Advanced Antenna Systems for 21st Century Satellite Communications Payloads

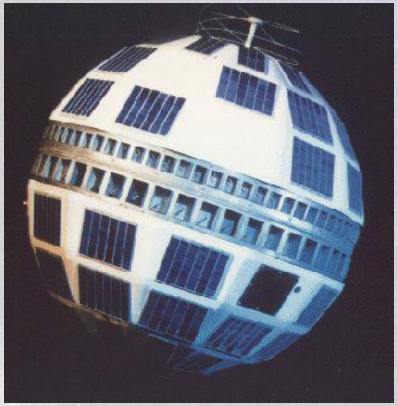
by

Dr. Sudhakar Rao, FIEEE
Distinguished Lecturer, IEEE APS
Technical Fellow, Electronics & Payloads Directorate
Northrop Grumman Aerospace Systems
Redondo Beach, CA 90278, USA

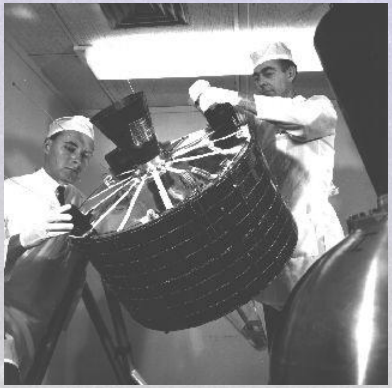
IEEE APS Distinguished Lecture 2015

AGENDA

- Introduction to Satellite Communications
- Contoured Beam Antennas
- Multiple Beam Antennas
- Multi-Band Antennas
- Reconfigurable Beam Antennas
- Hybrid Antennas
- PIM, Multipaction, Test Methods
- Conclusions



TELSTAR



SYNCOM 2

*S. Rao, L. Shafai, & S. Sharma, “Handbook of Reflector Antennas and Feed Systems”, Vol. 3, Artech House Publishers, June 2013
** S. Rao, “Advanced Antenna Technologies for Satellite Communications Payloads”, IEEE Trans. AP, Special Issue, Apr 2015

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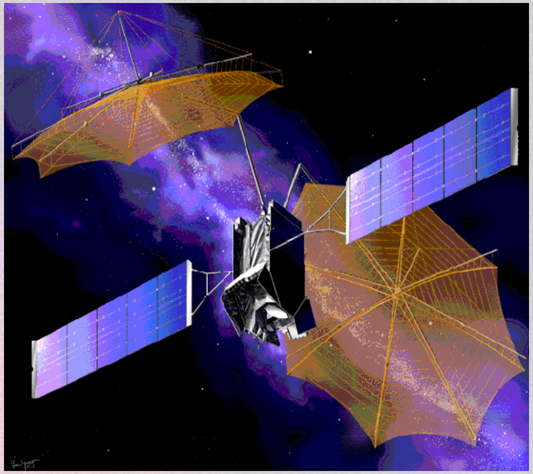
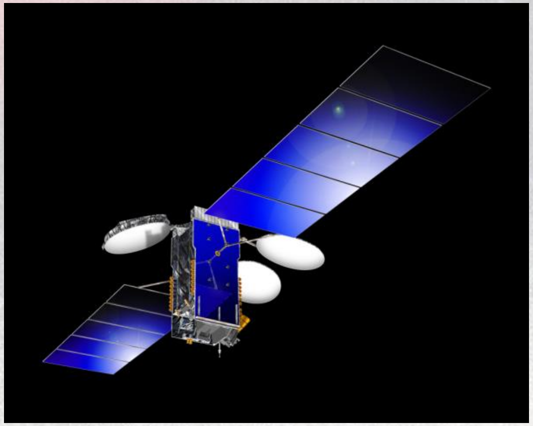
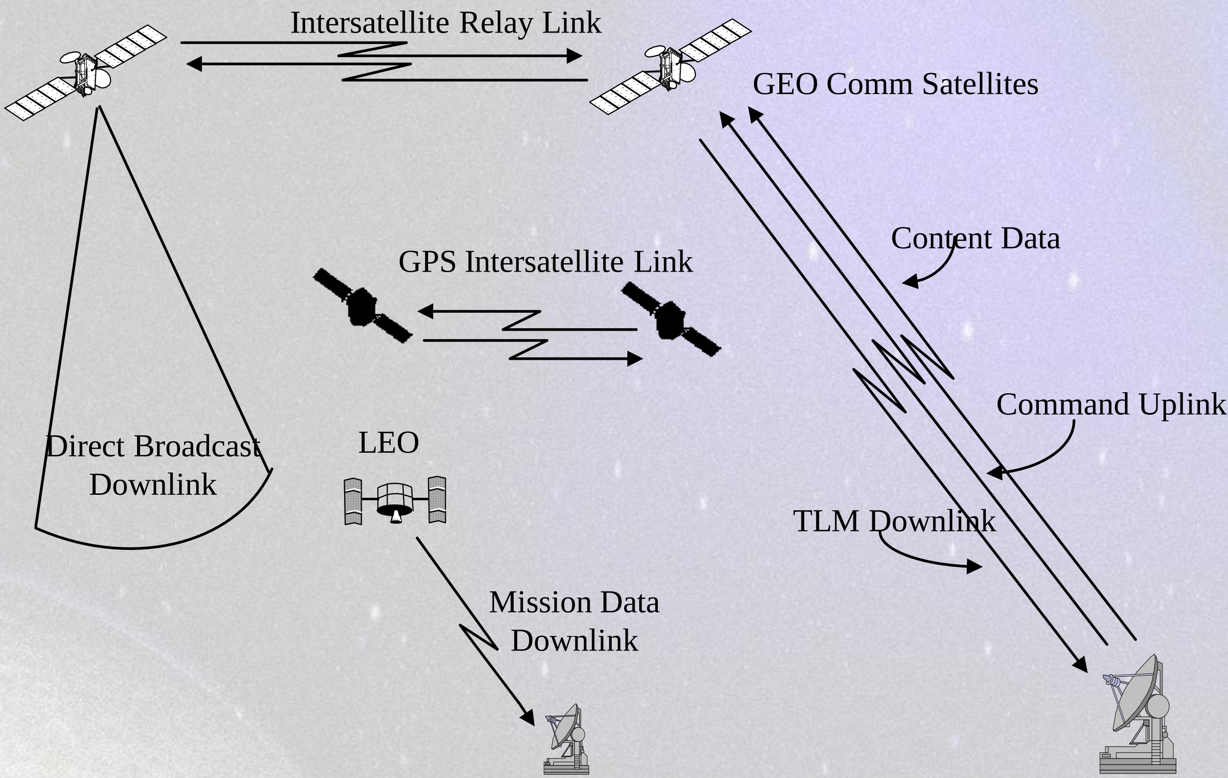
Introduction to SATCOM Antennas: Definition of Satellite Communications



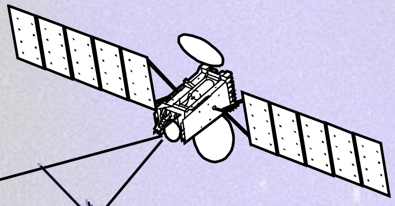




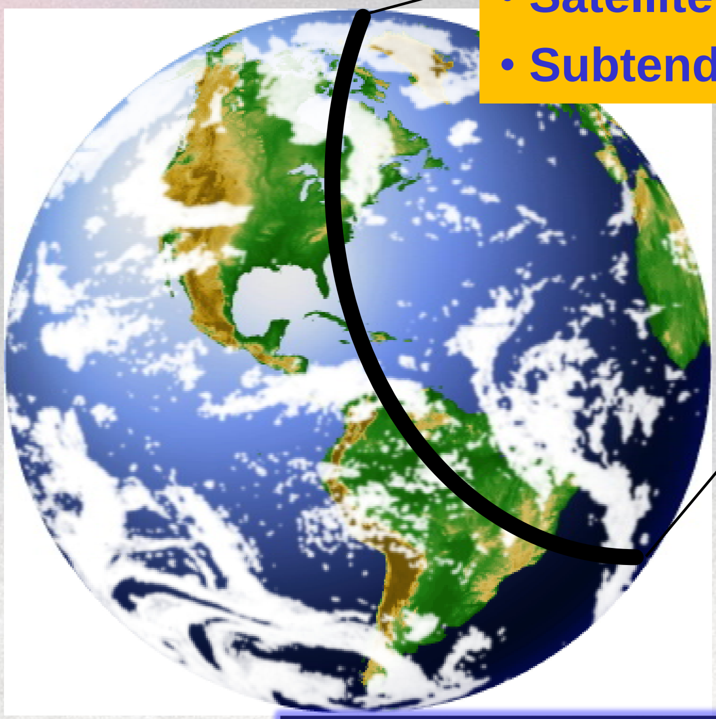
- ❑ Satellite uses a space platform as a relay or broadcast node
- ❑ Satellite serves as an information collection, management and dissemination center with a relatively vast communications area compared to ground based relay networks

Advantages of Satellite Based Communications

- **Only three or four satellites in geosynchronous orbit are necessary to provide near global coverage**
- **One satellite for national/regional coverage**



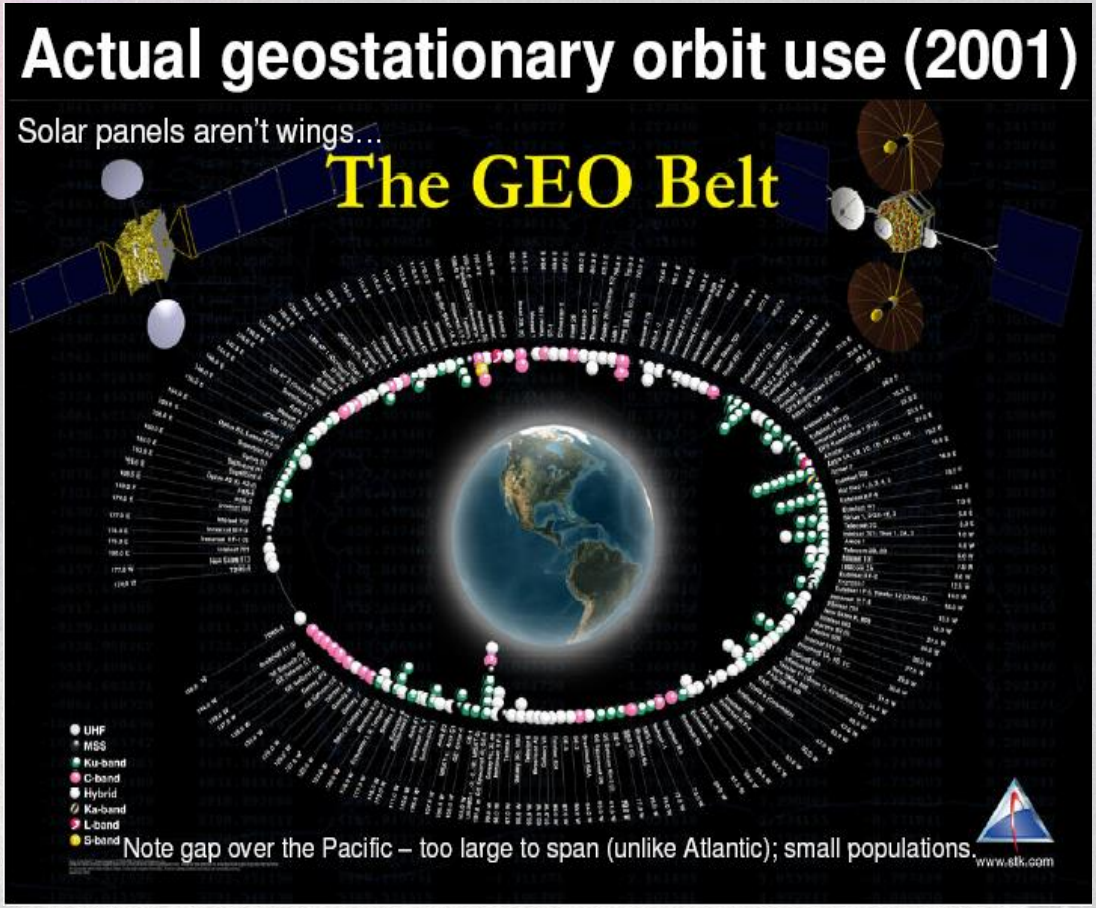
- **Earth Radius = 6832 kms**
- **Satellite Altitude = 35786 kms**
- **Subtended Angle = +/- 8.7^0**



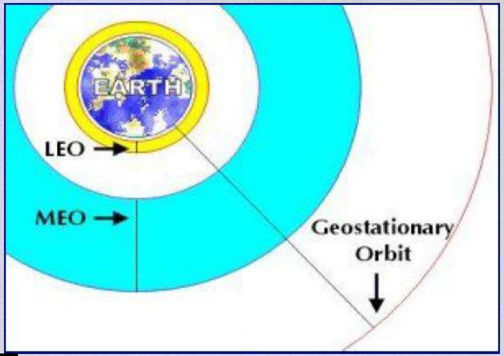
- **Benefits of satellites over conventional ground media (cable, wire, fiber, point-to-point) include:**
  - Fast development and establishment of a communications infrastructure
  - Higher availability
  - Immediate coverage of desired area after launch
    - Satellites do not respect natural limitations such as mountains, water, etc. or political boundaries
  - Distance insensitive for point-to-multi-point communications
    - Fiber optic systems are optimal for point-to-point connections with a limited number of distribution nodes
  - Lower cost for 100% coverage of a region
    - More cost effective for providing thin route services

Requires only 3 or 4 satellites for global coverage

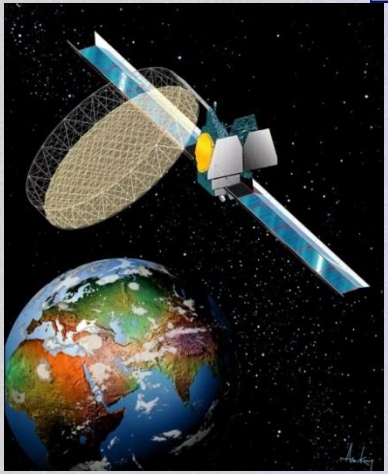
GEO Satellites

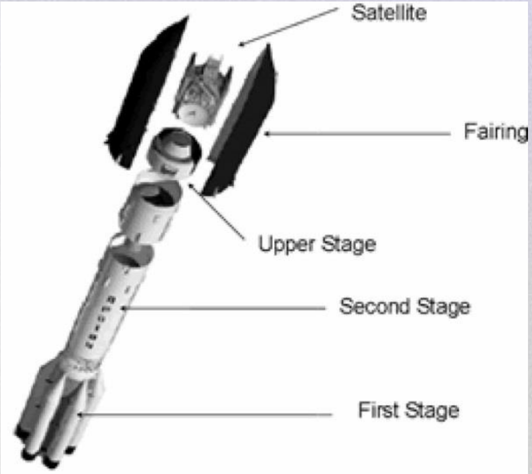


Designated Satellite Services (ITU)

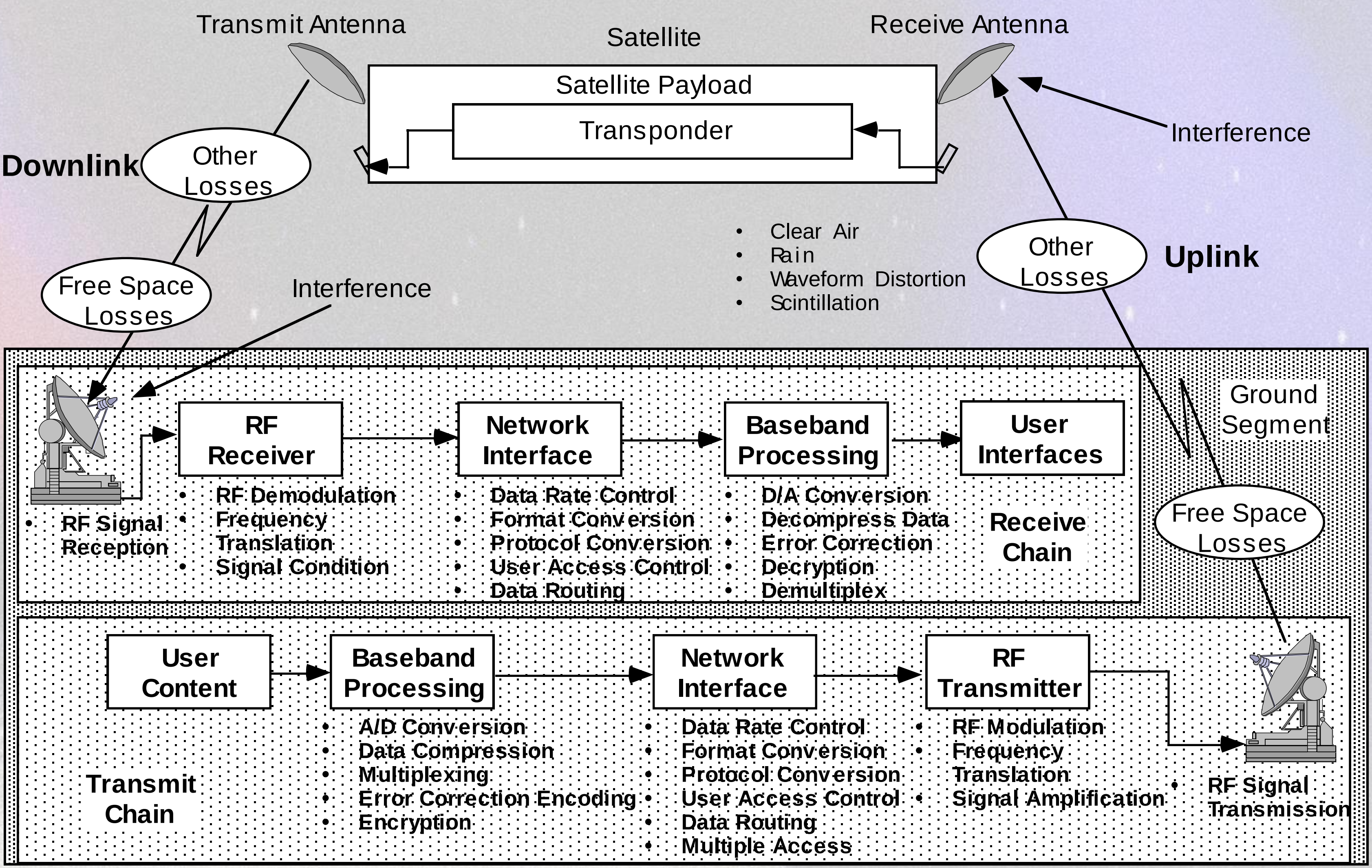


- Aeronautical Mobile Satellite Service (AMSS)
- Aeronautical Radio Determination Satellite Services (ARDSS)
- Amateur Satellite Service
- **Broadcasting Satellite Service (BSS)**
- Earth-Exploration Satellite Service (EESS)
- **Fixed Satellite Service (FSS**)
- **Inter-Satellite Service (ISS)**
- Land Mobile Satellite Service (LMSS)
- Maritime Mobile Satellite Service (MMSS)
- Meteorological Satellite Services
- **Mobile Satellite Service (MSS)**
- Radio Determination Satellite Services (RDSS)
- Space Operations Service
- Space Research Service
- Standard Frequency and Time Signal Satellite Service
- **Personal Communication Services (PCS)**





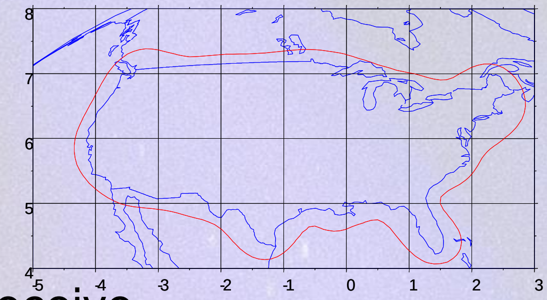
Communications Satellite System Connectivity



$$SNR = EIRP + G/T + 228.6 + S_L - 10\log_{10}(B_w)$$

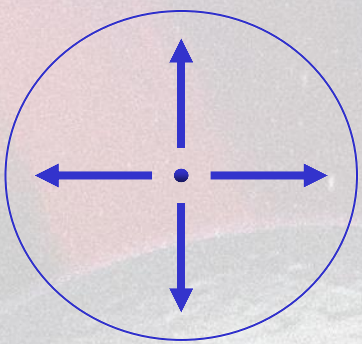
$$= G_T + P_i + G_R - T + 228.6 + S_L - 10\log_{10}(B_W)$$

Antenna Directivity, Gain, Polarization

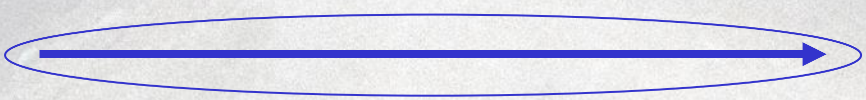


- **Isotropic radiator**
  - A point source that radiates equally in all directions
- **Directivity**
  - A measure in dB of an antenna's ability to transmit or receive energy in a given direction compared to an isotropic radiator.

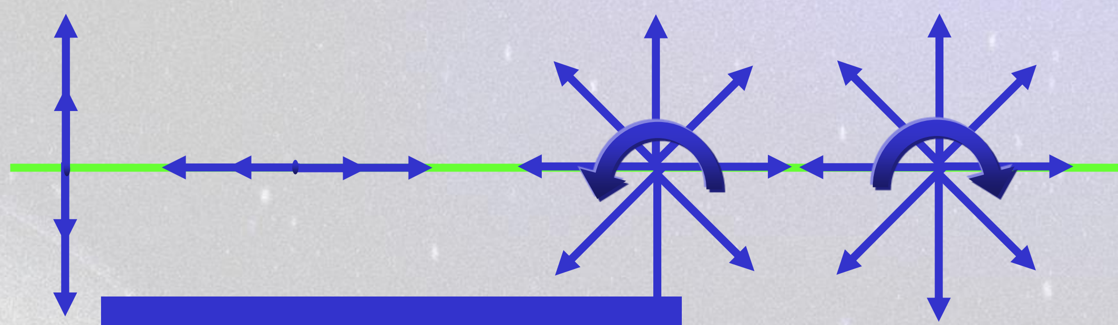
Isotropic Radiator



Directive Antenna



Vertical **Horizontal** **Left Hand Circular** **Right Hand Circular**



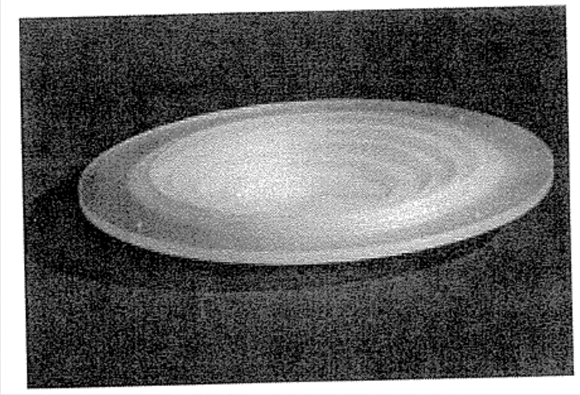
- **OMTs (symmetric, asymmetric)**
- **Polarizers**

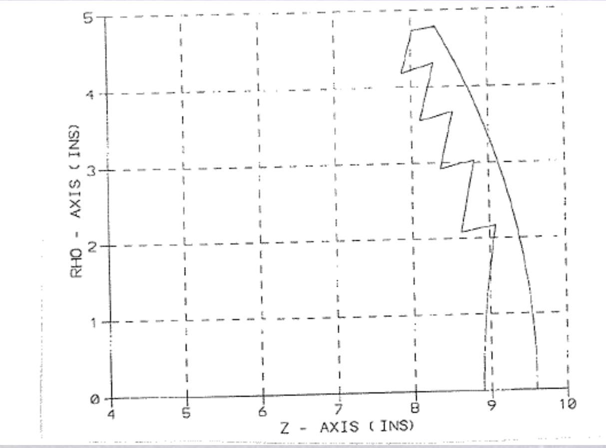
- **Gain**

  = Directivity – Antenna Losses

Spacecraft Antenna Types

- High Gain Antennas (30 dBi to 70 dBi)
  - Reflector Antennas
  - Lens Antennas
    - * Dielectric Lenses: ESD issues
    - * Waveguide Lenses: Narrow Bandwidth
  - Array Antennas





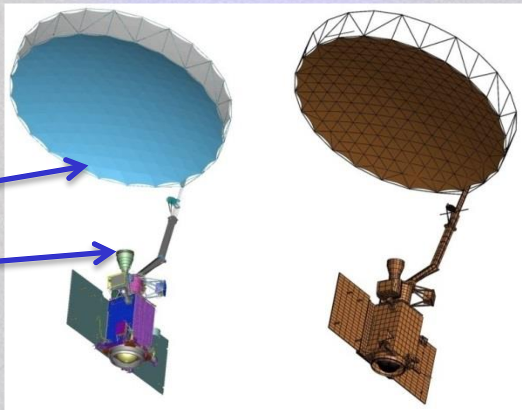
Dielectric Lens

- Medium Gain Antennas (15 dBi to 25 dBi)
  Global coverage horns

- Low Gain Antennas (0 dBi to 12 dBi)
  Biconical Antennas
  Waveguides
  Antennas

Radiation of satellite antennas is highly dependent on spacecraft structure, antenna suite, & mutual coupling effects. RF analyses and tests need to be carried out to validate the designs.

