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# MULTIFREQUENCY SYNTHETIC APERTURE RADAR ANTENNA COMPARISON STUDY

FINAL REPORT

by
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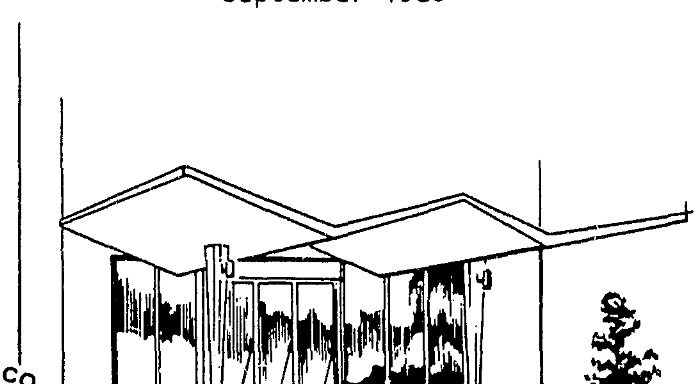
Prepared for:

NASA Johnson Space Center
Houston, Texas

CONTRACT NO. NAS9-95519



September 1983



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(NASA-CR-171736) MULTIFREQUENCY SYNTHETIC APERTURE RADAR ANTENNA COMPARISON STUDY Final Report (New Mexico State Univ.) 41 p HC A03/MF A01 CSCL 17I

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# MULTIFREQUENCY SYNTHETIC APERTURE RADAR ANTENNA COMPARISON STUDY

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September 1983

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## Introduction:

Synthetic aperture radars are of great current interest in the remote sensing community [1]. In order to expand the utility of SARs when used to perform remote sensing functions such as sea ice monitoring, sea wave spectra measurements, geological studies, crop inventories and other functions, future SARs will be multipolarization and multifrequency.

This report is a review of three multifrequency, dual polarization SAR antenna designs.

The SAR antenna design specifications were for a "straw man" SAR which would approximate the requirements for projected shuttle-based SAR's. Therefore, the physical dimensions were constrained to be compatible with the space shuttle. The electrical specifications were similar to those of SIR-A and SIR-B with the addition of dual polarization and the addition of C and X band operation. Early in the antenna design considerations, three candidate technologies emerged as having promise. They were:

1. Microstrip Patch planar array antennas
2. Slotted Waveguide planar array antennas
3. Open-ended waveguide planar array antennas.

Three companies were selected to perform design studies based on these technologies. Hughes Aircraft studied the slotted waveguide array, Ball Aerospace studied the microstrip patch antenna, and Goodyear Aerospace studied the open-ended waveguide array and any other antenna type which might be applicable to the SAR requirements.

Each contractor's antenna design was to try to meet or exceed the straw man SAR antenna design goals. Table 1 shows the NASA design goals for these designs. The antenna radiation pattern beam widths were determined by examining the required swath widths, orbit altitude, and applying the SAR design equations outlined in [2]. These calculations are not included in this report. Due to differences in interpretations of the design goals, the antenna dimensions and beam widths proposed by the three contractors were not identical.

The conclusion of this report will provide a detailed comparison of the three technologies and recommendations with respect to the "best" technology for particular missions.

Table 1. Functional Requirements for MSAR Antennas

| | | |
|---|---|---|
| Frequencies | - | L, C, and X band (1.275, 5.2 and 9.6 GHz) |
| Polarizations | - | HH, VV, and HV (H = horizontal, V = vertical) |
| Polarization Isolation | - | 20 dB minimum |
| Bandwidth | - | 50 MHz L-Band |
| | - | 150 MHz C-Band |
| | - | 300 MHz X-Band |
| Power (Peak) | - | 1.5 kW (L-Band), 10 kW (X & C Band) |
| Integrated Sidelobes | - | -15 dB maximum |
| Maximum Range Sidelobe | - | -18 dB |
| Maximum Azimuth Sidelobe | - | -14 dB |
| Range HPBW | - | 6.0° L-Band |
| | | 6.0° C-Band |
| | | 6.0° X-Band |
| Azimuth HPBW | - | 0.85° L-Band |
| | | 0.22° C-Band |
| | | 0.12° X-Band |
| Incidence Angles for operation | | 15 to 70 degrees |
| Swath Width | | 100 to 500 km |
| Orbit Altitude | | 250 to 400 km |

## Microstrip Patch Array Design

Three options for microstrip patch planar array antennas have been proposed by Ball Aerospace [3]. They are:

1. Stacked radiators (mechanical steering)
2. Side-by-side (mechnical or electronic steering)
3. Distributed (mechnical or electronic steering)

Each of these options is based on the technology used in SEASAT, SIR-A and SIR-B. The array is constructed using a printed circuit radiating patch fed by a microstrip printed circuit feed network separated from a ground plane by a dielectric honeycomb layer or a solid dielectric.

The stacked radiator option has dual polarized X band radiators next to dual polarized L band radiators, next to C-over-L band radiators. This arrangement has efficient antenna real estate utilization but suffers from extra complexity in the feed network and in assembly.

The side-by-side radiator option is a side by side arrangement of L, C, and X band arrays. This option is less complex but not quite as efficient in real estate usage.

The distributed option is a phased array version of the side-by-side option. Multiple transmit/receive modules which either do or do not contain programmable phase shifters are distributed throughout the array. This option provides better noise figures for the receiver system, a possibility for beam steering and warpage correction and graceful degradation of the array if electronic components fail. The disadvantages are increased complexity and cost in the antenna. This type of SAR is currently under study at PSL under another contract, at JPL [4] and at Ball Aerospace.

Figures 1 through 4 show the relative dimensions and the construction of the microstrip options. The distributed option would add to the thickness of a panel patch array.

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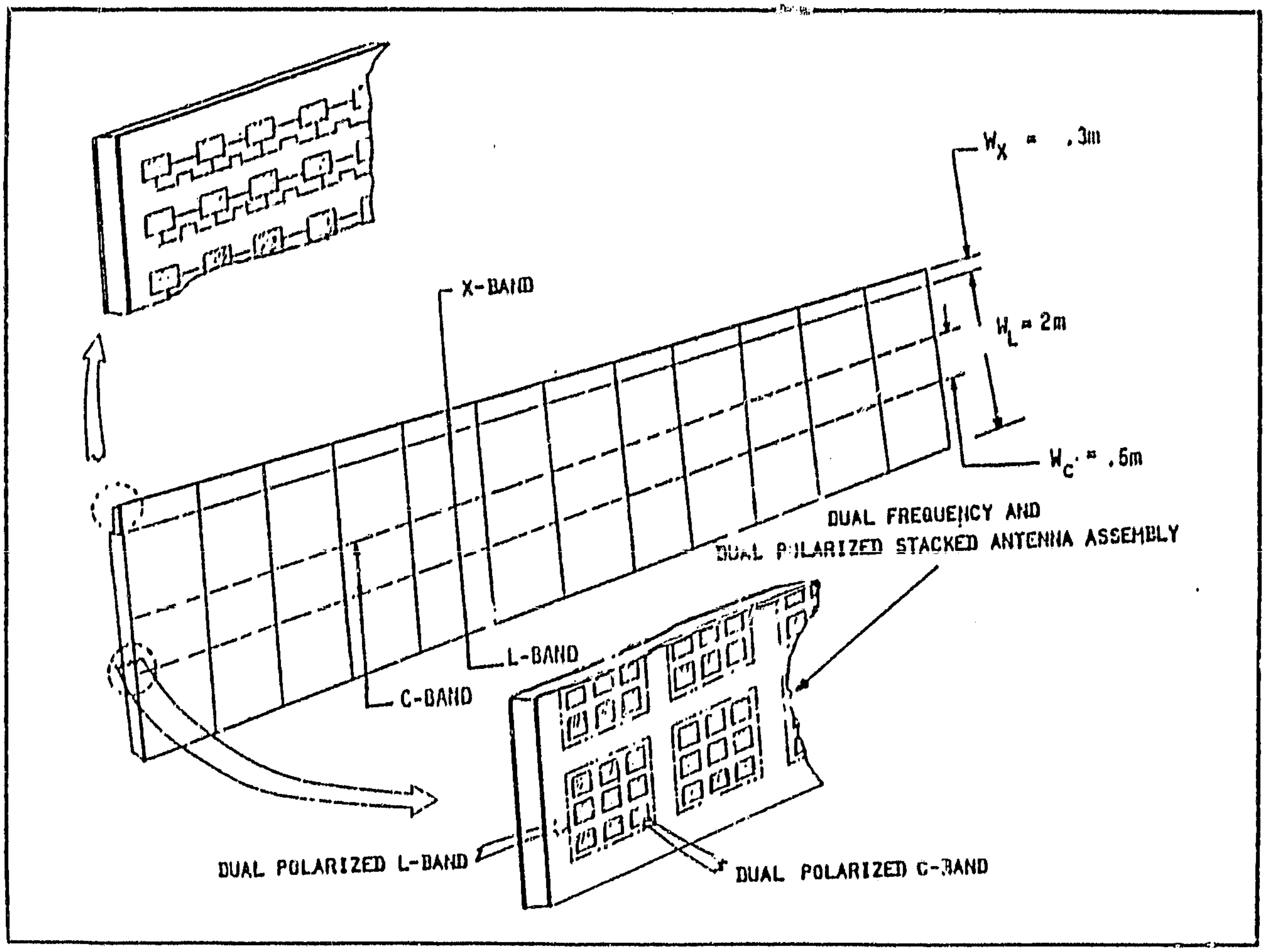


Figure 1. The Stacked Microstrip Antenna Array (Ball Aerospace)

