Advancing Small Satellite Mission Capabilities Through the Establishment of a Robust NanoSat Communications Network

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Introduction

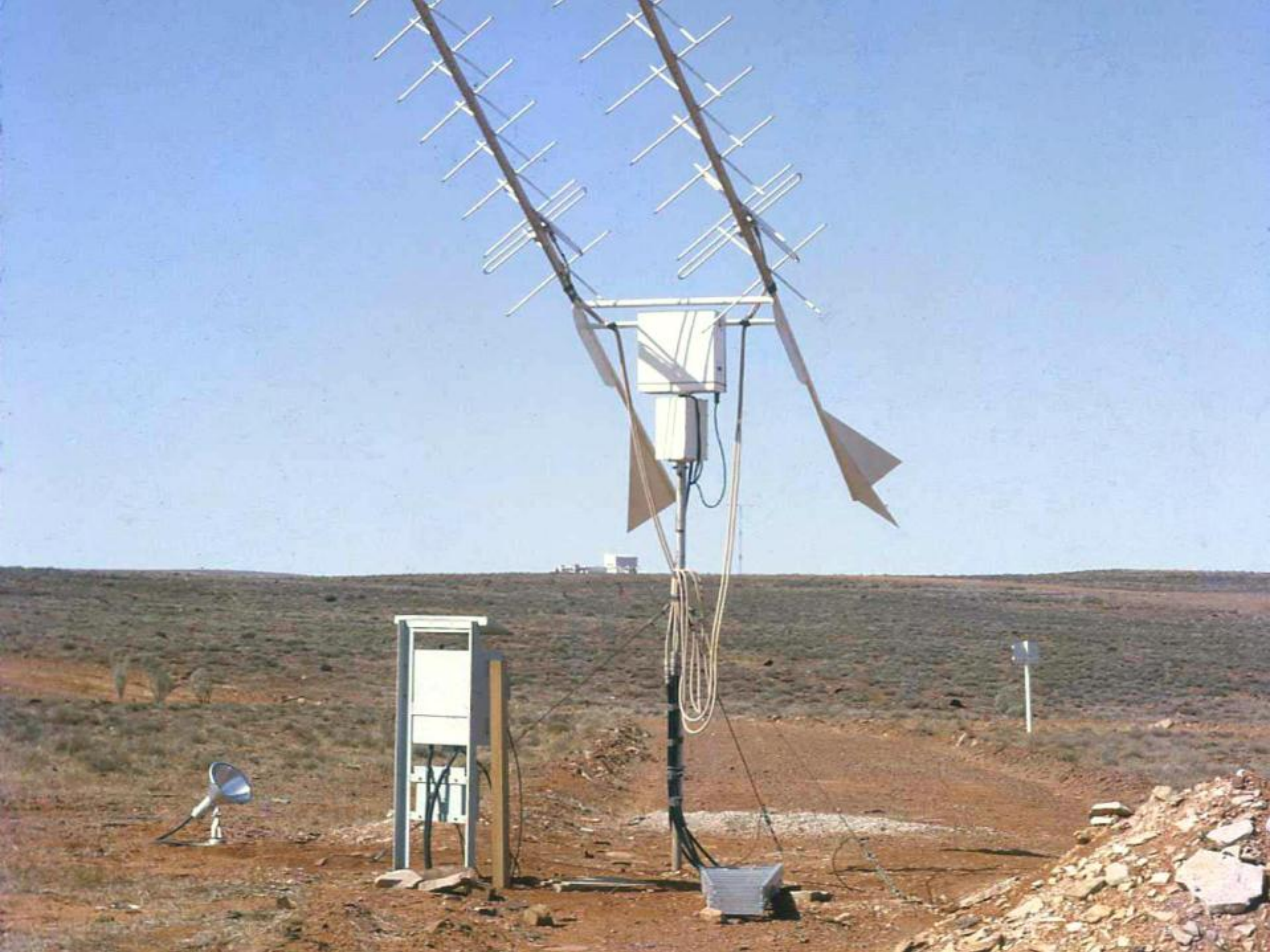
- Introduction of small spacecraft work at UND
- Overview of the trends in satellite communications
- Description of the problem faced by nano satellites
- Review of possible solutions
- Discussion of a proposed solution
- Assessment of the proposed solution from the prospective of a CubeSat mission operator