Reflector Antennas



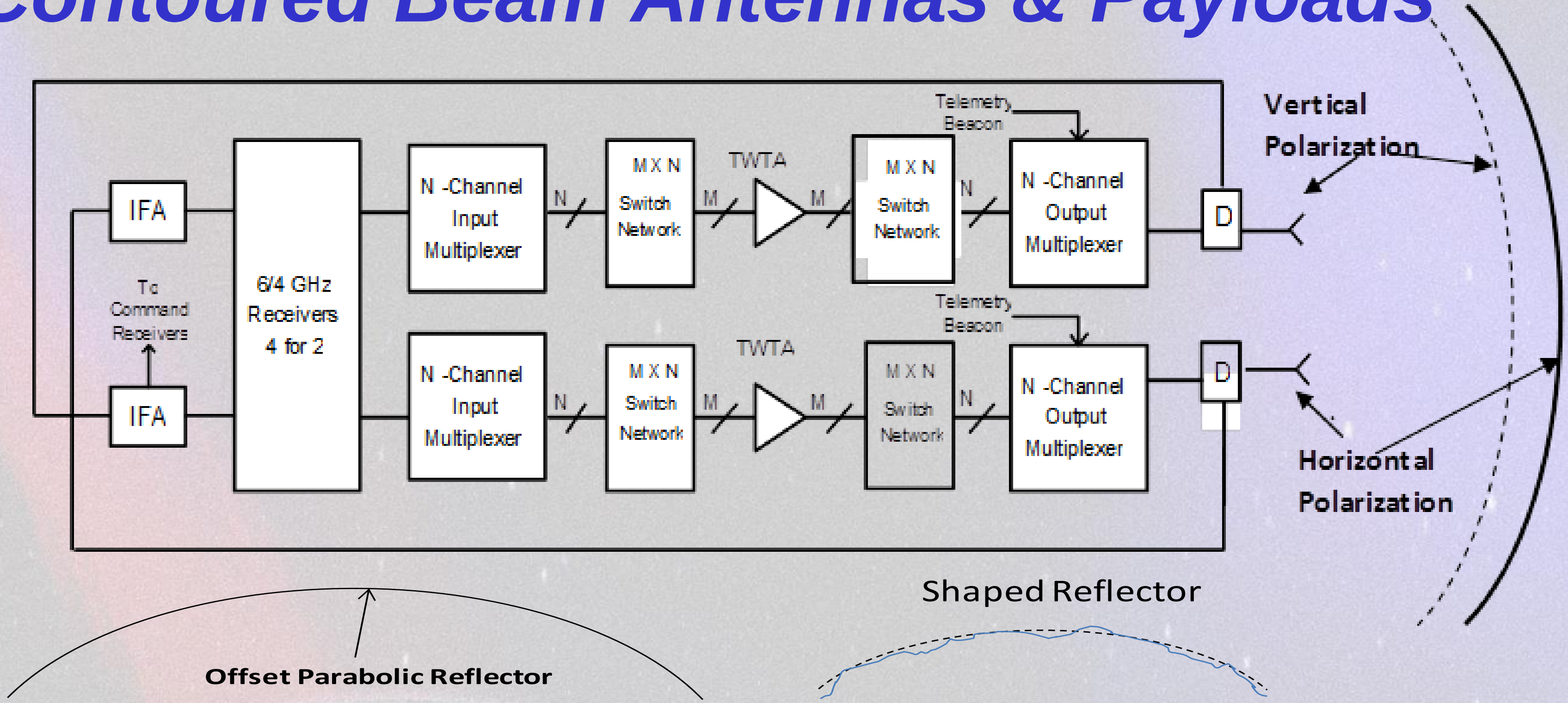
- **Consists of two major assemblies**
  - **- reflector assembly**
  - **- feed assembly**

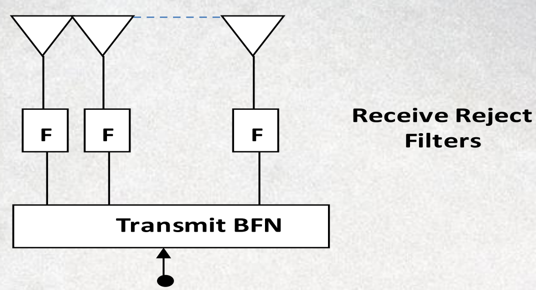
- **Reflector assembly: provides required gain, determines coverage shape, scan loss, beam squint etc. Comprises reflector, thermal paint/cover, deployment boom mechanisms/gimbals, pointing error**
  - key design drivers: surface accuracy, loss, X-pol, thermal stability

- **Feed assembly (horn + OMT + polarizer + filters/diplexers +TCs +W/G Interfaces to repeater): provides proper illumination on the reflector, dictates bandwidth, polarization, X-pol isolation, filtering etc.**
  - key design drivers: minimize loss, power handling, tolerances, thermal, low PIM, wide bandwidths

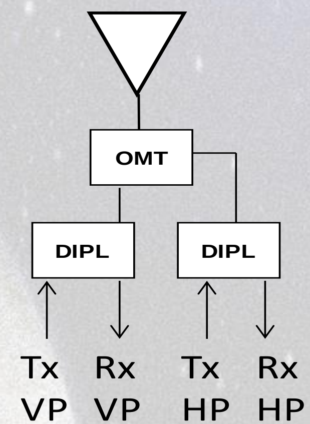
Reflector & Feed Assembly performances are most crucial for satellite antennas

Contoured Beam Antennas & Payloads





OLD TECHNOLOGY



Payload = Antenna + Repeater

High dissipation

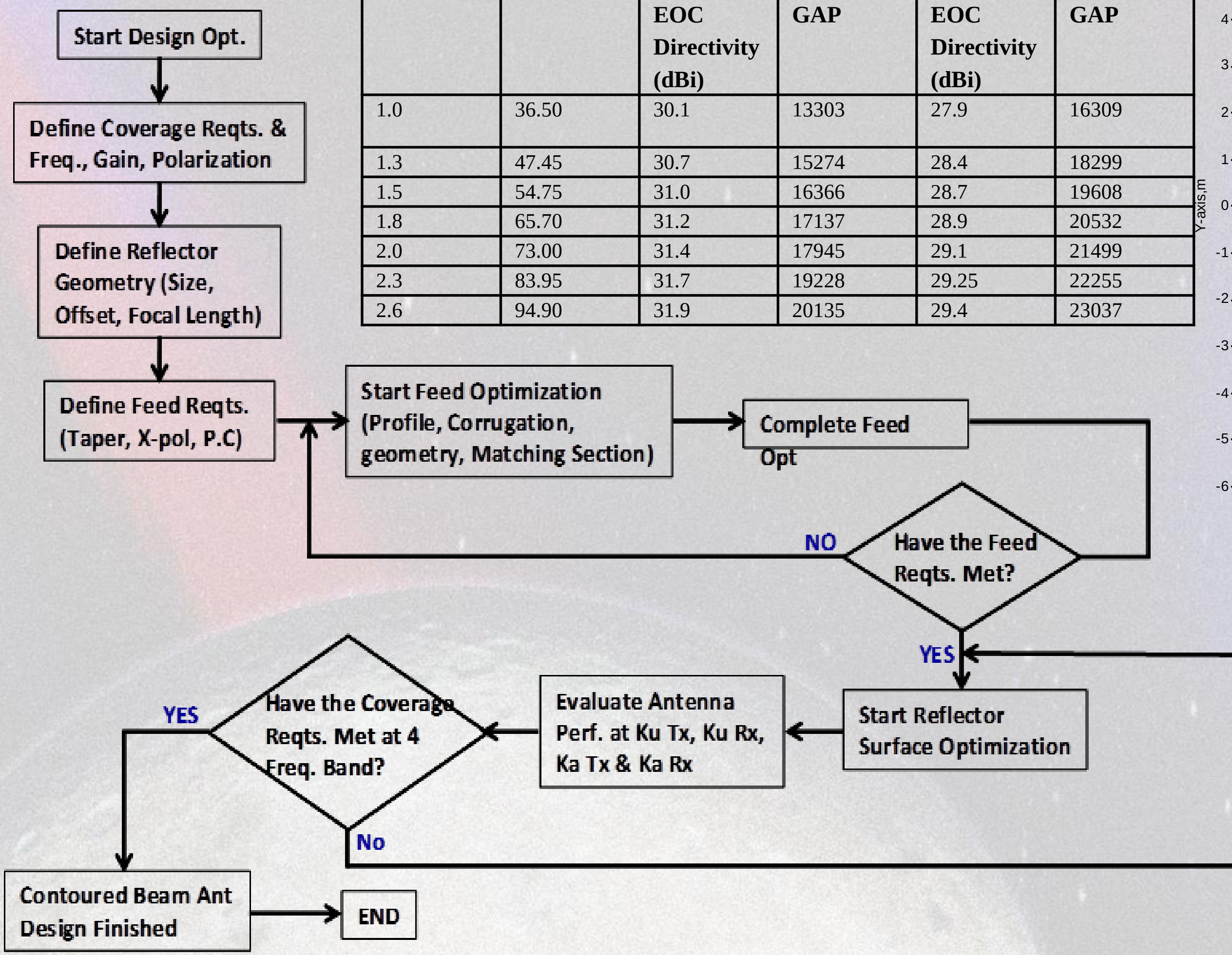
NEW TECHNOLOGY

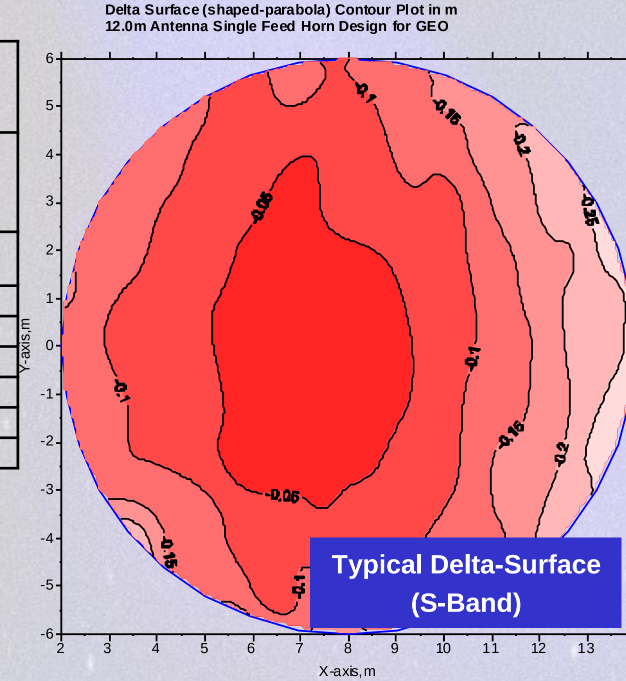
Contoured Beam Antennas

- The beam shape fits closely to the coverage of a country or a region. Used for FSS and BSS satellite services
- Contoured or shaped beams are synthesized using two methods
- Most common and cost-effective method is using shaped surface of reflector to synthesize the beam (phase-only synthesis)
- Key design aspects:
  - maximize the minimum coverage area gain (MCAG)
  - maximize the X-pol isolation within the coverage (C/X > 33 dB)
  - minimize the copol levels outside the coverage and with interfering beam (C/I > 30 dB)
- Antenna types:
  - parabolic reflector with feed array (old technology)
  - dual-gridded reflector (limited to LP applications only)
  - single shaped reflector (LP & CP)
  - dual-reflector shaped Gregorian antenna (LP & CP)
  - other types (SFOC, FFOC, Imaging, ADE etc.)

Synthesis Method for Shaped Reflector

Reflector Diameter (meters)	D/λ	CONUS (13 sq. degrees) Ku-Band		South America (26.45 sq. degrees) Ku-Band	
		EOC Directivity (dBi)	GAP	EOC Directivity (dBi)	GAP
1.0	36.50	30.1	13303	27.9	16309
1.3	47.45	30.7	15274	28.4	18299
1.5	54.75	31.0	16366	28.7	19608
1.8	65.70	31.2	17137	28.9	20532
2.0	73.00	31.4	17945	29.1	21499
2.3	83.95	31.7	19228	29.25	22255
2.6	94.90	31.9	20135	29.4	23037

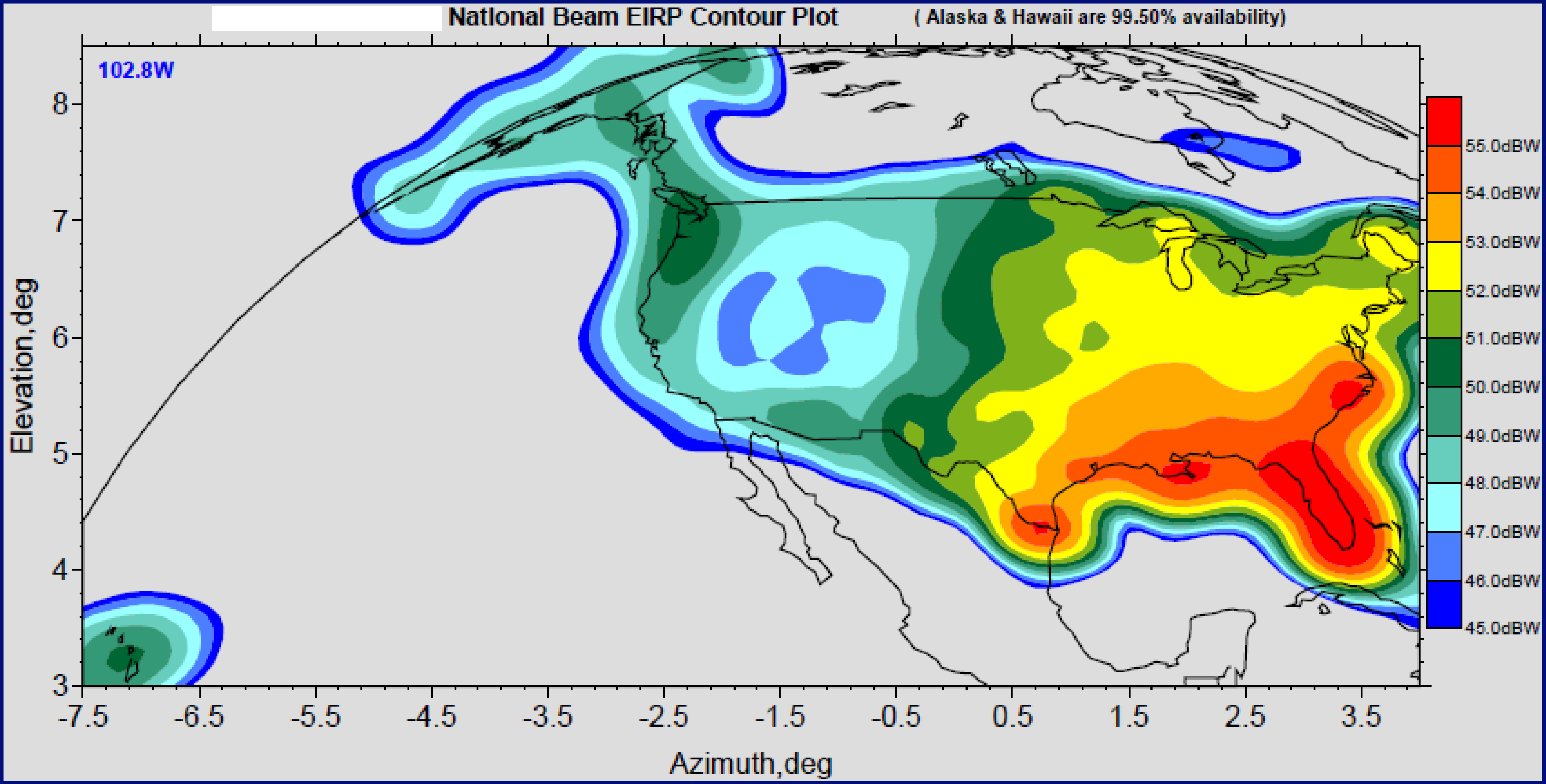




Antenna	Dir., Analysis (dBi)	Dir., Computed (dBi)
Case 1 (shaped)	27.66	27.60
Case 2 (shaped)	21.40	21.65
Case 3 (MBA)	46.68	46.54
Case 4 (MBA)	42.20	42.05

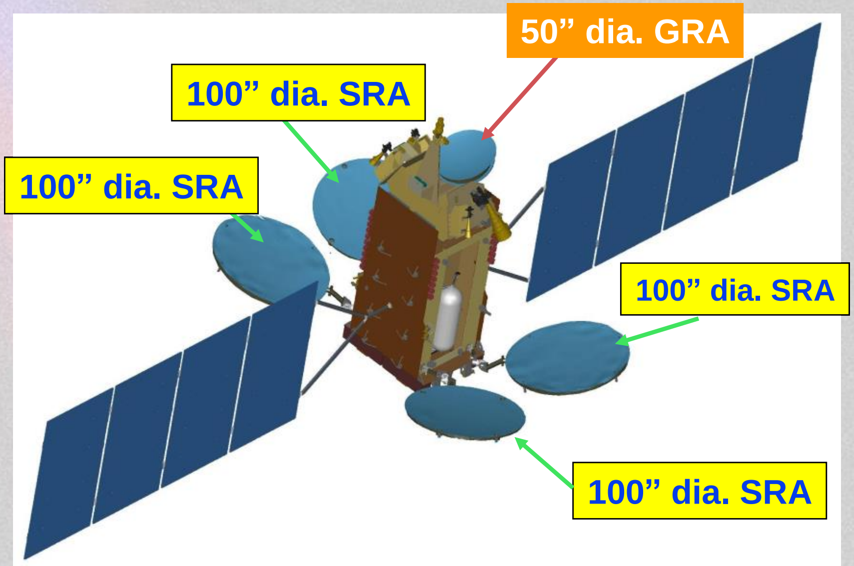
* S. Rao, "Design and Analysis of Multiple-Beam Reflector Antennas", IEEE AP-Magazine, pp. 53-59, August 1999

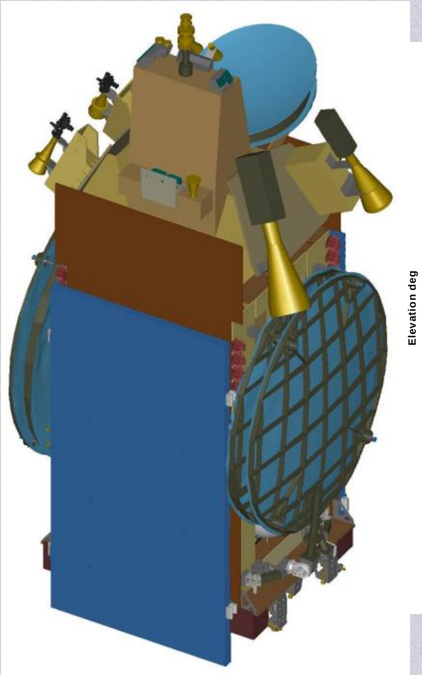
CONUS Beam for DBS

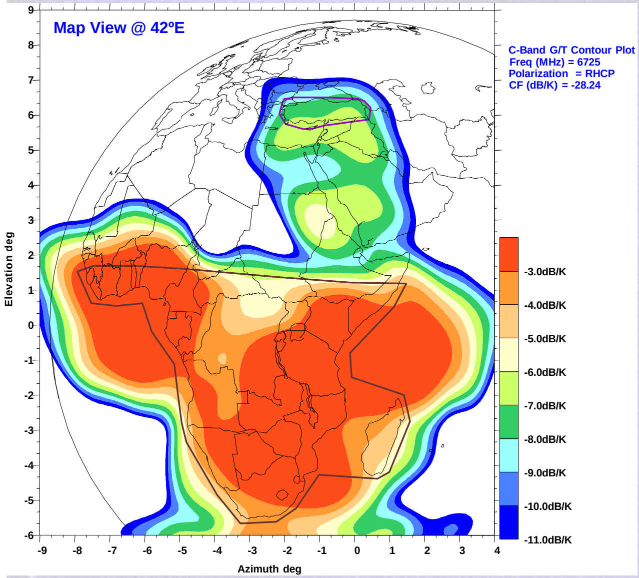


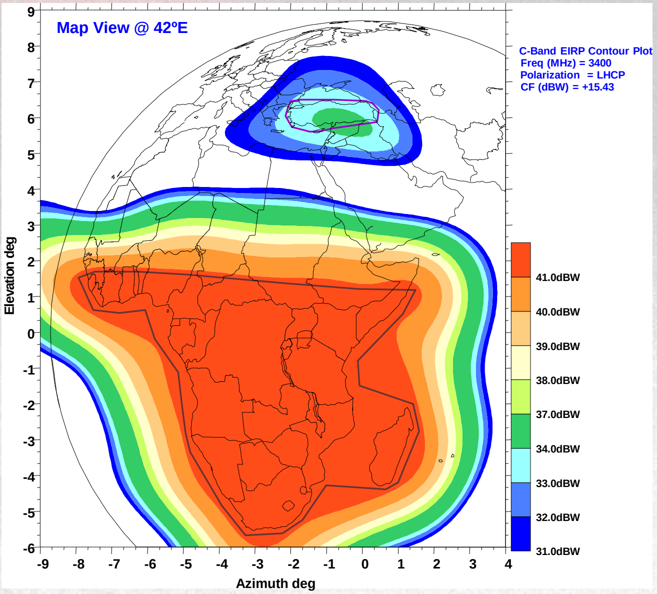
Highly Weighted Beam to compensate for Rain Fade

Contoured Beam Antennas: Multiple Coverage Regions



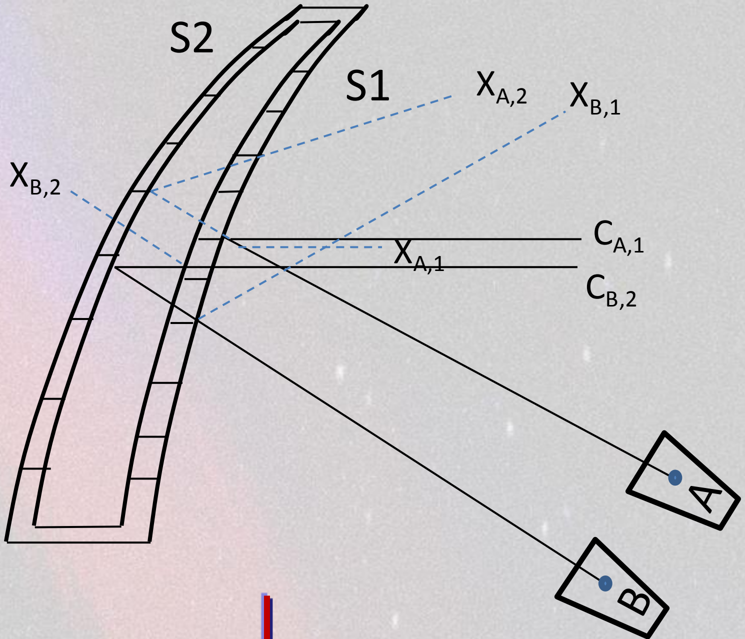


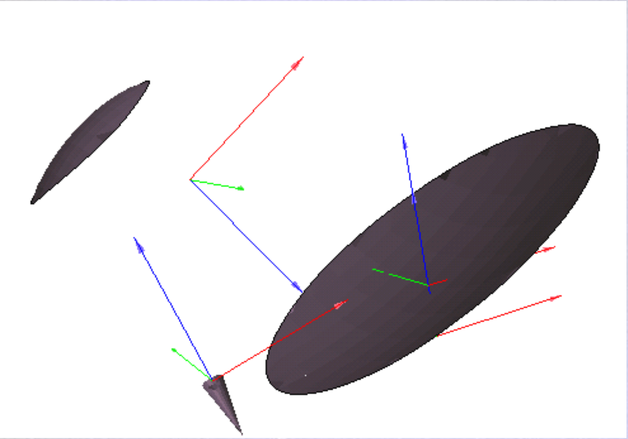


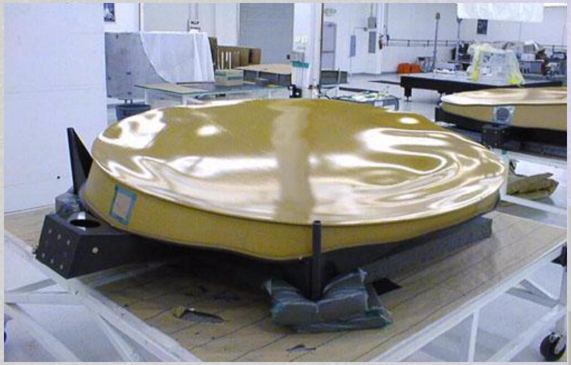


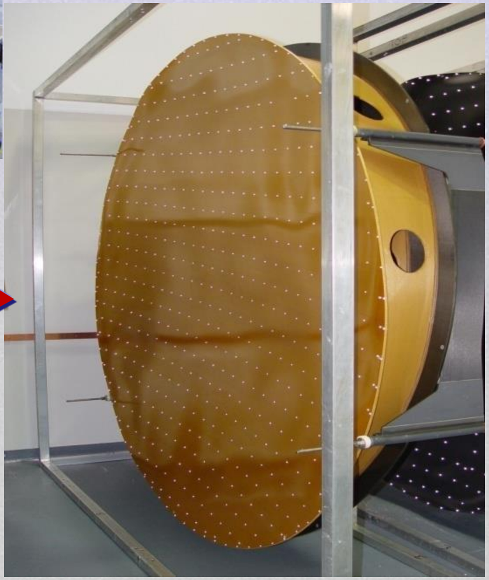
Single Beam Provides Weighted C-Band Coverage to Africa and Turkey