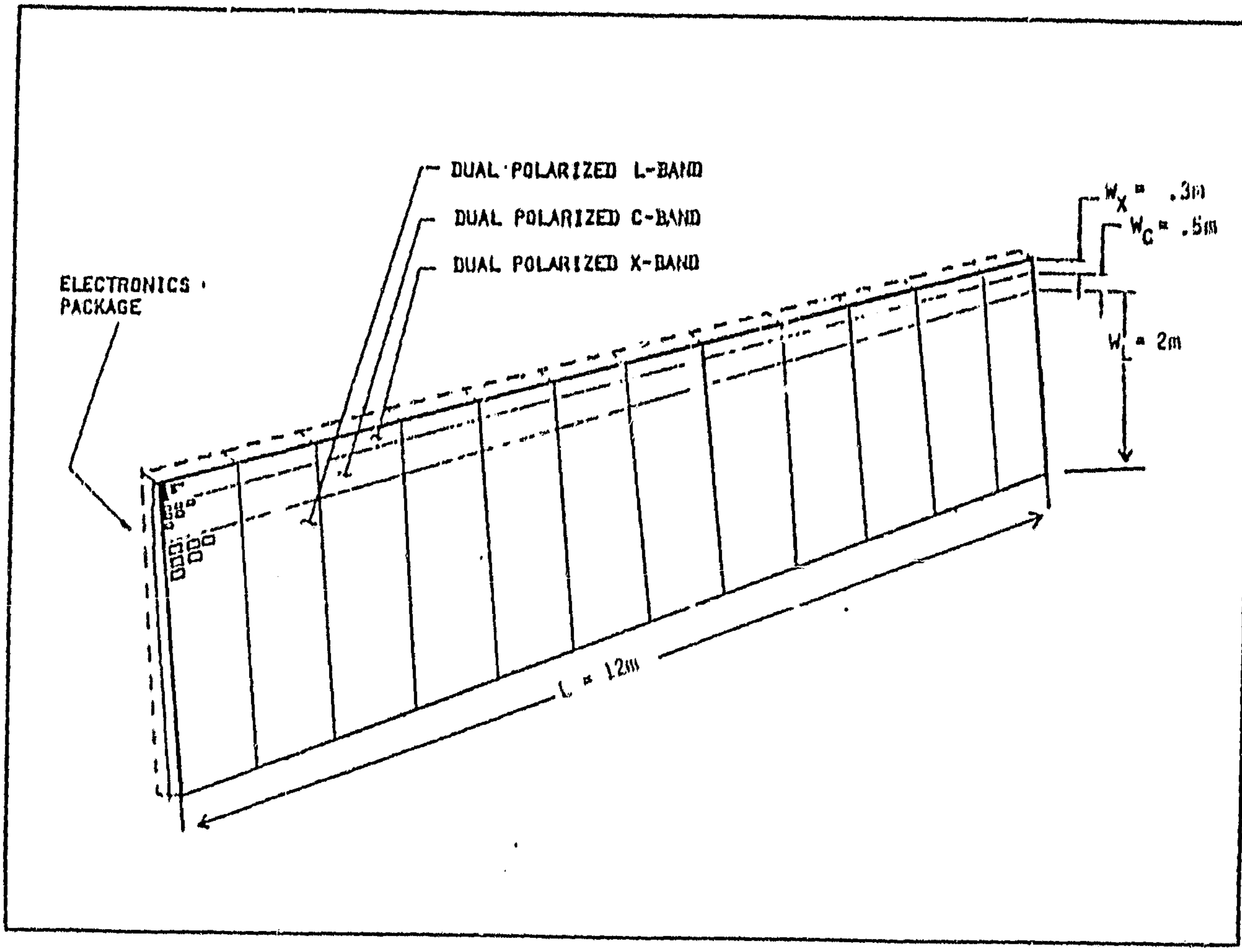


Figure 2. The Side-By-Side Microstrip Array (Ball Aerospace)

# SIDE-BY-SIDE MICROSTRIP ARRAY

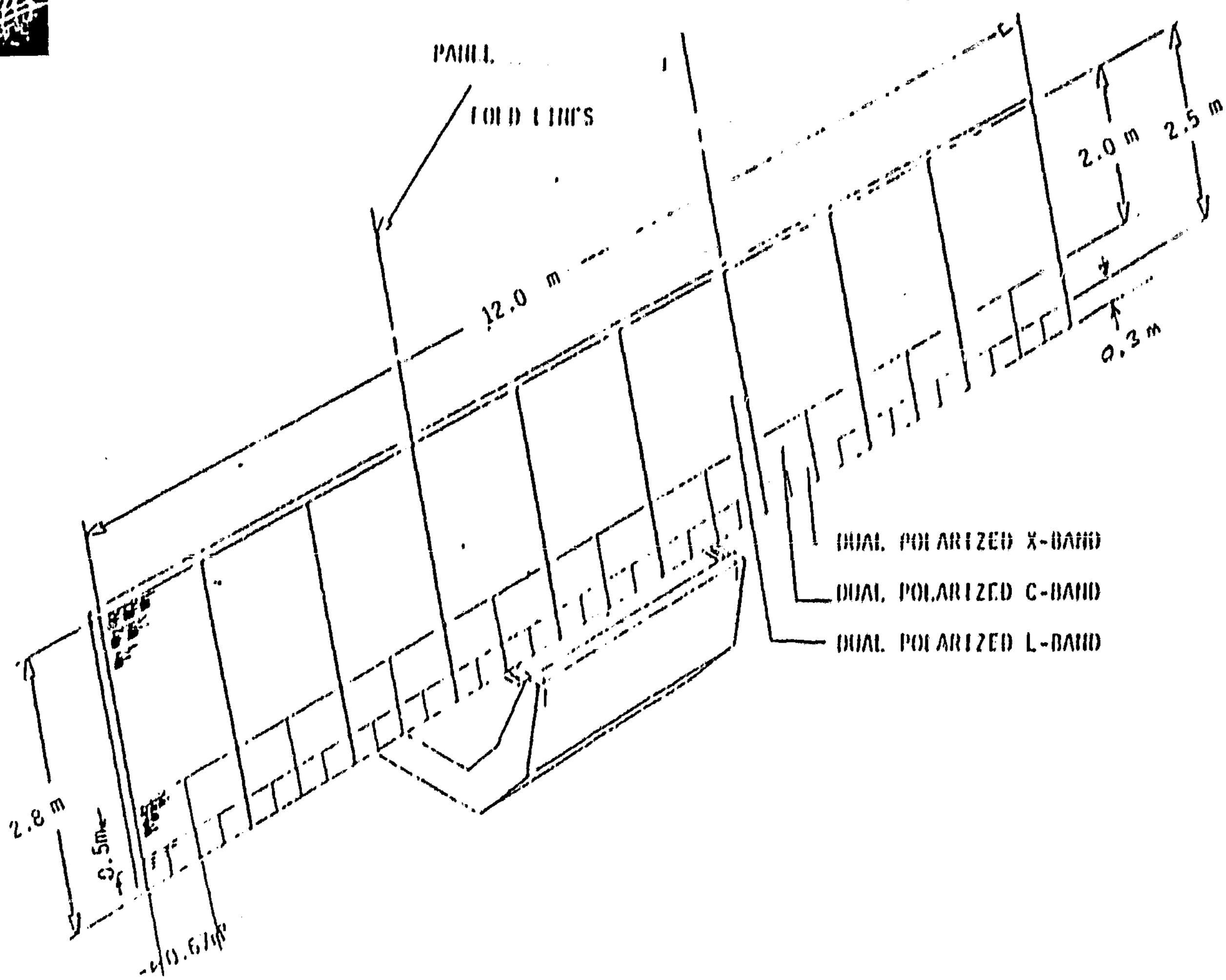


Figure 3. Side-By-Side Microstrip Array (Ball Aerospace)

# PANEL LAYOUT

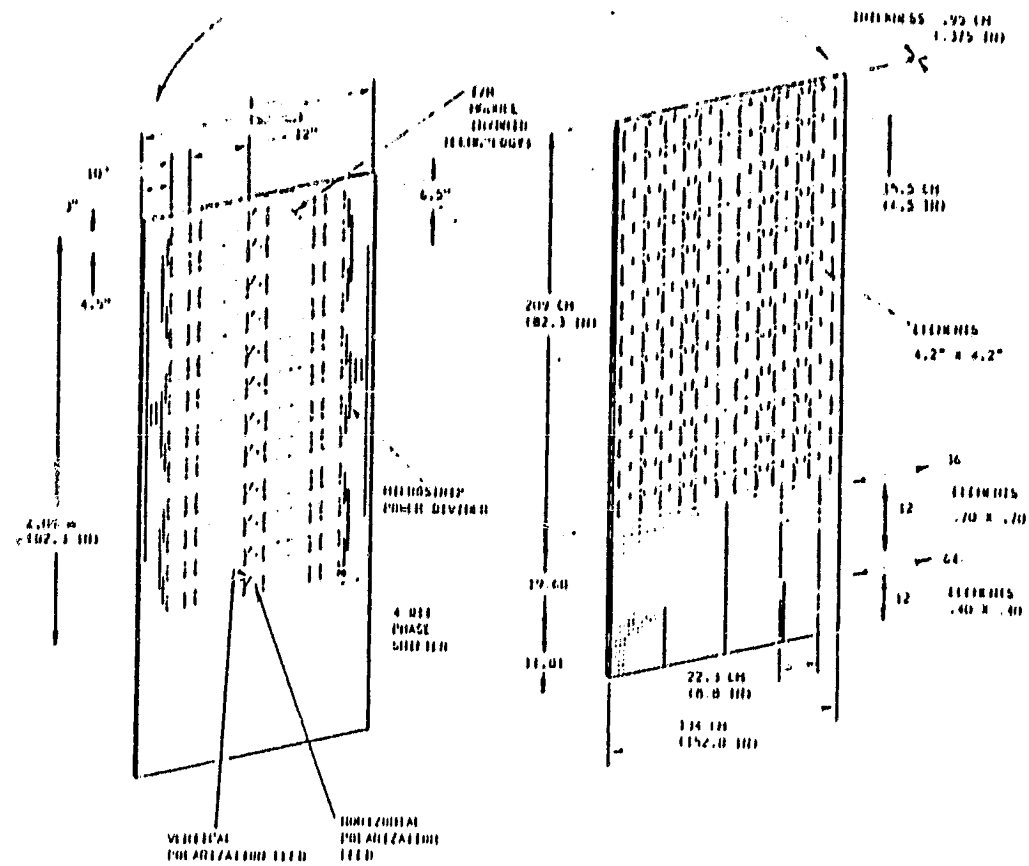

Figure 4. Side-By-Side Array with Electronic Phase Shifters (Ball Aerospace)

## Slotted Waveguide Planar Array Design

Hughes Aircraft has proposed a SAR antenna design using slotted waveguide techniques [5]. The technology used in the design has been proven in smaller planar arrays.

