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Overview

- Introduction
- Phased Array & NASA's Strategic Plans
- Current DSN Capabilities Within 2M-Kilometers
- Options For Replacement/Upgrade Of 26-M Antenna
- Summary & Conclusion

Introduction

Phased Array Systems Applied To Aerospace Over 5 decades Then, Space Surveillance With Satellite Detection & Tracking

- Simultaneous tracking of ballistic trajectories beyond Earth atmosphere
- AN/FPS-17, BNEWS, PAVEPAWS, COBRADANE, MILSTONE, HAYSACK

Motivation For Phased Array System Space Applications

- Heavy traffic in near Earth orbits and the need for multi-targeting
  - Imaging / Broadband Two-Way Communications / Space Sensors / GPS
- Deep space mission needs of the future
  - Increase in number of simultaneous, and smaller missions
- Global connectivity of various types of spacecraft at different orbits
- Needs For NASA's Deep Space Network (DSN) Large Antenna Upgrades

Phased Array & NASA's Strategic Plans

NASA

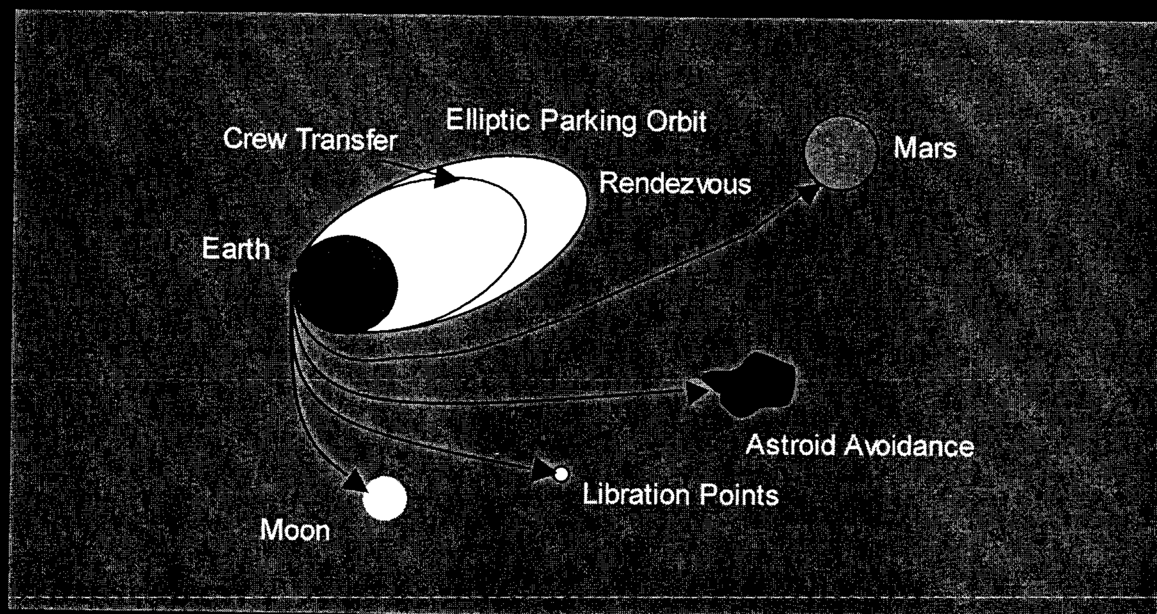
- Interest in Lagrange Libration Points (1.5-M Km)
- 10 to 100 times increase in data rates
- Four fold increase in number of missions
- Formation Flying & Multi-Platform Apertures (Light weight SAR)
- Dynamics of the robotic missions and proximity links
- Long-haul trunk lines and planetary network
- DSN Large antenna (26, 34, 70 - M) replacement

Phased Array & NASA's Strategic Plans
Human & Robotic Missions

NASA's objective is to promote human exploration beyond Low Earth Orbits

Mars robotic missions; logical step

- Demands intermediate stages LEO/HEO/GEO/Deep Space Connectivity
- Public interest via broadband uplink & tele-presence
- Diverse access to multiple spacecraft constellations
- Collision avoidance to space debris
- Dynamic channel assignment and packet switching



