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NASA Technical Memorandum 82952

Advanced 30/20 GHz Multiple-Beam Antennas for Communications Satellites

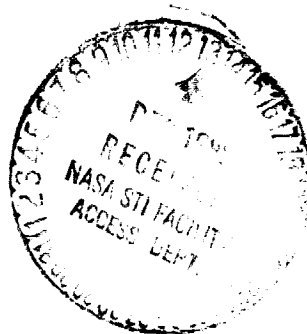
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NASA

ADVANCED 30/20 GHz MULTIPLE-BEAM ANTENNAS
FOR COMMUNICATIONS SATELLITES

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SUMMARY

Advanced offset-fed spacecraft antenna systems are being developed for the National Aeronautics and Space Administration (NASA) that will provide multiple radiating fixed spot-beams and regional coverage scanning beams for use on communications satellites operating in the 30/20 GHz frequency bands. Design concepts under development utilize two separate spacecraft antenna systems, one uplink at 30 GHz and the other a downlink at 20 GHz, where each antenna provides multiple fixed and scanning beams.

Parallel contracts were awarded to the Ford Aerospace and Communications Corporation (FACC) and TRW-Electronic Systems Group (ESG) to develop the multibeam antenna (MBA) technology. Both contractors have completed configuration trade-off studies and breadboarding of critical technology components, and are now fabricating and testing proof-of-concept (POC) models to demonstrate the technology feasibility.

Technology developments required for the proposed systems will be presented, along with each contractor's progress to date. The new technology development areas discussed include:

- (1) Offset Cassegrain and shaped reflector systems for narrow beams with low sidelobes and wideangle off-axis scan.
- (2) Diplexed beam forming networks for dual polarization, low sidelobes, and fixed and scan-beam operation.
- (3) Fast switching networks for scanning beams.
- (4) Fabrication of precision feed components and large offset reflectors.

(Another paper, "Application of MMIC Modules in Future Multiple Beam Satellite Antenna Systems" by J. Smetana, describes NASA's investigation of MBA's using MMIC feed systems.)

INTRODUCTION

The continued rapid growth of communications message traffic (voice, data, and video) requires the use of additional satellite communications frequency bands before the 1990 decade. The satellite communications bands currently in use at 4 and 6 GHz are already crowded and require the implementation of operational systems at 12 and 14 GHz. With the present constraints

on the 11.7 to 12.2 GHz downlink band, market study projections (contracts NAS 3-21359 and NAS 3-21366) indicate a band fill-up by the 1990 decade, requiring alternate frequency bands for expansion of satellite services. The capacity of present 6/4 and 14/12 GHz satellite communications systems are constrained by

- (1) Limited bandwidth available in these frequency bands.
- (2) Large beamwidths resulting from reflector size constraints.
- (3) Lack of flexibility to reconfigure the antenna patterns for more efficient use of RF power and frequency spectrum.
- (4) Limited orbital positions available for satellite operating in C and Ku band frequencies.

Thus, the next higher frequency bands allocated for this purpose are the 30/20 GHz bands.

The 30/20 GHz system offers 2.5 GHz bandwidth for both uplink and downlink communications, approximately five times greater than the existing 6/4 and 14/12 GHz systems. More importantly, it permits frequency reuse by means of multiple spot beams or shaped beams for large volume trunking service, and allows multiple scanning beams to serve a large number of small volume traffic users on a time division multiple access (TDMA) basis.

Current NASA sponsored communications R&D Program efforts are aimed at developing the technology required for commercial 30/20 GHz satellite configurations which will provide both trunking and scanning-beam service applications. The trunking beams will be directed to major cities of the Continental United States (CONUS) for large volume traffic, and the scanning beams will each cover sectors of CONUS for individual communications services, all at minimum RF radiated power from the spacecraft. Spacecraft systems for both trunking and scanning-beam services are being configured to permit maximum frequency reuse for conservation of the frequency spectrum. In order to implement frequency reuse for the 30/20 GHz bands, new spacecraft antenna technologies are required wherein a number of independently fixed and/or scanning beams will be radiated from a geostationary satellite. The efforts described in this paper are to develop and demonstrate the necessary antenna technologies which will permit multiple beams at higher frequencies and will allow maximum frequency reuse to be implemented. Other technology areas that are being pursued under separate contract efforts for the 30/20 GHz communications satellite program include: (1) baseband processor, (2) IF matrix switch, (3) low noise receivers, and (4) Rf power amplifiers, both traveling-wave-tube (TWT) and solid-state IMPATT and GaAs FET transmitter devices.

The MBA parallel contract efforts described in this paper are being conducted under NASA contracts NAS 3-22498 with FACC, Palo Alto, California (ref. 1) and NAS 3-22499 with TRW-ESG Redondo Beach, California (ref. 2). Both contracts were started in July 1980 for a 32-month period of performance, with the efforts funded by NASA Lewis Research Center under NASA's Advanced Communications Program Office.

OBJECTIVES AND REQUIREMENTS

The primary objectives of these contract efforts are to (1) perform technology trade-off studies of MBA systems capable of providing a number of fixed and scanning beams from a geostationary communications satellite operating at the 30/20 GHz frequency bands; (2) evaluate and select through analytical programs the concepts that will provide optimum performance at minimum complexity, weight, and cost; (3) breadboard, test, and evaluate those items that are considered critical technologies in the development program; (4) fabricate and test proof-of-concept (POC) model antenna systems to demonstrate the technology, and (5) provide data inputs for designing flight hardware for a 30/20 GHz Advanced Communications Technology Satellite (ACTS) to be flown in the late 1980's.

