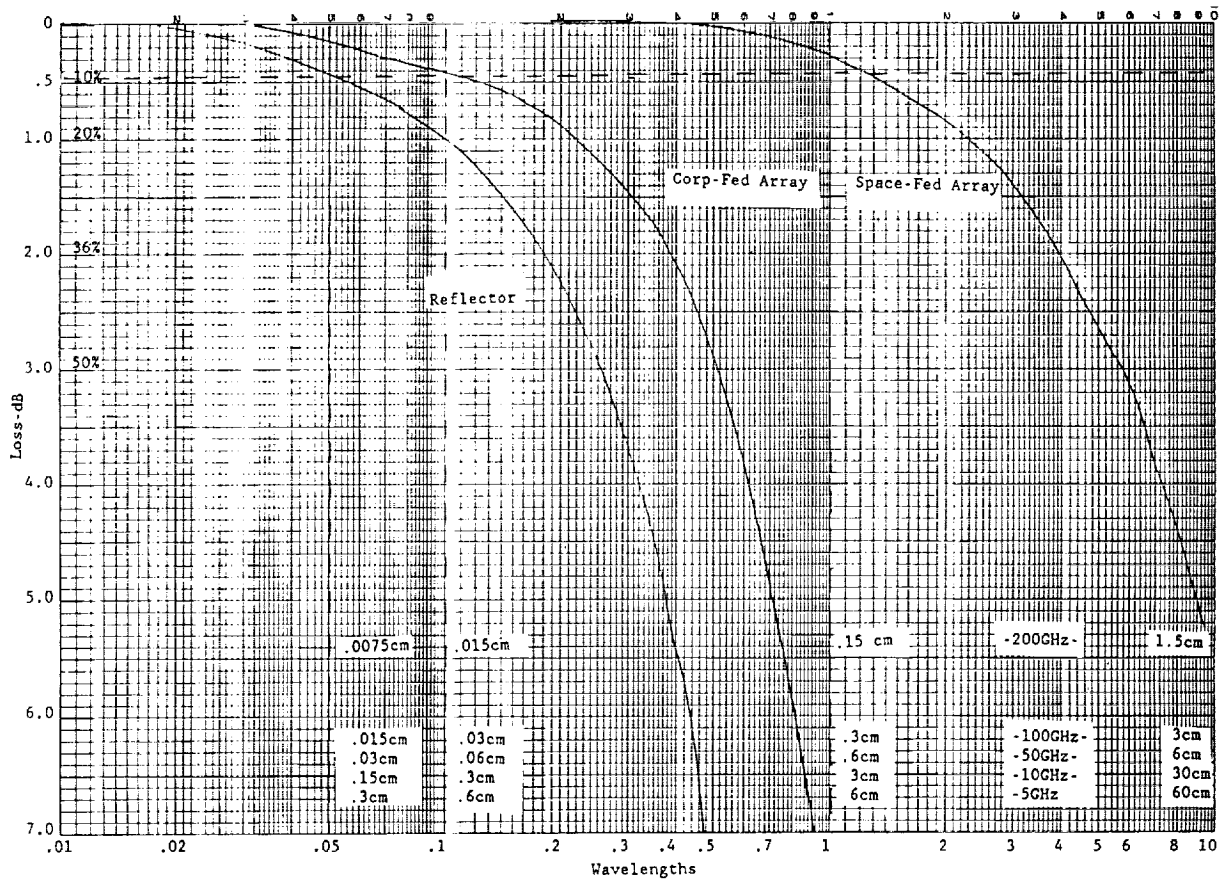
250

The requirements specified on this chart are the general specifications the authors have gleaned from previous presentations by other organizations. They are not necessarily the requirements for ESGP. These were requirements used to size a sample antenna system and to present possible concepts that could be used to meet these performance requirements.