Phased Array & NASA's Strategic Plans

Space-based Internet

Space-based phased array and Ka-band triggered a new space era

Public engagement in space exploration demands service oriented approach

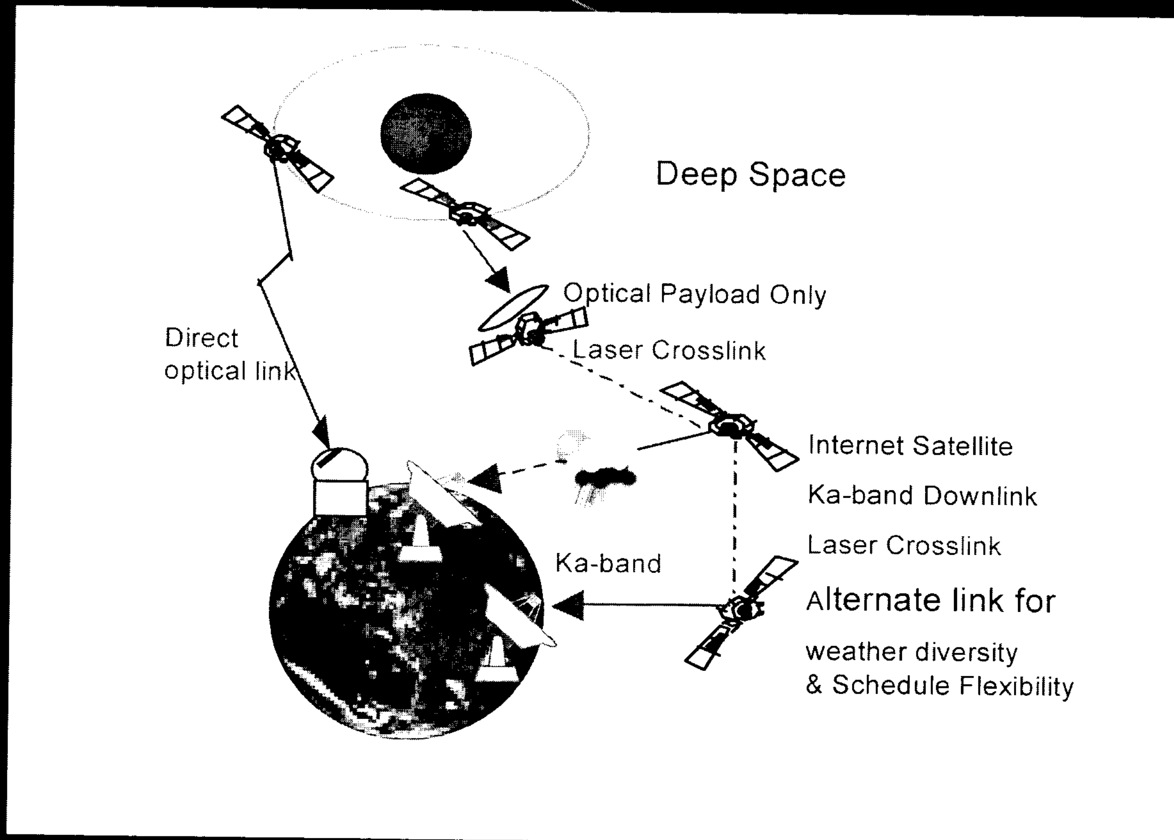
Related Events:

- Internet Satellite era and Ka-band upgrade of Deep Space Network (DSN)
- GLOBAL STAR, IRIDIUM, SPACEWAY usage of phased array for cellular comm.
- Direct user interface with space observations; multi-satellite links

Future NASA space assets IP-compliant (on-board LAN/WAN)

- User tailored direct downlink/uplink

Phased Array & NASA's Strategic Plans
Space-based Internet



Infusion of Space-based Internet is envisioned in NASA enterprise Missions (e.g., Technology for Space Internet Services (TSIS)

Phased Array & NASA's Strategic Plans
GPS and High Earth Orbits

NASA

Need for Advanced network architectures that integrate ground, and space-based resources into a coordinated, reliable observing system

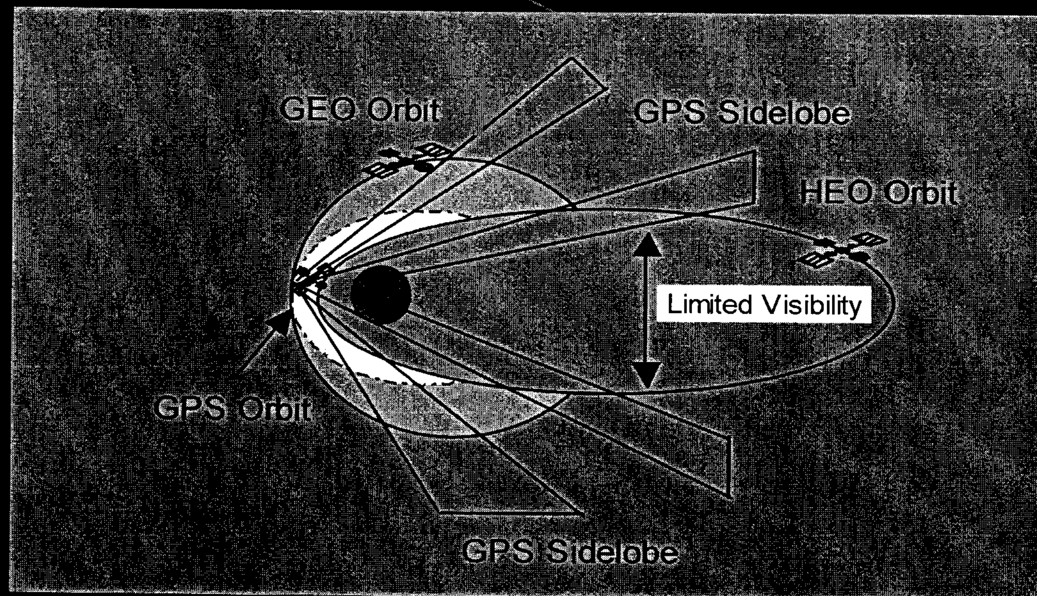
Space network synchronization requires GPS

- Network connectivity
- Timing
- Orbital accuracy for LEO/GEO/HEO

Conventional GPS has limited visibility at GEO/HEO

- Difference in altitude, Signal levels, Spacecraft dynamics, Geometry

Phased Array & NASA's Strategic Plans
GPS and High Earth Orbits – Cont.



GPS connectivity requires phased array capability

- Provide relative range information among clusters, or formation flying
- Spacecraft attitude relative to global network
- Phased array helps Multiple GPS satellites to become visible for better SNR

Phased Array & NASA's Strategic Plans
DSN – GPS – Phased Array

NASA

Phased array helps space observing spacecrafts orbital management through more connectivity of DSN to GPS

Future Ka-band needs of DSN for weather related media calibration puts a higher demand on DSN reliance on GPS,

It takes a phased array system to connect multiple missions to GPS network

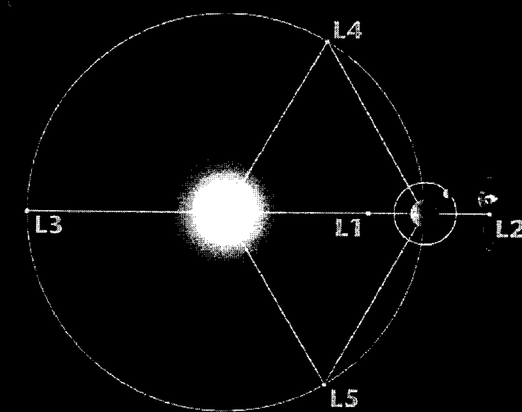
Deep Space Network (DSN) utilizes GPS on the ground for media calibration, not for navigational purposes