Gridded Reflectors & Gregorian Antennas









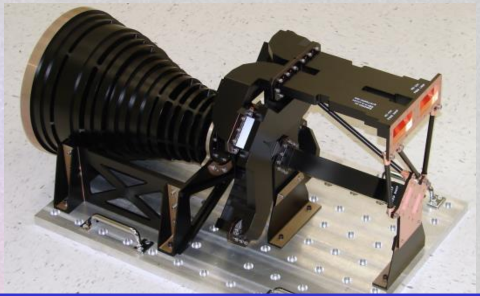
Feed Assembly Design Considerations

- Meet bandwidth requirements including thermal excursions
- Provide desired illumination (> 15 dB taper) for the reflector or beamwidth if used as the antenna
- Meet the low X-pol requirements (< -40 dB for FSS/BSS)
- Low sidelobe levels (to minimize spill-over losses)
- Power handling (6 dB margin by design, 3 dB by test)
- PIM-free design features (< -135 dBm typical, thermal PIM)
- Return loss > 25 dB
- Low insertion loss (< 0.25 dB)
- Meet desired isolation between bands (> 70 dB) & filter other bands
- Low mass
- Meet thermal requirements (-140^{0}c to +170^{0}c)
- Better manufacturing tolerances

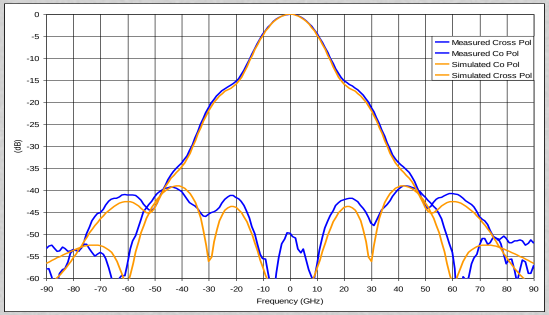
Horn Types for SATCOM

- Corrugated Horns: wideband, supports dual-band, low X-pol, heavy
- Potter Horns: Limited Bandwidth, smooth-wall, low mass
- Multi-flare Horn: Multi-band capability (> octave BW), high efficiency, low-mass, suitable for PCS 7 MBAs
- Tri-furcated Horn: Suitable for LP, low spill-over loss, low X-pol
- Bi-conical Horn: Suitable for TT&C
- Waveguides, Quadri-filar helices (volutes) etc. (low gain)
- Dielectric Horns: Not suitable for space (ESD issues)
- Cup-Dipoles & PEC: Suitable for mobile satellites
- Helical Antennas: Suitable at L-Band & UHF (GPS)

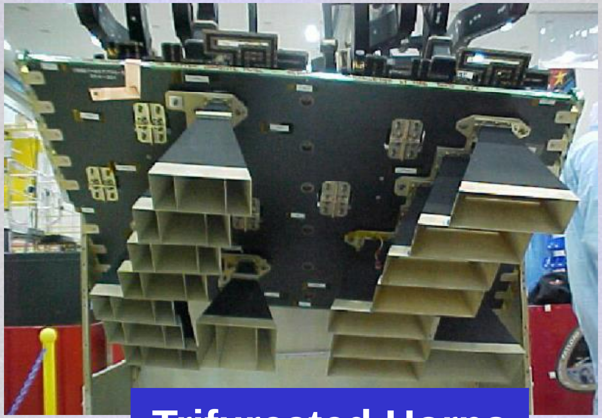
Feed Types



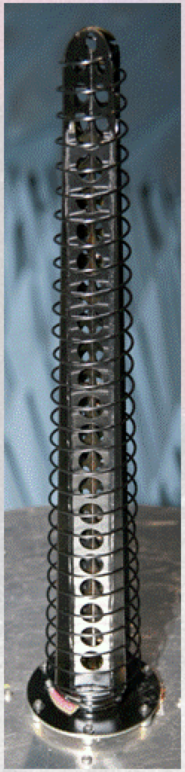
C-Band Tx/RX Feed Assembly



Parameters	Measured Performance
Frequency, GHz	Tx: 3.625 - 4.2 Rx: 5.85 - 6.425
Axial Ratio	< 0.2 dB on Axis
Insertion Loss	Tx: < 0.15 dB Rx: < 0.05 dB
Return Loss	Tx: > 28 dB Rx: > 32 dB
Isolation	RHCP ↔ LHCP > 25 dB Rx ↔ Tx > 60 dB
Peak Power	10 kW Multipaction
PIM	< -140 dBm, 7th Order
Edge Taper	20 dB (±30°) Typical
Cross-Polar Levels	< - 38 dB (±30°) relative to peak
Size, Feed	28.5"(L) x 12"(W) x 12.7"(H)
Mass, Feed	< 12 Kg (with brackets)

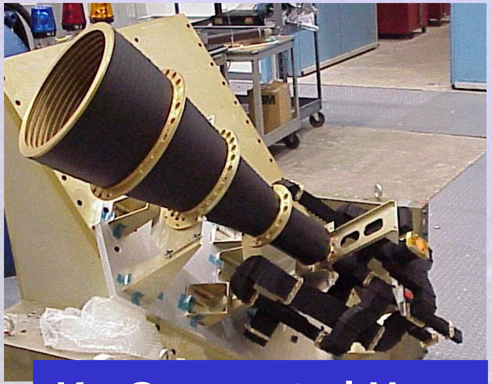


Trifurcated Horns

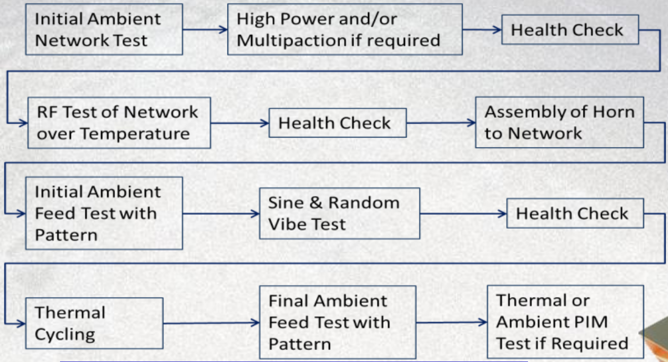


Helix

Multi-Mode Horn



Ku-Corrugated Horn

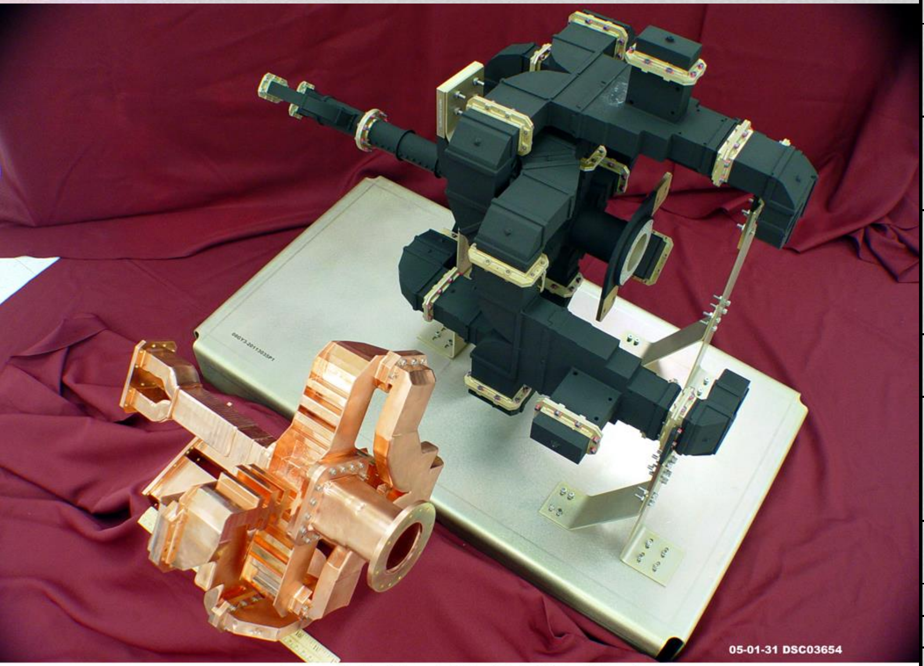


Typical Test Plan

Ku-Tracking Feed

PEC

C-Band Feed Assemblies (Discrete vs Integrated)



Copper unit : New Integrated C-Band Dual CP Feed Network
-Reduced Mass and Size
Black Unit : Old Discrete Components C-band Dual CP Feed Network
- Large Size and Mass

PARAMETER	Discrete	Integrated	COMMENTS
Size	**21" X 21" X 33"**	**12" X 12" X 12"**	**INTG Feed is 8 times more compact**
Mass	**18.3 lbs**	**12 lbs**	**INTG Feed is 35% lighter than ANTEK's**
Tx Insertion Loss, dB	**0.16**	**0.13**	**INTG Feed has lower insertion loss due to compact size and use of Cu**
Rx Insertion Loss, dB	**0.09**	**0.06**	
Tx Axial ratio, dB (Ambient/Thermal with 5 deg. delta)	0.13 / 0.26	0.15 / 0.20	Thermal A.R of INT feed is better
Rx Axial ratio, dB (Ambient/Thermal)	0.13 / 0.20	0.16 / 0.19	
Tx Return Loss, dB	30	30	
Rx Return Loss, dB	31	30	
Bench Tuning	**Extensive**	**None**	**Bench tuning is required for Disc feed**
Qualification Status	**Flight**	**Flight**	

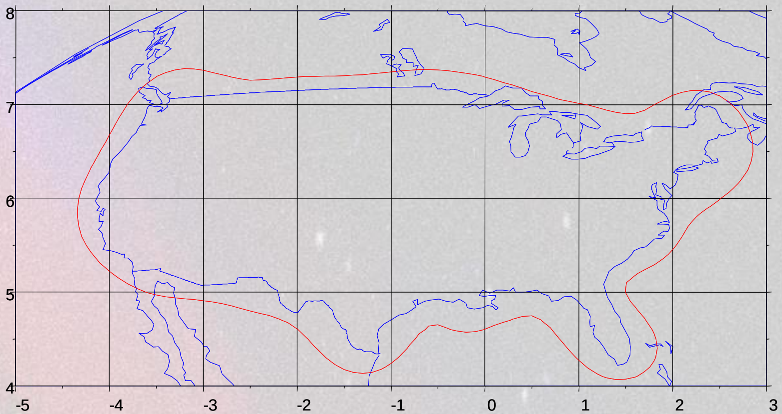
Integrated feed assembly is more compact, better RF performance and low PIM risk

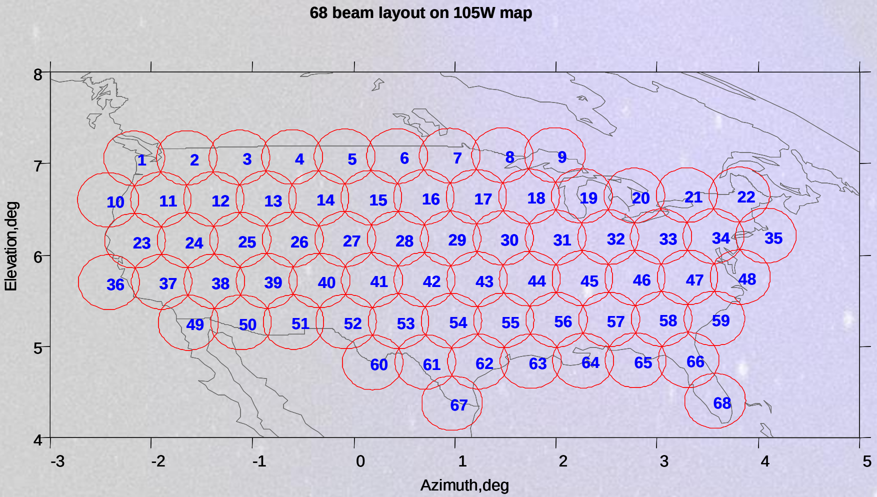
Multiple Beam Antennas

- **Multiple beam payload systems are extensively used for both military and commercial satellites. Advantages are higher EIRP, G/T, spectral re-use, & smaller ground terminals**
  - **- Direct Broadcast Satellites (12/17 GHz): EchoStar, DirecTV, HNS**
  - **- Ka Broadband Satellites (19/29 GHz): Anik-F2, ViaSat, EutelSat**
  - **- Military Satellites (20.5/30 GHz): Wideband Gapfiller Satellite (WGS)**
- **Above systems operate in dual-bands and support single service**
- **Future systems are required to support multiple satellite services**
  - **- Ku & Ka supporting DBS & broadband (12/18/20/30 GHz)**
  - **- TSAT and FABT (20/30/45 GHz) combining existing WGS & AEHF**
- **Advanced antenna systems developed recently that simultaneously supports three services (DBS, reverse DBS, and broadband) covering *FIVE DISCRETE BANDS* over 12.3 GHz to 30.0 GHz (with BWR of 2.44)**
- **Key components are:**
  - **- Multi-mode smooth wall horn supporting 5 discrete bands**
  - **- MBA design producing multiple beams at 5 bands simultaneously**

Single satellite supporting multiple services is the future trend

MBA versus Contoured Beam Payloads



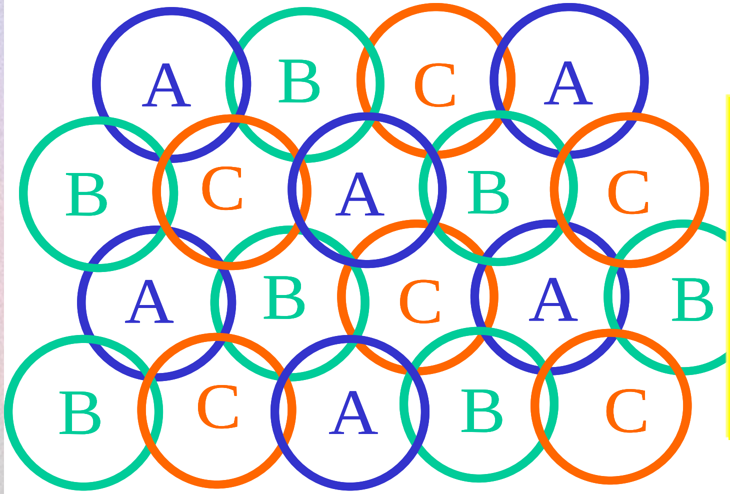


- EOC Gain ~ 31dBi
- Spectral Reuse Factor =1
- X-pol Isol ~ 30dB

- Beam diameter = 0.6°
- Beam Spacing = 0.52°
- EOC Gain ~ 46dBi
- Spectral Reuse Factor =15 (4-cell)
- X-pol Isol ~ 25dB
- C-pol Isol ~ 12dB

MBAs Allow Reuse of Spectrum Several Folds and Provide Increased Gain

Frequency Reuse Schemes for MBAs



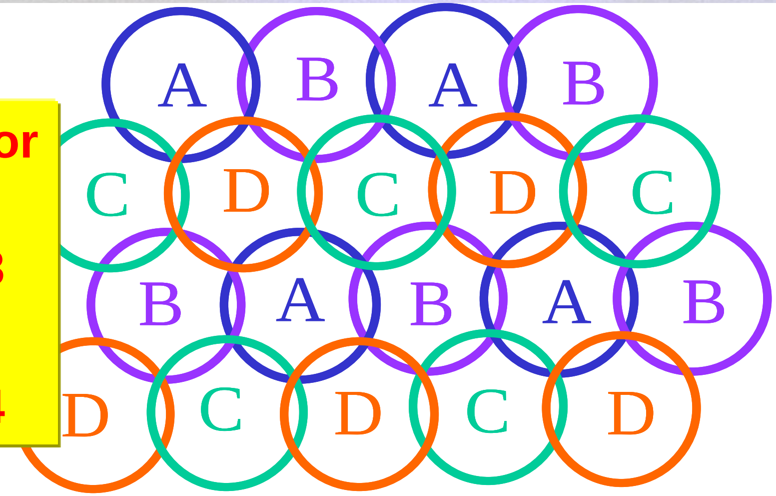
3-cell reuse

Reuse Factor (64 beams):

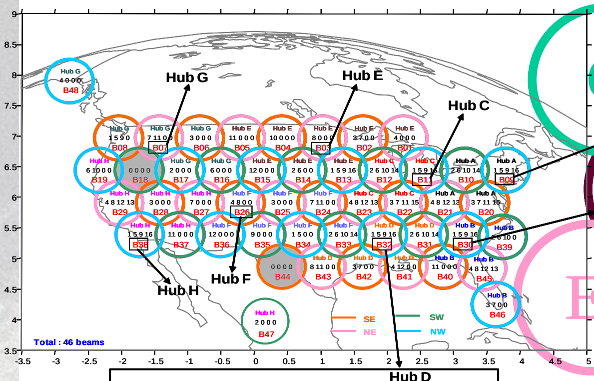
3-cell = 21.3

4-cell = 16

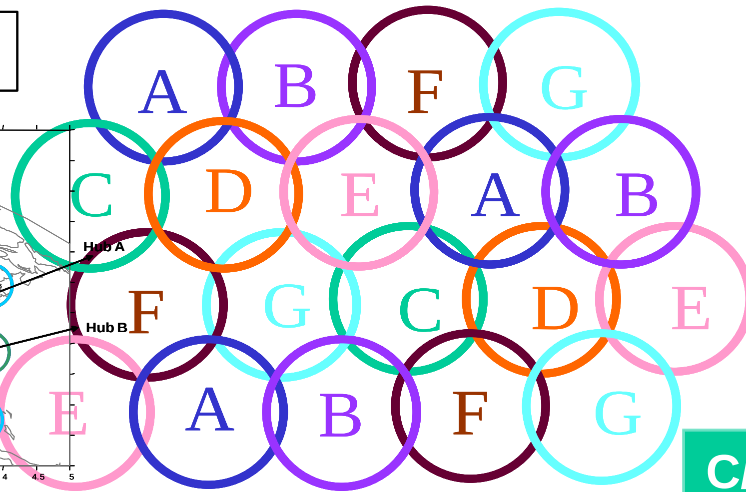
7-cell = 9.14



4-cell reuse



Hybrid-cell reuse



7-cell reuse

Closest Spacing Between Reuse Beams:

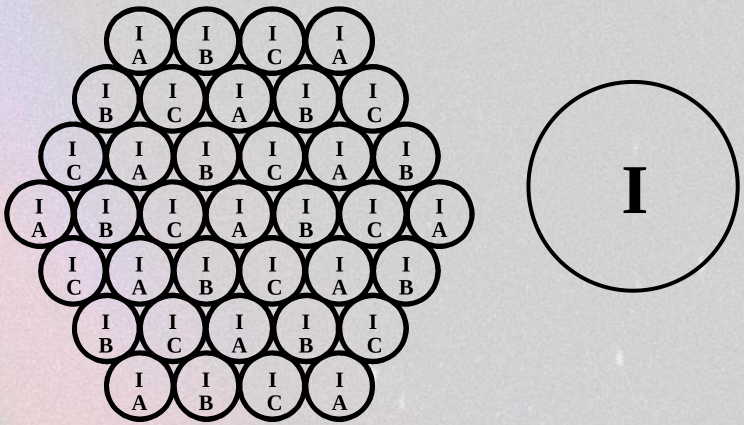
3-cell = 0.58 Adj. Beam Sp

4-cell = 0.85 Adj. Beam Sp

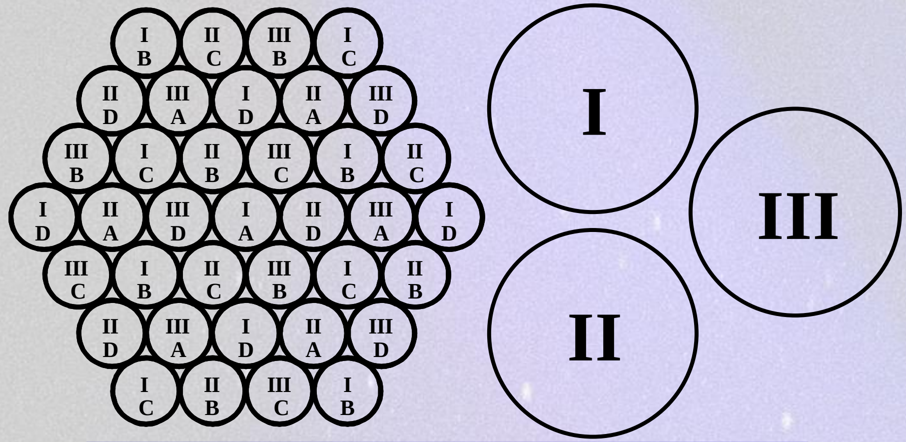
7-cell = 1.49 Adj. Beam Sp

C/I = 9 dB, 12 dB, & 18 dB for 3-C, 4-C, & 7-C

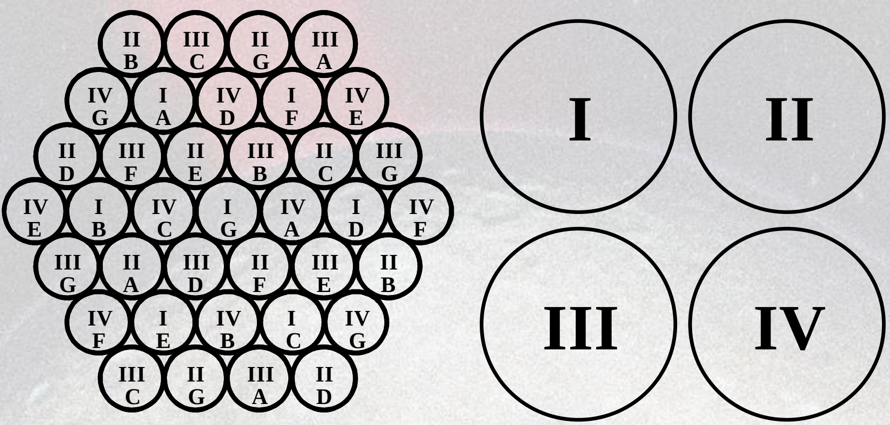
Frequency/Aperture Reuse Schemes



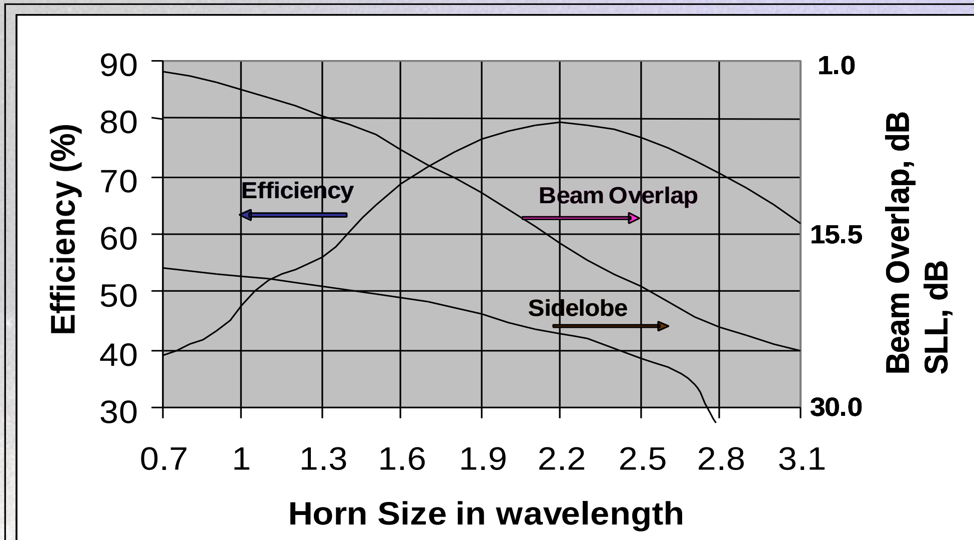
3-Cell Reuse with 1 Aperture



4-Cell Reuse with 3 Apertures



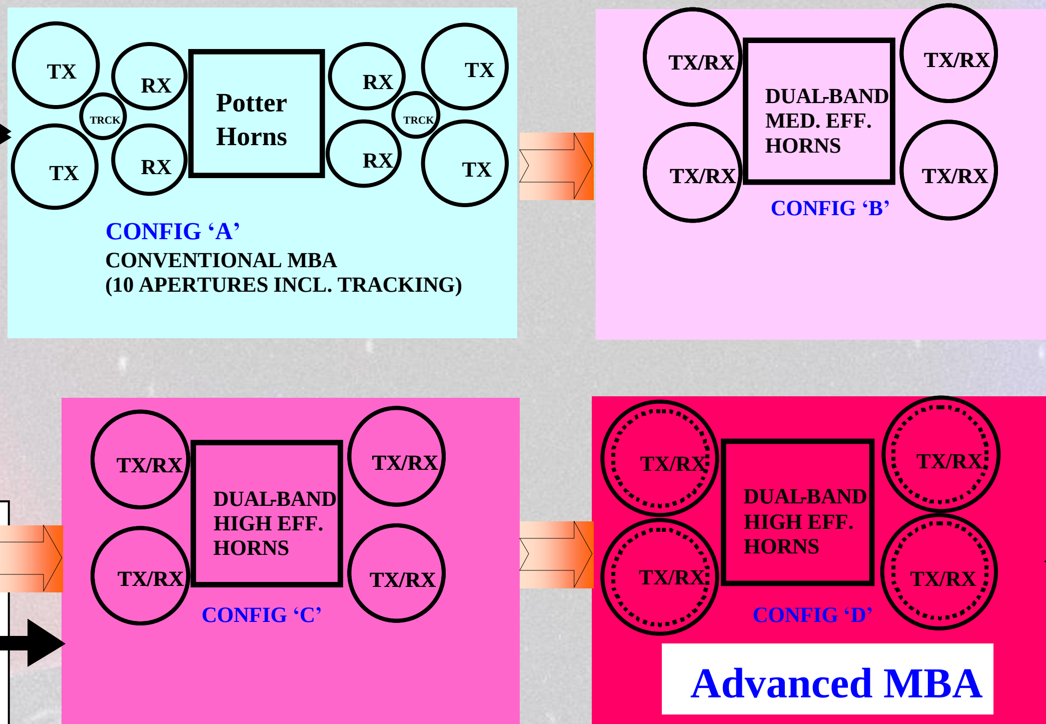
7-Cell Reuse with 4 Apertures



S. Rao et al., "Development of a 45 GHz multiple-beam antenna for military satellite communications", IEEE Trans. Antennas & Propagation, vol. 43, 00. 1036-1047, October 1995