- GEOSYNCHRONOUS ORBITS
    - SCAN ± 9 DEGREES

- FREQUENCY 5-200GHz

- PASSIVE RECEIVE ONLY (RADIOMETRIC)

- BEAMWIDTH <0.1 DEGREE

- GAIN >60DBI

- SIDELOBES <0DBI

GRATING LOBE LIMITATION ON FOV

   This graph shows the required element spacing of a phased array as a func-
tion of scan angle such that no grating lobe enters the scan cone (FOV). As an
example, for geosynchronous orbit (23,500 mm altitude) a scan volume or FOV of
plus and minus nine (9) degrees would require approximately a three (3) wave-
length element spacing.
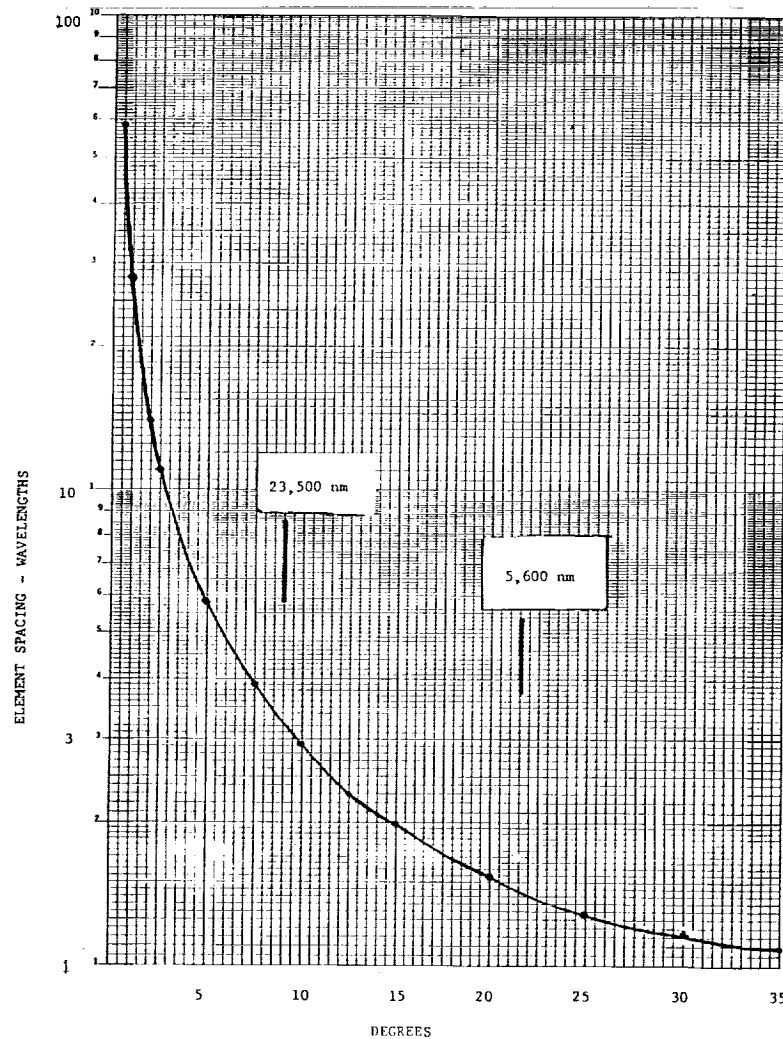
PHASE SHIFTER SAVINGS DUE TO SUBARRAYING

The area of a subarray is given by the product of the number of elements in the subarray (subarray element size) and the interelement area. An optimum interelement area was defined as the maximum for which no part of a subarray pattern grating lobe enters the visible range. With this choice of interelement area and the criteria that the interelement area be uniform throughout the array, the percent reduction in required number of phase shifters resulting from nonoverlapping subarrays is given by the curves shown in the figures. The percent reduction is a function of maximum scan angle as well as subarray element size because the nonsubarrayed interelement spacing decreases with maximum scan angle and the subarrayed "optimum" interelement spacing is independent of maximum scan angle.

With nonoverlapping subarrays the gain gradually deteriorates with increasing scan. The maximum acceptable gain loss and maximum scan angle essentially define the field of view. Gain loss curves of .5 dB, 1 dB and 3 dB are shown in the figure. For example, a field of view = $\pm 8^\circ$ with maximum acceptable gain loss of 1 dB would result in a greater than 80 percent savings in number of phase shifters. Nine radiators would be combined with a single phase shifter. Also, a FOV = $\pm 9^\circ$ with maximum acceptable gain loss of 3 dB would result in a greater than 90 percent savings in number of phase shifters. Sixteen radiators then would be combined with a single phase shifter.