New GPS capabilities for GEO/HEO can be better utilized with DSN antennas if DSN 26-M antenna is upgraded to Phased Array Systems

Phased Array & NASA's Strategic Plans
Lagrange Libration Points

NASA

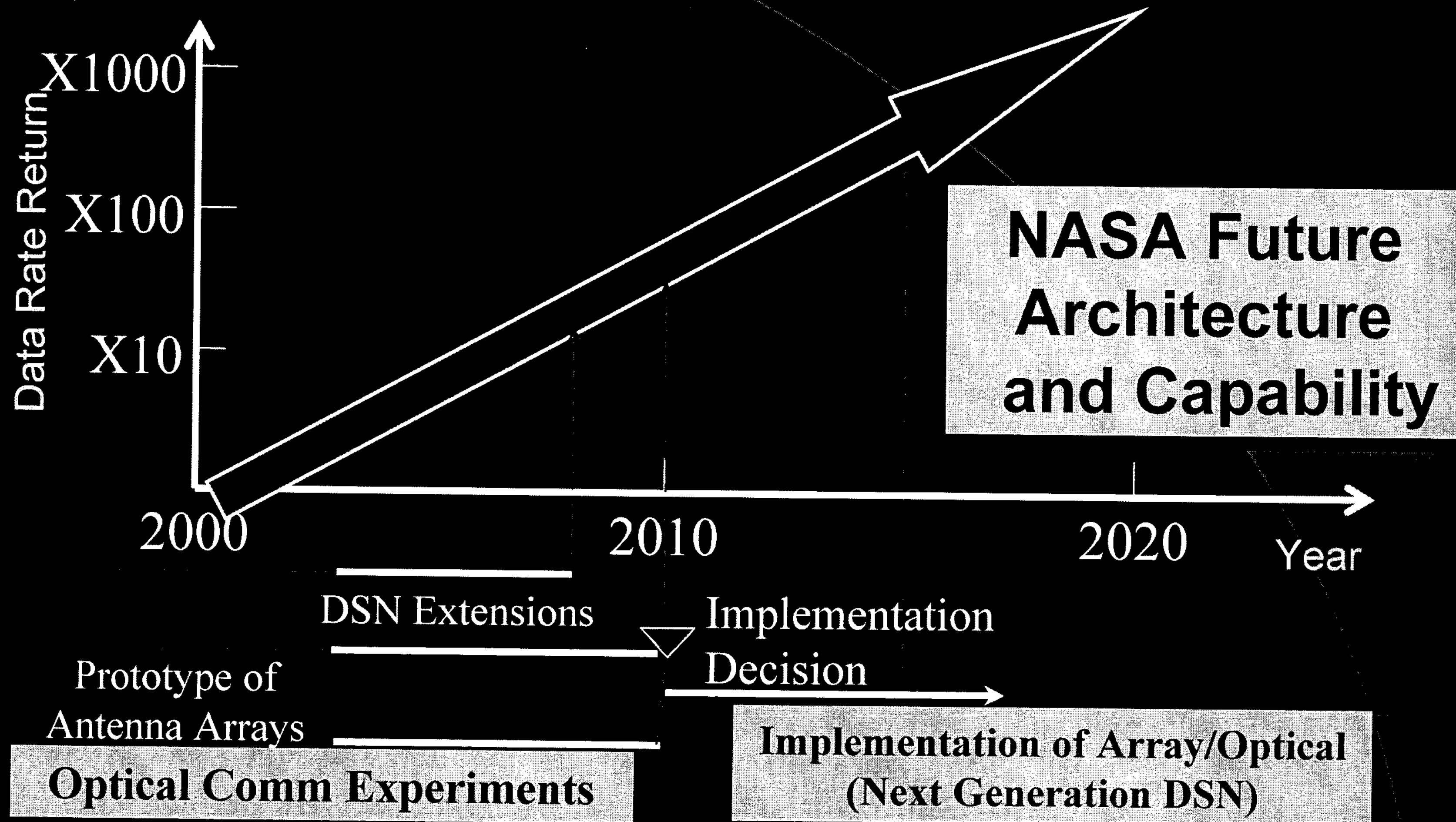
Space Based Infrared System (SBIR); an integrated system of systems brings new infrastructure from Lagrange Libration points down to low earth orbits and other Internet satellites based on phased array systems



Key advantages of Lagrange Libration point L2:

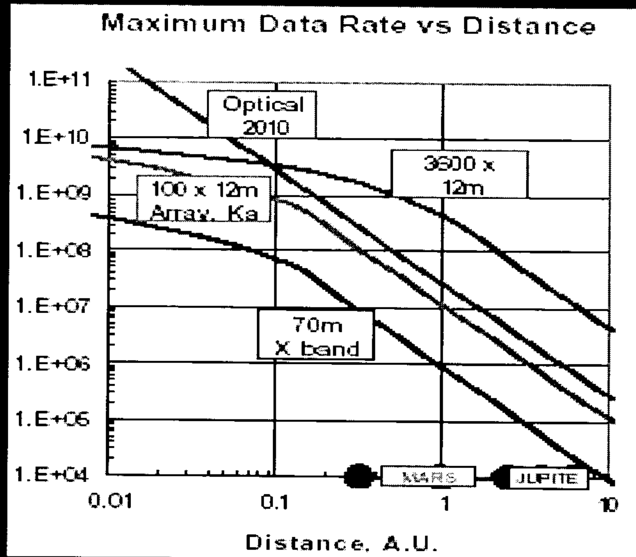
- Day/night (24/7) observation of Earth
  - All radiative interfering sources (Moon, Sun, Earth) lined up
- Sky coverage
- Stable gravitational conditions
- Save mass for missions
- Candidate location for optical relay terminals for deep space
- NASA astronomical missions (radiative cooling telescope slot)
- Earth observation without Sun interference