Evolution of MBA Technology

Single-Band Antennas (require 10 apertures)



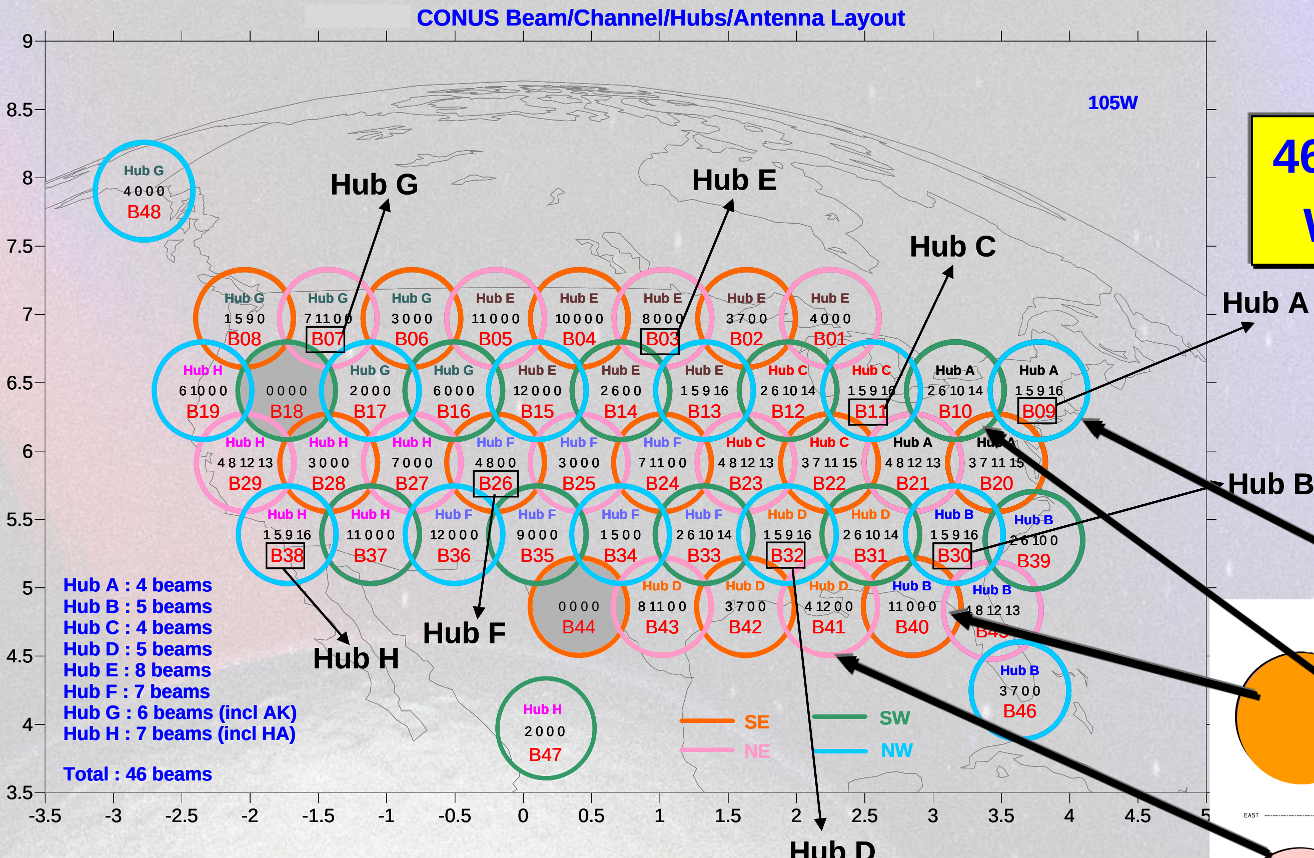
Dual-band Antennas (low efficiency of 54%): Corr. Feed

Dual-band Antennas (high efficiency of about 84%)

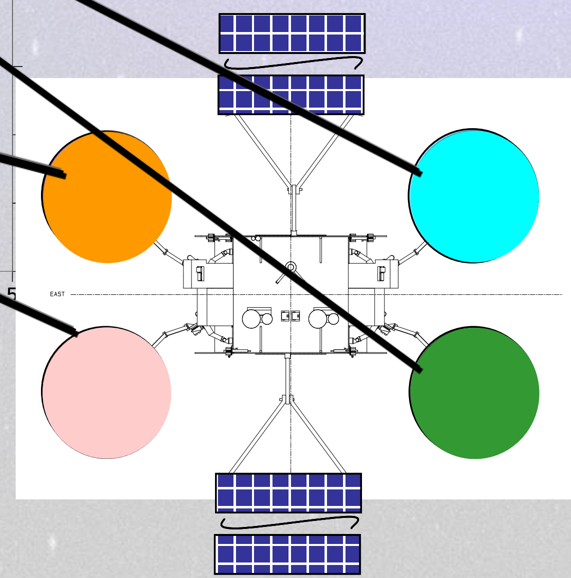
Multi-band Antennas (supports 5 bands with efficiency of 74% to 82%)

Example: MBA supporting 5 bands and 3 different services using Common antenna

Multiple Beam Layout

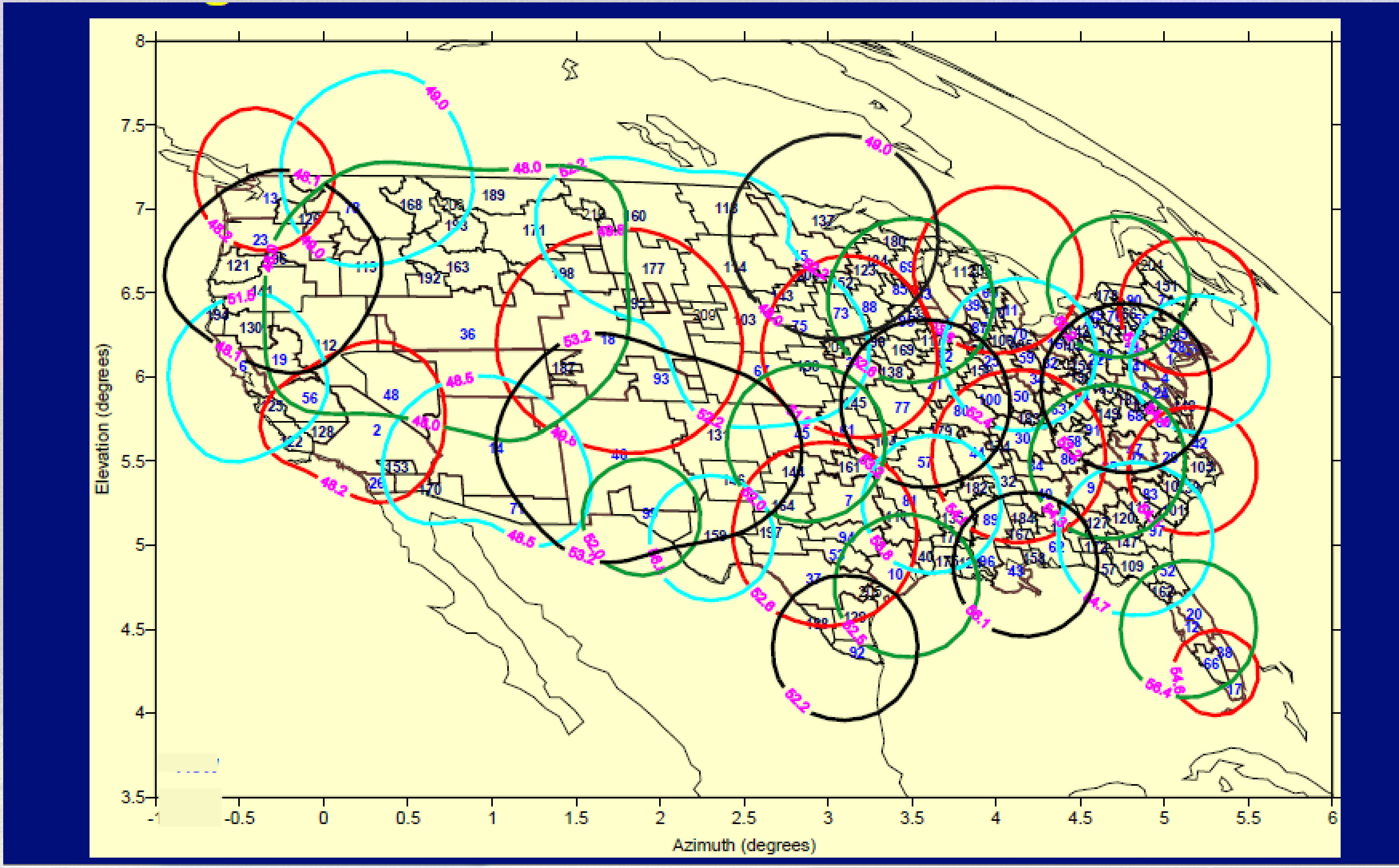


46 spot beams
With 8 hubs



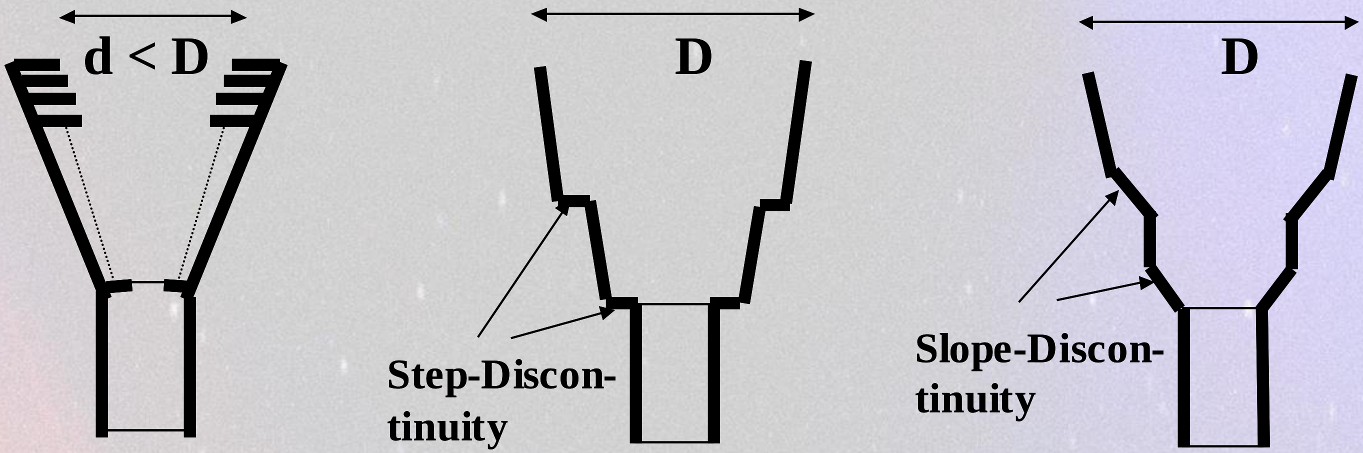
- **Higher EIRP & G/T**
- **High Spectral Re-use (8 times freq X 2 times pol = 16)**
- **Satellite Capacity > 100 Gbps**

MBA for Local-Channel Broadcast



Multiple Beams with Non-Uniform Spacing & Non-Uniform Size

MBA Horn Comparison



CONVENTIONAL HORN (CORRUG.)	**MULTI-MODE HORN NARROW BAND**	**MULTI-MODE HORN WIDE BAND**
DUAL-BAND	**SINGLE BAND**	**DUAL-BAND**
Thick Corrugations	**Step-Discontinuities**	**Slope-Discontinuities**
54 % Eff. Tx & Rx	**> 85 % over Tx or Rx**	**> 85% over Tx & Rx**
Heavy & Bulky	**Light & Compact**	**Light & Compact**

Design Procedure for HEH

- **Define horn aperture size, waveguide size, and the efficiency**
- **Select modal content (e.g., TE11, TE12, TE13/1.0, 0.31, 0.21)**
- **Determine radial dimension based on modes to set profile breakpoints for the horn & use "slope-discontinuities"**
- **Optimize horn geometry to satisfy cost function:**

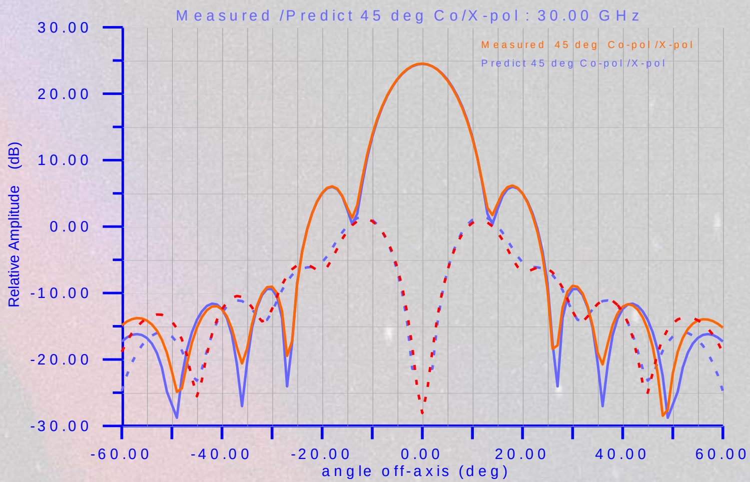
$$F = \sum_{i=1}^{nfrq} \left[wt_r (\rho_i - \rho_{di})^2 + wt_x (xp_i - xp_{di})^2 + wt_a (\eta_i - \eta d_i)^2 \right]$$

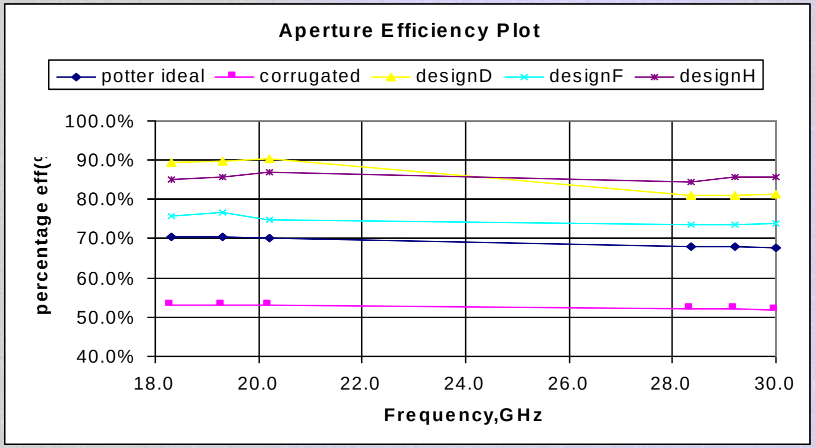
- **Aperture efficiency that can be achieved depends on the horn size.**
  - Larger the size, higher will be the aperture efficiency and lower bandwidth
  - Typical efficiency values for dual-band operation at K/Ka are in the range 85% to 90%
  - Trade is the higher efficiency at K, better match at K, and lower off-axis x-pol at K/Ka

1) S. Rao and M. Tang, "High-efficiency horns for an antenna system", U.S. Patent # 7,463,207, December 09, 2008

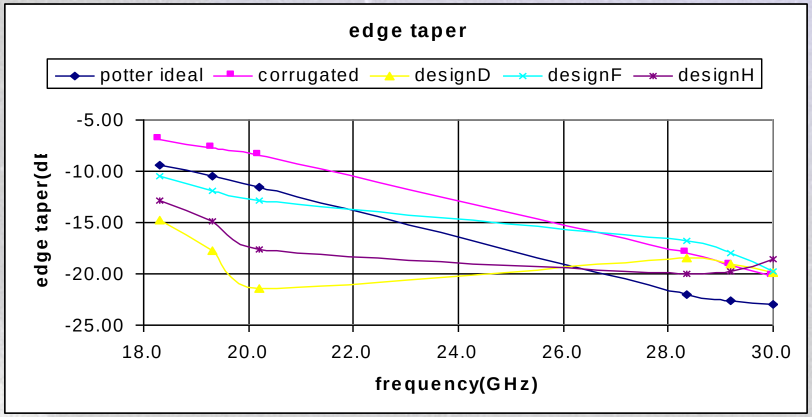
2) K. K. Chan ad S. Rao, "Design of high efficiency circular horn feeds for multi-beam reflector applications", IEEE Trans. Antennas & Propagation, Vol. 56, pp. 253-258, January 2008

HEH Performance Summary



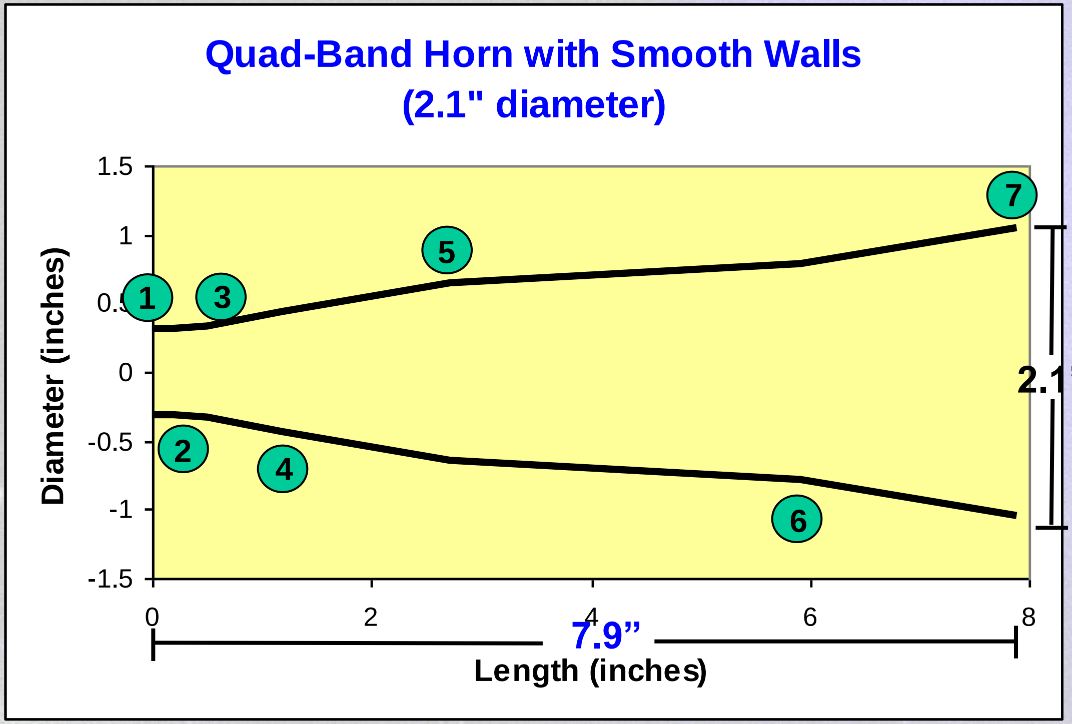


Frequency (GHz)	Directivity (dBi)/ Efficiency		Cross-Pol (dB)		Return Loss (dB)	
	Predict	Measured	Predict	Measured	Predict	Measured
18.30	20.08 (83.4%)	20.10 (83.8%)	19.8	18.8	30.6	30.8
19.30	20.60 (84.5%)	20.60 (84.5%)	20.5	20.5	26.5	25.7
20.20	21.05 (85.6%)	21.1 (86.6%)	20.6	20.7	24.2	24.2
28.30	23.89 (83.9%)	23.8 (82.1%)	24.1	23.1	30.8	29.0
29.20	24.23 (85.2%)	24.2 (84.6%)	26.0	24.2	33.0	34.7
30.00	24.46 (85.1%)	24.5 (85.9%)	23.0	24.4	36.3	27.6



Multi-band Horn Geometry & Performance

	D	L
	(in.)	(in.)
1	0.640	0.000
2	0.640	0.200
3	0.646	0.506
4	0.877	1.175
5	1.299	2.718
6	1.560	5.918
7	2.100	7.901



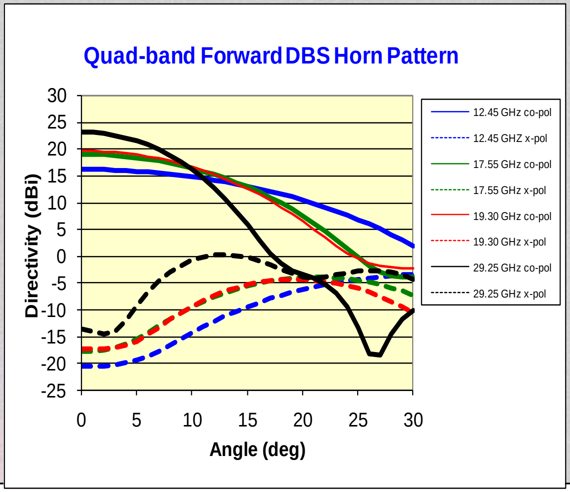
2.2 λ to 5.3 λ

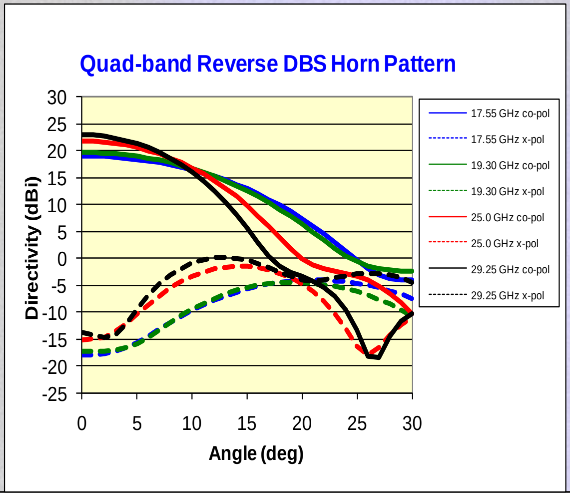
Frequency (GHz)	Return Loss (dB)	X-pol (20º) (dB)	Efficiency (%)
12.5	-26.5	-22.3	82
17.3	-48.0	-22.5	80
17.8	-50.2	-23.6	80
18.4	-43.6	-23.6	79
20.2	-41.7	-22.1	76
24.8	-50.1	-23.0	76
25.3	-44.3	-23.7	76
28.5	-44.0	-23.9	75
30.0	-45.2	-22.1	74