A typical spacecraft configuration for a 30/20 GHz communications satellite system might look as shown in figure 1, where the smaller antenna system would provide the 30 GHz receiver uplink and the larger antenna system the 20 GHz transmit downlink. Preliminary NASA trade-off studies of MBA spacecraft configurations, link budget gain requirements, terrestrial system sizes and complexities, and proposed cities and user areas to be served, indicated that these antenna systems should have RF gains on the order of 50 to 53 dB (0.3° beam widths) for minimum cost to large numbers of terrestrial station users. These studies also indicated that spacecraft sizes and weights, based on packaging within the shuttle launch vehicle, should be limited to reflector sizes that are a maximum of 14 ft in diameter, again consistent with the concept of high-gain 0.3° beamwidth antenna systems.

Proposed Antenna Coverages

Figure 2 illustrates one of the antenna coverage scenarios contemplated for an operational communications satellite system in the 1990s. There are 18 fixed beams for large volume traffic trunking service interconnecting 18 major cities of the CONUS. This 18-city coverage plan would provide approximately 20 percent of the total domestic traffic demand in the United States. The remaining 80 percent would be provided to the small terminal users by six independently scanned beams, each scanning within approximately one-sixth of CONUS on a TDMA basis. The connectivities between the small terminal scanning beams and fixed trunking beams are provided by an on-board processor. The proposed frequencies and coverage plans are:

- (1) The allocated 2.5 GHz bandwidth for both uplink and downlink is divided into five subfrequency bands. Each subfrequency band has 500 MHz bandwidth.
- (2) CONUS coverage is divided into six sectors for six scanning beams. The selection of these sector boundaries is arbitrary, depending on the traffic demand in each of the sectors and the layout of fixed and scanning-beam feeds.
- (3) Within the same scan sector, all fixed beams could be copolarized. Widely spaced beams with good spatial isolation may operate at the same frequency, but closely spaced beams must operate at a different frequency or be orthogonally polarized to prevent mutual interference.

(4) Fixed and scanning beams in the same sector could be of the same polarization and use only frequency for isolation, or could be orthogonally polarized and operated at different frequencies to achieve additional isolation between beams in a given area.

(5) The respective scanning beams in adjacent sectors are orthogonally polarized. Unless two scanning beams are momentarily steered to the vicinities of the same boundary at the same instant, combined polarization and spatial isolation will provide over 30 dB isolation between two scanning beams.

This antenna coverage scenario (TRW's approach) requires two frequencies for fixed trunking beams with the possibility of 13 times frequency reuse, and one frequency for scanning beams with six times frequency reuse. The FACC approach uses only one frequency for fixed beams providing 18 times frequency reuse, and one frequency for scanning beams with six times frequency reuse.

The design goals for the antenna performance are shown in table I. In order to obtain 53 dB gain at the peak of the beams, a 4m diameter reflector at 20 GHz, and a 3m diameter reflector at 30 GHz are required to produce 0.3° beams. Also, the requirement of a 30 dB carrier-to-interference (C/I) ratio requires large precision offset reflectors for low sidelobe radiation.

Selection of Antenna Configurations

Various antenna configurations were considered for this application, including lens, reflector, and array antennas. The reflector antenna approach was chosen because of its light weight, lower cost, wide bandwidth, and design simplicity. Particularly in the millimeter frequency range, it offers the advantages of low feed network losses and higher efficiencies compared with the lens and array antennas. Both contractors have completed extensive computer trade-off studies in optimizing the RF gains for their approaches. Because of the requirement to scan ± 12 by ± 5 beamwidth for full CONUS field of view, it was particularly important to minimize the scan aberrations and thus the scan losses in order to meet the beam RF gain requirements. Each contractor's approach to solving these complex problem areas and their progress to date are described in the following paragraphs

FORD AEROSPACE MULTIBEAM ANTENNA

The MBA trade-off analysis, design, and performance calculations have been completed by FACC. The selected concept consists of an offset dual-reflector microwave optical subsystem with feed array and multiple-port beam forming network (BFN) (fig. 3). A unique feature of the FACC concept is the computer-aided synthesis of shaped main and subreflector surfaces to minimize aberrations over the required 12 beamwidth CONUS field of view. Scan loss performance over the 12 beamwidth scan area is less than 1 dB. The algorithm for complete synthesis of the main and subreflector surfaces is based on minimization of ray path-length error surfaces for several specified feed (beam) positions in the reflector system. Thus, the resulting reflector surfaces are not portions of a figure of revolution surface, but

are each generally optimized, doubly-curved surfaces. Furthermore, the feed-array surface can then be specified as to size, shape (flat, doubly-curved, etc.), position, and orientation with respect to the subreflector surfaces. The dual reflector system then has no true focal point at the zero scan-beam position so that worst-case defocusing at the edges of the scan field of view is minimized. Other more conventional reflector designs based on classical optics were first attempted, prior to development of the doubly-curved dual reflectors; however, all were found to be less desirable due to their higher scan losses over the CONUS coverage area.

During the early phases of the two parallel contract development efforts, TRW and FACC indicated that both the 20 GHz and 30 GHz antenna systems are directly scalable between the two frequencies. As a result, FACC selected to concentrate their efforts on the design and proof-of-concept for the 20 GHz transmit antenna system, and TRW chose to develop, fabricate and test the 30 GHz receive antenna system.