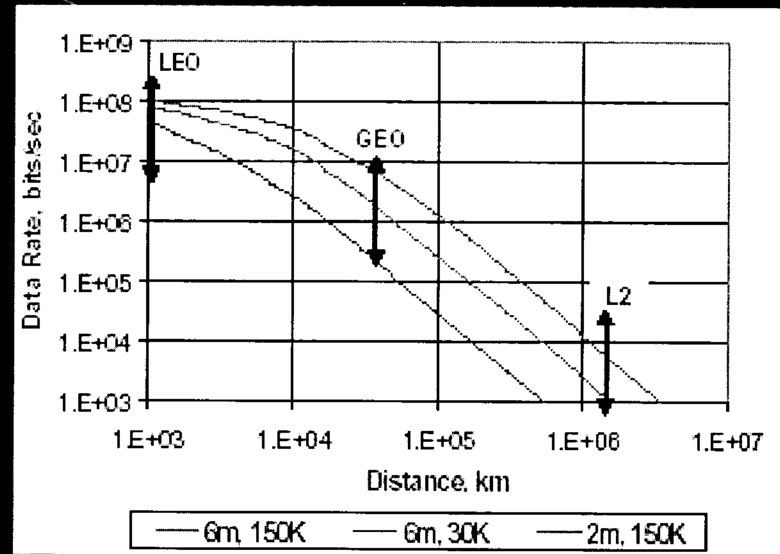
NASA Future Data Rate Capability Options



DSN Downlink Data Rates vs Distance For Various Sizes of Reflector Antennas

NASA





[Ref. Sander Weinreb, " *Low Cost Microwave Ground Terminals For Space Communications* " – RCGSO Conf, Pasadena, July 10, 03)]

P_t=10W, G_t=6dB, BW=10 MHz, For reflector antennas, 6dB margin

We need a complete link analysis with phased array for comparison

Phased Array & NASA's Strategic Plans
2M-Km Activity Summary

NASA

Space-based Internet era began with phased array systems

GPS extended service to GEO/HEO and Formation Flying was made possible by phased array systems

SBIR infrastructure from Lagrange Libration points down to LEO is based on phased array systems capability

Phase array systems is the core capability required for future DSN ground systems to provide service to missions within this range

Current DSN Capabilities Within 2-M Km

NASA

Deep Space Network (DSN): Three major complexes (120 degrees)

- Australia (Canberra)
- Spain (Madrid)
- California (Goldstone)
- 26-M, 34-M, 70-M antenna sizes

DSN tracks and communicates with interplanetary spacecrafts

DSN also tracks and communicates with spacecrafts beyond TDRSS

DSN 26-M antenna supports

- Launch and Early Orbits (LEOP) 160 Km to 1000 Km (NOAA, TDRSS)
- Initial spacecraft acquisition
- Emergencies (GOES, Hubble Space Telescope)
- Continuous support (SOHO)
- Supports S-band uplink/downlink 3deg/sec tracking speed

Current DSN Capabilities Within 2-M Km (Cont.)

26-M antenna functionality is limited to initial stages

Hands over to the 34m antenna for X-band (Ka-band) telemetry

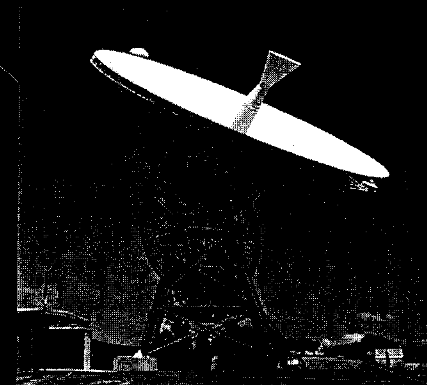
Only provides S-band telemetry for Near Earth orbiters

26-M uses two X, S-band reflectors (on its sides) for acquisition aid

26-M antenna is a very busy antenna with current and near future mission supports, its replacement requires careful planning

Shortcomings of DSN 26-M antenna

- Different design and operations from all other DSN antennas
- Old (since 1967) and inefficient (effective aperture size of 18m)
- Can not support longer term missions of the future
- Has no X-band telemetry capability
- Not suitable for Ka-band upgrade plan of DSN
- Low Noise Amplifier (LNA) temperature is high
- Not very immune to RFI
- Does not support multiple spacecraft launch
  - Limited slew rate for short interval between launches
- When some missions require longer supports, other get hit (no multiplexing)
- No communication support during maneuvering period (near future needs)
  - Carrier only (Doppler), but no telemetry
- No broadband communication capability



Options For Replacement Of 26-M Antenna

1) Refurbish the 26-M antenna

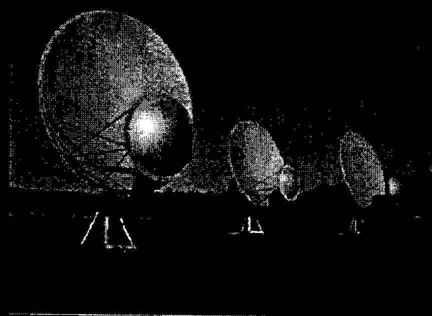
- Replace LNA, acquisition aid by phased arrays
  - Low cost quick fix

2) Use of elements of future large array of small 12M antennas (LASA)

- Large DSN antennas can be effectively synthesized with a set of 12m reflectors
  - Shares cost of resources with a scalable array of 12m antennas