The slotted waveguide array proposed is side-by-side arrays of single frequency, single polarization radiators. The waveguide in the C and X band portions of the array would be manufactured using standard aluminum dip brazing techniques. The waveguide used in the L band portion would be formed aluminum sheet metal bonded by using a continuous ultrasonic welding technique. The slots in the array would be machined using EDM techniques. Figures 5 through 9 show the physical layout of the array and a detail of the waveguide forming technique.

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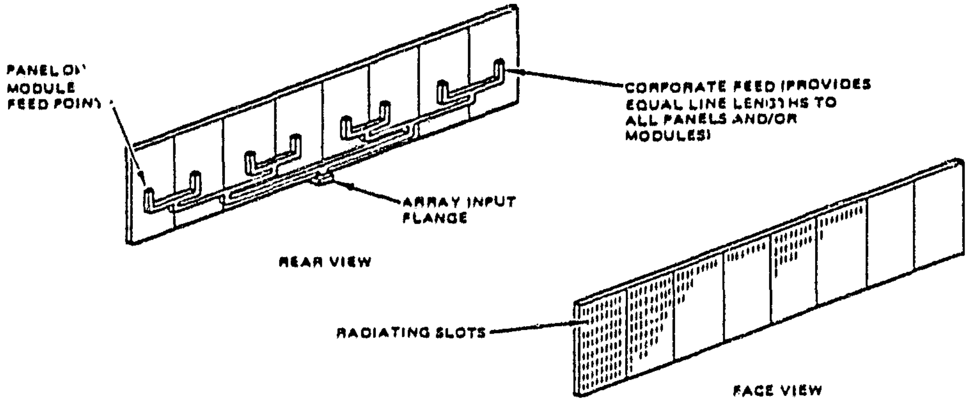



Figure 5. Subdivided Aperture (Hughes Aircraft)

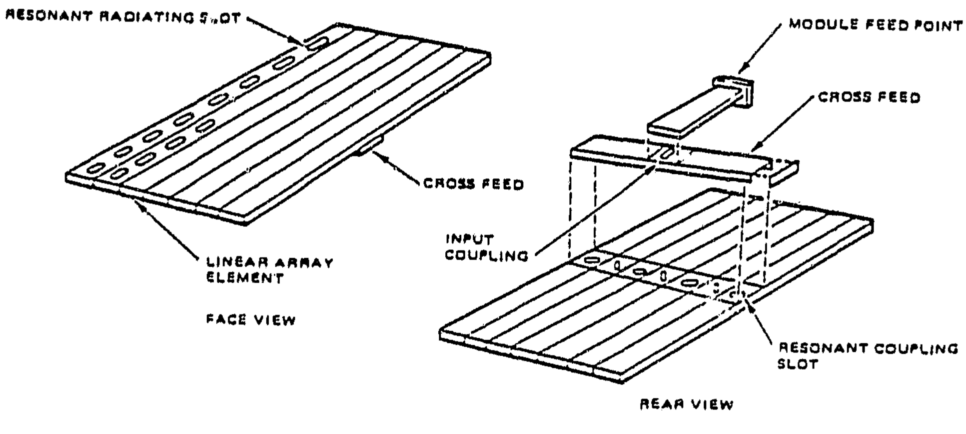
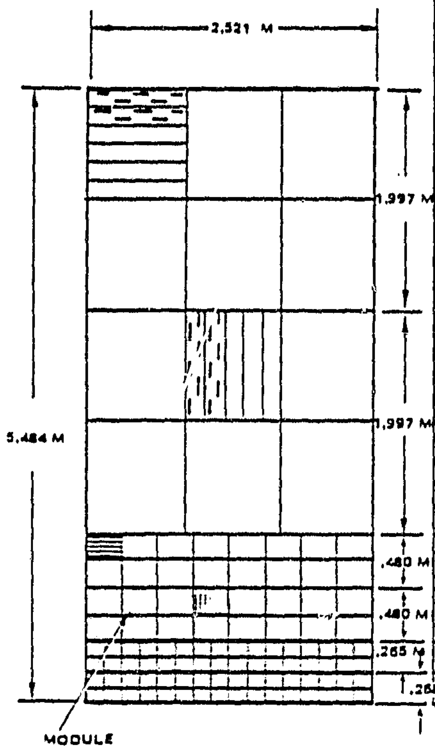



Figure 6. Typical Module Construction (Hughes Aircraft)




| BAND | POLARIZATION | NO. OF MODULES |
|---|---|---|
| L | VERTICAL | 6 |
| L | HORIZONTAL | 6 |
| C | VERTICAL | 16 |
| C | HORIZONTAL | 16 |
| X | VERTICAL | 32 |
| X | HORIZONTAL | 32 |

Figure 7. Module Layout of Panel, SAMEX 3,4 (Hughes Aircraft)

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# ALUMINUM, FOAM-FILLED WAVEGUIDE ARRAY

HUGHES
HUGHES AIRCRAFT COMPANY
RADAR SYSTEMS GROUP

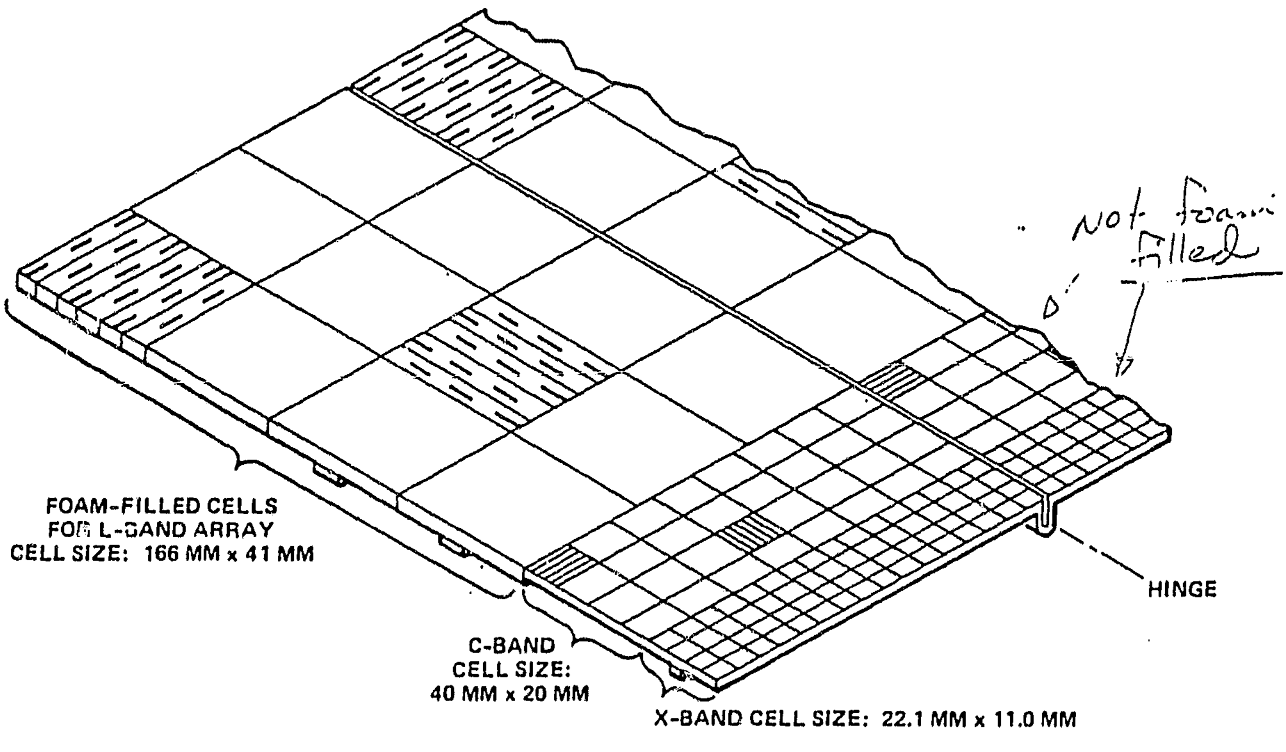
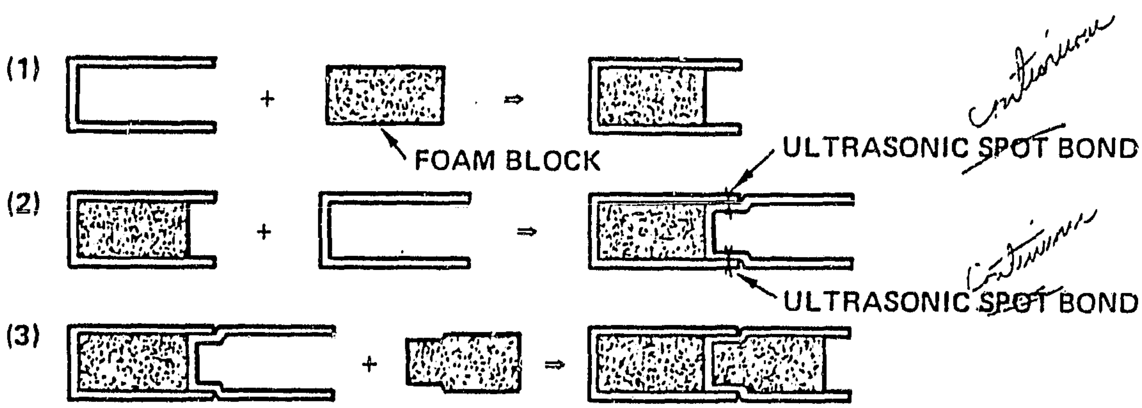



Figure 8. Detail of Slotted Waveguide (Hughes Aircraft)

# MANUFACTURING METHOD FOR L-BAND ARRAY

HUGHES
HUGHES AIRCRAFT COMPANY
RADAR SYSTEMS GROUP




(4) REPEAT (2) AND (3) AS REQUIRED

Figure 9. Construction Technique for Slotted Wavequide (Hughes Aircraft)

## Open Ended Waveguide Array Design

After considering various options other than planar array, Goodyear Aerospace settled on a planar array of open-ended waveguide radiating elements [6]. They proposed to build this array using graphite-epoxy waveguide components. This would provide a structure with a high strength to weight ratio and a low thermal expansion coefficient.