Feed Array

Figure 4 shows the FACC CONUS coverage feed array for a 20 GHz operational satellite MBA system that develops 18 fixed trunking beams and six scanning spot beams. The BFN lattice array as shown uses 480 square radiating elements, where each horn is two wavelengths on a side. A seven element coherently-driven horn cluster for each beam then produces the 0.3° beam with the desired low sidelobes. Each small horn cluster is coherently excited to form each beam via a microwave power dividing circuit with non-uniform amplitude and phase coefficients applied to each element. For example, a seven-element cluster of horns is typically chosen with the central element given most of the excitation power and the six surrounding elements each given a weaker portion of the transmitted power, each with a particular phase value.

For each desired fixed beam location on a city of CONUS, a particular cluster of feed elements must be excited so as to shape a low sidelobe envelope. A one-to-seven port nonuniform corporate network is designed for each trunk beam. Since offset reflectors are asymmetric, each beam network coefficient would appear to be different since the aberrations for a northeast corner CONUS beam are different from that of a southwest corner beam, etc. With the doubly-curved surface reflector, however, FACC has found the calculated network coefficients to be virtually identical over all of CONUS.

For the scanning beams, each scan sector contains a large number of array elements. For a given instantaneous-scan secondary-beam position within a given sector, the BFN function is to interconnect the sector input port to a particular seven-element cluster of the elements in the sector array such that the required beam position results. Likewise, for the next desired scan beam position in the sector, the first cluster must be disconnected, the second cluster of seven elements connected and the amplitude and phase coefficients reset to achieve the new beam position. The control system for the scanning beams will allow any one uplink or downlink beam to be independently sequenced to any one of its positions. The dwell time for a beam to be held at any position will be programmable between $10\mu\text{s}$ and $100\mu\text{s}$, and the time to move a beam to any other position will be no greater than 500Ns . The instructions for the beam scanning controller will be supplied by an onboard

computer. To accomplish the switching and provide the scanning beams, each scan sector contains a number of array elements for connecting a preselected seven-element cluster at any instant.

The output of each switch tree in a sector (fig. 5) is interconnected by a single eight-to-one corporate tree where a combination of VPD tree output ports can be connected to any seven-element cluster in the sector array. Behind each element is an orthomode junction with two ports - one for vertical polarization and the other for horizontal polarization. Each of the OMJ ports is connected to a diplexer. Each diplexer has two ports - one for the fixed beam band and one for the scan beam band. All sector scan network terminals connect only to the scanning diplexer terminals. For those elements contained in a fixed beam cluster, the fixed beam band diplexer port is connected to a fixed beam BFN terminal. Thus, only certain elements are operating as both fixed and scanning radiators. All of the elements, however, will become part of a scan-beam cluster at one time or another.

FACC Progress to Date

Extensive computer analysis trade-off studies have been completed for both the operational and the experimental spacecraft systems, based on a number of reflector antenna concepts. These included the offset paraboloid and feed array, the offset Cassegrain dual reflector, the offset Gregorian dual reflector, and the offset Schwarzschild dual reflector, each with feed array. Each of these types of focused reflectors was optimized by minimization of calculated ray path errors for various extreme beam positions over CONUS. All were found to have performance deficiencies due to excessive scan beam aberrations over CONUS, or required complex curved-feed arrays. As a result, the doubly-curved dual-reflector approach employing a flat focal field was developed that would provide off-axis scan with losses of less than 1 dB for CONUS coverage.

Breadboarding and testing on development of critical technology 20-GHz microwave components of the multiport feed array and BFN components have been completed. These include the seven-element cluster, OMJ, diplexer, power dividers, and engineering model ferrite scan-beam components, namely, ferrite circulator switches, variable power dividers and variable phase shifters. The 20 GHz ferrite components are being developed by Electromagnetic Sciences (EMS) Corporation, Norcross, Georgia, under subcontract to FACC.

Fabrication of the 20 GHz transmit POC model MBA is now in progress. A 13.5-ft-diameter main reflector and 9.5-ft by 4.0-ft subreflector are under construction, with fabrication of aluminum sector plates mounted to a rigid truss structure and milled to mirror surface tolerances. Since these complex reflectors are not surfaces of revolution, their design, manufacturing, and optical calibration have been subcontracted to an optical company (Tinsley Corporation, Berkeley, California) for developing the high precision surface areas. Surface tolerances are expected to be held to within .003 in. RMS over the reflecting surfaces in order to minimize off-axis beam RF losses.

A partial feed array and BFN is being fabricated for the POC model, where this subarray can be manually repositioned during the testing program to check all of the fixed beam and scan beam positions. The POC antenna sup-

port structure is now in fabrication by FACC, and EMS is under subcontract for the additional ferrite switches, variable power dividers, and variable phase shifters.

The FACC anticipated POC-BFN component performance is given in table II, and the estimated gain performance of the MBA is given in table III.