Scalable Reflector Arrays

6m Offset Parabolic



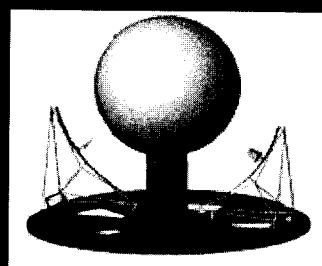
70m: 17x12m

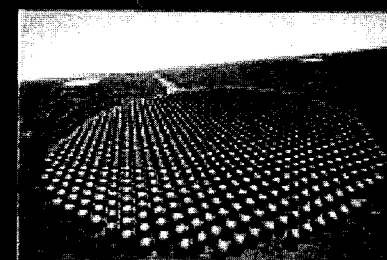
4x34m: 32x12m

26M: 4x12m

DSN: 53 of 12m antennas

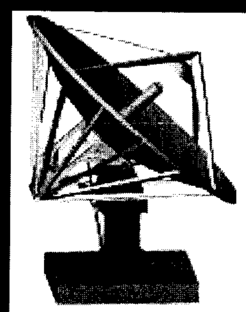
Australian Lunenburg Lens 7m Dielectric Sphere 0..5 - 5GHz

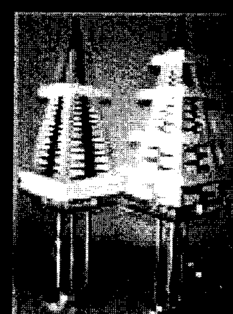


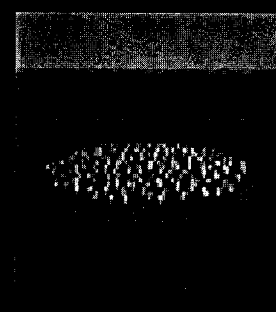


Broadband (.5-1GHz) 12m for DSNA

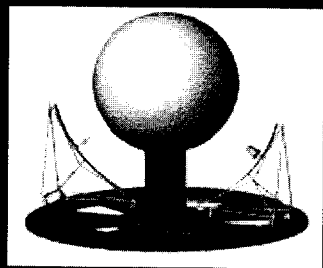
Entire band is transmitted to a central processing building through fiber optics

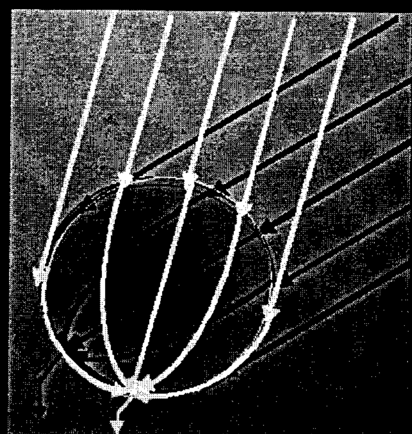


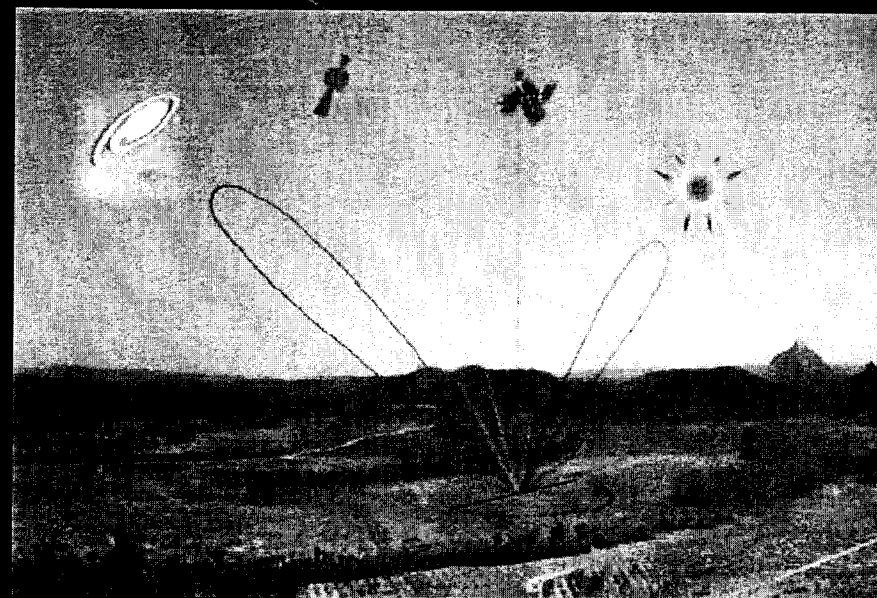




Beamforming Capability of Reflector Arrays







Collimated beam focused on opposite side [*Ref. CSIRO-SKA*]

Beams can come from any direction

Widely separated Multi-beam

Wide sky coverage

Active interference mitigation

Broadband

[*Ref. CSIRO-SKA*]

Options For Replacement Of 26-M Antenna Cont.

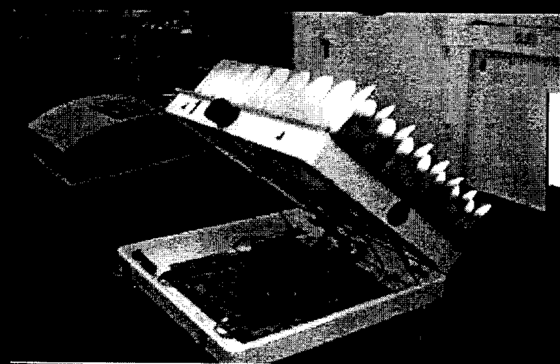
3) Additional 34-M instead of the 26-M

- Use an existing 34-M antenna and add the 26-M functionalities
- [illegible]
- [illegible]