The radiating elements are completely interleaved in this design -that is- the X and C band elements are placed between L band elements. This interleaving results in very efficient antenna real estate utilization. Table 2 and Figures 10 through 15 show the various options considered by Goodyear before the interleaved open-ended waveguide array was selected as the most viable candidate. Figures 16 through 20 show the physical layout of the array and its elements.

## Table 2

### Antenna Concepts Considered by Goodyear

(1) Reflector — Prime focus fed paraboloid
Cylindrical parabola with line source feed
Near field cassegrain with cylindrical wave feed
Dual shaped reflector

(2) Log Periodic Array

(3) Quad-Ridged Radiators (array)

(4) Stripline Notch Radiator Array

(5) Space Fed Lens

### Main Reasons for Discarding

(1) Aspect ratio required for SAR too great and restorage too difficult and risky
(2) Very thick array - requires too much room, difficult to deploy, high losses
(3) Must be dielectrically loaded, difficult to manufacture, cross polarization isolation problems.
(4) Complex with high losses
(5) Aspect ratio makes illumination difficult, lens very thick.

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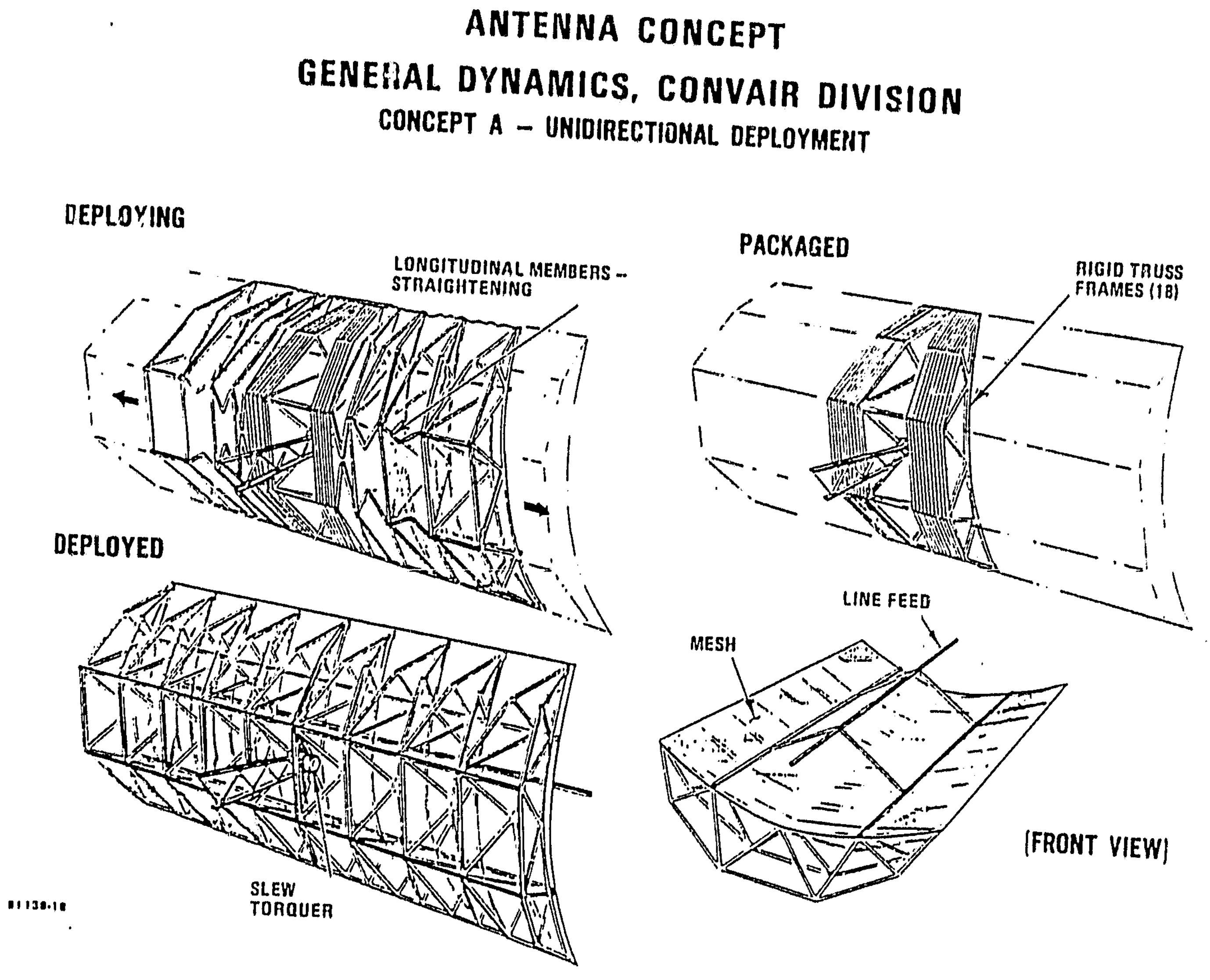