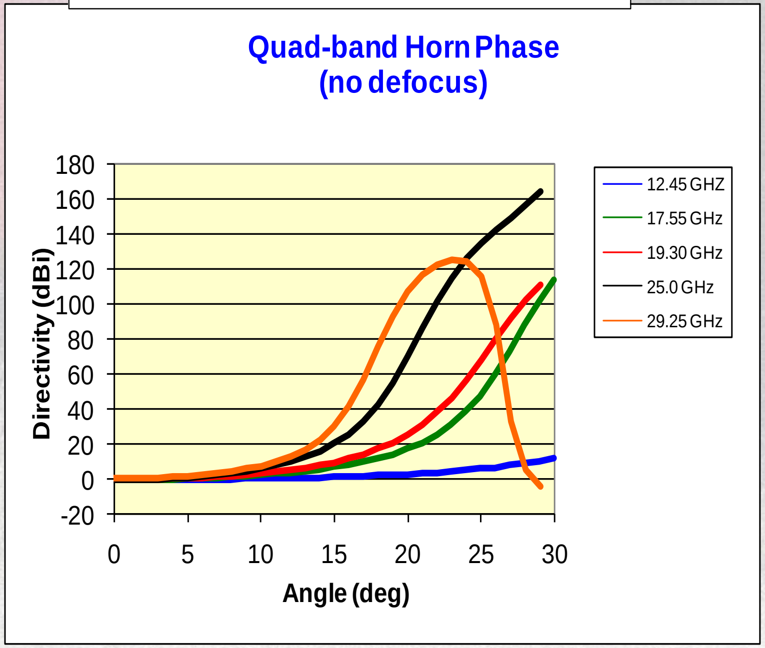
Key Performance Results

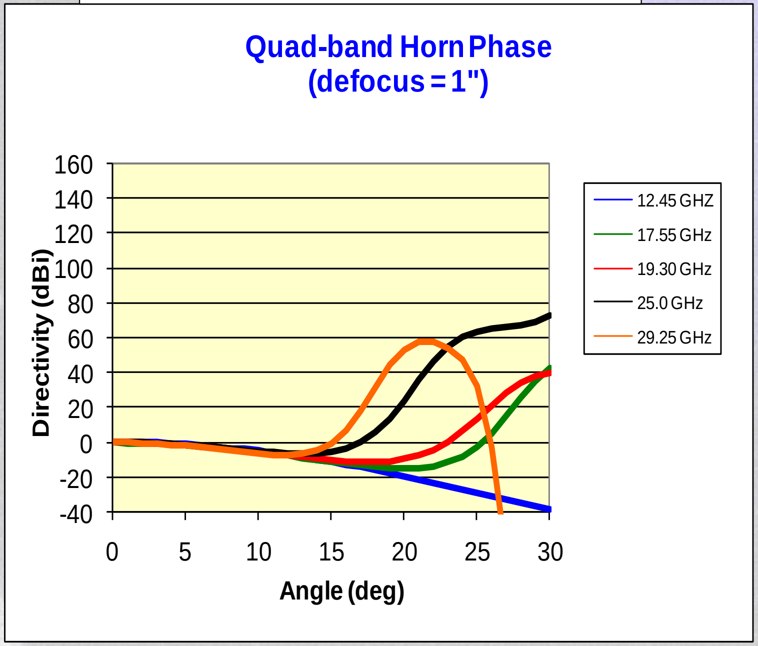
- Return Loss: > 26 dB
- Efficiency: 74% to 82%
- X-pol: < -22 dB

Feed Pattern (Defocus=0” & 1”)



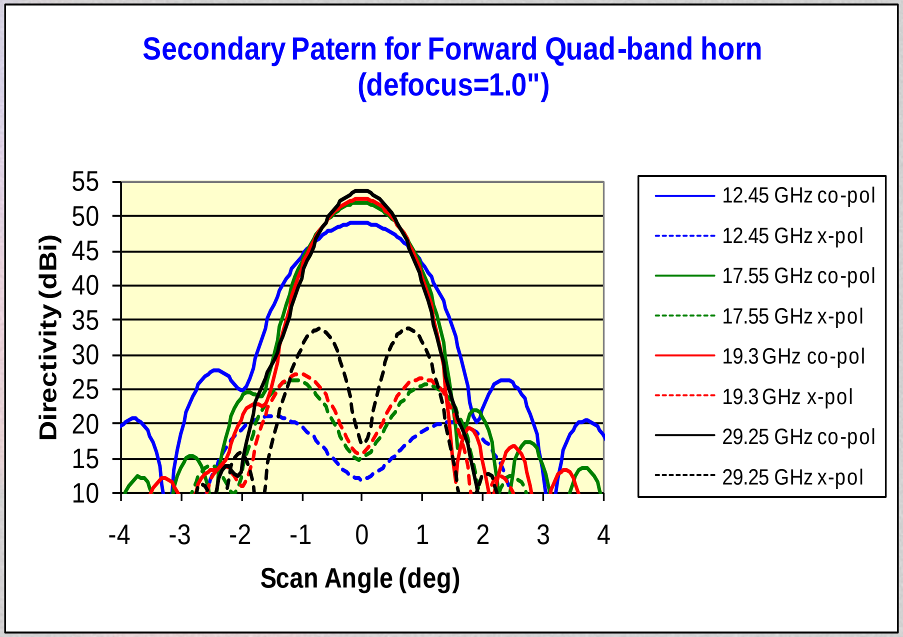


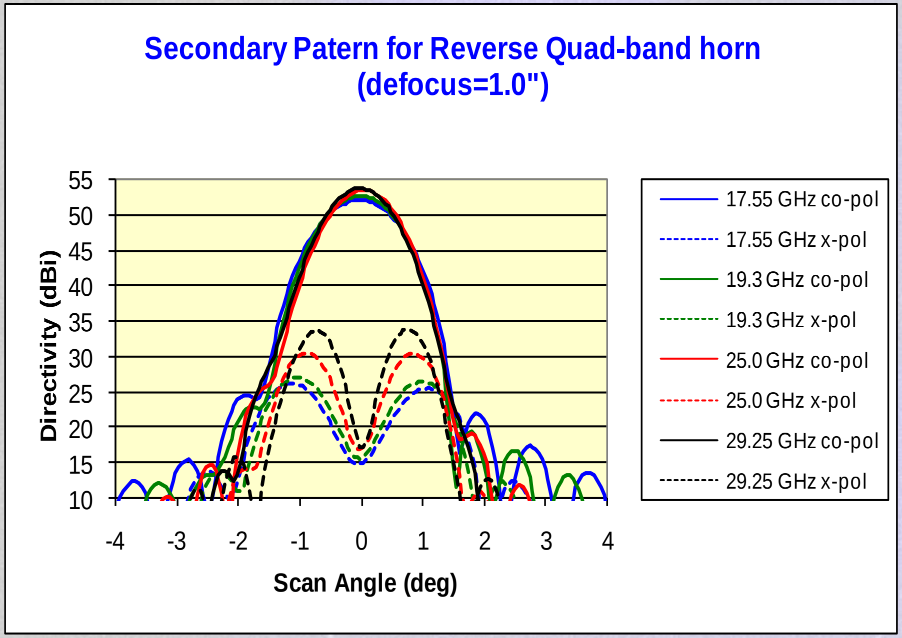




Feed defocus of 1.0” improved higher band performance

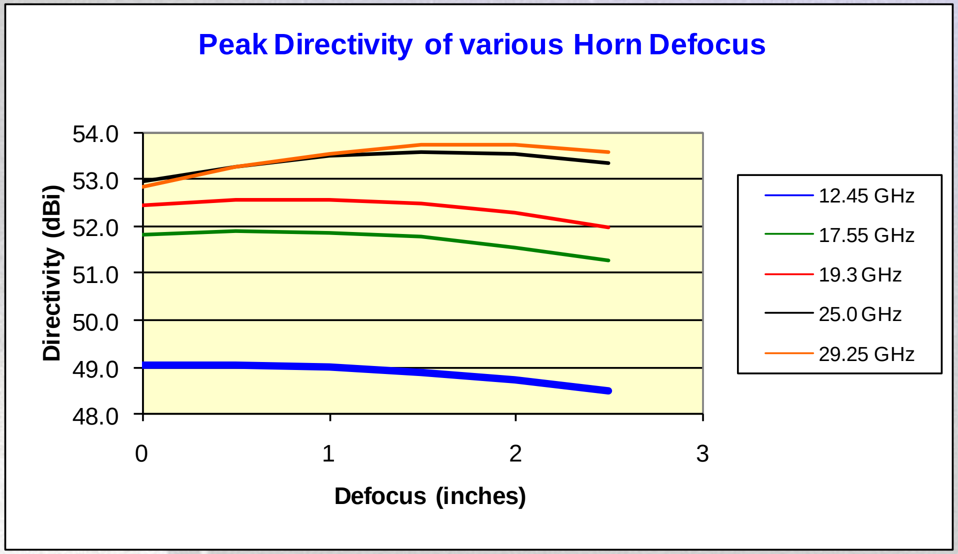
Secondary Pattern (Defocus=1.0”)



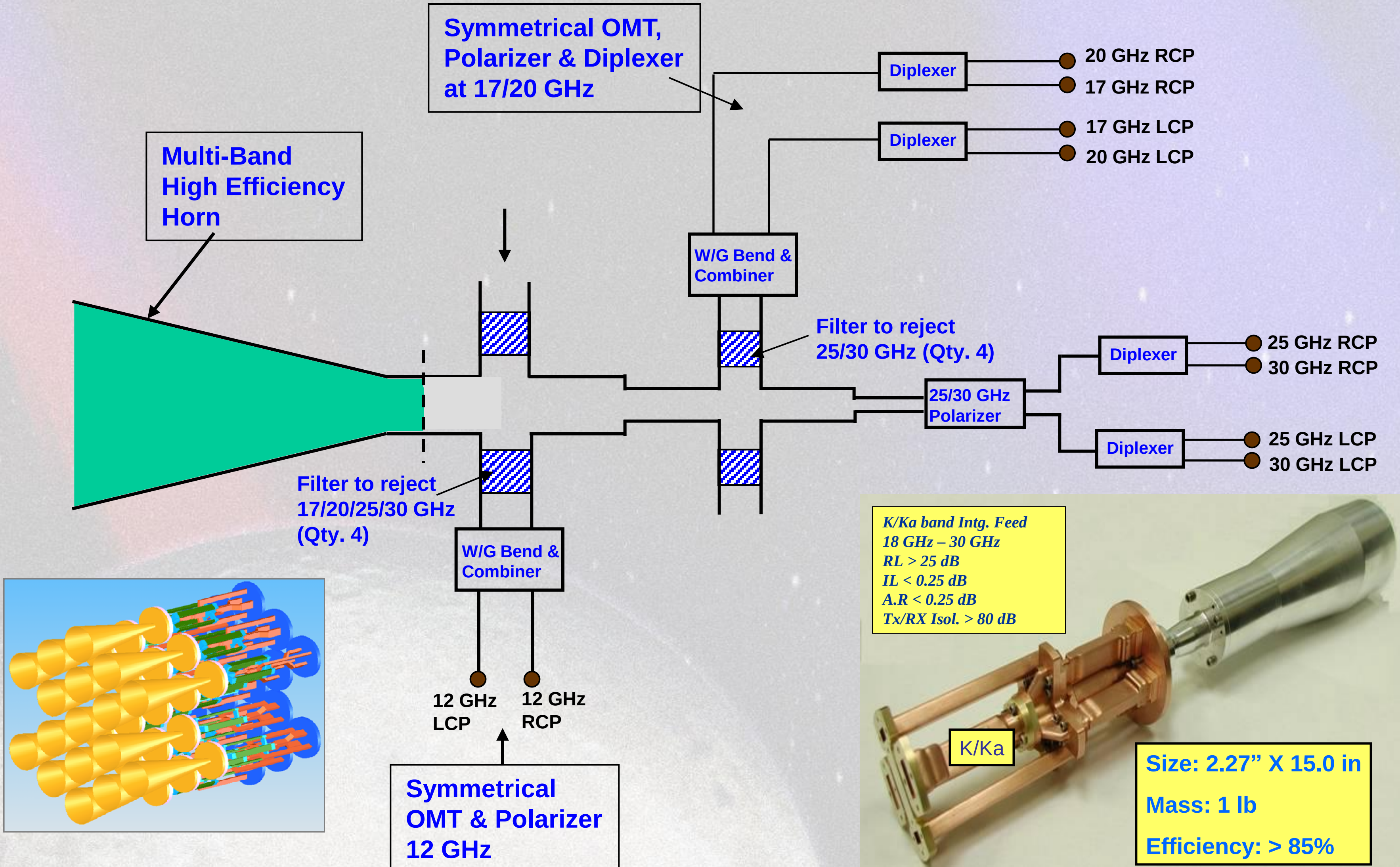


EOC Directivity

Freq	Coverage	Peak	Co-pol	C/X
12.45	±0.5º	49.0	47.4	32.8
17.55	±0.5º	51.9	49.5	28.7
19.30	±0.5º	52.6	49.8	27.4
25.00	±0.5º	53.5	50.1	23.3
29.25	±0.5º	53.6	50.0	18.4



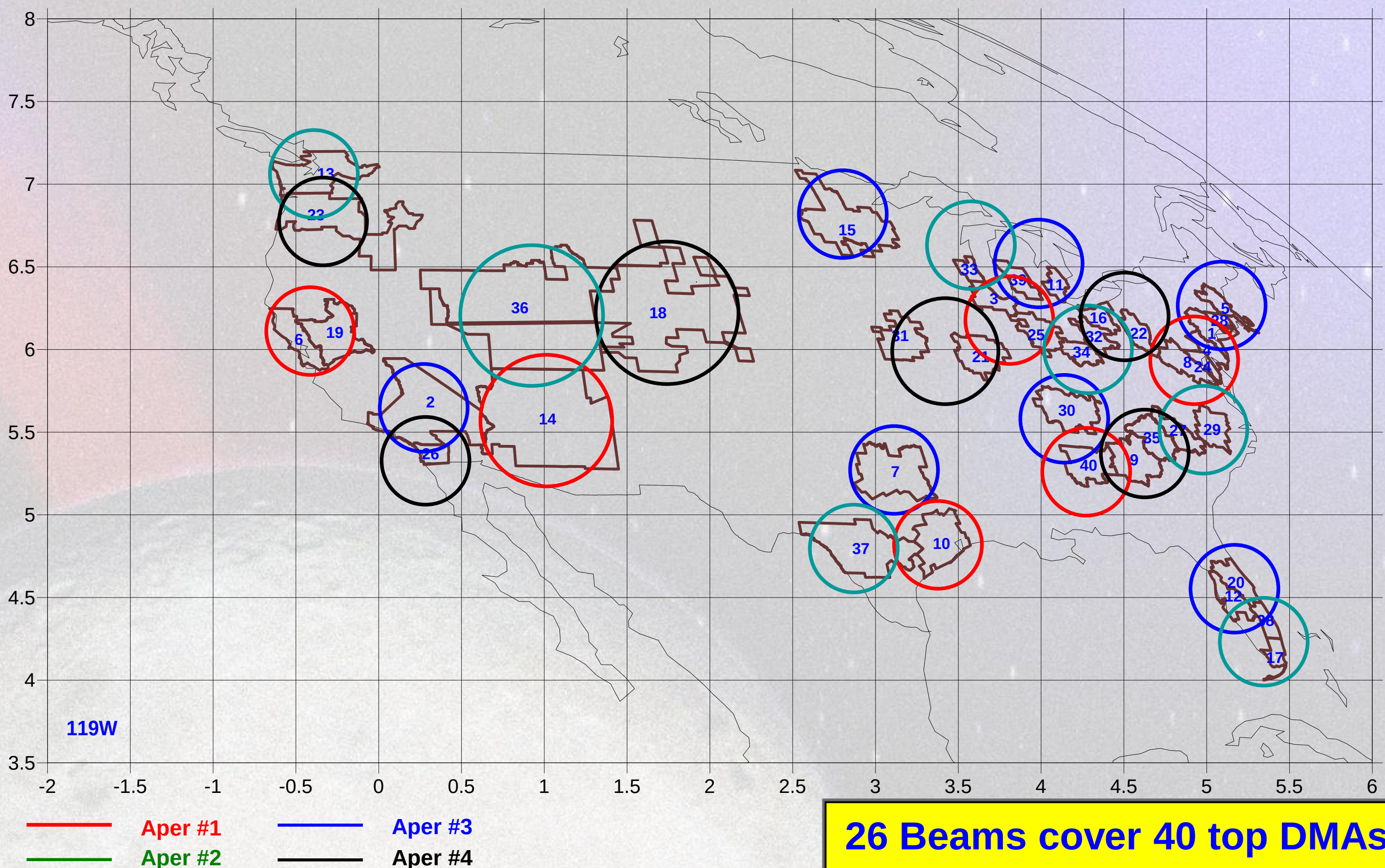
Multi-Band Feed Assembly Schematic



The feed network need to fit within the real-estate dictated by the horn aperture

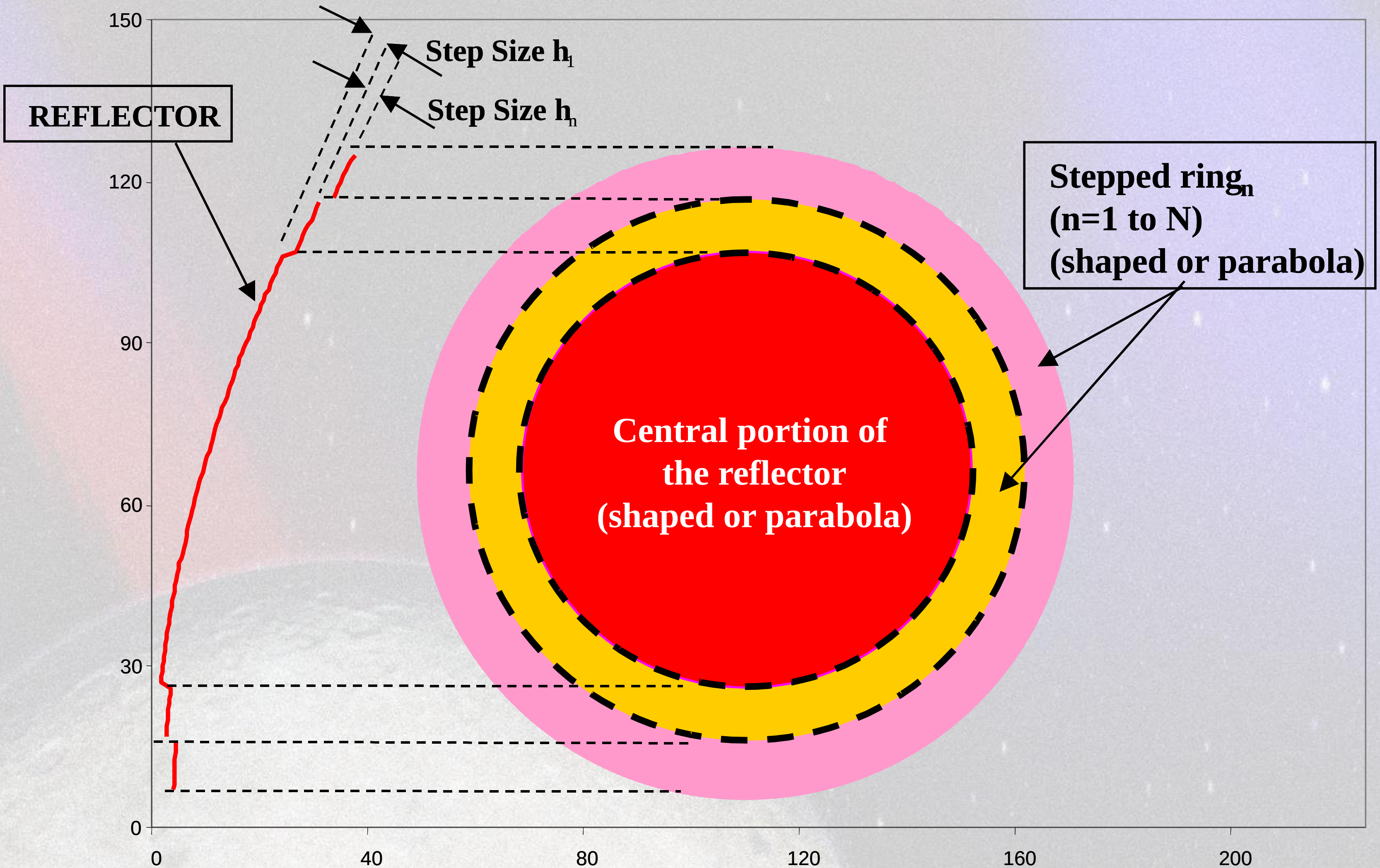
Typical Multiple Beam Layout over CONUS Coverage (119° W orbital location)

DMA Ranking (2006 Nielsen Ranking)



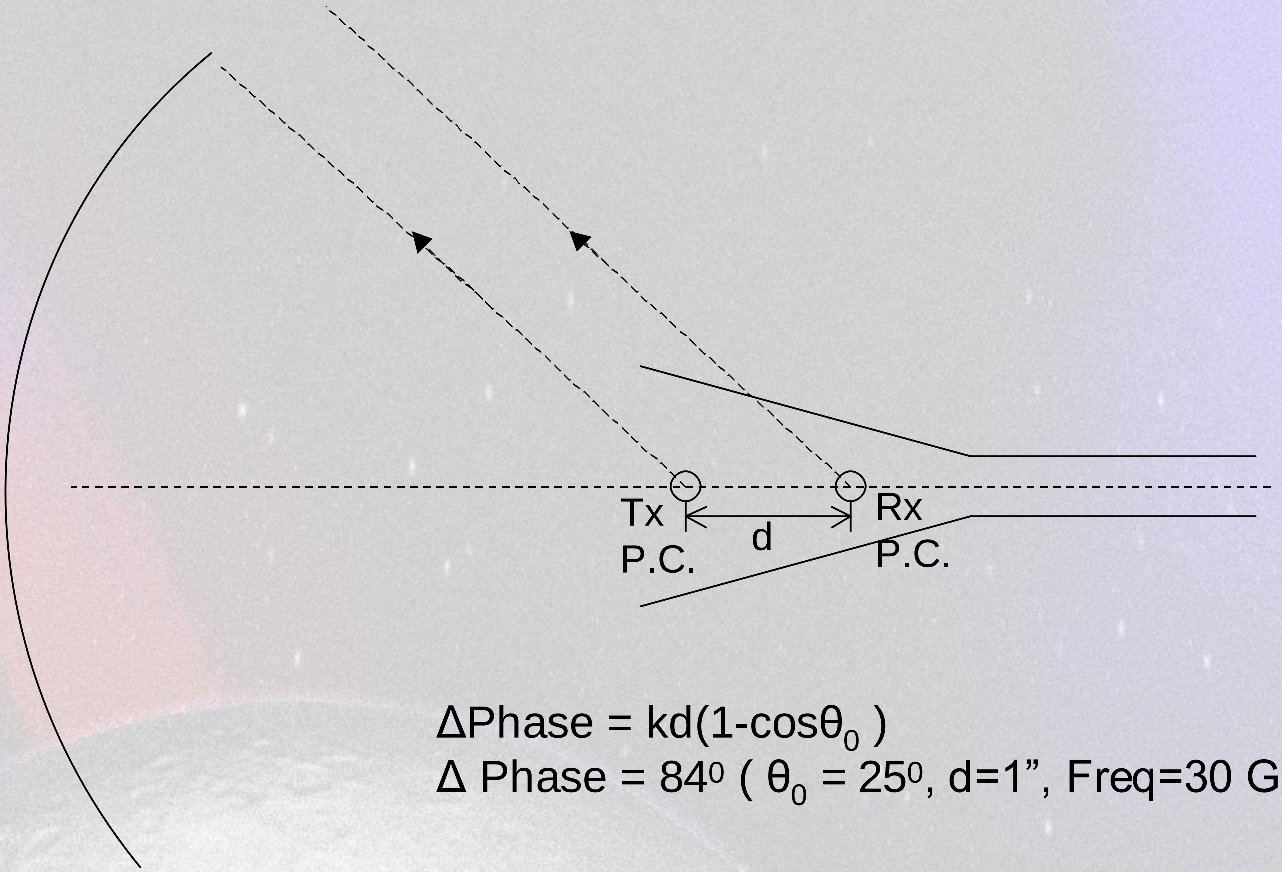
26 Beams cover 40 top DMAs (6 to 7 beams per aperture)

Stepped Reflector Antenna for Multi-Band Applications



Step Size h = m * [180 ± (feed phase(Θ_i)-feed phase(Θ_0))] * (π/180) * (λ/2π) * (1/2)