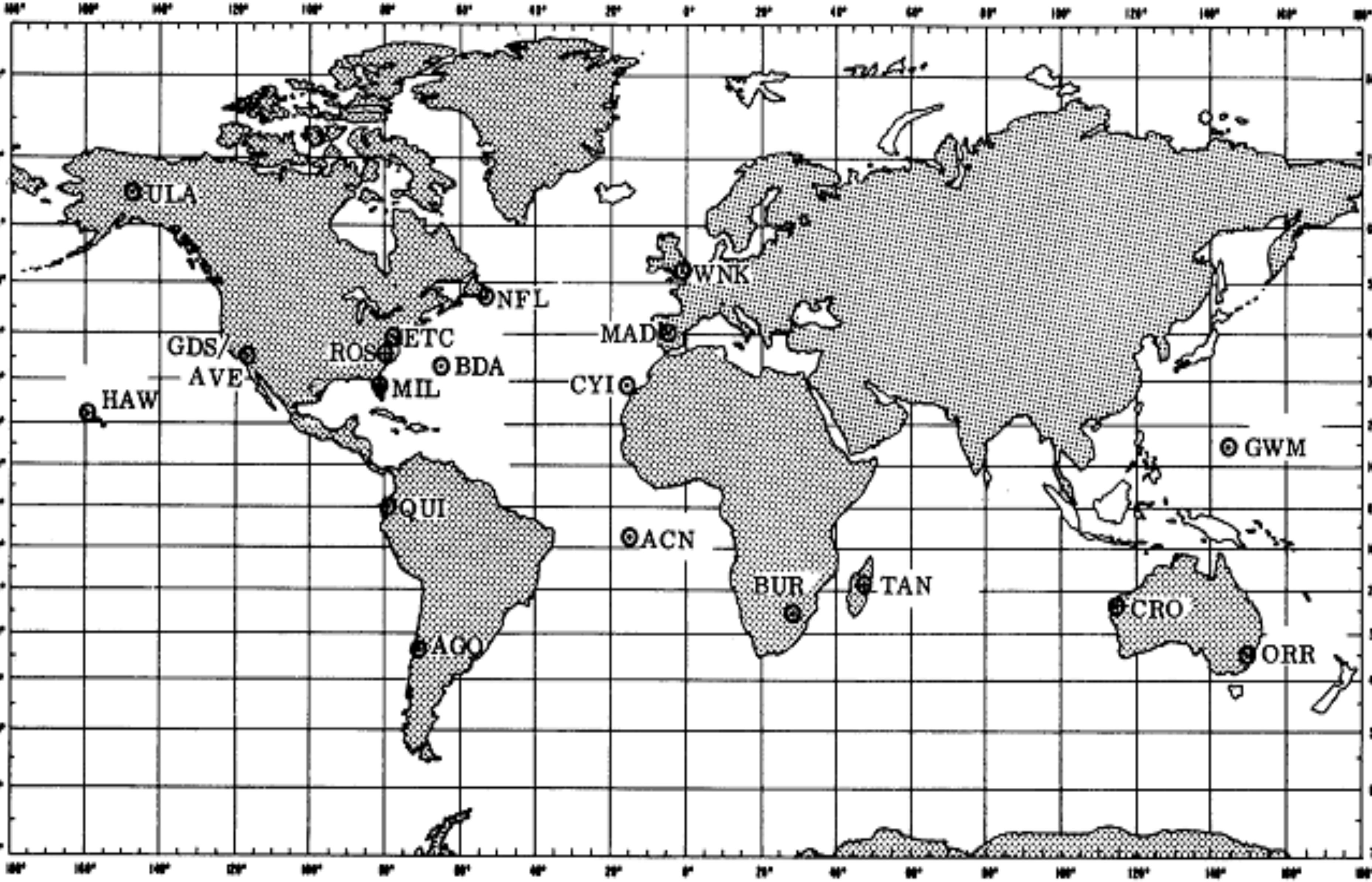
Introduction of Small Spacecraft Work at UND

- Work is ongoing to build a:
  - 1-U CubeSat (10 cm x 10 cm x 10 cm) for Earth sensing purposes, which will test technologies to be deployed on the 6-U CubeSat
  - 6-U CubeSat (30 cm x 20 cm x 10 cm) to test technologies required for a visit to a near-Earth asteroid (NEA)
- UND Engineering and (separately) two Space Studies faculty members have built small satellites previously