MAXIMUM SCAN ANGLE (DEGREES)
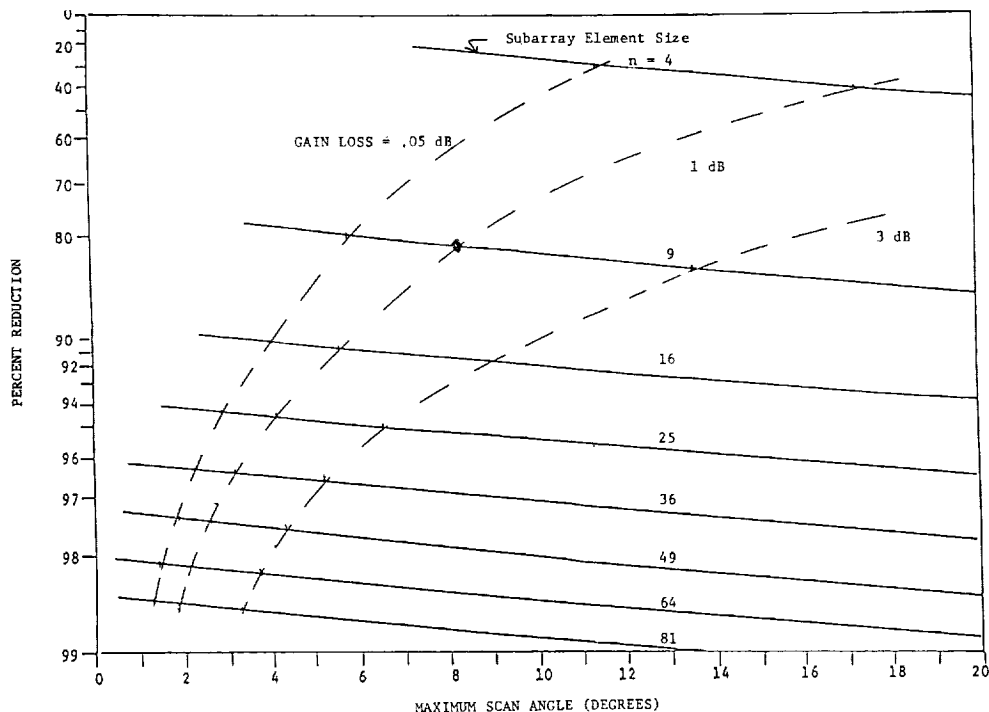
ANTENNA ARRAY DESIGN PARAMETERS

This graph shows parametric curves of antenna aperture diameter in meters, as a function of frequency, diameter in wavelengths, number of elements or subarrays of three (3) wavelengths on a side or $(9\lambda^2)$, beamwidth in degrees and Earth surface resolution at the antenna 3 dB beamwidth. As an example, an 0.1 degree beamwidth at 10 GHz with a 20 meter diameter antenna would require 48,000 subarrays and produces a resolution cell of 40 nautical miles. Other antenna diameters and frequencies with corresponding parameters can be extracted from the graph.
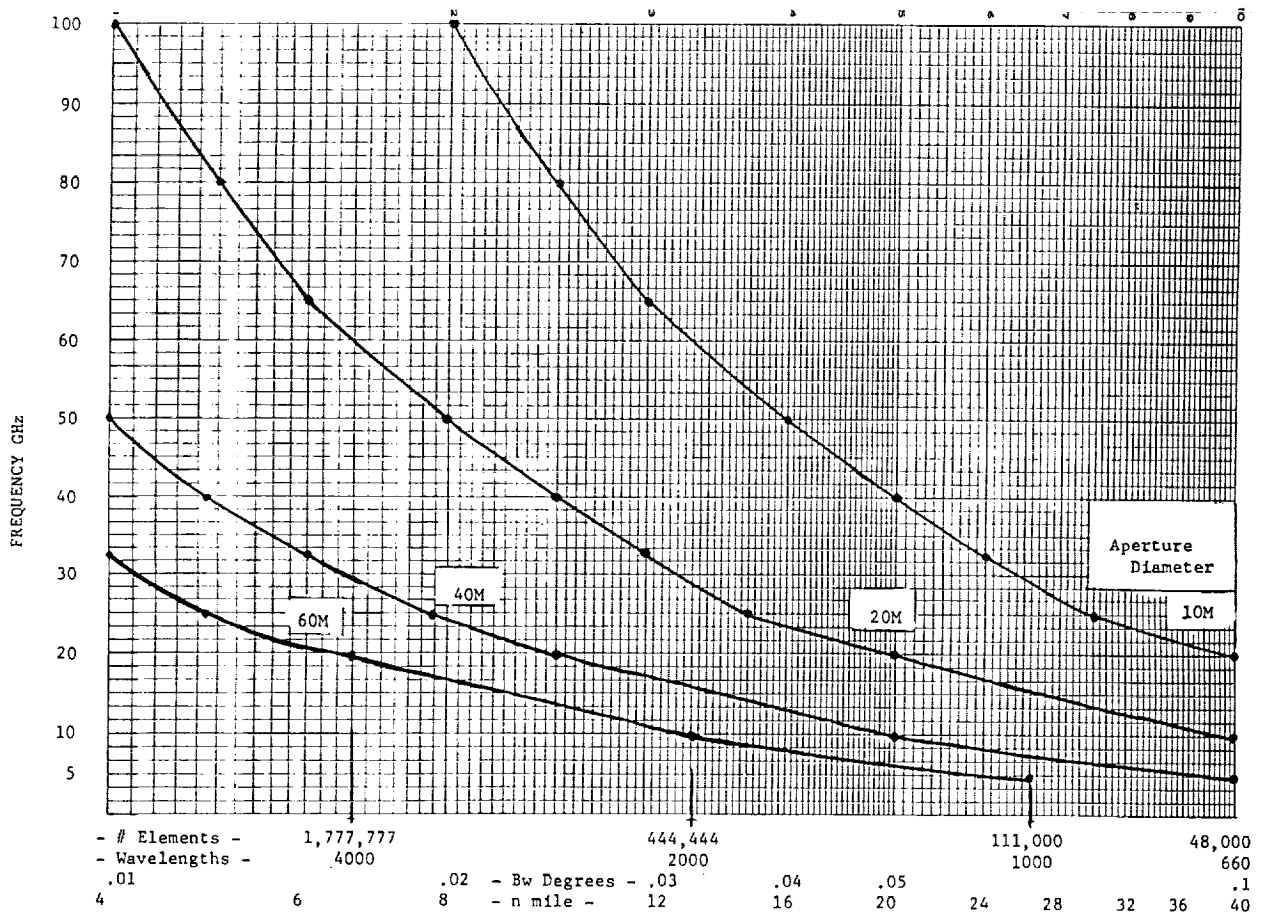
NEW IDEAS
FOR
NARROW FOV

- **ARRAYS**

- **SUBARRAYS**

- **SPACE-FED ARRAYS**

Narrow beam implies large aperture and wide field of view implies small interelement spacing (as dictated by the onset of grating lobes at the edge of the scan volume). Consequently, narrow beam, wide FOV electronically scanned antennas typically contain large numbers of phase shifter/radiators. If the number of phase shifter/radiators is reduced and their placement randomized (to suppress grating lobes), the sidelobes will rise and the gain will diminish (but the beam will remain narrow).

NARROW BEAM, WIDE FIELD OF VIEW PHASED ARRAYS ARE EITHER

- **FULLY POPULATED**

  - **REQUIRE LARGE NUMBER OF PHASE SHIFTERS**

- **RANDOM SPARSE**

 - **HIGH SIDELOBES**

  - **DIMINISHED GAIN**

A limited field-of-view system requires fewer phase shifters. The phase shifter reduction can be accomplished by subarraying whereby each of the remaining phase shifters is tied to a group (subarray) of radiators. The subarrays can be disjoint or overlapping. Disjoint subarrays are less effective but simpler to implement especially for constrained feed arrays. Overlapped subarrays are especially suited for fixed focus array lenses and reflectors whereby the subarray signal distribution is via the space feed.