SRA with Frequency-Dependant Horn Design

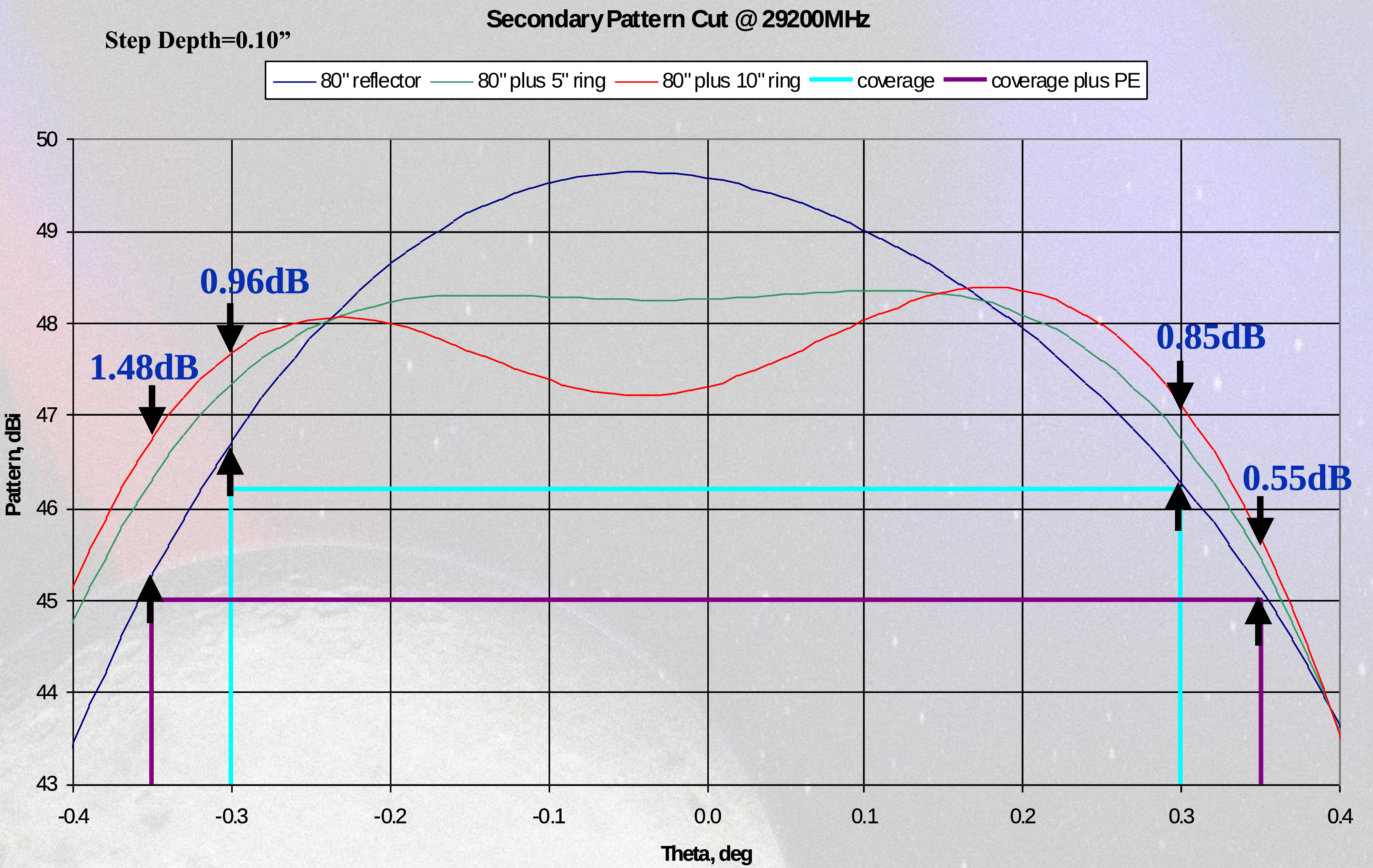


ΔPhase = kd(1-cosθ_0)

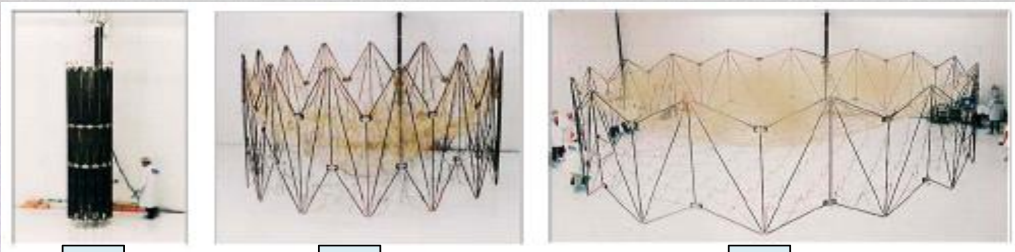
Δ Phase = 84^0 (θ_0 = 25^0, d=1", Freq=30 GHz)

- **DBHEH Design can exploit phase center variation between bands to minimize SRA step height**
- **Phase patterns of horns for dual-band & multi-band horns are critical to optimize antenna performance**

Impact of SRA on Receive Beam Patterns

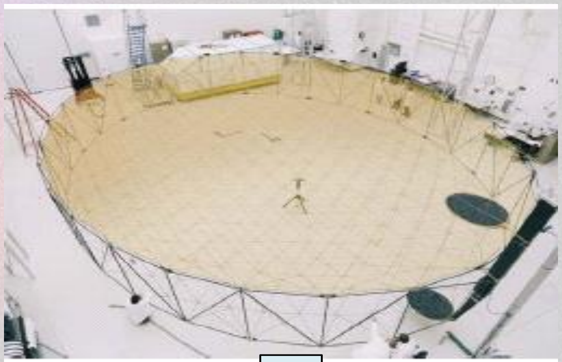


Large Deployable Reflectors for MSS



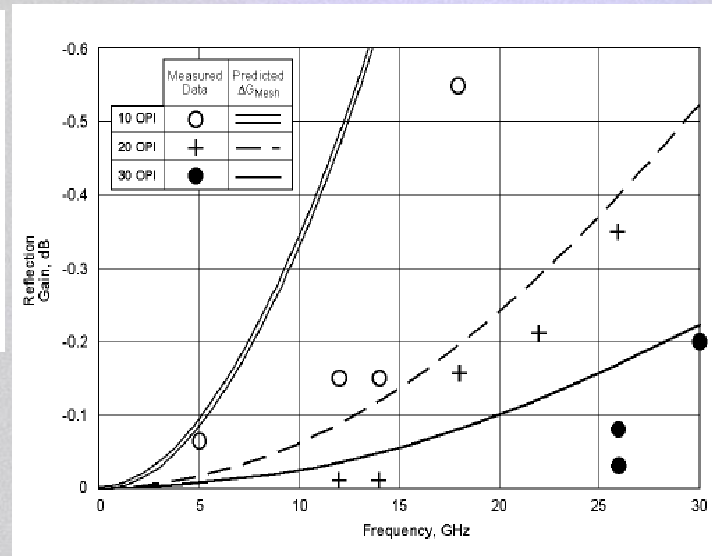
(a) (b) (c)

AstroMesh
12 meter Antenna
(Perimeter Truss)



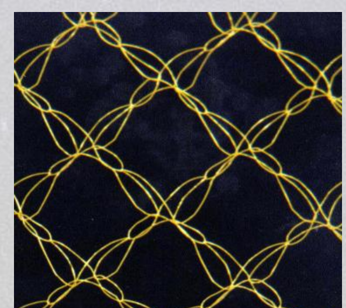
(d)

(e) (f)



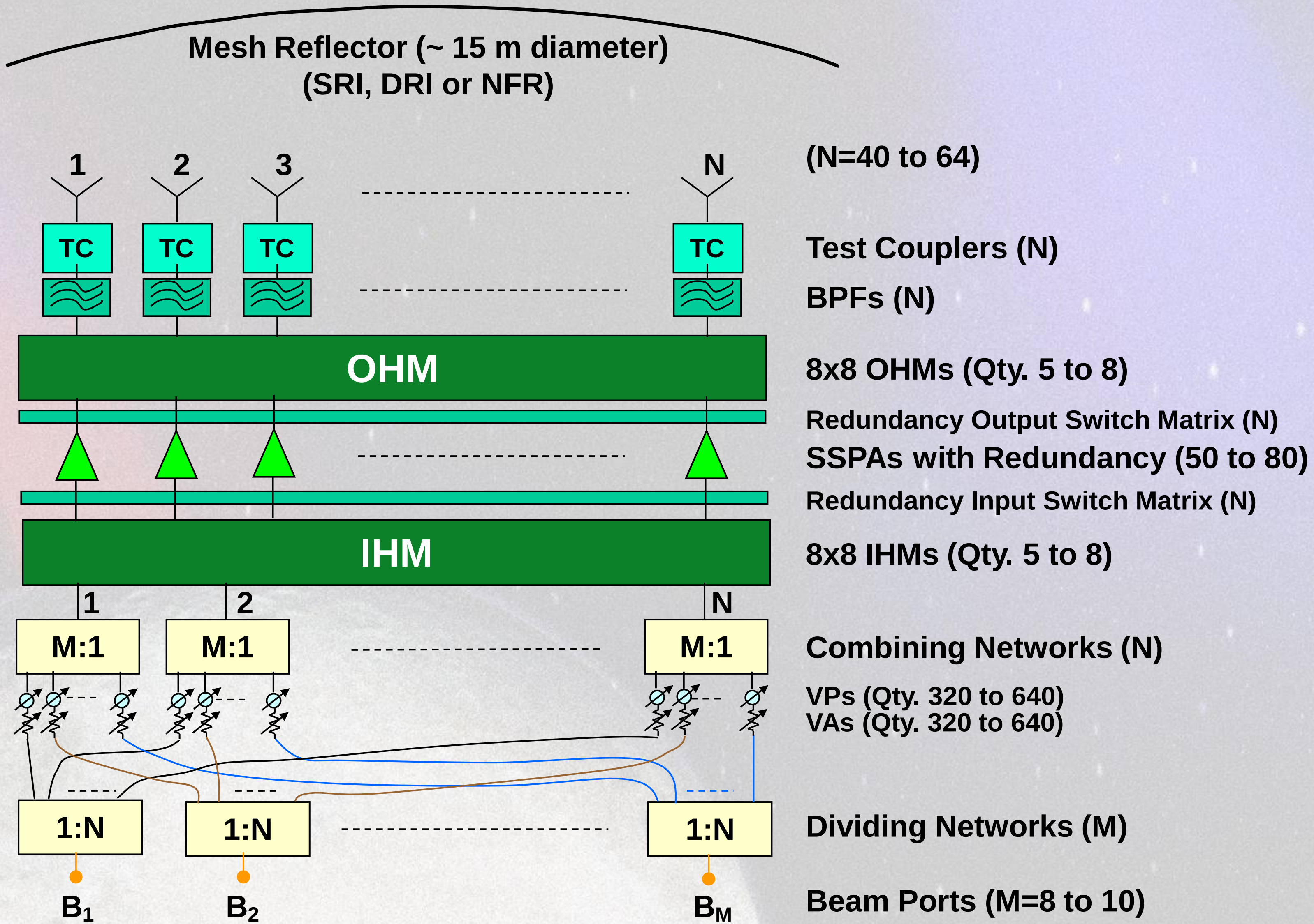
Mesh Reflectivity Loss [13]

Harris 22 meter Antenna (Hoop Truss)



Knitted gold -moli mesh closeup [8]

Reconfigurable Antenna Block Diagram

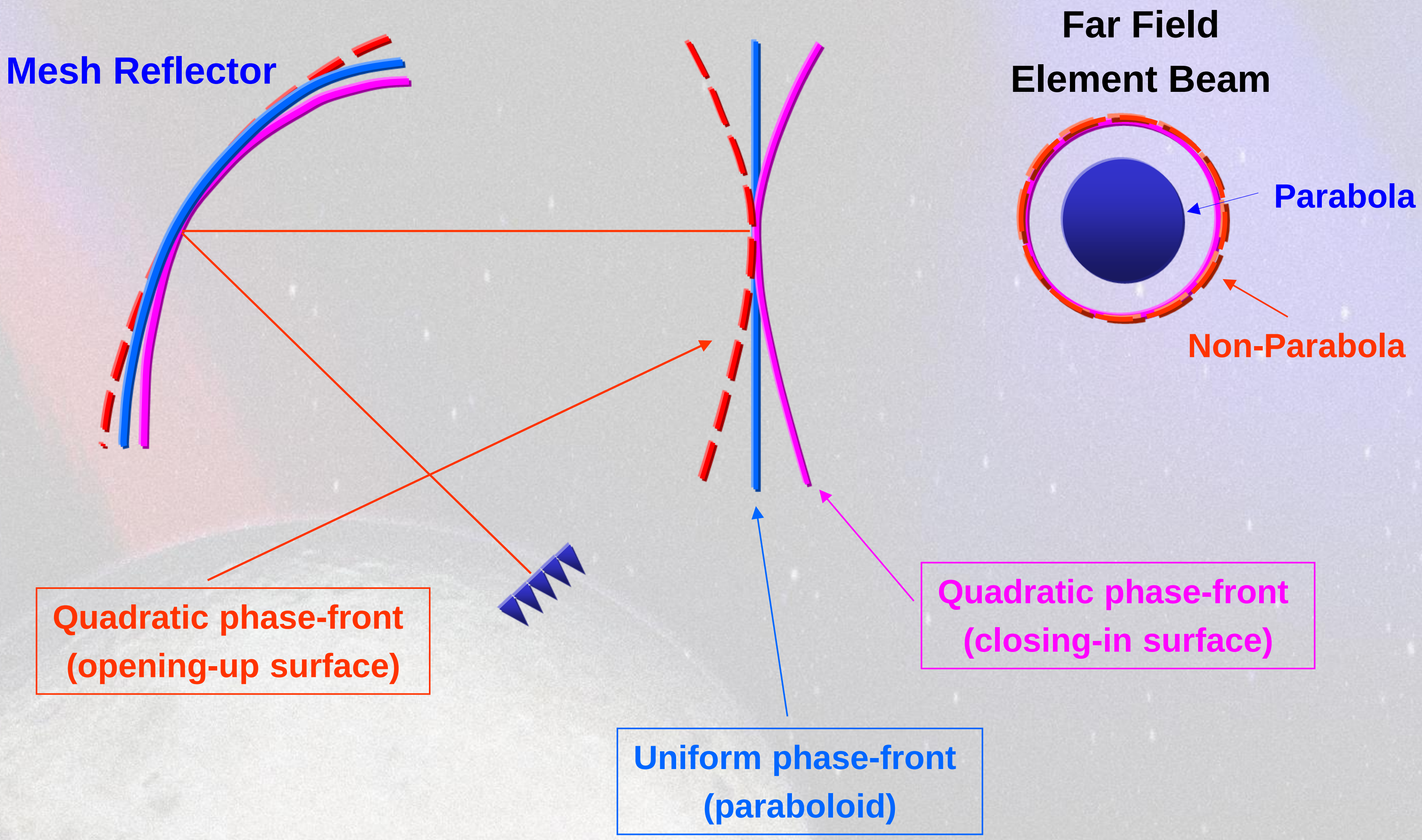


Non-Focused Reflector (NFR) Concept

- **Non-Focused Reflector (NFR) with symmetrical shaping**
- **By opening-up or closing-in the paraboloid gradually, a quadratic phase-front is created in the aperture plane (instead of uniform phase-front)**
- **The quadratic phase-front broadens the element beams significantly (1.5 to 3 times)**
- **Main advantage is fewer number of feed elements (by a factor of 3 or more)**
- **Scan performance improves (a) due to symmetrical shaping, and (b) due to feed array & reflector geometrical relation is more optimal**
- **Element beams are combined in the far-field with non-uniform amplitude and non-uniform phase excitations to synthesize the antenna beam contour**
- **MPA allows uniform loading of the amplifiers**

S. Rao et al., “Reconfigurable Payload Using Non-Focused Reflector Antenna for HEO and LEO Satellites”, U.S. Patent # 7710340, May 04, 2010

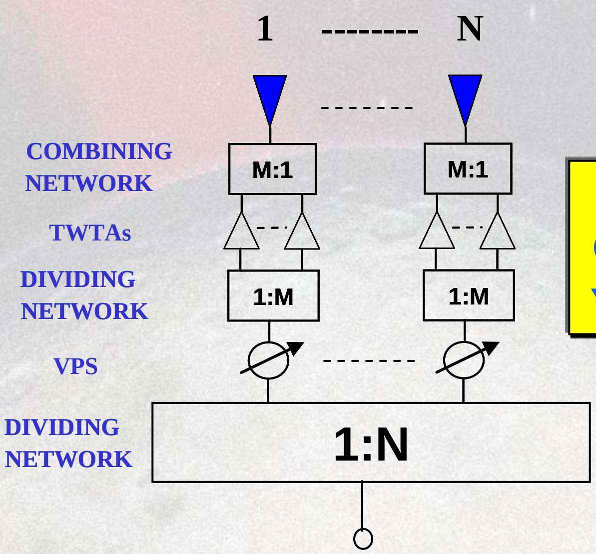
NFR Concept



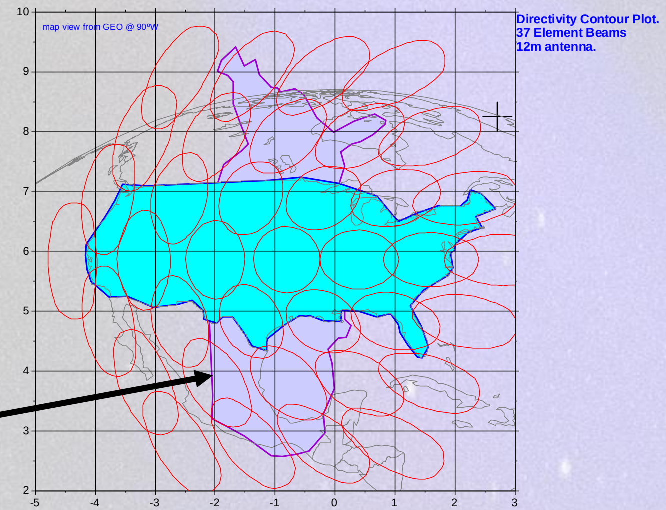
Mesh Reflector
Far Field
Element Beam
Parabola
Non-Parabola
Quadratic phase-front
(opening-up surface)
Quadratic phase-front
(closing-in surface)
Uniform phase-front
(paraboloid)

NFR For Flexible CONUS Coverage (DABS)

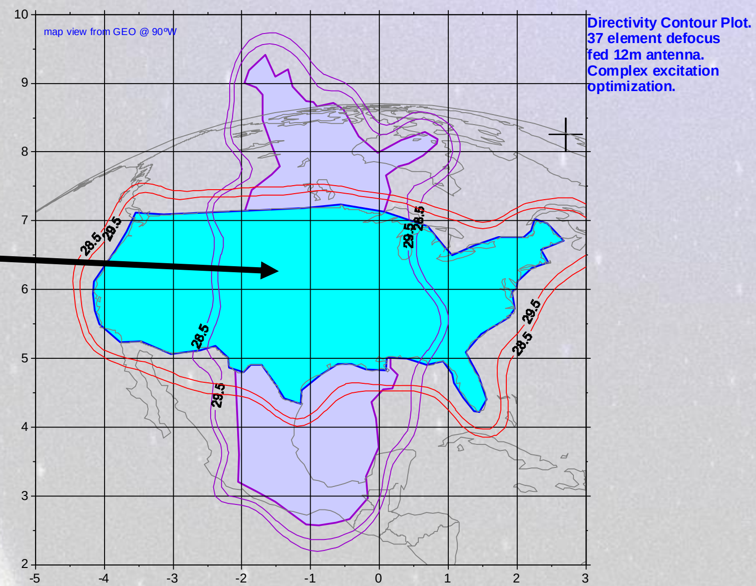
12m Mesh Non-Focused Reflector
(non-parabolic)



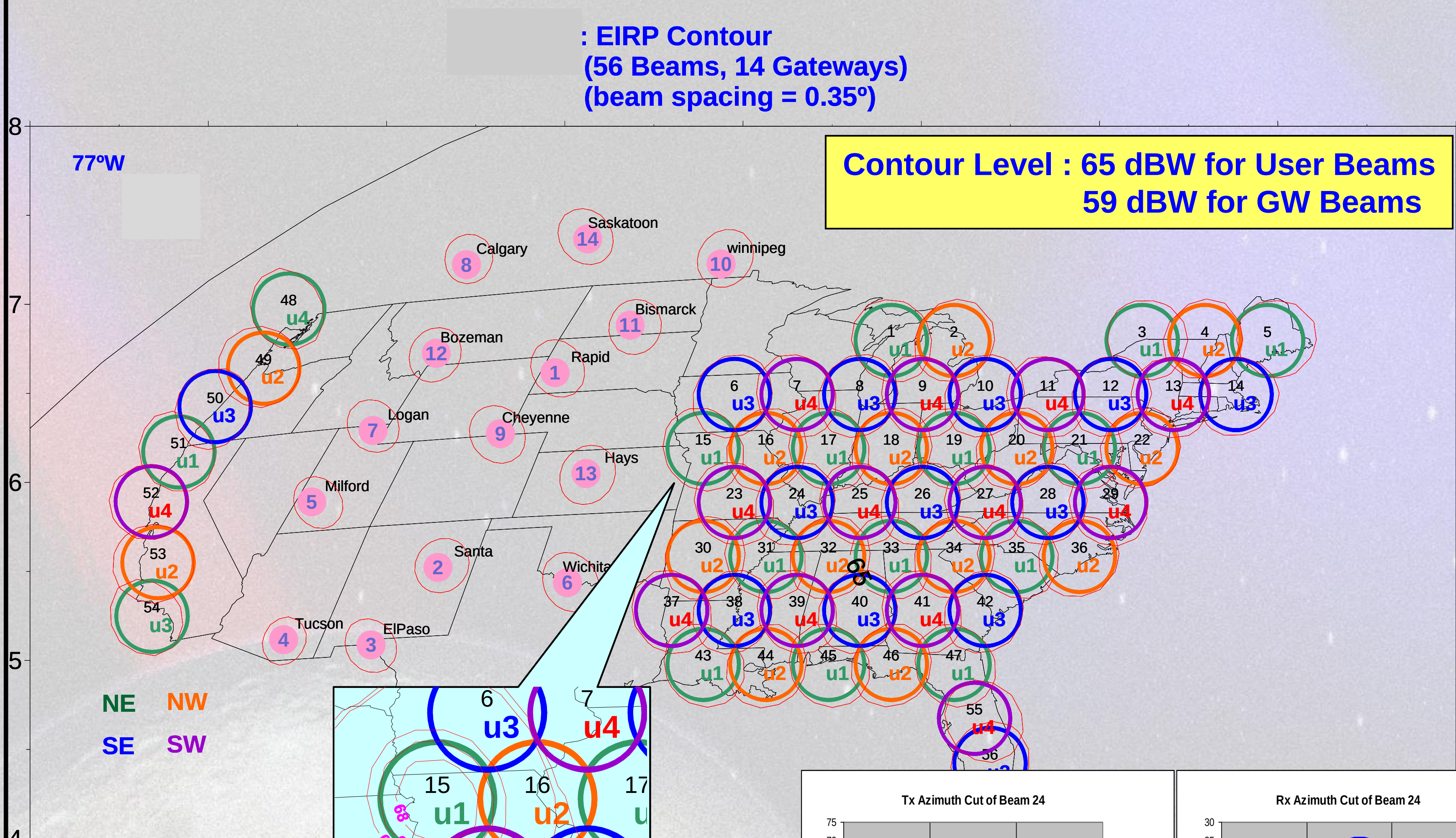
Element Beams

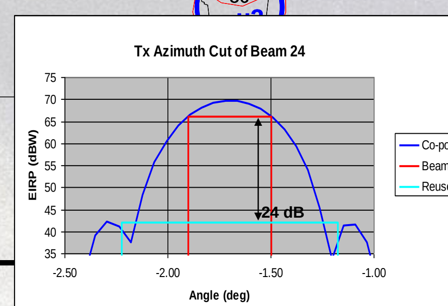


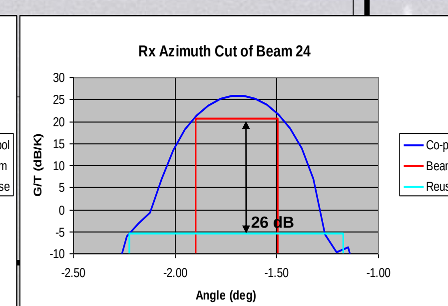
Synthesized CONUS Beam for Yaw = 0 & 90 deg.