TRW MULTIBEAM ANTENNA

The trade-off analysis, design, and performance calculations have been completed by TRW for the MBA concepts, where the selected approach is an offset Cassegrain reflector geometry with two hyperbolic subreflectors stacked to form a double-layer bifocal subreflector system, and two orthogonally polarized feed assemblies diplexed by the front wire-grid subreflector (fig. 6). Each of the two feed assemblies consists of multiple fixed and scanning-beam feed cluster for low sidelobe operation. The uniqueness of this arrangement is that it enables multiple fixed and scanning-beams to be radiated through a large common aperture and permits the multiple-beam feed assemblies to be placed close to the spacecraft body. The front-gridded polarizer focuses the vertically polarized field to a point located on the right side of the paraboloidal axis and is transparent to the horizontally polarized field. The back solid-surface subreflector focuses the horizontally polarized field to the left. Thus, two orthogonally polarized feeds are completely separated into two focal-point feed areas. In this MBA approach, the high gain characteristics of the BFN compensate for the increase in scan loss for off-axis scanned beams when using the Cassegrains paraboloid reflector approach.

During the analytical trade-off studies, two separate and complex computer programs were used to evaluate the performance and cross-check the results of this complex antenna system - a multireflector ray tracing program and a vector diffraction computer program.

The ray-tracing program does not take into account the edge diffraction and the vector nature of the scattering patterns. Nevertheless, it is a simple and useful tool for determining the subreflector boundary, best feed locus, and optimum feed orientation of each off-axis scanned beam in the preliminary design stage. For example, to improve the wide-angle scanning capability of this antenna, the subreflector is substantially oversized to reduce the spillover loss from the main reflector. Although the ray tracing program provides more physical insight for optimizing the reflector/feed geometry, the analysis could not be used to determine the best feed position. As a result, the vector diffraction program using physical optic (PO) or geometric theory of diffraction (GTD) analysis was used for accurate prediction of the far-field radiation patterns. And because of the oversized hyperbolic subreflector, the PO program with the capability for computing scattered fresnel fields was used to optimize the scanning beam performance.

Feed Array

Figure 7 shows the TRW vertically polarized CONUS coverage feed layout for a 30 GHz MBA operational spacecraft providing 18 fixed trunking beams and six scanning spot beams. A similar type of layout will provide the horizontally polarized scan beams and trunk beams in the alternate sector

coverage areas. There are three types of feed clusters in this assembly: multimode conical horns for widely spaced trunking beams, diplexed circular horn clusters for closely spaced cities, and an array of square horns for scanning beams.

Since the low sidelobe beams produced by two adjacent horns are approximately two half-power beamwidths apart, any two cities separated by less than two beamwidths must use a cluster of feeds and diplexers to obtain the overlapping beams unless they are orthogonally polarized. For example, a 16-element diplexed feed cluster is being used to obtain three contiguous low sidelobe beams for Boston, New York, and Washington, D.C., coverages (fig. 8). The beams for Boston and Washington will be copolarized and operate at the same frequency; the beam for New York coverage will be at a different frequency, but due to the close proximity of the three cities will share some of the same feed horns through waveguide diplexers.

The scanning beam beam-forming network (BFN) is the more complex of these three types of feeds. In the TRW approach, the feed horns and the feed network are divided into three groups, and the feed horns are arranged in an equilateral triangular lattice. A scanning beam can be formed in the reflector by energizing any combination of three adjacent horns in the array aperture. Each horn, however, can only be energized by one of the three BFN branches, with the other two adjacent horns energized by the other two branches. Consequently, for the 19-element scan-beam array being developed for the POC model, only two variable power dividers, one variable phase shifter, and 21 circulator switches are required to scan a beam to any location within the scan sector. Because of the reduction in component requirements, this feed concept will reduce the RF losses as well as the power consumption in the driver and control electronics. The estimated loss in the 19-element BFN is 2.8 dB.

TRW Progress to Date

TRW has also completed extensive computer analysis trade-off studies for both the operational and the experimental spacecraft MBA concepts on a number of different multireflector antenna configurations. These configurations included concepts using four separate antenna systems to concepts combining both the 20 GHz and 30 GHz frequencies into a single complex antenna system with a dichroic outer-ring main reflector to achieve the 0.3° beamwidths at each of the frequencies. The offset Cassegrain with the doublelayer bifocal subreflectors and separate 20 GHz and 30 GHz antenna systems was selected as the optimum approach in order to reduce the complexity of each polarized feed cluster and minimize the overall losses in the BFN. The off-axis scan losses at ± 12 beamwidths for this approach are expected to be approximately 1.4 dB.

Breadboarding and testing of the critical technology microwave components at 30 GHz has been completed. These include a section of a polarization wire-grid subreflector, multimode horns with sidelobes near -40 dB, diplexed feed cluster for forming three contiguous beams, two and three-way power dividers, and 30 GHz engineering model ferrite circulator switches, variable power dividers and variable phase shifters. The 30 GHz ferrite components are being developed by Electromagnetic Sciences (EMS) Corporation under sub-contract to TRW.

Fabrication of the 30 GHz receive POC model MBA is now in progress. A 9.5-ft-diameter graphite fibre-reinforced plastic (GFRP) main reflector with surface accuracies of .003 in. RMS has been completed. The solid surface and wire-grid subreflectors are near completion, and the POC model support-structure weldment assembly is near completion. The 16-element diplexed feed cluster for the Boston/New York/Washington beams is now in testing, and a 19-element scanning beam-forming network using ferrite switches, power dividers, and phase-shifters is now under subcontract to EMS. These component assemblies, when completed, will be assembled into a POC model that will be capable of producing 10 fixed trunk beams and one scan beam. These horn and cluster assemblies will be relocatable on the feed-support structure in order to test alternate beam positions and adjacent beam-interference conditions.

The TRW-anticipated POC-BFN component performance is given table IV, and the estimated gain performance of the MBA is given in table V.