Figure 10. Cylindrical Parabola Reflector Antenna

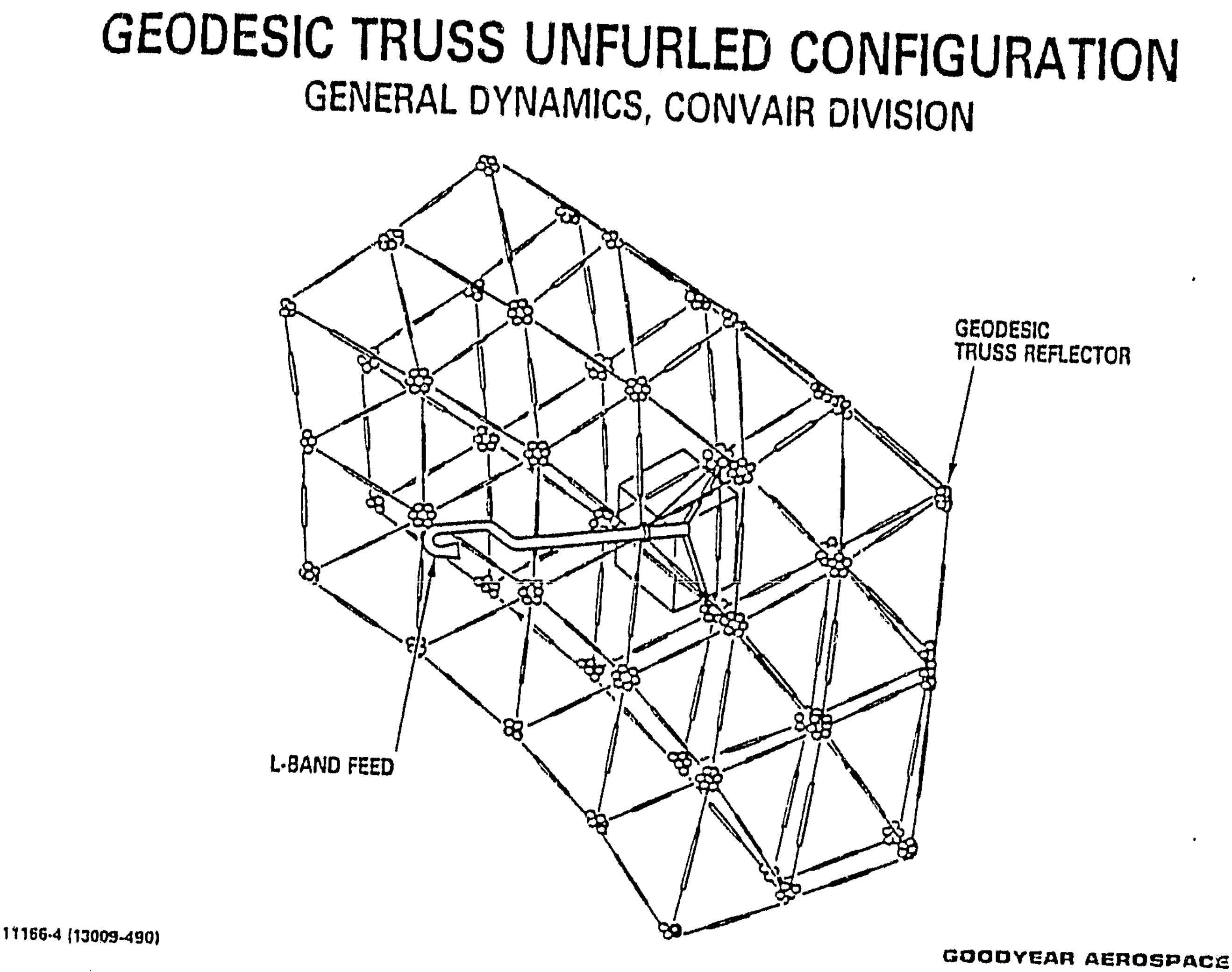


Figure 11. Geodesic Truss Reflectors

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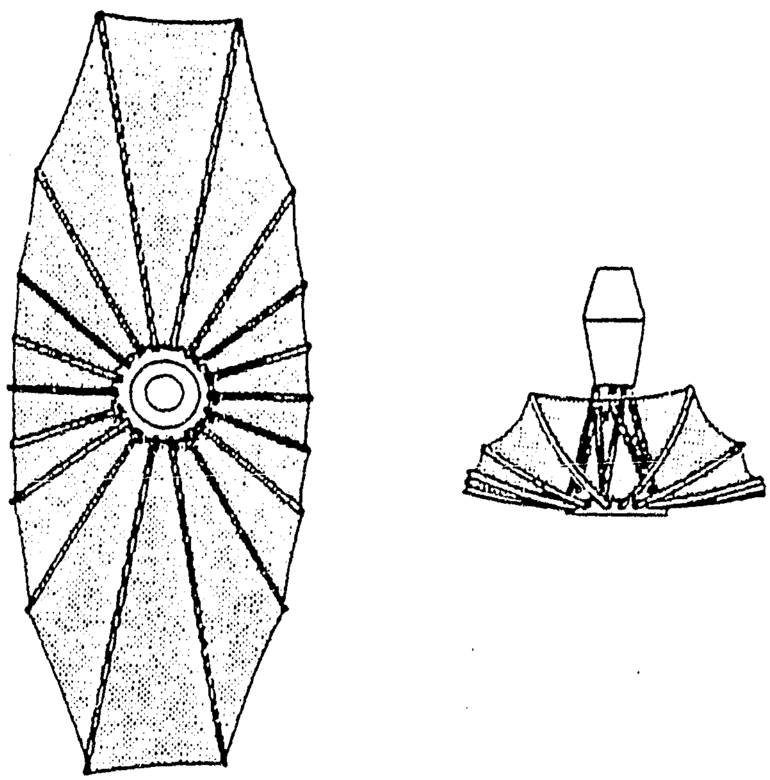
# ELLIPTICAL ANTENNA

## HARRIS CORPORATION CONCEPT



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GOODYEAR AEROSPACE

Figure 12. Elliptical Reflector Antenna

# RECTANGULAR ANTENNA

## HARRIS CORPORATION CONCEPT

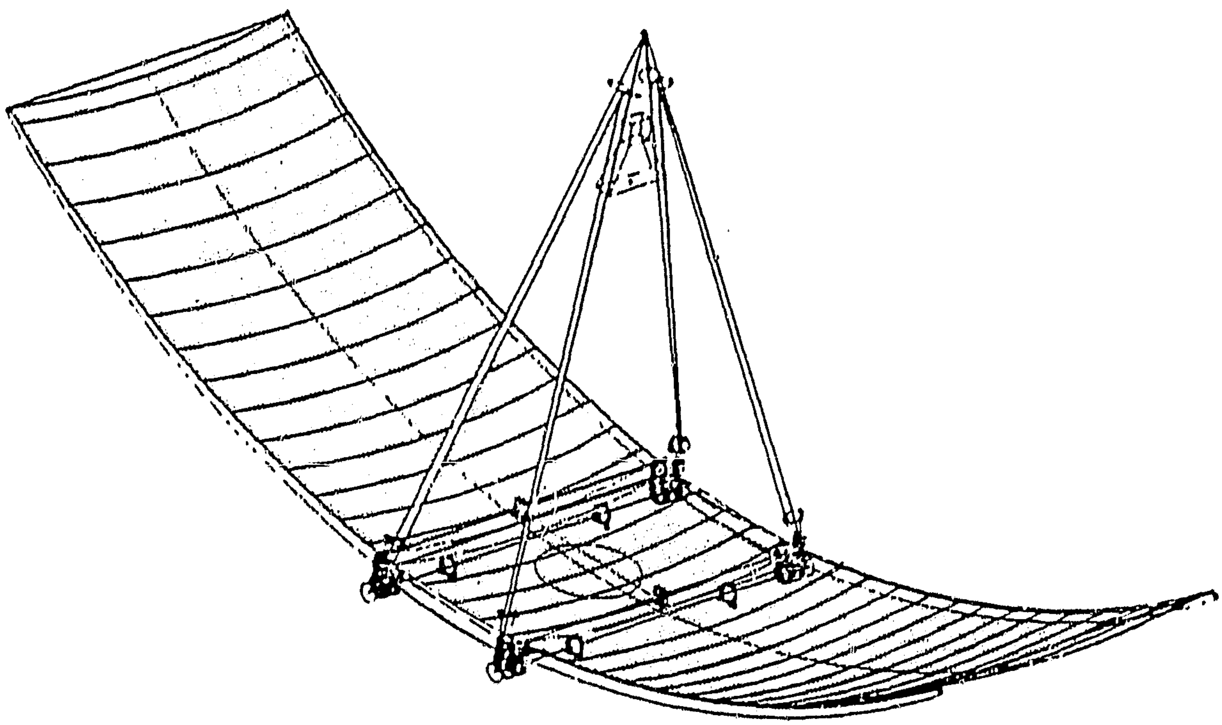

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Figure 13. Rectangular Reflector Antenna

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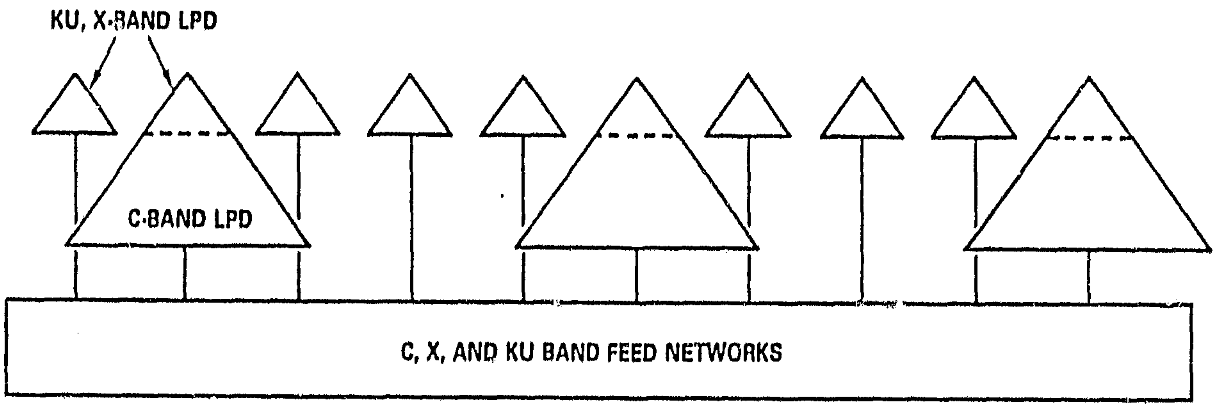
# LOG PERIODIC ARRAY

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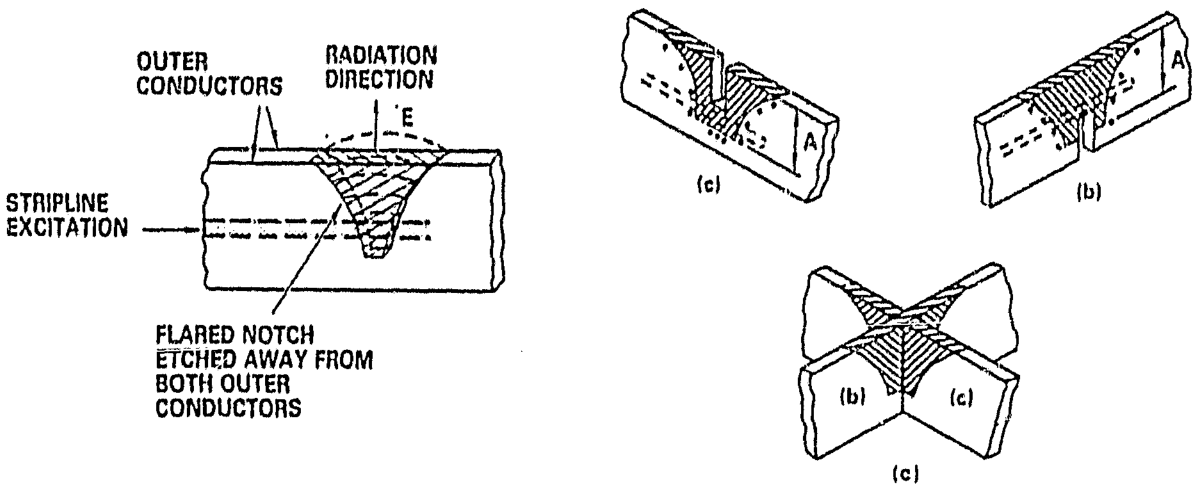
GOODYEAR AEROSPACE

Figure 14. Log Periodic Array

# STRIPLINE NOTCH RADIATOR




(A) NOTCH CONCEPT

(B) DUAL POLARIZED NOTCH

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Figure 15. Stripline Notch Planar Array Element