EARTH VIEWING, GEOSYNCHRONOUS SENSOR HAS LIMITED FIELD OF VIEW (~ $\pm 8^o$). NUMBER OF PHASE SHIFTERS CAN BE REDUCED BY EITHER

- **NONOVERLAPPING (CONVENTIONAL) SUBARRAYS**

  - GAIN LOSS WITH SCAN

  - CLOSE IN SIDELOBES INCREASE WITH SCAN

- **OVERLAPPING SUBARRAYS**

  - NOT PRACTICAL FOR CONSTRAINED FEED

 - ATTRACTIVE FOR

    - FIXED FOCUS ARRAY LENS

    - REFLECTOR

Consider, first, nonoverlapping subarrays. A rectangular lattice 2 x 2 (4:1) subarray is identified by the dashed contour.
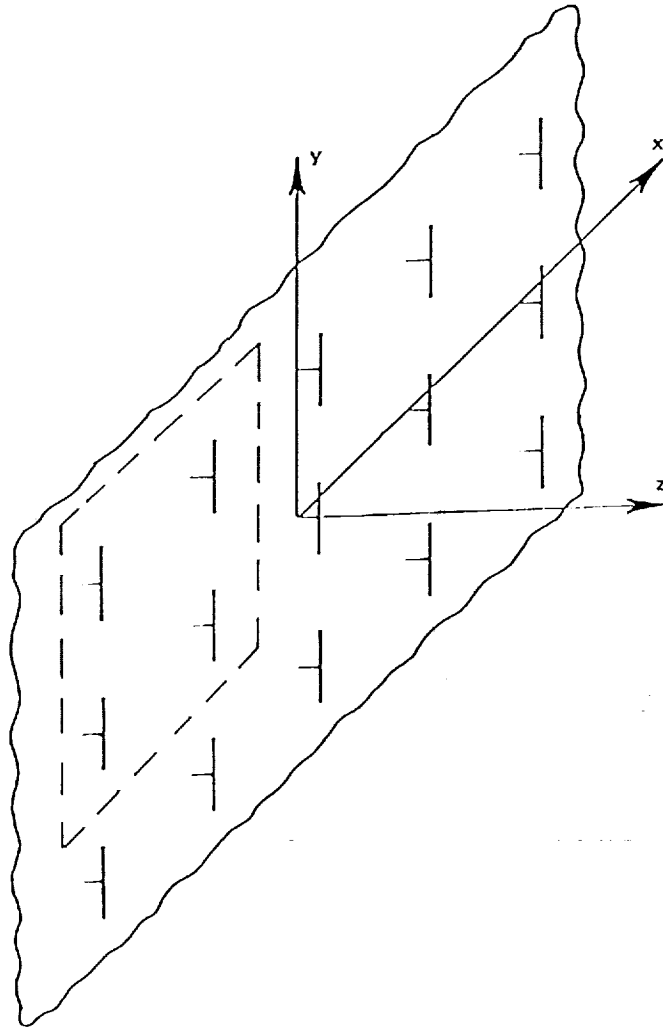
NONOVERLAPPING SUBARRAY PATTERN COMPONENTS

Typical subarray pattern and subarray array factor main lobe and first grating lobe are shown in the figure. Radiator interelement spacing is assumed to be uniform throughout the array and the "optimum" interelement spacing is chosen to be the maximum spacing for which no part of a subarray pattern grating lobe falls within the visible range. Neglecting impedance mismatch loss and beam broadening, scan loss is given by the subarray pattern gain rolloff. This roll off is gradual and corresponds to the positioning of subarray array factor grading lobes in the main lobe of the subarray pattern.