POC TESTING PROGRAM

Fabrication of the POC models by the contractors will be completed during October to November 1982. Far-field (F-F) range testing at the contractor's facilities for various levels of testing and beam configurations (trunk beams only, scan beams, and combined testing) will be conducted during the period October 1982 through April 1983.

On delivery of the POC models to the NASA Lewis Research Center in June 1983, verification testing will be conducted in NASA's near-field antenna test range as part of the overall 30/20 GHz communications satellite feasibility program to provide data for design of flight hardware.

CONCLUSIONS

Multiple fixed and scanning beams can be radiated effectively through a large common aperture by means of offset-fed multireflector antenna arrangements. The technologies required for successful spacecraft MBA systems have been validated by fabrication and testing of breadboard hardware in the critical technology areas. Proof-of-concept models are now being fabricated under parallel contract efforts using two distinctly different approaches to offset-reflector technologies in demonstrating multibeam antenna capabilities. Current development efforts will culminate in extensive range testing and evaluation, and will conclude with detailed technical reports and recommendations on multibeam spacecraft antenna systems.

Continuations of advancements in multibeam antenna technology beyond the efforts described in this report are now in process at NASA that will initiate phased array feed networks for offset-fed multireflector antenna systems where feed arrays are composed of distributed monolithic amplifier devices. These future technology approaches will reduce the spacecraft BFN losses and provide higher overall spacecraft efficiencies for improved advanced communications links.

REFERENCES

1. Scott, W.G.: 30/20 GHz Communications Satellite Miltibeam Antenna, AIAA Paper 82-0449, 1982.
2. Chen, C.C.: Advanced 30/20 Multiple Beam Antenna for Future Communications Satellites, Presented at the IEEE International Conference on Communications, (Philadelphia, PA.), June 13-17, 1982.

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Table I. - Operational and Demonstration Satellite Multiple Beam Antenna Specifications

Antenna configuration		Trunking fixed beam	Customer premise scanning beam
Operation frequency range (GHz)	downlink uplink	17.7 to 20.2 27.5 to 30.0	17.7 to 20.2 27.5 to 30.0
Number of beams	operational	18 TX 18 REC	6 TX 6 REC
	demonstration	10 TX 10 REC	2 TX 2 REC
Minimum peak gain (dB)	20 GHz	53	50 ± 1 dB ripple
	30 GHz	53	50 ± 1 dB ripple
Bandwidth (MHz)	20 GHz	500	500
	30 GHz	500	500
Polarization		dual linear	dual linear
C/I Performance (dB)		>30	>30
Pointing accuracy (degrees) relative to spacecraft bus	pitch & roll yaw	<0.02	<0.02
		<0.4	<0.4
Power/beam (EIRP) dBw		58-65	63-69

Table II. - Anticipated POC-BFN Component Performance, Ford Aerospace 20 GHz MBA

Characteristic	Switching circulator	VPD	VPS	Fixed power divider
Center freq, GHz	19.1	18.95	18.95	18.7
Bandwidth, MHz	500	500	500	1300
Insertion loss, dB	0.1	0.4	0.6	0.2
Isolation, dB	23	20	--	20
Max. power, W	30	60	40	50
VSWR, Max	1.15	1.2	1.2	1.2
Switching tim, μ s	0.4	0.4	0.4	--
Switching energy, μ J	40	75	75	--
Range of adjustment	--	0, -25 dB	0 - 360°, 6-31t	0 - 6 dB
Accuracy	--	repeatable to -20 dB	$\pm 2^\circ$ to $\pm 8^\circ$ over temp & freq.	± 0.2 dB
Size (excl. drivers)	.75" x .312"	4" x 1.34 x 0.9"	2.25 x 0.85" sq.	1 x 1.5 x 0.3"
Driver	4" sq. x .7"	2 x 4" sq. x .7"	4" sq. x 0.7"	--
Temp. range	0 - 50° C	0 - 50° C	0 - 50° C	-100 to +70° C
Weight, oz. - component	2.0	6	1.2	2.0

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Table III. - Estimated Gain Performance, Ford Aerospace 20 GHz M&A

	Fixed beams				Scan beams				
	Seattle	Zero scan Oklahoma City	Washington, D.C.	Boston	Miami	Seattle	Zero scan Oklahoma City	Miami	
	Calculated directivity, dBi	55.1	55.8	55.3	55.2	55.8	55.1	55.8	55.8
Calculated BFN loss, dB	-1.3	-1.3	-1.3	-1.3	-1.3	-3.2	-3.2	-3.2	
Gain, dBi	53.8	54.5	54.0	54.1	54.5	51.9	52.6	52.6	
	BFN Loss breakdown, dB								
			OMJ (1)		-0.1	OMJ (1)		-0.1	
			Diplexer (1)		-0.5	Diplexer (1)		-0.5	
			Hybrid (2)		-0.2	Switches (5)		-0.2	
			3 way divided (1)		-0.2	VPS (1)		-0.2	
			Comm waveguide		-0.3	VPD (3)		-1.2	
					-1.3	Comm waveguide		-0.3	
								-3.2 dB	

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Table IV. - Anticipated POC BFN Component Performance - TRW 30 GHz MBA