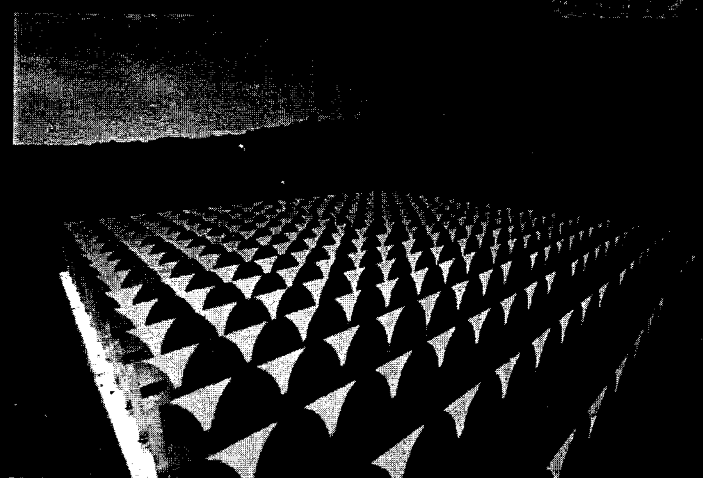
4) Phased Array System*

- Substitute the acquisition aids with phased array (near term prototype)
- Replace the entire 26-M antenna with phased array system (long-term)
- Requires further study for cost effective design but promising

Modular Flat Plate Array (FPA)



Vivaldi Antenna Elements



Thousand Element Array (THEA) – ASTRON

Two level (RF & Digital) Beamforming

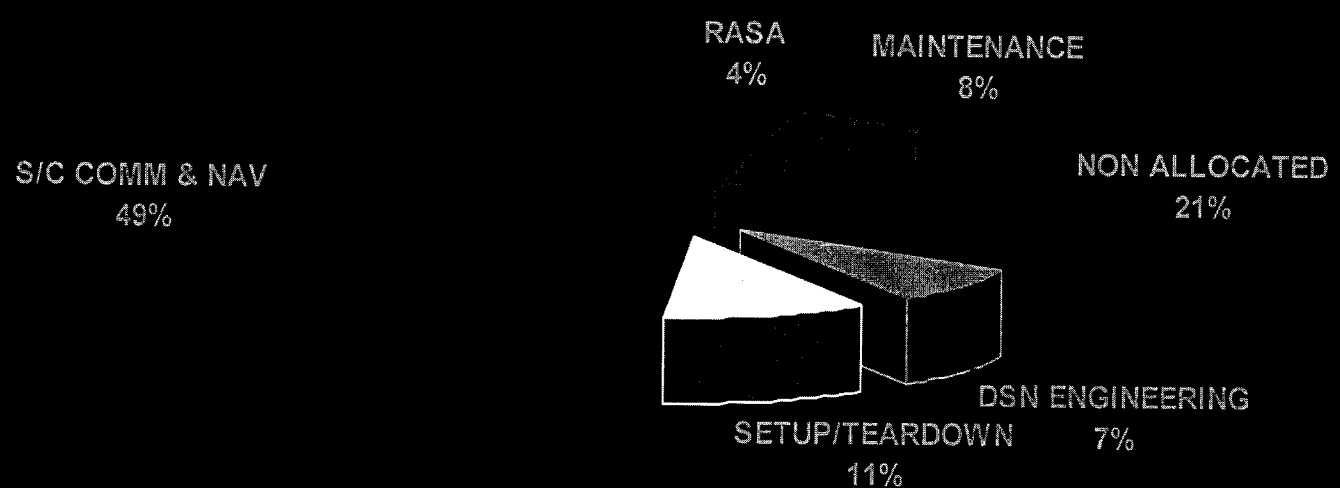
(600-1700 MHz)

Multiple Satellite Detection & Tracking

Tracks GPS satellites

DSN Antenna Resource Utilization (2002)

- All large array development so far are tailored for wide field of view imaging capability
- DSN primary objective is S/C COMM and NAV



26-M Replacement Option (4)
Phased Array System Trades

	Aperture Diam.	Gain Zenith	Gain 30° El.	HPBW deg	Aperture Efficiency	Polarization
Reflector	26 m	52.8	52.8	0.4+/-.03	60%	RCP/LCP
FPA*	37 m	57.3	54.3	0.26/0.36	90%	RCP/LCP

	Coverage	# of passes	Multiple Beam	Beam Switching		
Reflector	Restricted	6 per day	No	No		
FPA*	Unrestricted	Unlimited	Yes	Yes		

	Track rate (deg/s)	Slew rate (deg/s)	Acceleration (deg/s^2)	Pointing	Scan period, s	Scan modes
Reflector	3	3	5	Servo constrain	30-120	Mechanical
FPA*	Near inst.	Near Inst.	NA	Phasor constrain	Near inst.	Electronic

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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	Tx Power (dBm)	Stability	Cooling			
Reflector	47-63	'+/-0.25 dB/8hr	Fair			
FPA*	47-63	TBD	Difficult			

Phased Array DSN 26-M Challenges

Multi faceted versus planar

LNA temperature requirements and cost effective cooling system

Optimal size (less than 26m) when trading the cost with new capabilities

Cost barriers due to large number of Transmit/Receive (TR) modules

No previous deep space experience with large phased array systems

Phased Array Cost Trade For 26-M DSN Antenna - I

NASA

Case 1: Gain equal to reflector at Zenith

Reflector Diam.	12m ($2M)			26m ($10 M)		
Array Diam.	12m			26m		
Frequency	S	X	Ka	S	X	Ka
# of elements	20×10^3	300×10^3	5×10^3	100×10^3	1.5×10^6	24×10^6
Unit cost	$40	$60	$100	$40	$60	$100
All units	$0.8M	$18M	$500M	$4M	$90M	$2.4B
Assembly (%40)	$0.3M	$7M	$200M	$1.6M	$36M	$1B
Total cost	$1.1M	$25M	$700M	$5.6M	$126M	$3.4B