The subarray weights can be adjusted to reduce subarray pattern sidelobes and, hence, full array far sidelobes. However, close in high sidelobes are inevitable as a consequence of grating lobes in the subarray pattern main lobe.
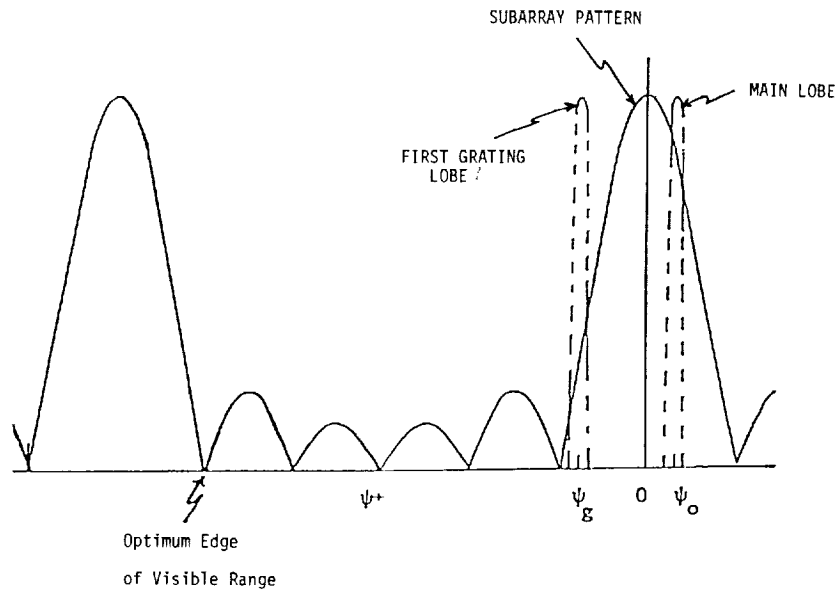
OVERLAPPING SUBARRAYS

Now consider overlapping subarrays. A fully overlapped, "orthogonal beam", subarray pattern is shown in the figure. There is minimal gain loss throughout the field of view. The subarray centers must be spaced such that a subarray array factor grating lobe, at maximum scan, would just be excluded from the field of view. Low level close in sidelobes, as well as ultralow far out sidelobes, are feasible design specifications.