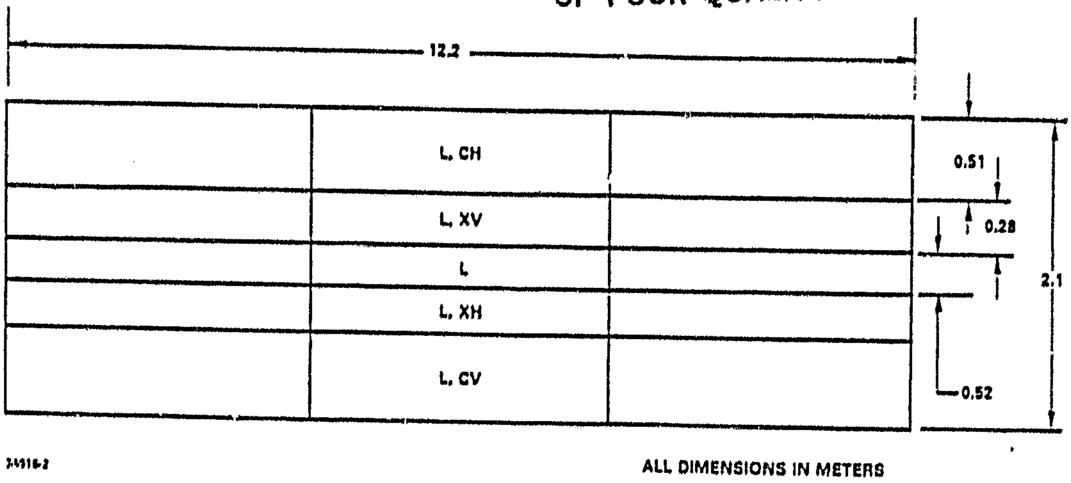


Figure 16. Interleaved Array Configuration (Goodyear Aerospace)

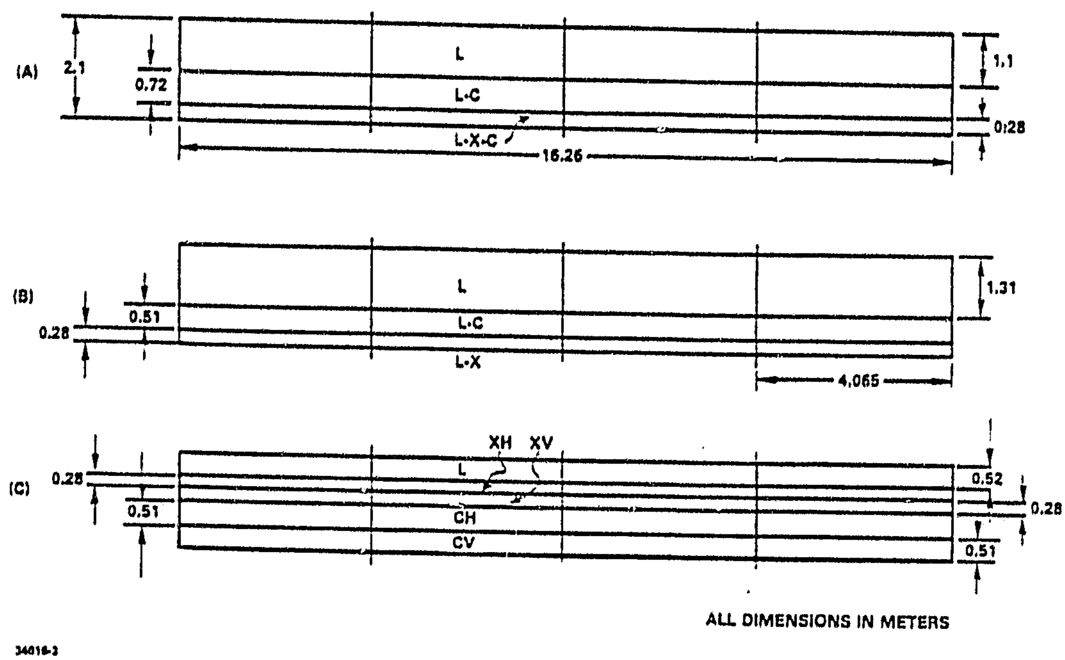


Figure 17. Alternate Interleaved Array Configurations (Goodyear Aerospace)

# ARRAY CONFIGURATION V

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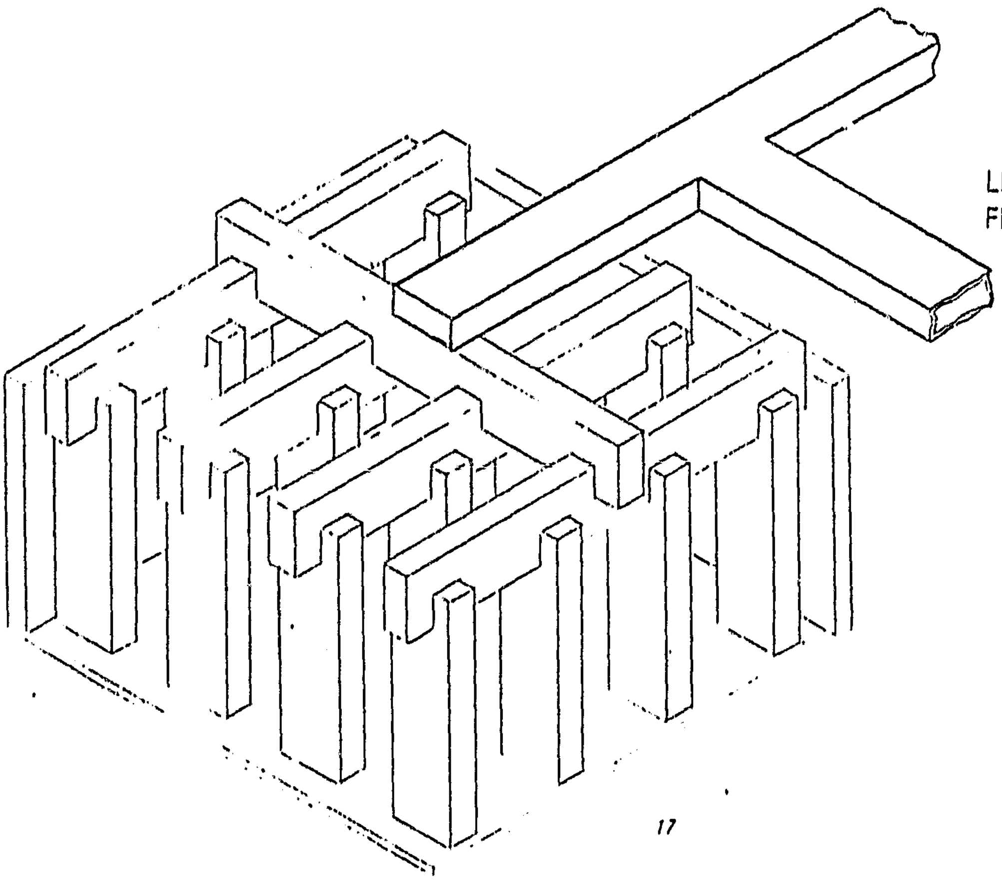


Figure 18. Detail of Open Ended Waveguide Array, Rear View

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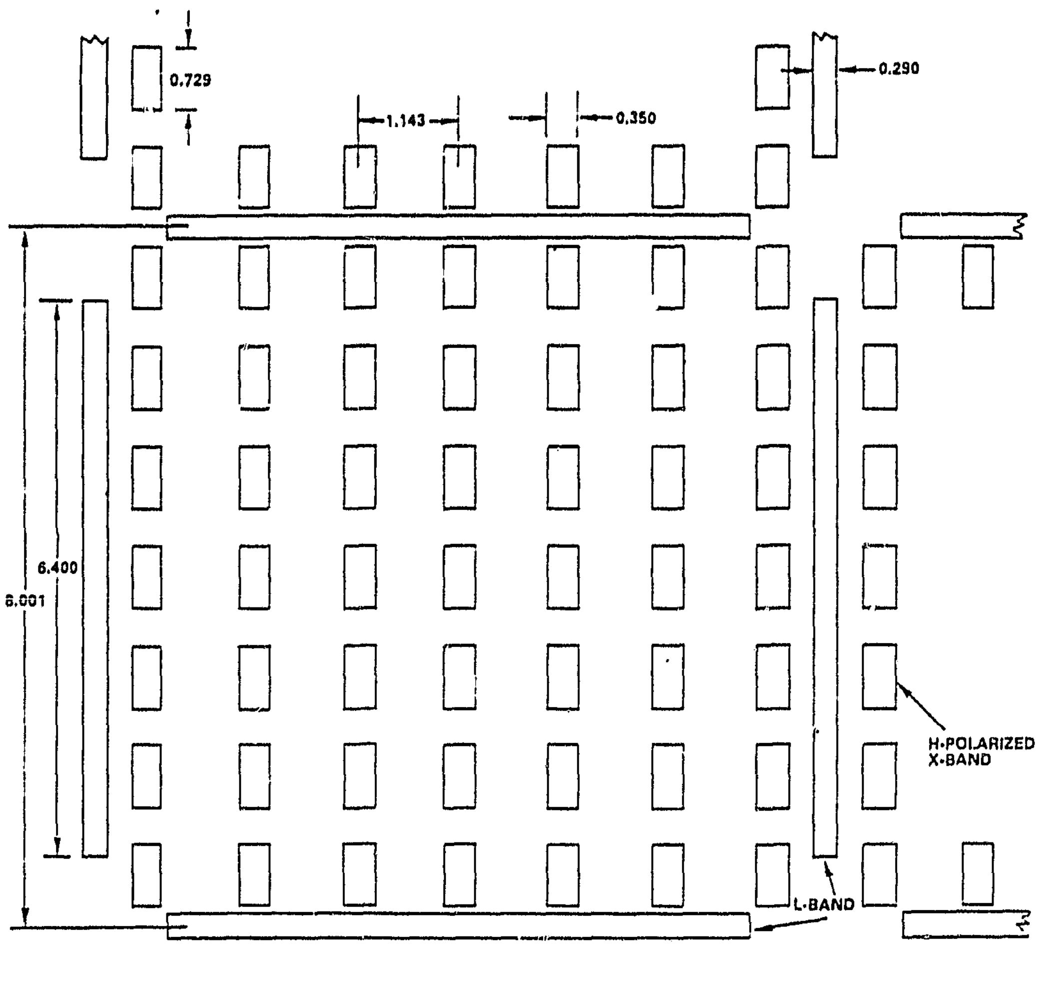


Figure 19. Interleaved L-Beand Wavequide Slot and X-Band Horizontally Polarized Waveguide Radiating Elements, Front View, (Goodyear Aerospace)