Characteristic	Switching circulator	VPD	VPS	3-Way PWR Divider
Center frequency, GHz	28.6	28.6	28.6	28.6
Bandwidth, MHz	--	1500	1500	2500
Insertion loss, dB	0.15	0.6	0.85	--
Isolation, dB	28	25	--	--
Max power, W	1	1	1	--
VSWR, max	1.1	1.1	1.2	1.12
Switching time, μ s	0.4	0.5	0.5	--
Switching energy, μ J	17	48	70	--
Range of adjustment	--	-25 dB	0 - 360°, 6-bit	--
Accuracy	--	--	3°	--
Size (excl. drivers)	.85x.85x.5"	.75x1.13x3.04"	.75x.88x2.02"	2.23"lg
Temp. range	0 - 50° C	0 - 50° C	0 - 50° C	--
Weight, oz-component	0.35	1.9	1.2	3.0

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Table V. - Estimated MBA Gain Performance, TRW 30 GHz MBA

Beam location	Fixed beam					Scan beam	
	$\theta=0^\circ$	Seattle	S.F.	Miami	Boston	$\theta=0^\circ$	$\theta=3.5^\circ$
Directivity, dBi	56.7	55.4	55.0	56.0	54.2	54.7 ± 1.0	53.0 ± 1.0
BFN loss, dB	0.8	0.8	0.8	0.8	1.2	2.8	2.8
Gain, dBi	55.9	54.6	54.2	55.2	53.0	51.9 ± 1.0	50.2 ± 1.0
Antenna loss budget				Dual mode horn	Cluster of horns	Scan beam array	
Polarization grid				0.25	---	0.25	
Reflectors				0.1	0.1	0.1	
Waveguides (0.25 dB/ft)				0.15	0.5	0.5	
Feed horn (ideal)				0.3	0.3	0.3	
Diplexer (≤ 0.5)				---	0.3	---	
Switches (3)				---	---	0.45	
VPD's (2)				---	---	1.2	
Total loss, dB				0.8 dB	1.2 dB	2.8 dB	

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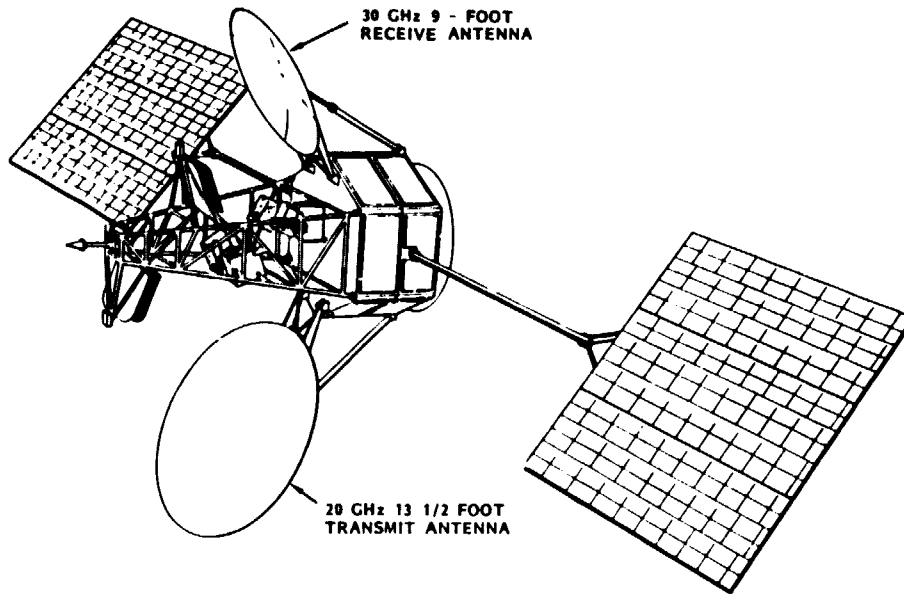


Figure 1. - Proposed 30/20 GHz experimental flight model advanced communications technology satellite.

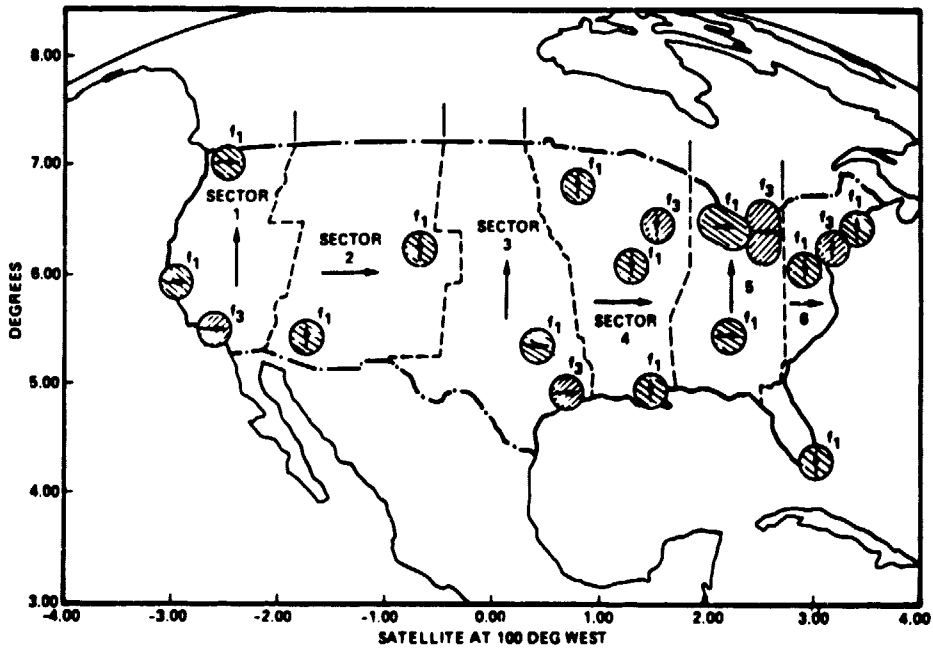


Figure 2. - 18 fixed beams and 6 scanning beams antenna coverage scenario.