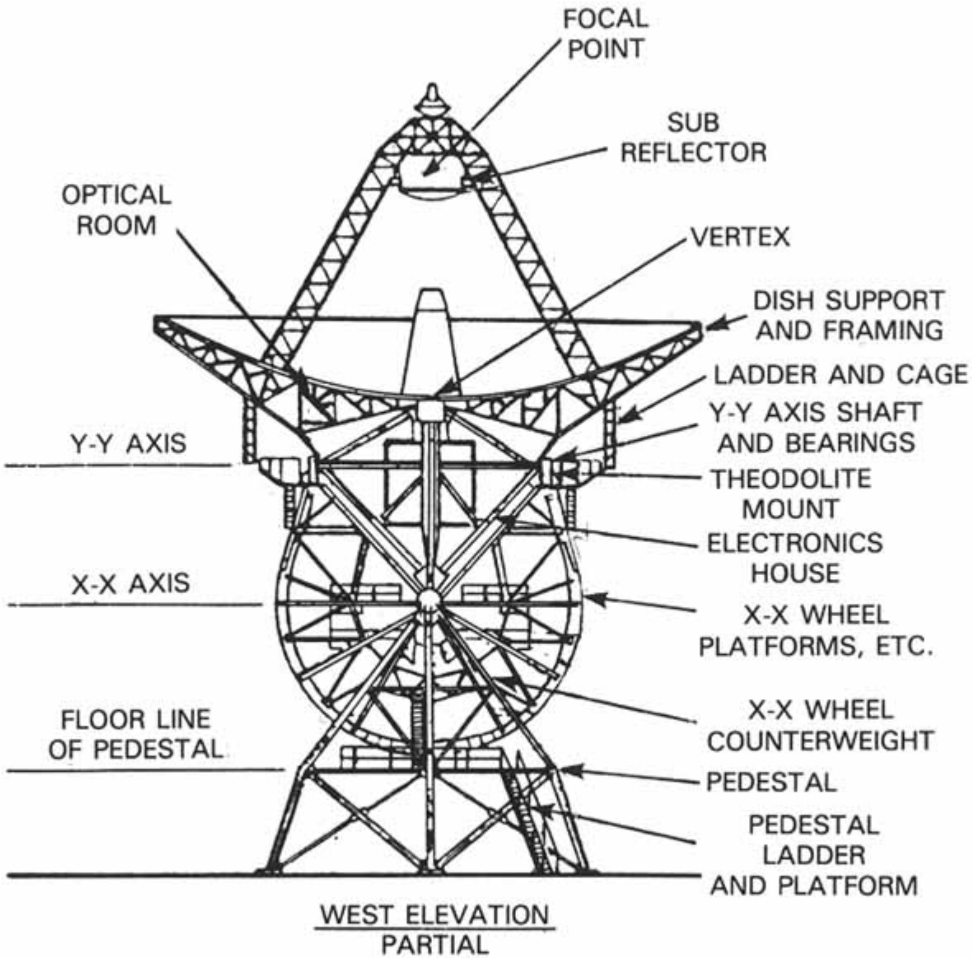
Trends in Satellite Communications

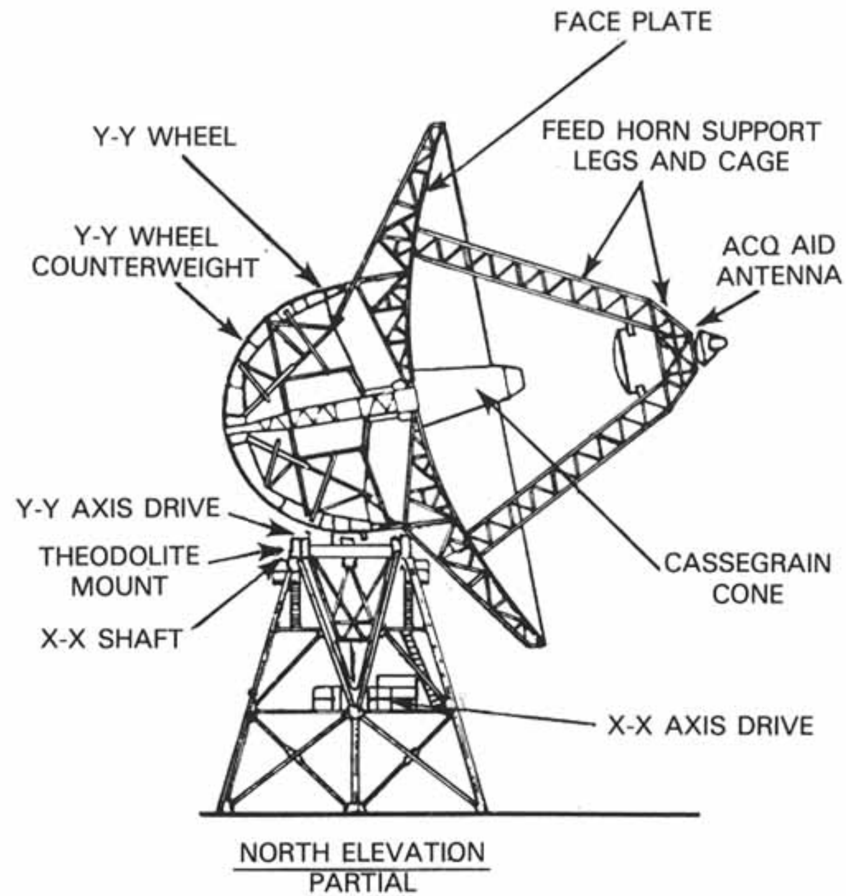
- **Minitrack** was the first US satellite tracking network. It was implemented as a string of stations along the 75th meridian. The tracking frequency was 108 MHz—hence NASA could not track the 20MHz and 40MHz ham bands of Sputnik.
- Minitrack was followed by NASA's Spacecraft Tracking and Data Acquisition Network (**STADAN**). There were 22 STADAN stations. Most of these were 9m Unified S-Band (USB) systems; a few were 26m systems.