MBA for High Capacity Satellites



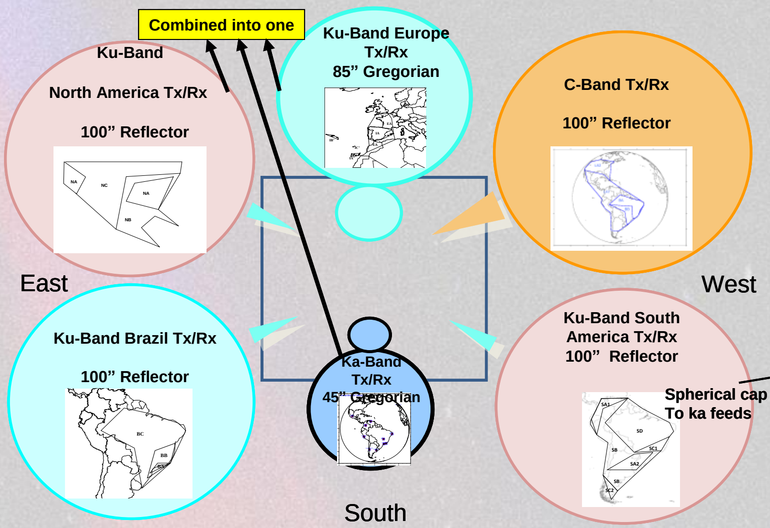


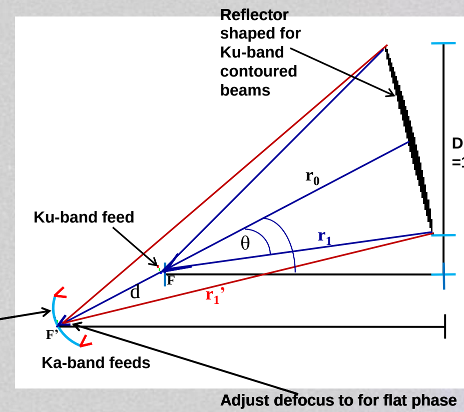


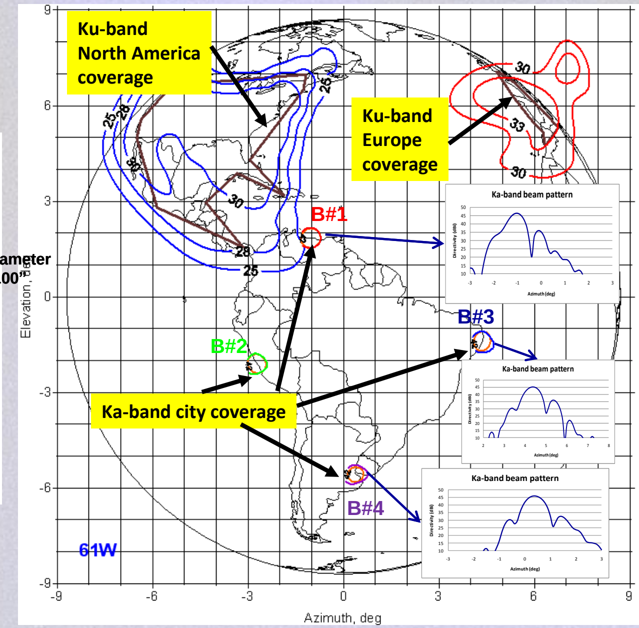
EIRP > 65 dBW
C/I > 24 dB (single interferer)

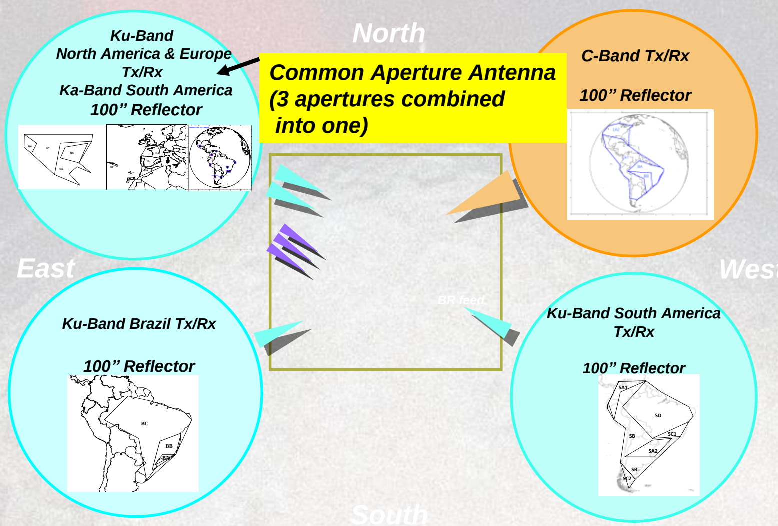
G/T > 20 dB/K
C/I > 26 dB (single interferer)

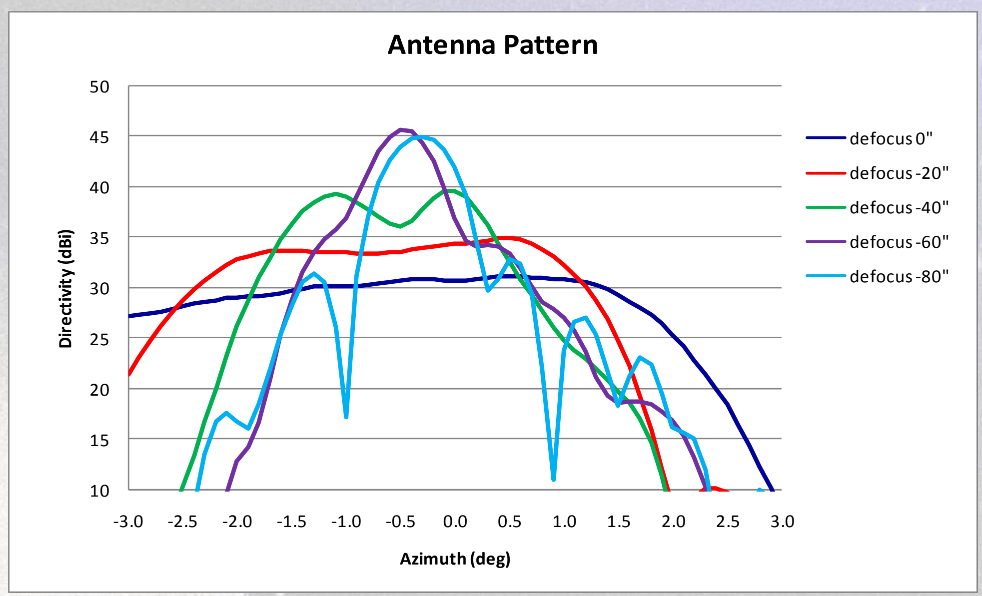
Common Aperture Antenna for Shaped and Spot Beams



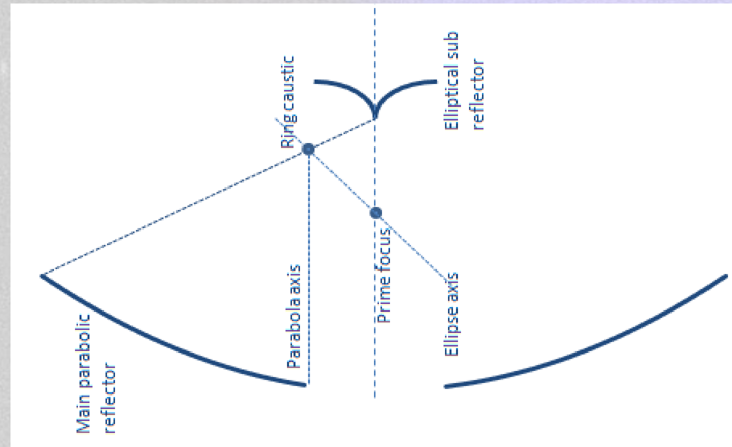


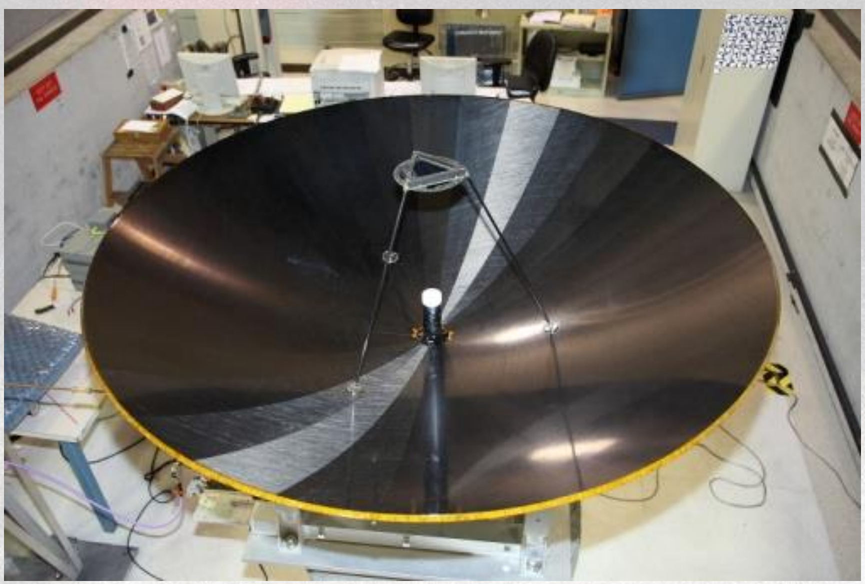


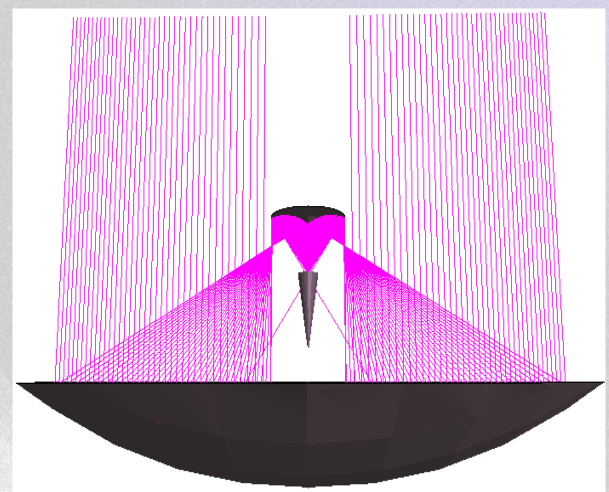




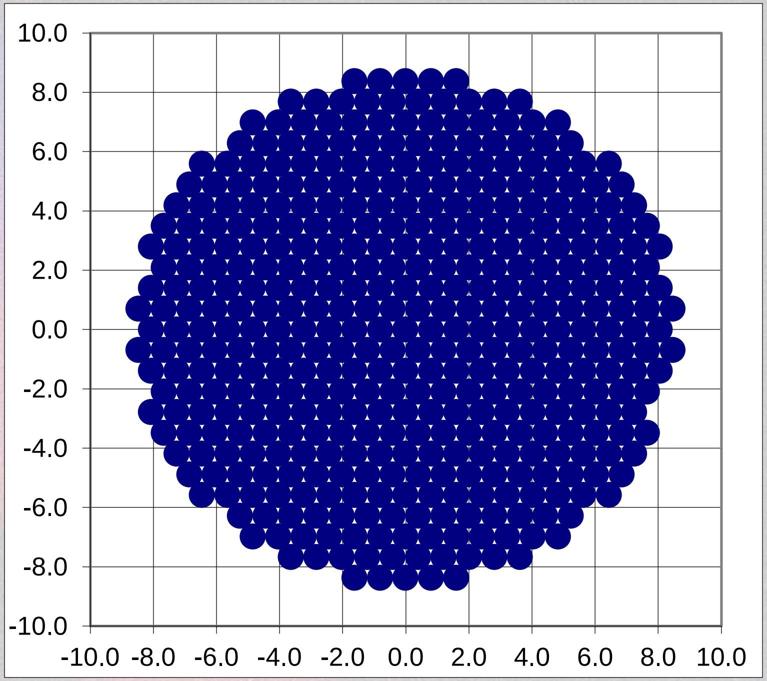
Advanced Reflectors: X-Link & Gateway Applications

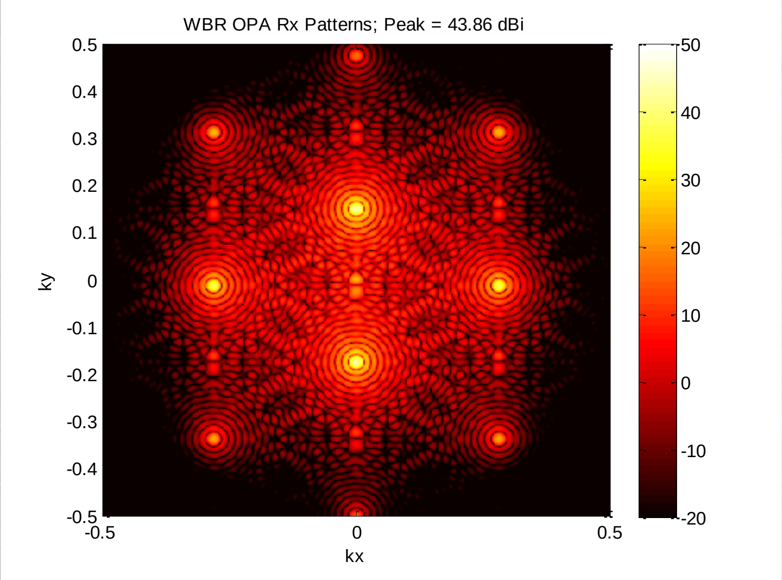


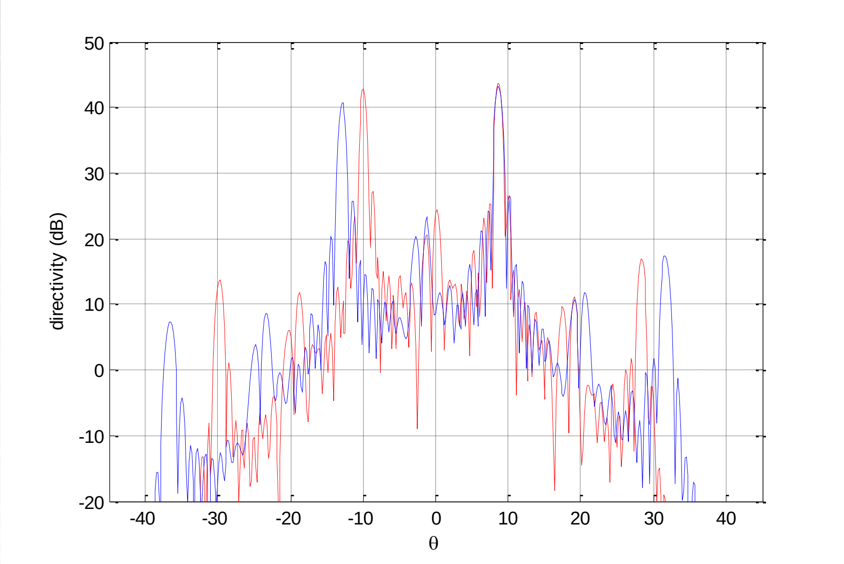




Phased Arrays with Flexible Beams







Array Design

- Number of Elements: $N = 10^{0.1(D_A - D_e)}$
- D_e is the element gain at bore-sight
- Array Directivity:

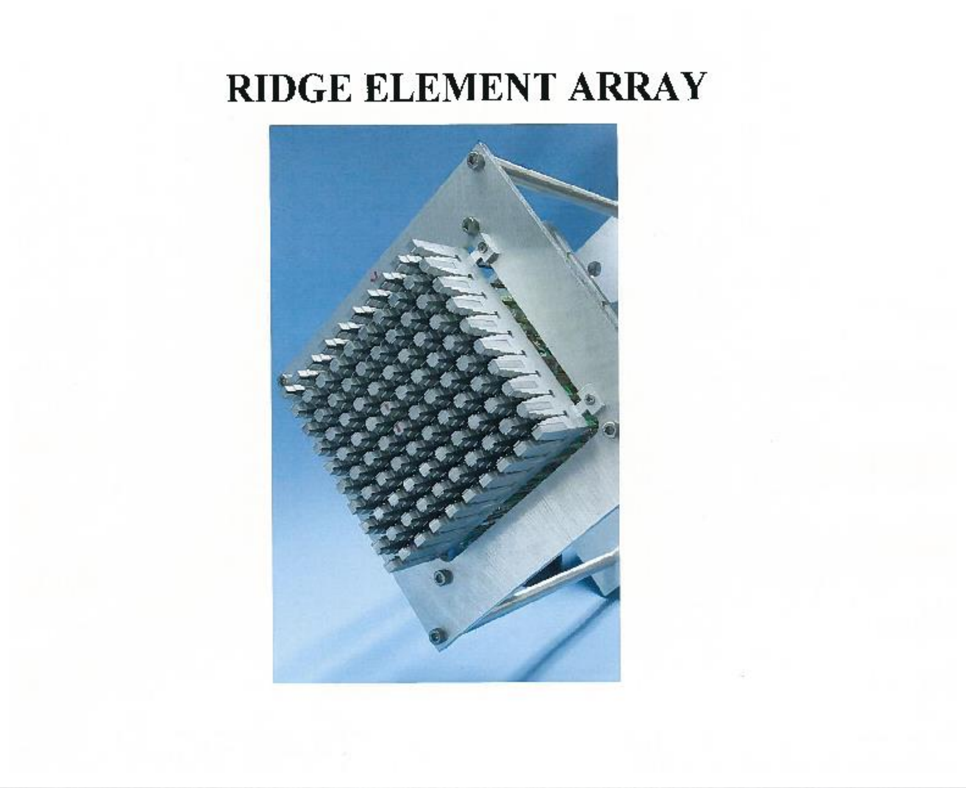
$$D_A = G_p + L_S + SL + T_L + I_m$$

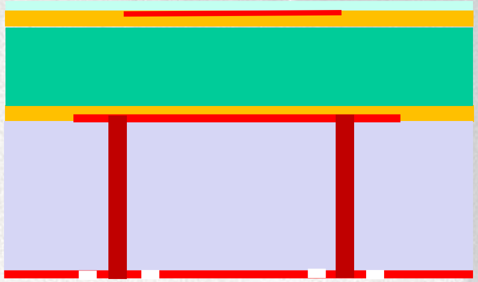
- Peak Gain (over cov.)
- Insertion Loss
- ScanLoss (elem.Patt roll-off)
- Taper Loss (about 90%)
- Impl. Margin

Scan Angle (degrees)	Element Spacing in λ at Highest Freq. *		Number of Elements for 1000 λ**2 at Highest Freq	
	Square Lattice	Hexagonal Lattice	Square Lattice	Hexagonal Lattice
80	0.50	0.58	4000	3464
70	**0.52**	**0.60**	**3698**	**3208**
60	**0.55**	**0.64**	**3306**	**2863**
50	**0.61**	**0.70**	**2687**	**2327**
40	0.71	0.82	1984	1718
30	0.88	1.02	1291	1118
20	1.19	1.37	706	611

*** Assumes closest grating lobe location as 10 deg. larger than the maximum scan angle**

Wideband Arrays (> 3:1 BWR)

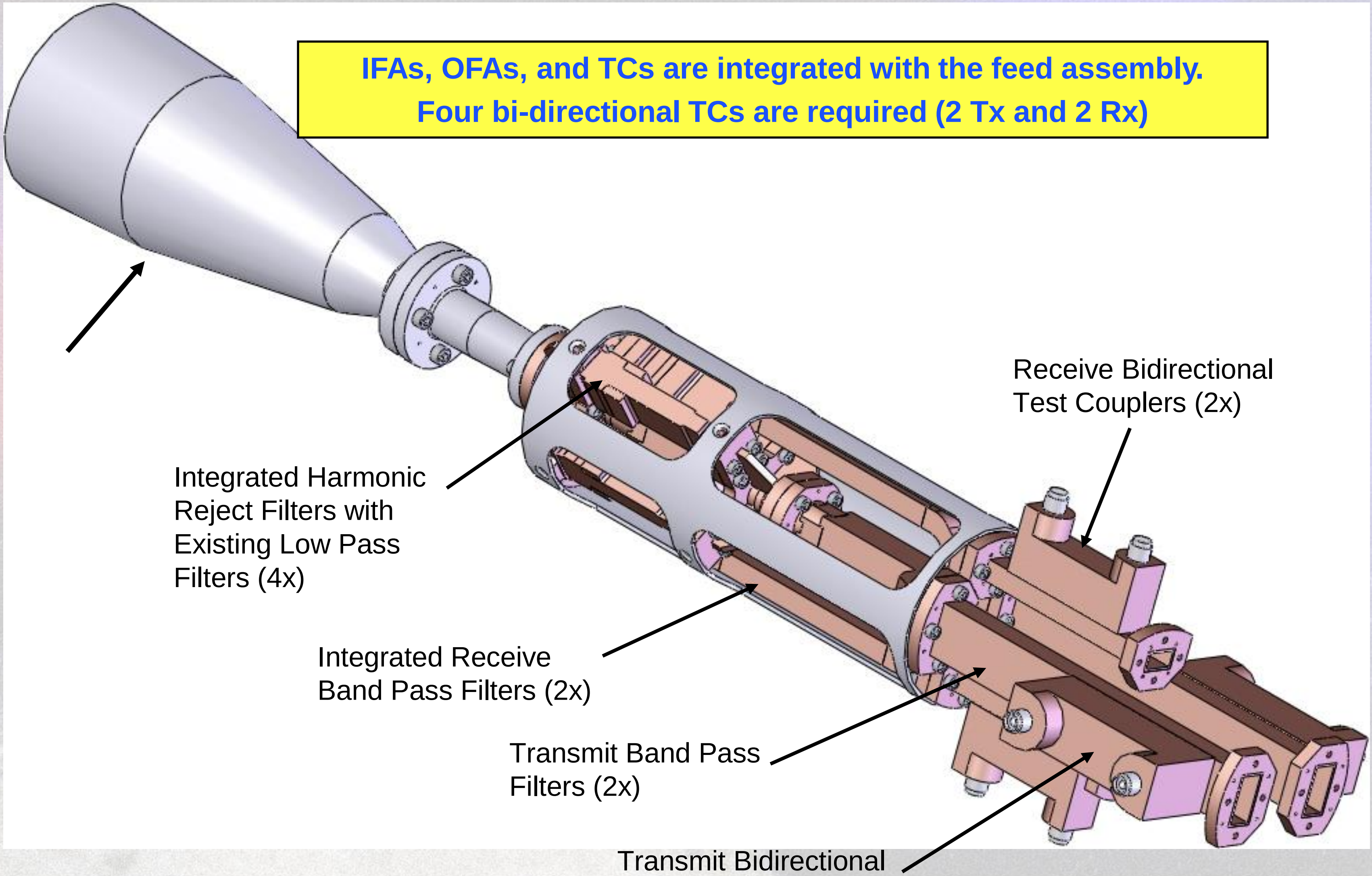




Stacked-Patch Array

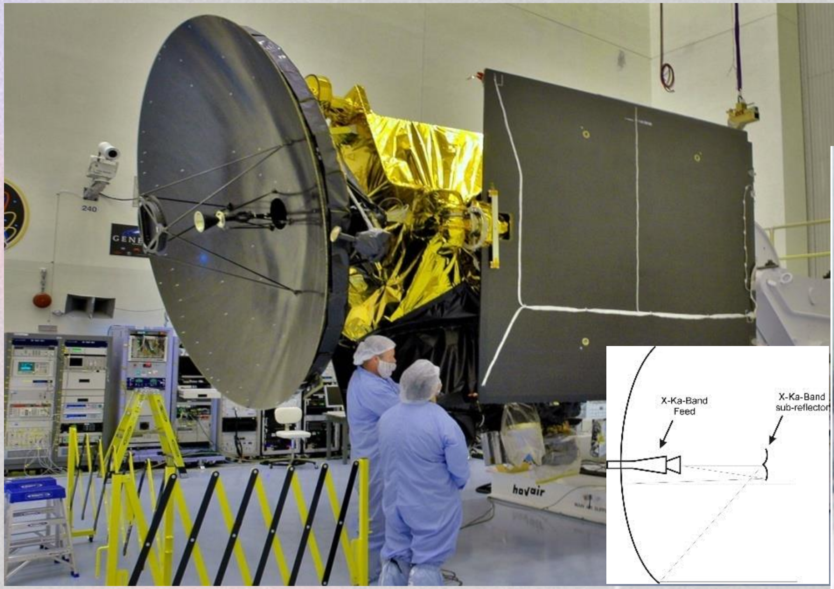
Dual-Band Feed Assembly Integrated with IFAs & OFAs, & TCs

IFAs, OFAs, and TCs are integrated with the feed assembly.
Four bi-directional TCs are required (2 Tx and 2 Rx)

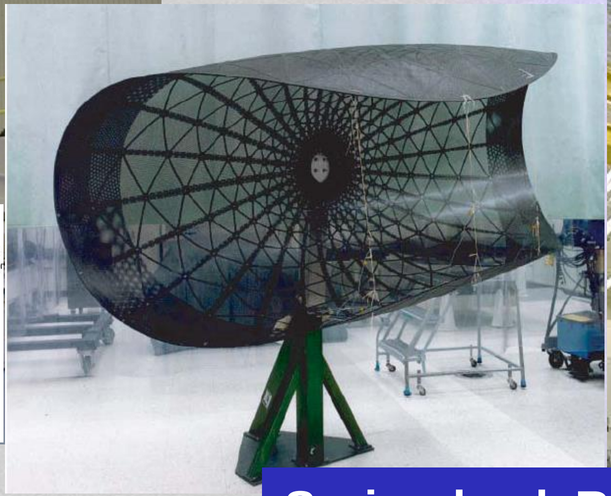


High-level integration of the feeds provides about 21 Kgs mass savings, $ 6 million cost saving, and 0.40 dB improved RF performance

Antennas for Scientific Missions (cont'd)

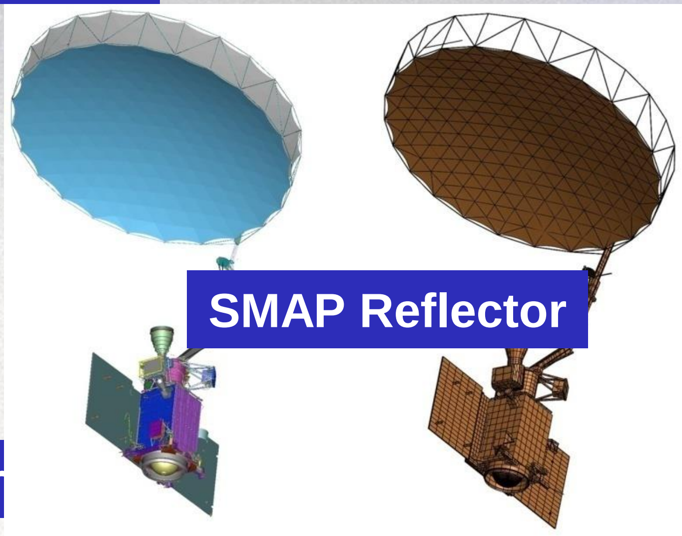


MRO's antenna after integration.