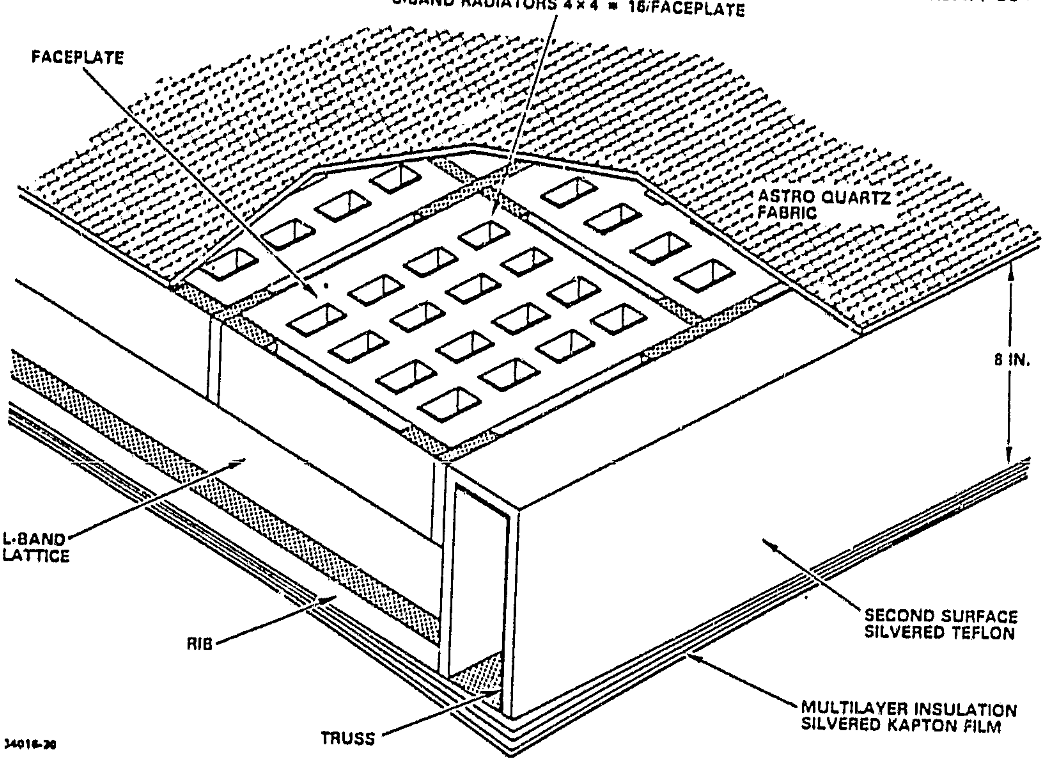


Figure 20. Passive Thermal Control and Detail of Open Ended Wavequide Array Structure (Goodyear Aerospace)

## Analysis and Comparison of SAR Antenna Designs

The three proposed antenna technolgies for shuttle-borne synthetic aperture radars are:

1. Microstrip patch planar array
2. Slotted waveguide planar array
3. Open ended waveguide planar array.

Due to differences in interpretation of NASA's antenna requirements the three investigations assumed slightly differing antenna principal plane half power beam widths. To make the antenna designs strictly comparable, the antenna dimensions would have to be adjusted to some nominal antenna size. Even though the antenna beam widths are different, important comparisons may be made with the proper assumptions about scaling to the nominal size. Figure 21 illustrates the differences in size between the antennas as designed. As shown in the figure, the differences between the designs are primarily in the overall antenna length. This can be seen by noting that the widths of the singly polarized L-band radiating areas are almost identical for each antenna. However, the Hughes slotted waveguide array antenna must be twice as wide, due to the single polarized elements. This is a major drawback of this antenna type.

The three antenna design results are summarized in Tables 3, 4, and 5. These tables compare the gains, loss budgets and other parameters as functions of frequency for the three antenna types. As usual in antenna designs and measurements, the determination of the actual gain of a large antenna is subject to different interpretations. For example, the loss in the waveguide structure at X band frequency is estimated by Hughes to be 6.5 dB and by Goodyear to be 4.3 dB even though the total number of waveguide joints and length of waveguide run in the two antennas is very comparable. This discrepancy is due to difference in engineering judgement and degree of optimism between the two organizations. On the other hand, Ball Aerospace estimates a 3.7 dB loss total for their microstrip antenna, a figure even lower than that used in the waveguide technologies. What figure is correct? The answer is - we don't know because measurements of these high gain, narrow beam width physically large antennas are difficult. The conclusion from this is: Do not base your technology selection very heavily on the relative projected efficiencies of the antennas.

When the antenna losses, gains, beam widths, efficiencies, mass and other parameters are normalized from the design studies dimensions to a nominal antenna length of 14 meters and a constant range half power beam width of 6.3° then Table 6 may be used to directly compare the performances of the antennas.

Several major conclusions can be drawn from this table. First, the waveguide technologies have almost identical loss figures for all frequencies. This should be expected since the radiator-to-source distance in the feed network is almost identical for both types of antennas. Second, the microstrip antenna has a slightly higher losses when compared to the waveguide antennas. This also agrees with intuition since the average distance to a microstrip radiator is slightly shorter than that to a waveguide radiator (due to the series feed arrangement), but the losses in microstrip transmission lines are slightly higher due to the dielectric layer under the microstrip patches and distribution lines.

Third, the antenna patterns are easily synthesized by all three technologies with no problems encountered in attaining the sidelobe specifications. Fourth, the antennas have almost identical masses with the open-ended waveguide antenna being slightly heavier due to the large quantity of waveguide required in the feed network. Fifth, the electrical efficiencies of the antennas are slightly higher for the waveguide technologies when compared to the microstrip technology. This is due to the higher losses associated with the microstrip antenna technology.

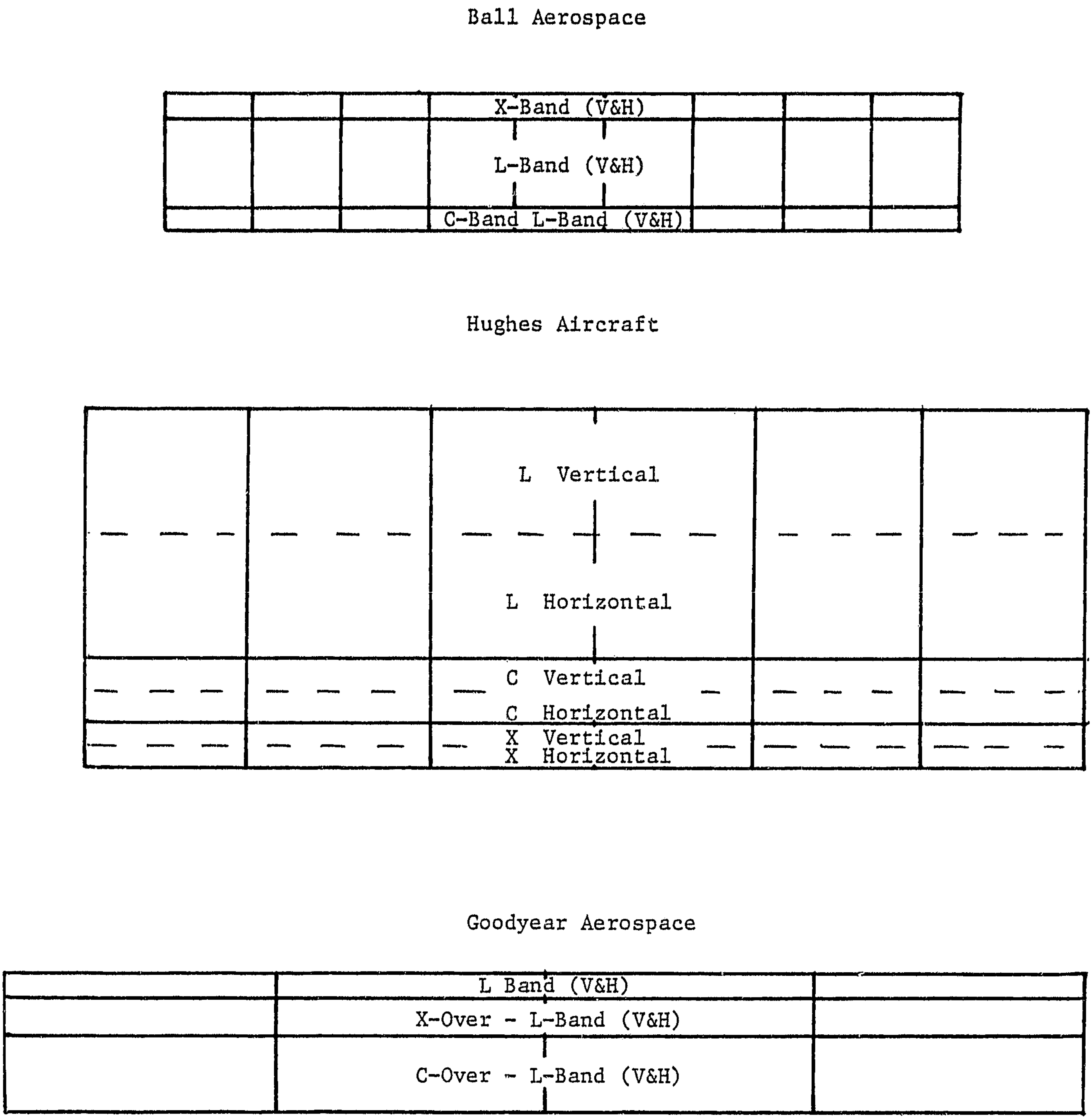


Figure 21. Physical Configuration of Study Antennas as Designed (Relative Scale Correct; for Absolute dimensions see Tables 3,4 & 5).