STADAN Stations



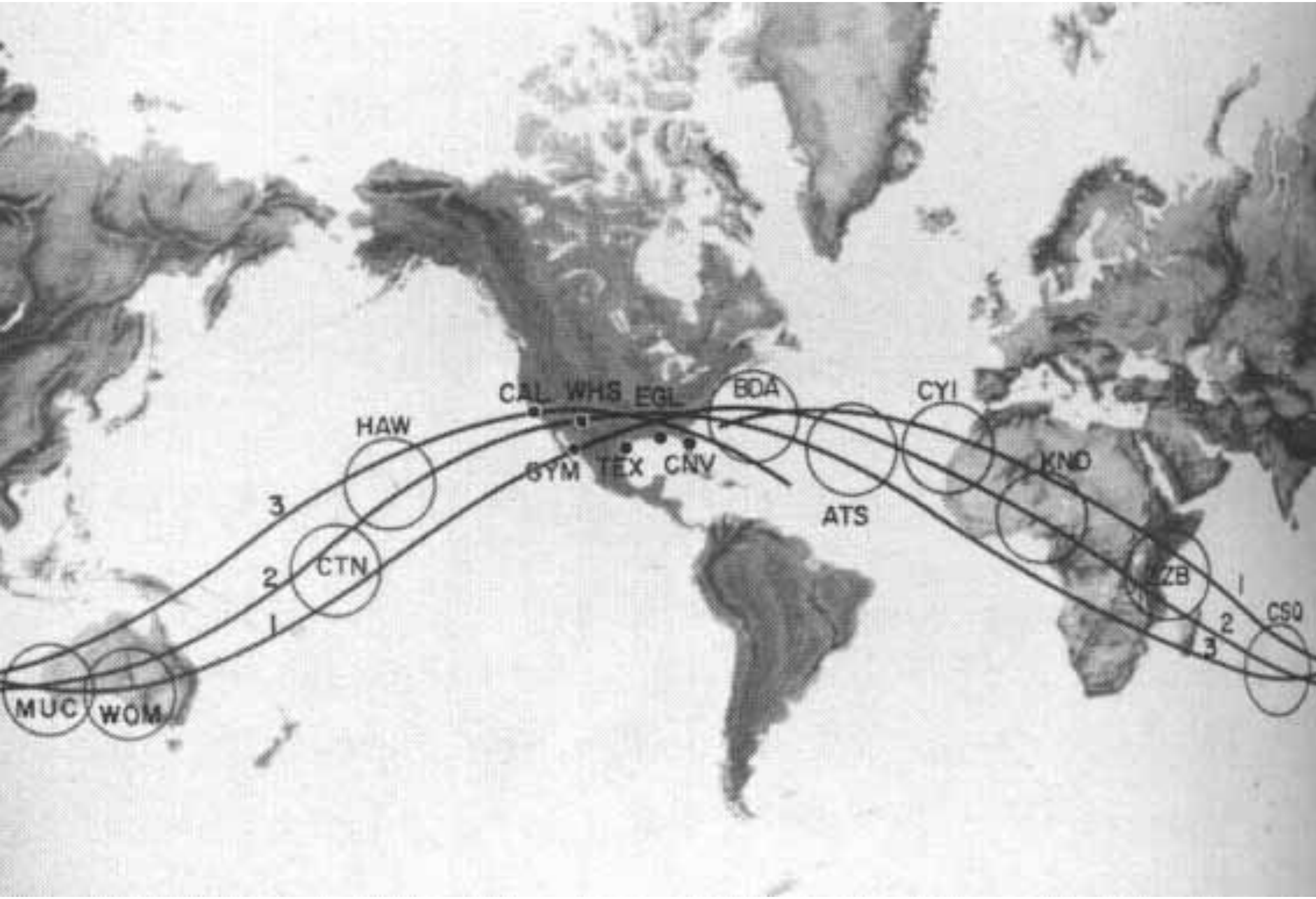


STADAN and MSFN X-Y Mount
85’ 26m


U.S. ARMY SHIP
AMERICAN MARINER

Trends in Satellite Communications (cont.)

- A separate tracking network, the Manned Space Flight Network (MSFN) was established for human spaceflight. In 1971, STADAN and MSFN were merged to form STDN (later GSTDN)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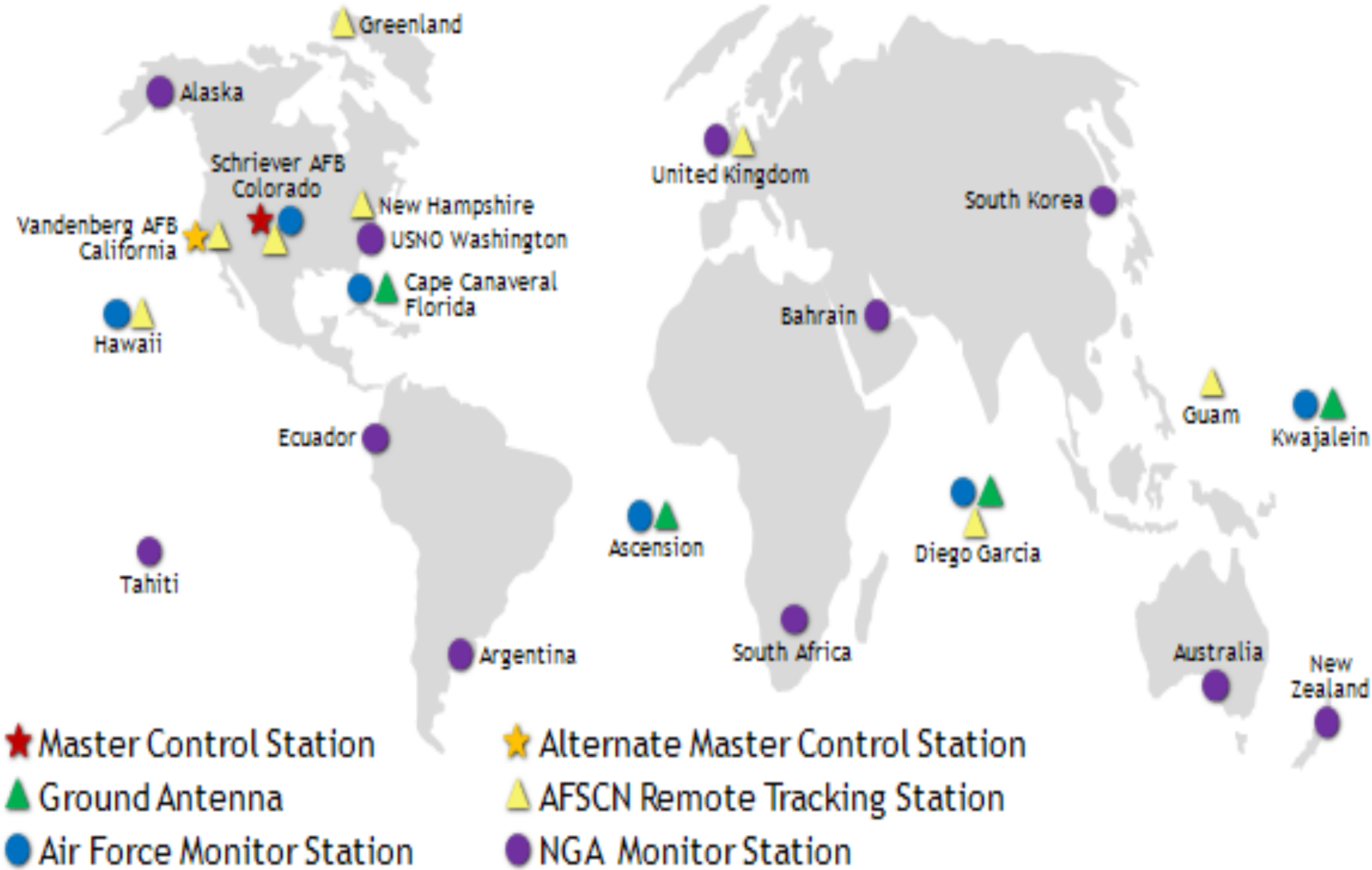
Trends in Satellite Communications (cont.)