SUBARRAY
PATTERN

MAIN
LOBE

FIRST GRATING
LOBE
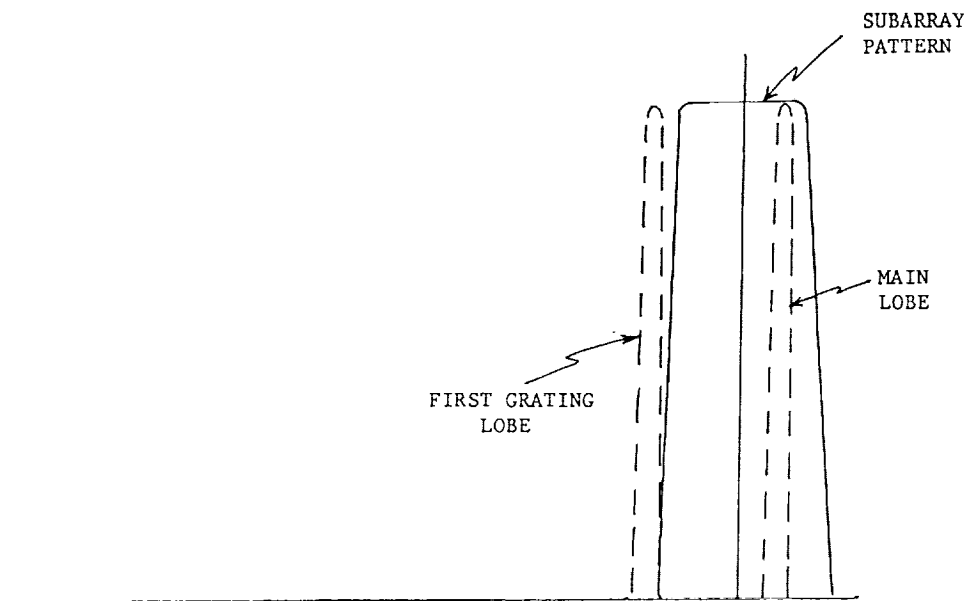
SPACE FED LENS OVERLAPPING SUBARRAY CONCEPT

A practical overlapping subarray concept is shown in the figure. This concept was analyzed by G. Borgiotti as reported in IEEE T-AP, Vol. AP-25, No. 2, March 1977. The focal plane array can be implemented as a conventional Butler matrix. In addition to being a lightweight, practical implementation of overlapping subarrays, the concept has inherent wide bandwidth, in excess of 20 percent, as a consequence of the frequency independence of the pattern beamwidth and of the array factor main beam direction. Performance is limited in part by the finite lens length, beamforming hardware (transmission lines, combiners, etc.) bandwidth and loss, and radiating element impedance match (mutual coupling).
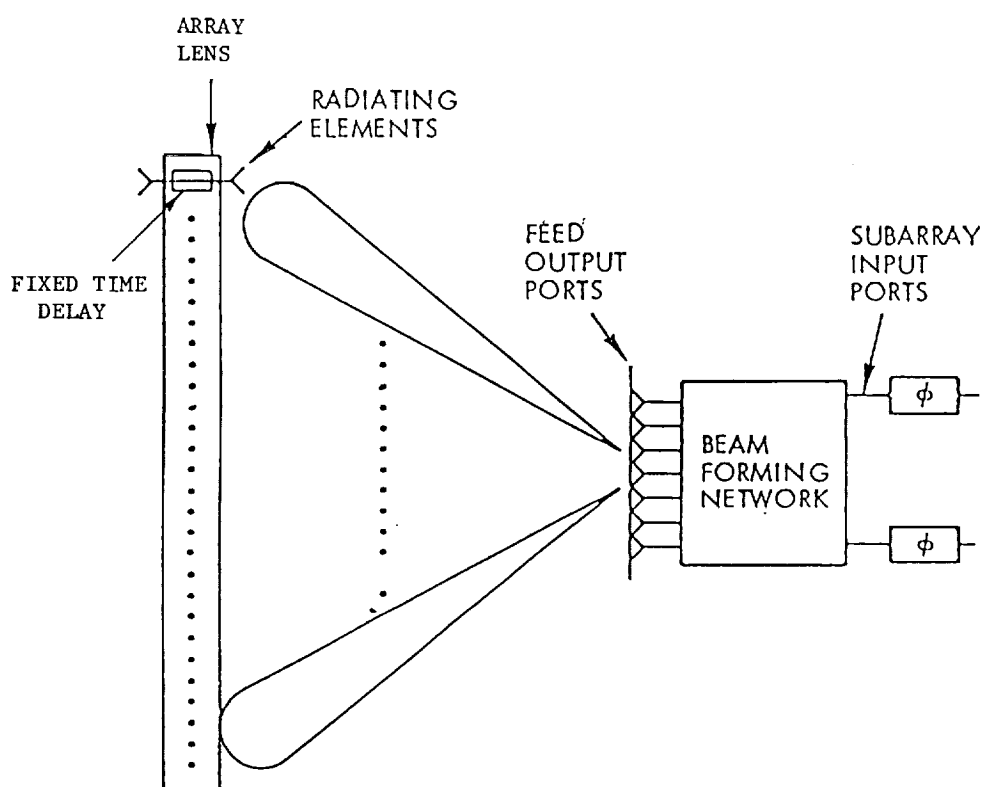
CRITICAL TECHNOLOGY AREAS

- RECEIVE MODULES (ACTIVE LENS)

- DEPLOYMENT

- PRIME POWER DISTRIBUTION (ACTIVE LENS)

- FEED SYSTEM (TRANSFORM FEED)

- LOW LOSS LENS (PASSIVE)

- BANDWIDTH (ELEMENTS-FEED-LENS)

VALIDATION

ANOTHER MAJOR "TECHNOLOGY" CONCERN IS VALIDATION

- SPACE TESTING TOO EXPENSIVE

- GROUND TESTING NOT FEASIBLE WITH FULL-SCALE SYSTEM

DETAILED COMPUTER SIMULATIONS PRESENT A SOLUTION

- SOFTWARE CAN BE VALIDATED WITH MANAGEABLE GROUND—BASED EXPERIMENTS

- APPLIED TO VALIDATING FULL-UP SYSTEM

- NOW AVAILABLE (E.G. RADC'S* "PAAS" PROGRAM - CONTACT J. CLEARY) *Rome Air Development Center, Rome, NY