Table 3

L Band Antenna Comparison

$\lambda = 23.45$ cm

| PARAMETER | BALL MICROSTRIP | HUGHES SLOTTED | GOODYEAR OPENENDED |
|---|---|---|---|
| Antenna Directivity | 37.4 dB ±0.4 dB | 38.4 dB ±0.4 dB | 38.7 dB ±0.4 dB |
| Antenna Gain | 34.9 dB | 36.5 dB | 36.8 dB |
| Antenna Losses (Total) | 2.45 dB | 1.3 dB | 1.9 dB |
| Antenna Area (Single pol) | 24 $m^2$ | 60 $m^2$ | 34 $m^2$ |
| Aperture Efficiency (Single pol) | 57% | 64% | 61% |
| Antenna Dimensions | 2 X 12 m | 2 X 15 m | 2.1 X 16.2 m |
| Range HPBW | 5.9° | 6.76° | 6.59° |
| Az HPBW | 1.0° | 0.85° | 0.75° |
| Cross Pol. | -25 dB | -30 dB | -40 dB |
| Sidelobes Az | -14 dB | -16 dB | -14 dB |
| Sidelobes El | -18 dB | -18 dB | -20 dB |
| Electrical Eff | 56% | 74% | 64% |
| Directivity of a Panel | 26.6 dB | 30.6 dB | 32.76 dB |
| H Plane Taper Loss | 0.2 dB | 0.4 dB | 0.18 dB |
| Panel Feed Loss | 1.1 dB | 0.02 dB | 0.1 dB |
| Feed to Panel Level Loss | 0.4 dB | 0.08 dB | 0.4 dB |
| Radiating Element Loss | 0.15 dB | -- | -- |
| Power Dividers Loss | 0.4 dB | 0.3 dB | 0.6 dB |
| Rotary Joint Loss | 0.1 dB | 0.2 dB | 0.2 dB |
| Array Distortion Loss | 0.05 dB | 0.05 dB | 0.05 dB |
| Misc. loss | 0.1 dB | 0.25 dB | 0.43 dB |

Table 4
C Band Antenna Comparison
$\lambda = 5.65$ cm

| PARAMETER | BALL MICROSTRIP | HUGHES SLOTTED | GOODYEAR OPENENDED |
|---|---|---|---|
| Antenna Directivity | 43.7 dB ±0.5 dB | 44.5 dB ±0.5 dB | 45.1 dB ±0.5 dB |
| Antenna Gain | 40.5 dB | 41.9 dB | 36.8 dB |
| Antenna Losses (Total) | -3.2 dB | -3.1 dB | -2.53 dB |
| Antenna Area (Single pol) | 6 $m^2$ | 14.4 $m^2$ | 16 $m^2$ |
| Aperture Efficiency (Single pol) | 47.5% | 54%/ 45% | 58% |
| Dimensions | 0.5 X 12 m | 0.48 x 15 m | 0.5 X 16.2 m |
| Range HPBW | 5.9° | 6.76° | 6.34° |
| Az HPBW | 0.24° | 0.21° | 0.18° |
| Cross Pol. | -25 dB (measured) | -30 dB (estimated) | -40 dB (estimated) |
| Sidelobes Az | -14 dB | -16 dB | -14 dB |
| Sidelobes El | -18 dB | -18 dB | -19 dB |
| Electrical Eff | 47% | 55%/ 46% | 55% |
| Directivity of a Panel | 32. 9 dB | 36.7 dB | 39.1 dB |
| H Plane Taper Loss | 0.2 dB | 0.4 dB | 0.18 dB |
| Panel Feed Loss | 1.5 dB | 0.3 dB | 0.2 dB |
| Feed to Panel Level Loss | 0.5 dB | 0.6 dB | 0.6 dB |
| Radiating Element Loss | 0.2 dB | -- | -- |
| Power Dividers Loss | 0.4 dB | 1.1 dB | 0.9 dB |
| Rotary Joint Loss | 0.1 dB | 0.4 dB | 0.2 dB |
| Array Distortion Loss | 0.05 dB | 0.05 dB | 0.05 dB |
| Misc. loss | 0.5 dB | 0.25 dB | 0.6 dB |

Table 5
X Band Antenna Comparison
$\lambda = 3.12$ cm

| PARAMETER | BALL MICROSTRIP | HUGHES SLOTTED | GOODYEAR OPENENDED |
|---|---|---|---|
| Antenna Directivity | 46.2 dB ±0.7 dB | 47.1 dB ±0.7 dB | 46.2 dB ±0.7 dB |
| Antenna Gain | 42.0 dB ±0.5 | 40 ± 0.5 db | 42 ± 0.5 |
| Antenna Losses (Total) | -3.7 dB | 6.5 dB | 4.3 dB |
| Antenna Area (Single pol) | 3.6 $m^2$ | 4.0 $m^2$ | 4.536 $m^2$ |
| Aperture Efficiency (Single pol) | 40% | %20 | 40% |
| Antenna Dimensions | 0.5 X 12 m | 0.48 X 15 m | 0.5 X 16.2 m |
| Range HPBW | 5.9° | 6.76° | 6.12° |
| Az HPBW | 0.149° | 0.119° | 0.10° |
| Cross Pol. | -25 dB | -30 dB | -40 dB |
| Sidelobes Az | -14 dB | -16 dB | -14 dB |
| Sidelobes El | -18 dB | -18 dB | -18 dB |
| Electrical Eff | 42% | 46% | 44% |
| Directivity of a Panel | 35.4 dB | 39.4 dB | 41.8 dB |
| H Plane Taper Loss | 0.2 dB | 0.4 dB | 0.5 dB |
| Panel Feed Loss | 0.9 V<br>0.45 H | 0.5 dB | 0.4 dB |
| Feed to Panel Level Loss | 1.1 dB | 3.2 dB | 1.13 dB |
| Radiating Element Loss | 0.2 dB | -- | -- |
| Power Dividers Loss | 0.4 dB | 1.6 dB | 1.1 dB |
| Rotary Joint Loss | 0.1 dB | 0.5 dB | 0.2 dB |
| Array Distortion Loss | 0.2 dB | 0.2 dB | 0.2 dB |
| Misc. loss | 0.4 dB | 0.1 dB | 0.34 dB |

TABLE 6

Electrical and Mechanical Characteristics of Candidate Antennas (Normalized to a 14 meter azimuth length).

FREQUENCY INDEPENDANT PARAMETERS

| | Microstrip | Slotted Waveguide | Open-ended |
|---|---|---|---|
| Overall (1) Dimensions | 2.3 x 14 m | 5.4 x 14 m | 2.3 x 14 m |
| Range HPBW | 6.3° | 6.3° | 6.3° |
| Overall mass (excluding truss) | 283 Kg | 276 Kg | 322 Kg |
| Sidelobe levels aximuth | -14 dB | -16 dB | -14 dB |
| elevation | -18 dB | -18 dB | -18 dB |
| Cross Pol isolation | -25 dB * | -30 dB † | -40 db † |

* measured † estimated

FREQUENCY DEPENDANT PARAMETERS

| | L Band(2) | | | C Band(3) | | | X Band(4) | | |
|---|---|---|---|---|---|---|---|---|---|
| | micro | slot | open | micro | slot | open | micro | slot | open |
| Aximuth HPBW | 0.85° | | | 0.21° | | | 0.12° | | |
| Loss (db) | 2.5 | 1.9 | 1.9 | 3.2 | 2.5 | 2.5 | 3.8 | 3.4 | 3.4 |
| Gain (dB) | 35.6 | 36.2 | 36.2 | 41.0 | 41.7 | 41.7 | 43.2 | 43.6 | 43.6 |
| Electrical Efficiency | 56% | 65 | 65 | 47 | 56 | 56 | 42 | 46 | 46 |

(1) width of antennas L = 2.0, C = 0.48, X = 28 meters
(2) F = 1.278 GHz, $\lambda$ = 23.45 cm
(3) F = 5.306 , $\lambda$ = 5.65
(4) F = 9.608 , $\lambda$ = 3.12

## Costs

Cost estimation for these SAR antenna technologies is a risky business. There are many uncertainties - espically with unproven designs such as the open ended waveguide technology. In addition, companies which are probably required to engage in a competative bidding process are in general relunctant to provide "hard" cost figure projections.

Two of the three investigators did provide estimated costs for a dual polarized antenna with three frequencies and dimesions of about 2.3 X 14 meters. The antenna costs did not include electronic beam steering. These estimated costs are summarized in Table 7. The costs for the waveguide antenna are presented as reasonably firm figures by Hughes Aircraft. On the other hand, the costs for the open ended waveguide antenna are very soft. Cost estimates for the microstrip technology were not available. It should be noted that the waveguide technology antenna requires a very large structure - almost twice as wide as the other choices. This extra area will drive up the costs of support structures and may even be too large for the Shuttle due to other payload requirements.

## Conclusions:

A definite choice of a technology for SAR antennas is a difficult one to make. The slotted waveguide technology probably has cost advantages but is more difficult to adapt to electronic beam steering and is probably too large to use in a dual polarized L-band mission. The open ended wavequide design is fraught with cost and performance uncertainties. There may or may not be a large development effort required to realize an operating antenna. Microstrip technology is proven and can be easily adapted to electronic beam steering. The microstrip technologies only apparent disadvantages are slightly higher losses (as projected by the contractors) and slightly higher cross coupling between polarizations. We recommend here that the following be done.

1. Test panels of an open-ended array be constructed using the carbon filament/epoxy technique to firm the cost figures and the expected performance of that technology.

2. A systems and user requirement study be made for the next SAR mission after SIR-C. Definite antenna requirements should be established during this study.

3. The SAR antenna should be designed using the best technologies for each frequency - the antenna does not have to be constructed from only one technology.

Table 7

Estimated Costs of SAR Antennas

| Microstrip Array | Slotted Waveguide Array | Open-Ended Interleaved Array |
|---|---|---|
| ----- | \$300k ± \$50k | \$1,500k ± \$500k |

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