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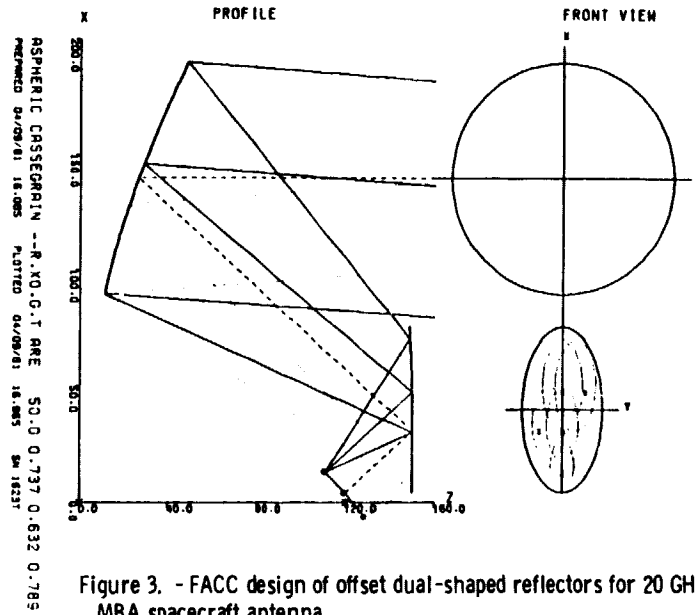


Figure 3. - FAC design of offset dual-shaped reflectors for 20 GHz MBA spacecraft antenna.

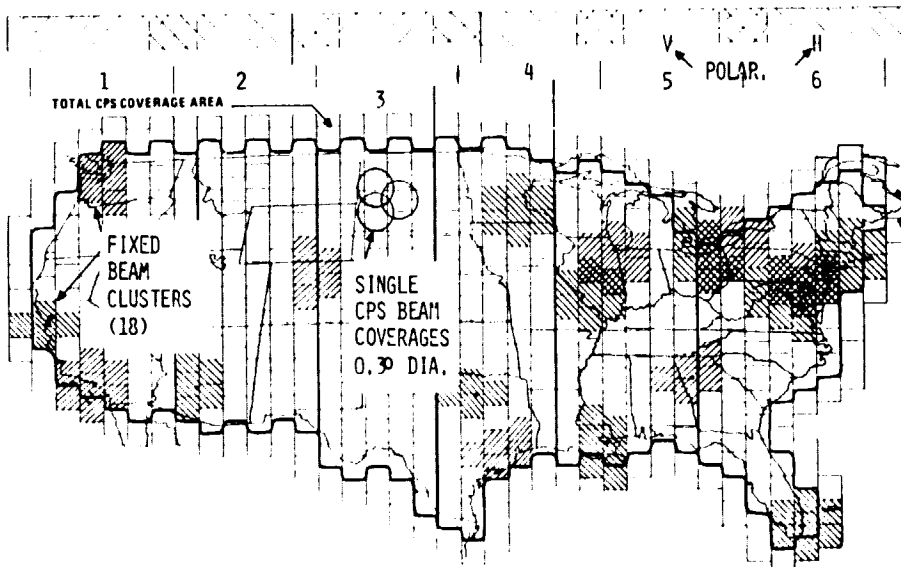


Figure 4. - FAC CONUS coverage feed array for 20 GHz MBA spacecraft antenna.

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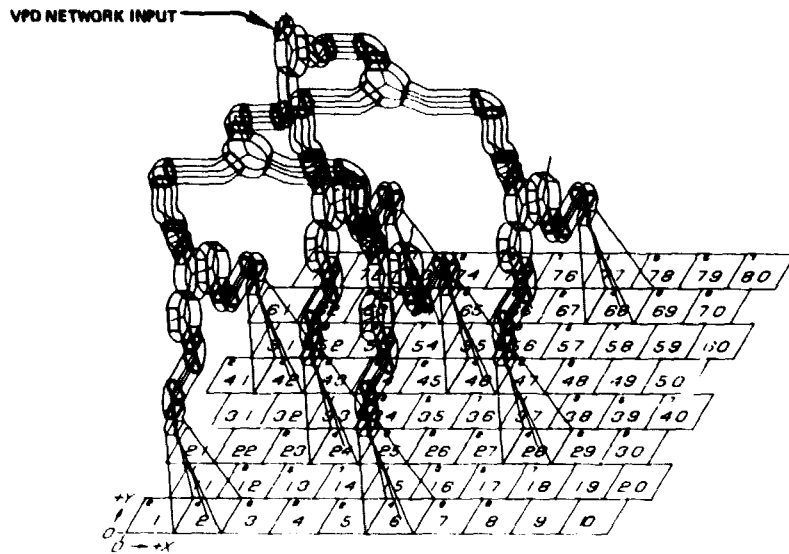


Figure 5. - FACC BFN switching tree for 20 GHz MBA spacecraft antenna.