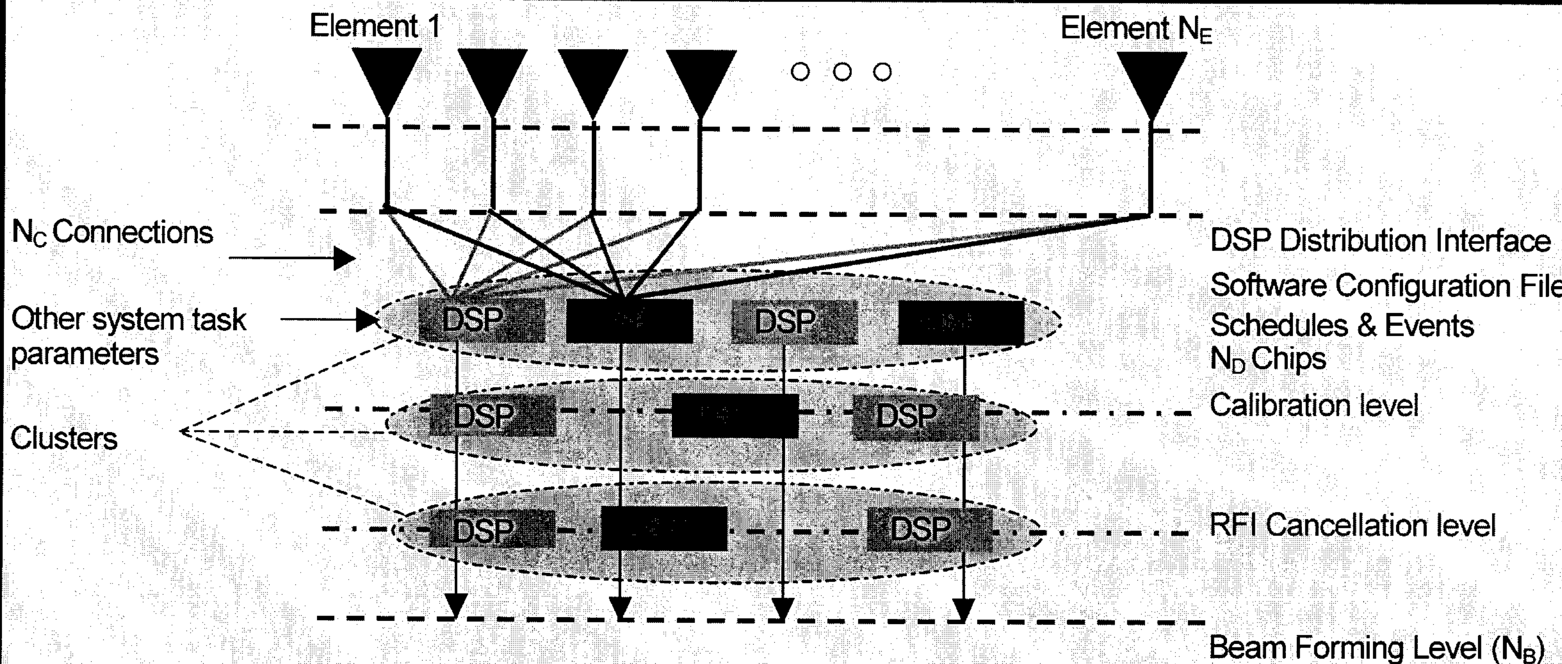
Phased Array Cost Trade (RF Modules) For 26-M DSN Antenna - II

NASA

Case-2: Gain equal to reflector at 30 degrees Elevation

Reflector Diam	12m ($2M)			26m ($10M)		
Array Diam	14m			37m		
Frequency	S	X	Ka	S	X	Ka
# Of elements	28×10^3	420×10^3	7×10^6	140×10^3	2.1×10^6	34×10^6
Unit cost	$40	$60	$100	$40	$60	$100
All units	$1.1M	$25M	$700M	$5.6M	$126M	$3.4B
Assembly (%40)	$0.4M	$10M	$280M	$2.2M	$50M	$1.4B
Total cost	$1.5M	$35M	$980M	$7.8M	$176M	$4.8B

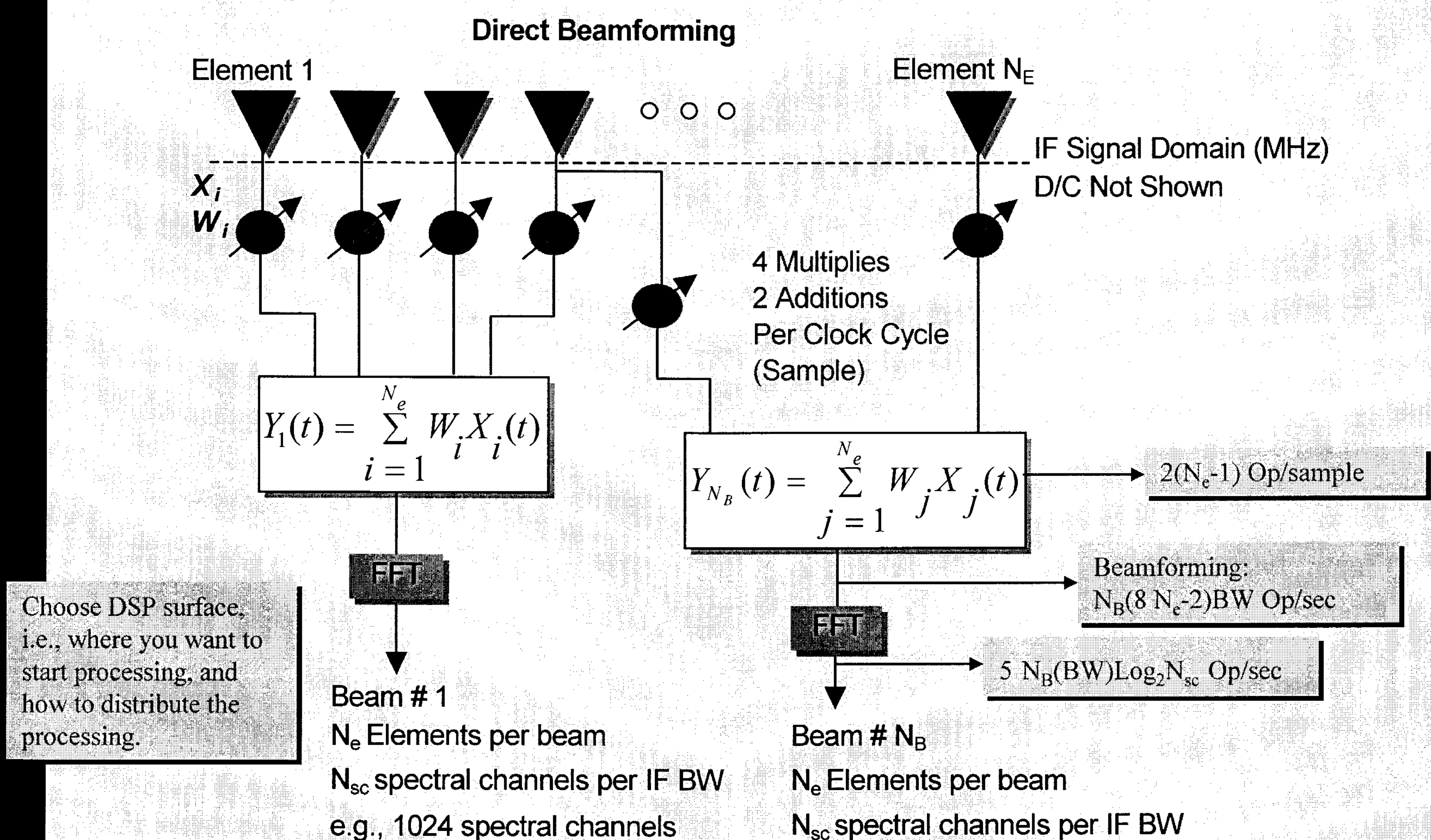
26-M Equivalent Phased Array Back End Cost
DSP Architecture & Distributed Processing