Spring-back Reflector

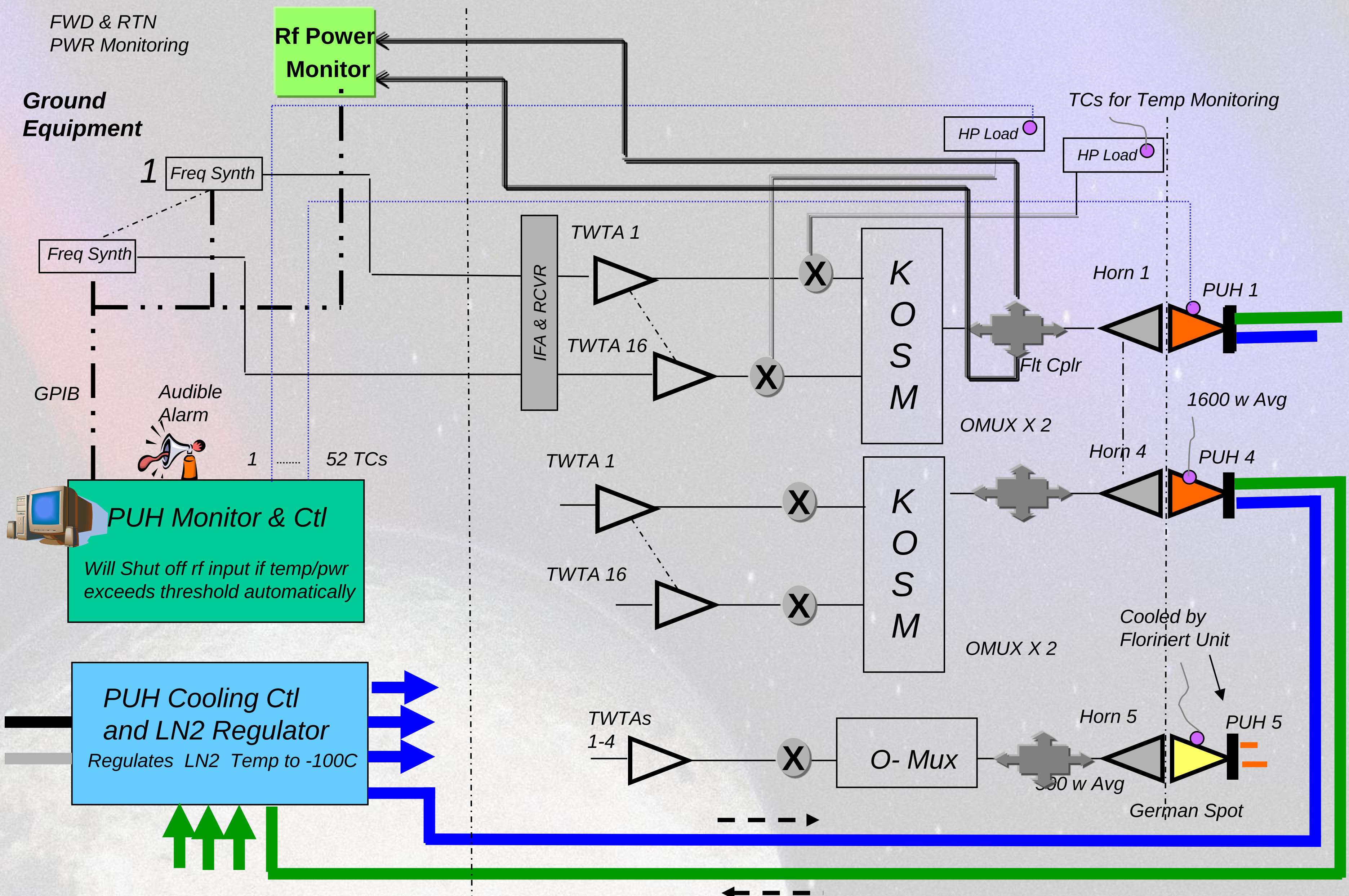
Galileo Reflector



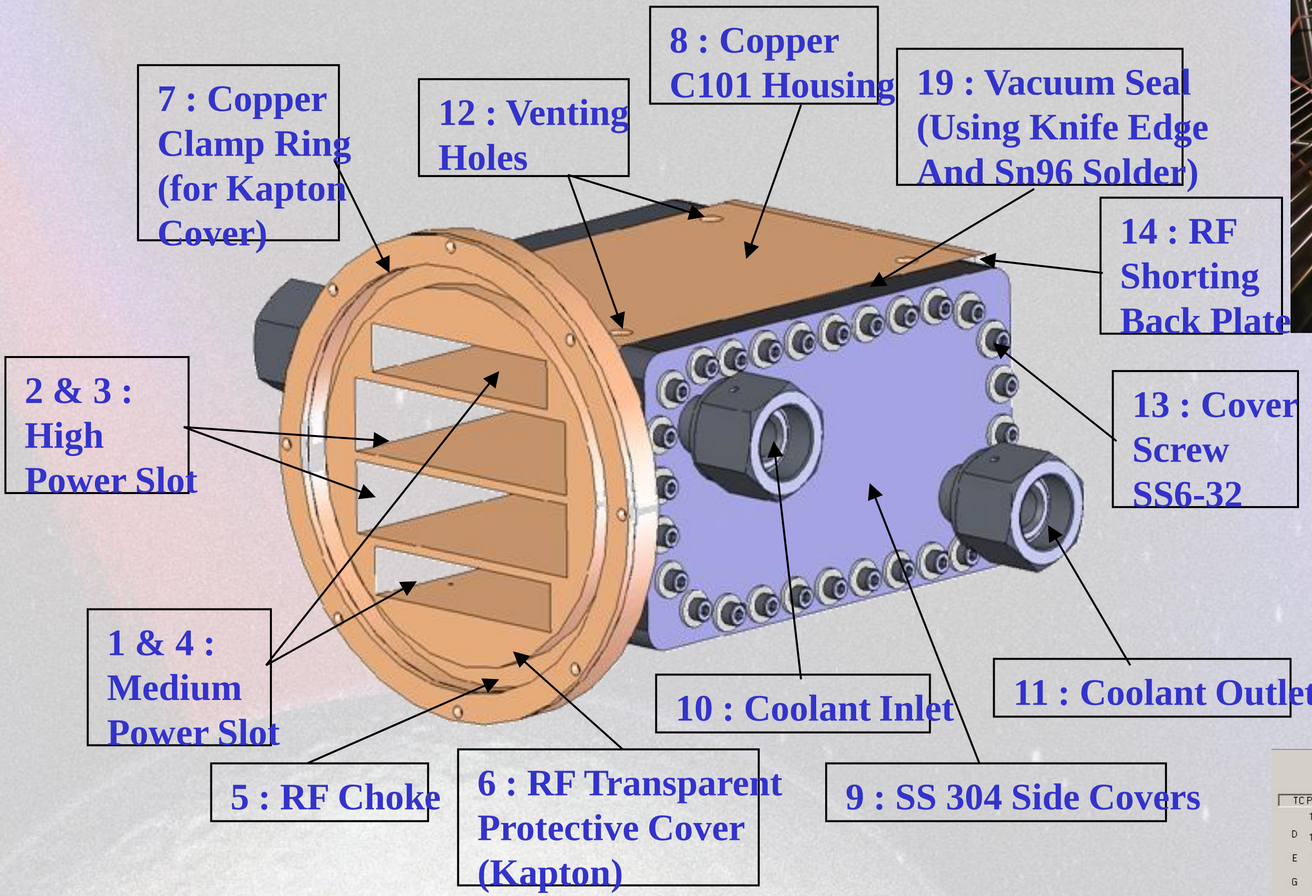
SMAP Reflector

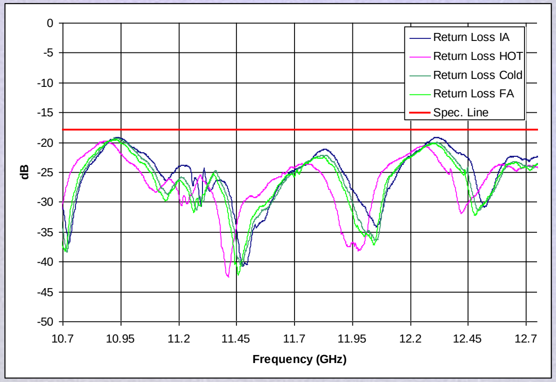
Voyager Mission

High Power TVAC Test Method Using Pick-Up Horn (PUH) Loads



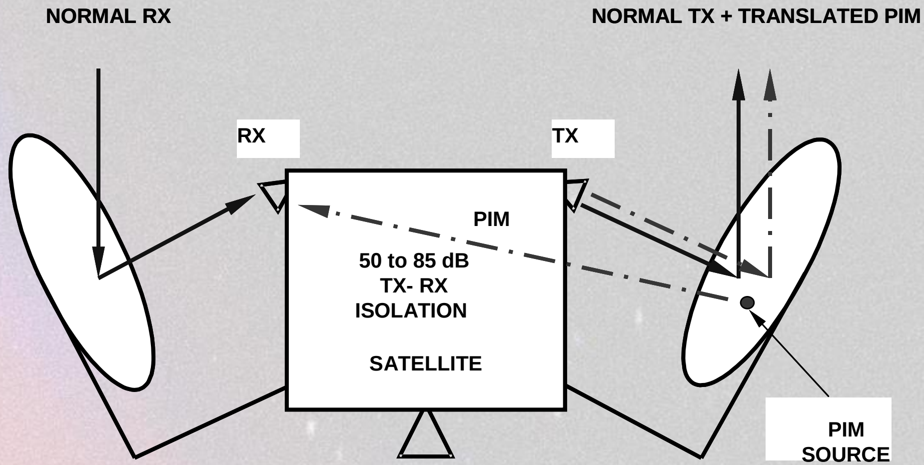
PUH Load

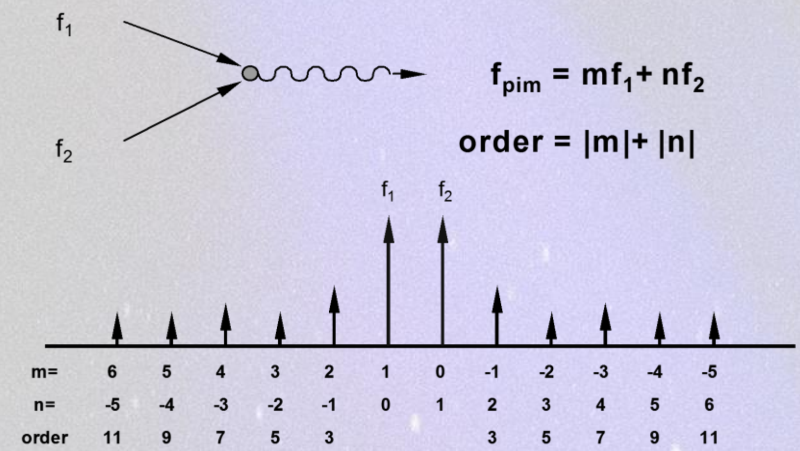


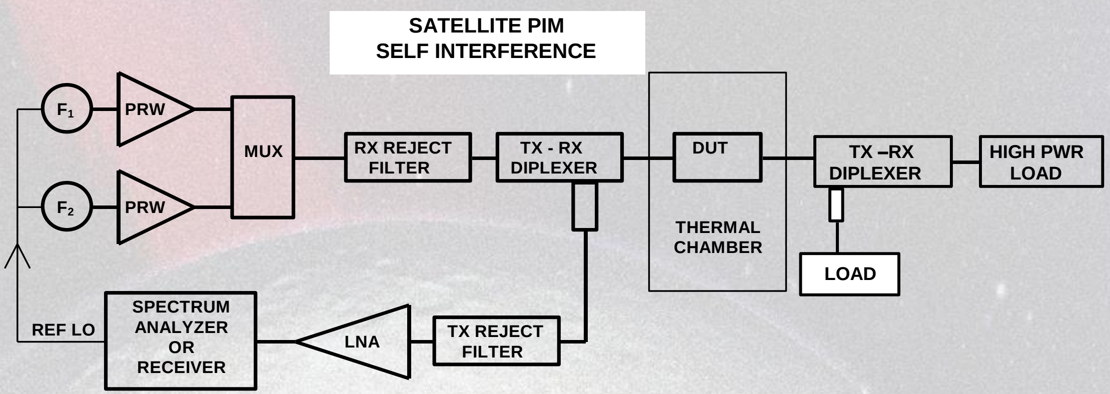


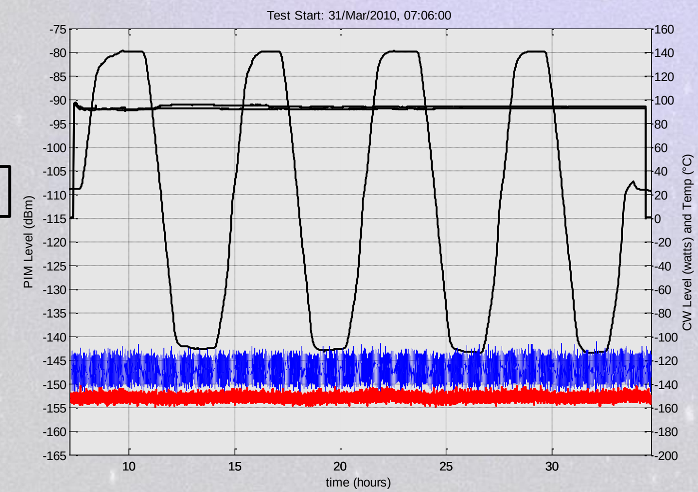
S. Rao et al., “A novel method for high-power thermal vacuum testing of satellite payloads using pick-up horns”, IEEE Antennas & Propagation Magazine, Vol. 49, #3, pp. 134-145, June 2007
S. Rao et al., U.S. Patent #s 7598919 & 7692593, 2010

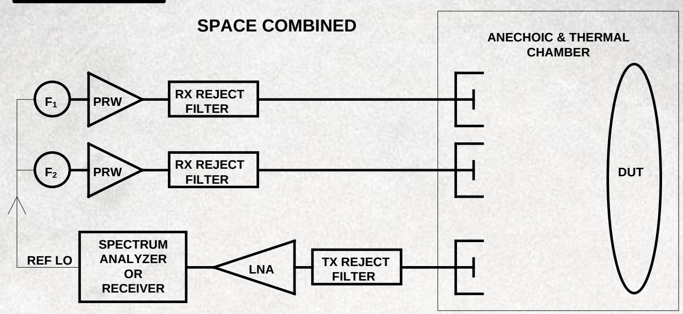
Passive Inter-modulation (PIM)

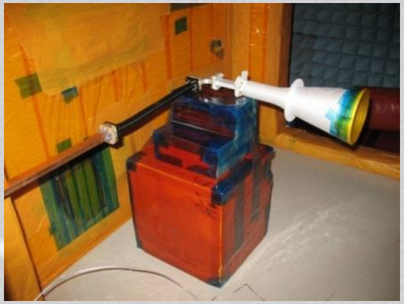




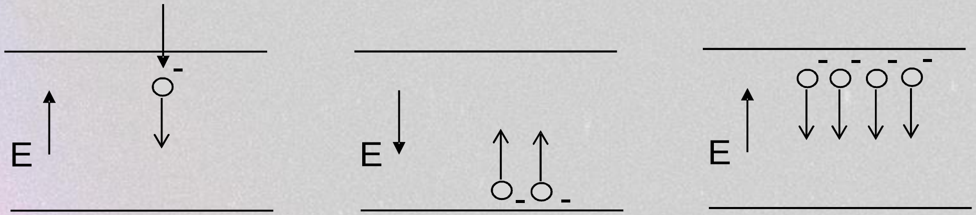








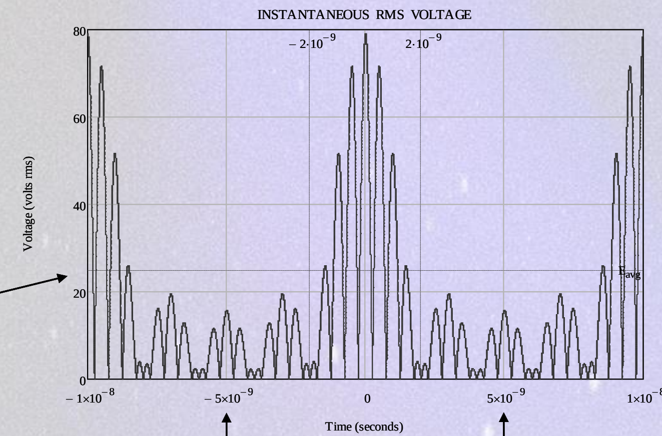
Multipaction



A stray electron from the environment enters and is accelerated by the RF electric field

Striking the opposite surface at high velocity produces 2 secondary electrons accelerating in the opposite direction $\delta=2$

Electrons striking the opposite surface at high velocity form a *sheet* of secondary electrons

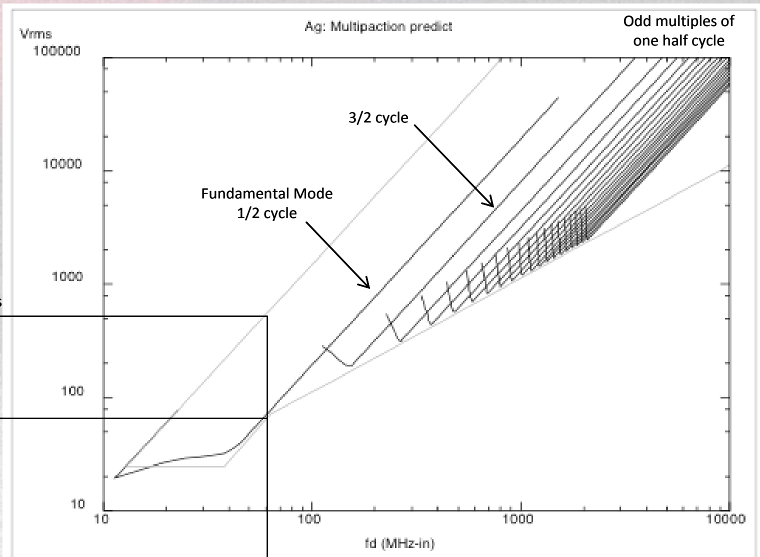


Average voltage 25 volts RMS

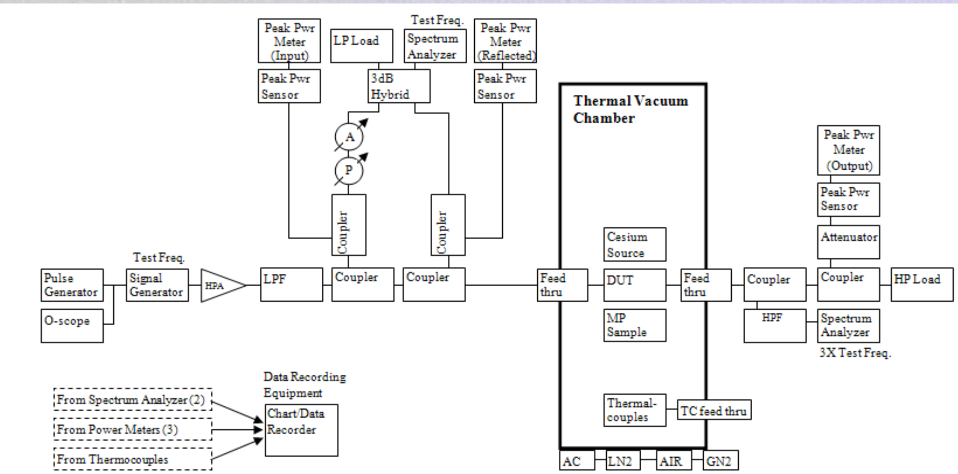
20 Crossing period 10 ns

≈ 510 volts

≈ 65 volts



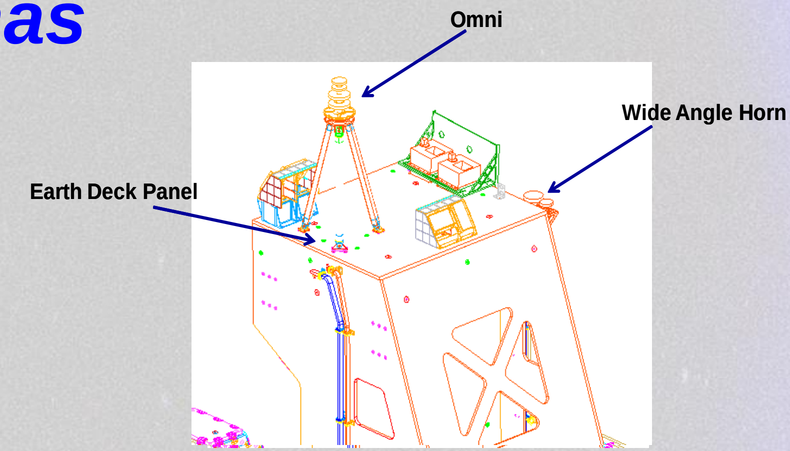
fd = 1 GHz*0.06 inches

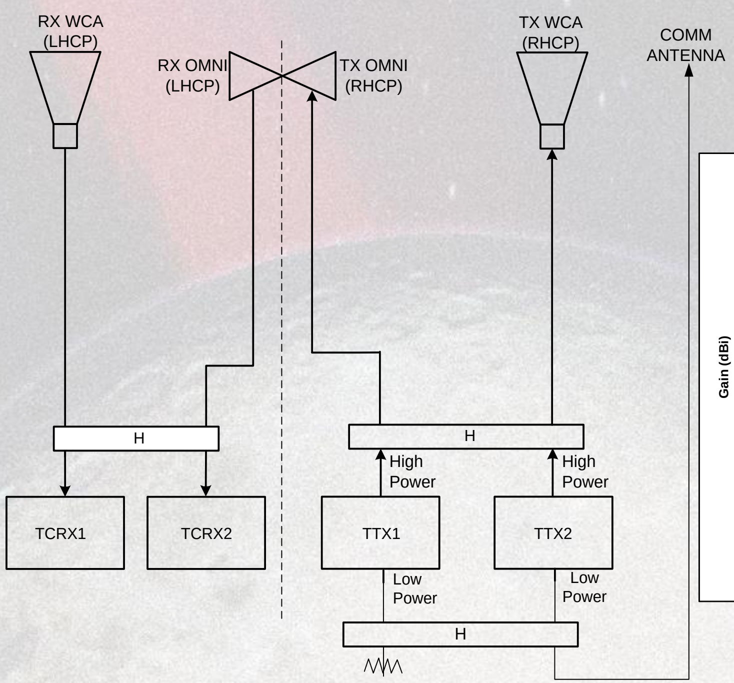


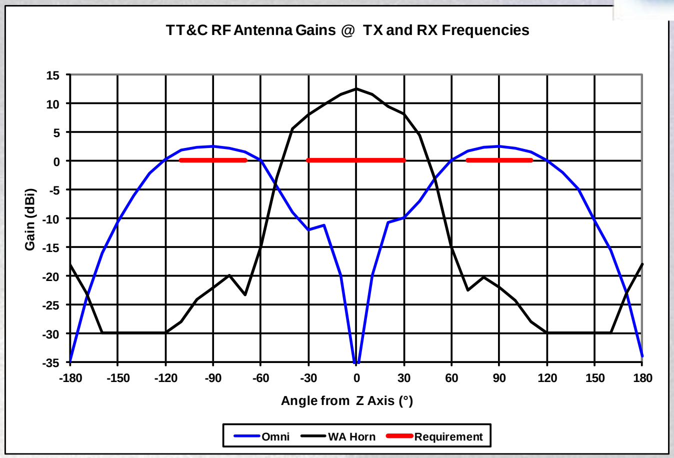
TT&C Antennas

TT&C RF Equipment

- Command receivers
- Telemetry transmitters
- Command Horn Antenna(s)
- Telemetry Horn Antenna(s)
- Command and Telemetry Omni Antenna
- Miscellaneous RF Hardware







Test Ranges & Equipment

- High Bay
- Planar near-field range: High gain and medium gain antennas
  - measure near-fields over +/- 80^0
- Spherical near-field range: Typically used for medium gain and low-gain antennas
  - precise probe to AUT alignment and probe compensation required (not used often)
- Far-field range: Out-door range with real-time measurements
  - suffers from ground reflections and weather conditions
- Compact range: the best range allowing real-time measurements of high gain/medium gain antenna patterns
  - employs SFOC dual-reflector system to create plane-wave quiet-zone region for AUT placement and measurements
- Anechoic chamber: indoor far-field measurements for medium and low gain antennas
  - global horns, omni-antennas
- Test Equipment: PIM test equipment, high power test set-up, thermal chamber, TVAC chamber, network analyzer etc.

Conclusions

- Future trends in satellite antennas and payloads include:
  - high capacity satellites for PCS with > 500 Gbps capacity
  - used of large deployable mesh-reflectors with apertures > 20 meters
  - multiple band hybrid payloads, light-weight compact feed assemblies
  - larger power TWTAs, larger power spacecrafts (> 20 KW DC)
  - reconfigurable antennas with flexible beam shape and beam location, origami based antenna structures
  - agile payloads with anti-jamming capability
  - low-cost payloads, meta-materials, EBG, nano-technology etc.
  - ultra wideband antennas with > 20:1 bandwidth ratio
  - high power handling and low PIM feed technologies
- Antenna plays a critical role in future payloads for satellites.
- Conceptual development matching the customer needs
- Antenna engineer needs several skills to develop advanced hardware needed for complex antenna systems of the 21st century

21st Century satellites need innovative antenna solutions leading to advanced payloads