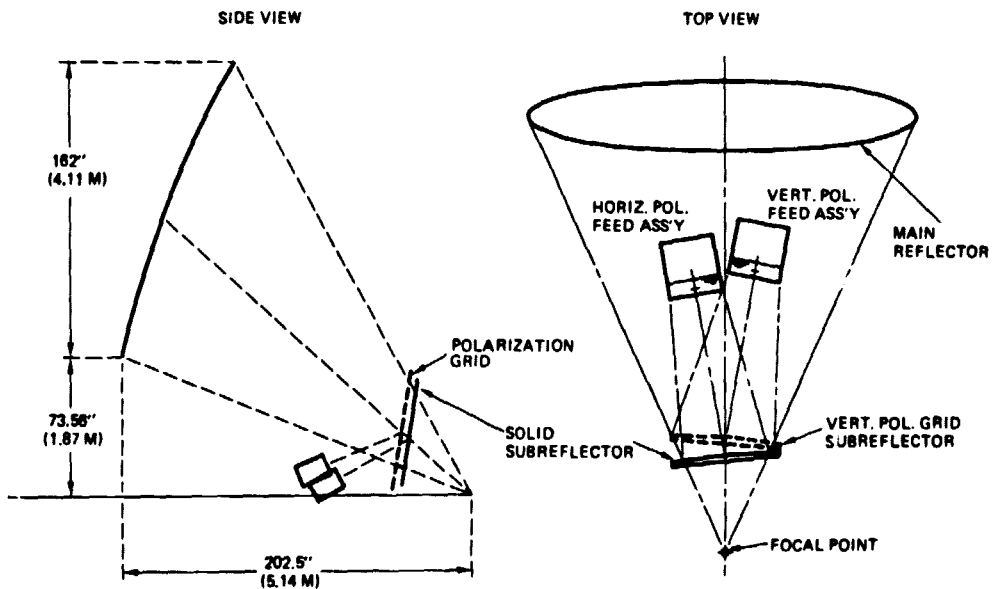


Figure 6. - TRW offset dual-subreflector for 30 GHz MBA spacecraft antenna.

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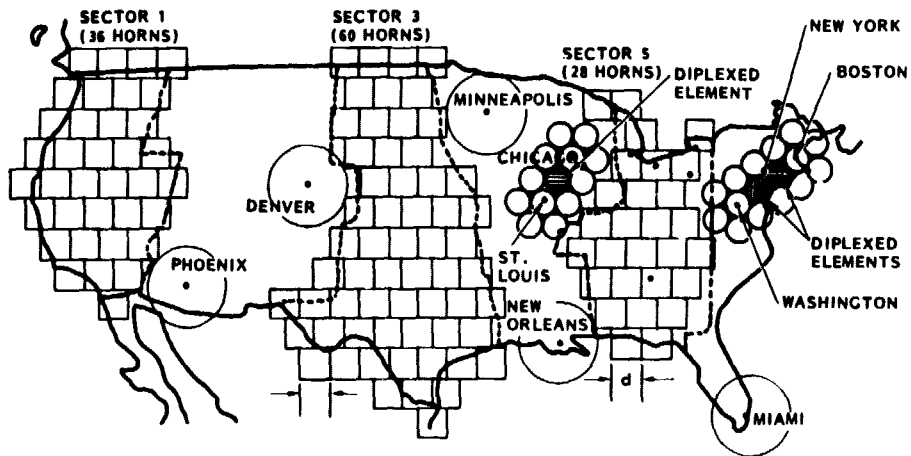


Figure 7. - TRW feed layout for 30 GHz MBA spacecraft antenna.

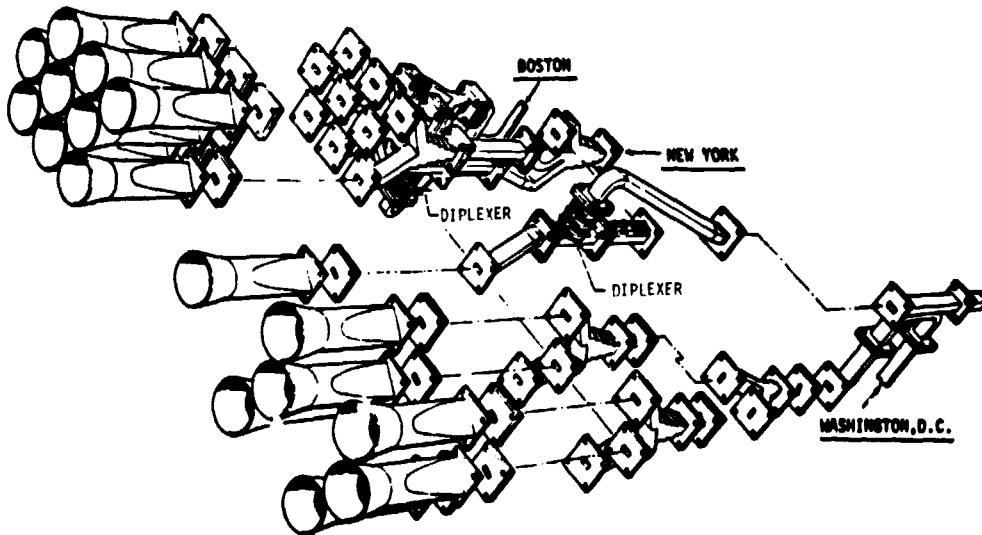


Figure 8. - TRW diplexed fixed beam feed cluster for Boston, New York, and Washington, D.C. for 30 GHz MBA spacecraft antenna.