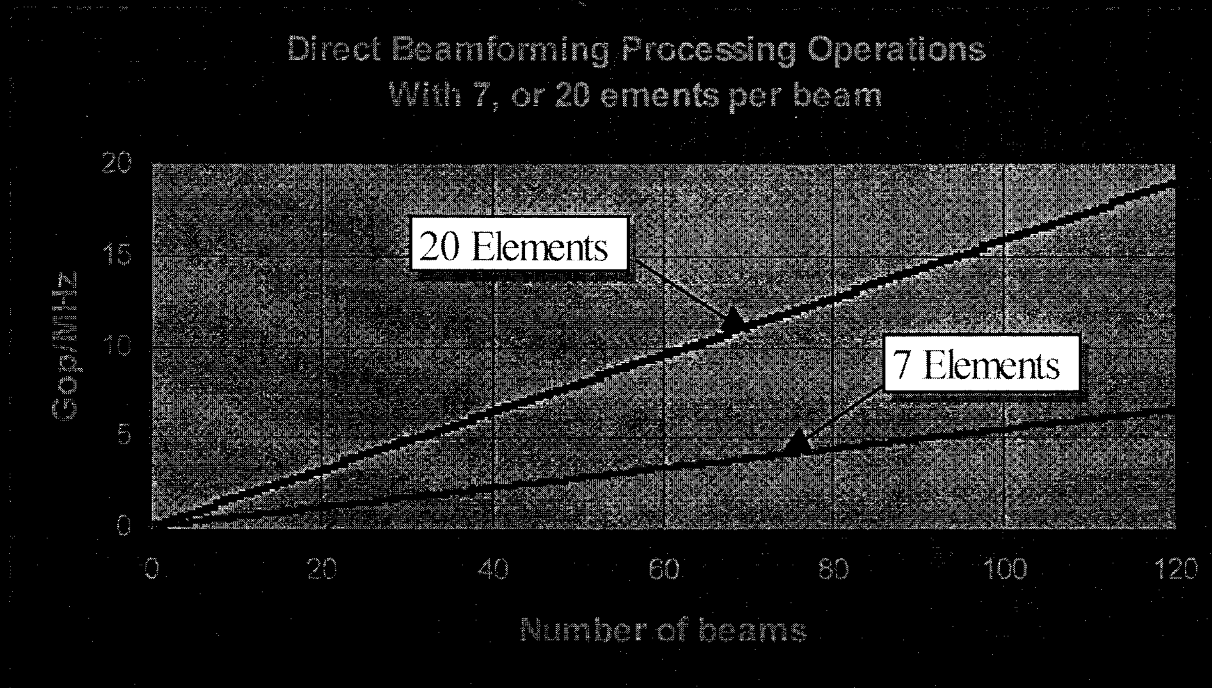
Scalable Architecture
Each level may require different I/O BW and storage
Too many levels may creat conflicts between signal processing and data transmission

Each cluster has to wait for the next one to wrap up with previous snap shot

Beamforming Computational Cost Breakdown



Direct Beamforming DSP Chip/MHz Requirement



Using 1- Gflop DSP, e.g., TMS320C6701 4800 DSP Chips (30% efficiency) for 100 MHz BW is required for 64 Beams, 1024 Spectral Channels & 20 elements per beam

Only 500 FPGA required to do the same job. FPGA is faster but less adaptable to array configurations.

Summary & Conclusions

DSN antennas are aging and need upgrade plan

Modular Phased Array System is a viable option for 26-M antenna

Preliminary trade studies revealed that the overall cost and performance *trends* of flat plate array is promising although some challenges still exist and require further analysis

The first 2-M km is a potential good starting zone for DSN phased array to prepare for the IP-based mission era and get experienced for other space explorations, e.g., In-Situ, robotics communications, etc.,

DSN capability extends with 26-M replacement with phased array

Need to absorb the phased array technology for deep space applications

Need to develop functional design and simulation of phased array system for deep space applications

Need the back end link analysis and data rate comparison with reflector arrays