- In 1959, the USAF activated the Air Force Satellite Control Network (AFSCN) to support DISCOVERER/CORONA. Initially, seven stations were built. These were originally 85-footers.


Greenland
Alaska
Schriever AFB
Colorado
New Hampshire
Vandenberg AFB
California
USNO Washington
Cape Canaveral
Florida
Hawaii
United Kingdom
South Korea
Bahrain
Guam
Kwajalein
Ecuador
Ascension
Diego Garcia
Tahiti
South Africa
Argentina
Australia
New
Zealand
Master Control Station
Alternate Master Control Station
Ground Antenna
AFSCN Remote Tracking Station
Air Force Monitor Station
NGA Monitor Station

AFSCN

Trends in Satellite Communications (cont.)

- Over the years, NASA and the Air Force have eliminated many of the expensive large antennas in their networks and replaced them with satellites: TDRS and SDS.

Trends in Satellite Communications (cont.)

- GEO communications satellites are in highly elliptical orbits when first launched. A tracking network is needed to pick up the satellites after launch when they are at low altitudes. This has usually been accomplished by temporary lease of an antenna or two from an existing operator.
- A few years ago, Universal Space Network determined to build a non-government satellite tracking network that could be leased for private or governmental use. In 2009, the Swedish Space Corporation bought USN. The new network is called PrioraNet

PrioraNet

Inuvik, Canada
Poker Flat, AK, USA
North Pole, AK, USA
Riverside, CA, USA
Newport Beach, CA, USA
Horsham, PA, USA
Miami, FL, USA
South Point, HI, USA
Esrange, Sweden
Weilheim, Germany
Fucino, Italy
Bangalore, India
Mauritius
Santiago, Chile
Hartebeesthoek, South Africa
Dongara, Australia
Punta Arenas, Chile
O'Higgins, Antarctica
= PrioraNet Stations
= Collaborative Stations
= Network Management Centers
April 2011

The Problem Faced by Nano Satellites

- Possible bandwidth diminishes as the spacecraft moves further-and-further from the Earth
- Mission utility is generally limited by the amount of data that can be sent from the spacecraft to the Earth
- Data is limited by:
  - Time "in sight" of a ground station
  - Low transmission rates possible
  - Distance from the Earth (for interplanetary missions)
- Limited onboard power generation and antenna size limits ability to augment communications capabilities from the satellite-side

Possible Solutions

- Single spacecraft-owner operated ground station
- Existing networks:
  - GENSO
  - DSN
- Collaborative ground station network

Overview of Ground Segment

- Dual-band (S and X-band) phased array antennas used for data downlink
- Command and control is performed via UHF/VHF uplink
- Uses low noise amplifiers (typical 35K noise temperature).
  - Cryogenic cooling being considered for deep space applications
- Colorado ground station has been designed with the option for a 1 km baseline interferometer to support spacecraft tracking

Overview of Ground Segment
(cont.)

RF Hardware:

- COTS satellite modems (Comtech SDM300 & SDM9000) with standard 70/140 MHz IF architecture
  - allows multiplexing of multiple satellite signals onto different antenna sub arrays.
- Comtech EF Data Up/down converters (UT-4579 and UT-4572)

Satellite Modems

- SDM-300A modem:
  - supports data rates from 2.4kbps to 5 Mbps
  - OQPSK or 8 PSK modulation
  - can track a Doppler shifted signal +/- 35 kHz from the nominal carrier frequency
  - has a user configurable data buffer (1 to 99 ms)
- The SDM-9000 modem:
  - currently in service with the US Navy
  - has a maximum data rate of 51 Mbps using 16 QAM modulation

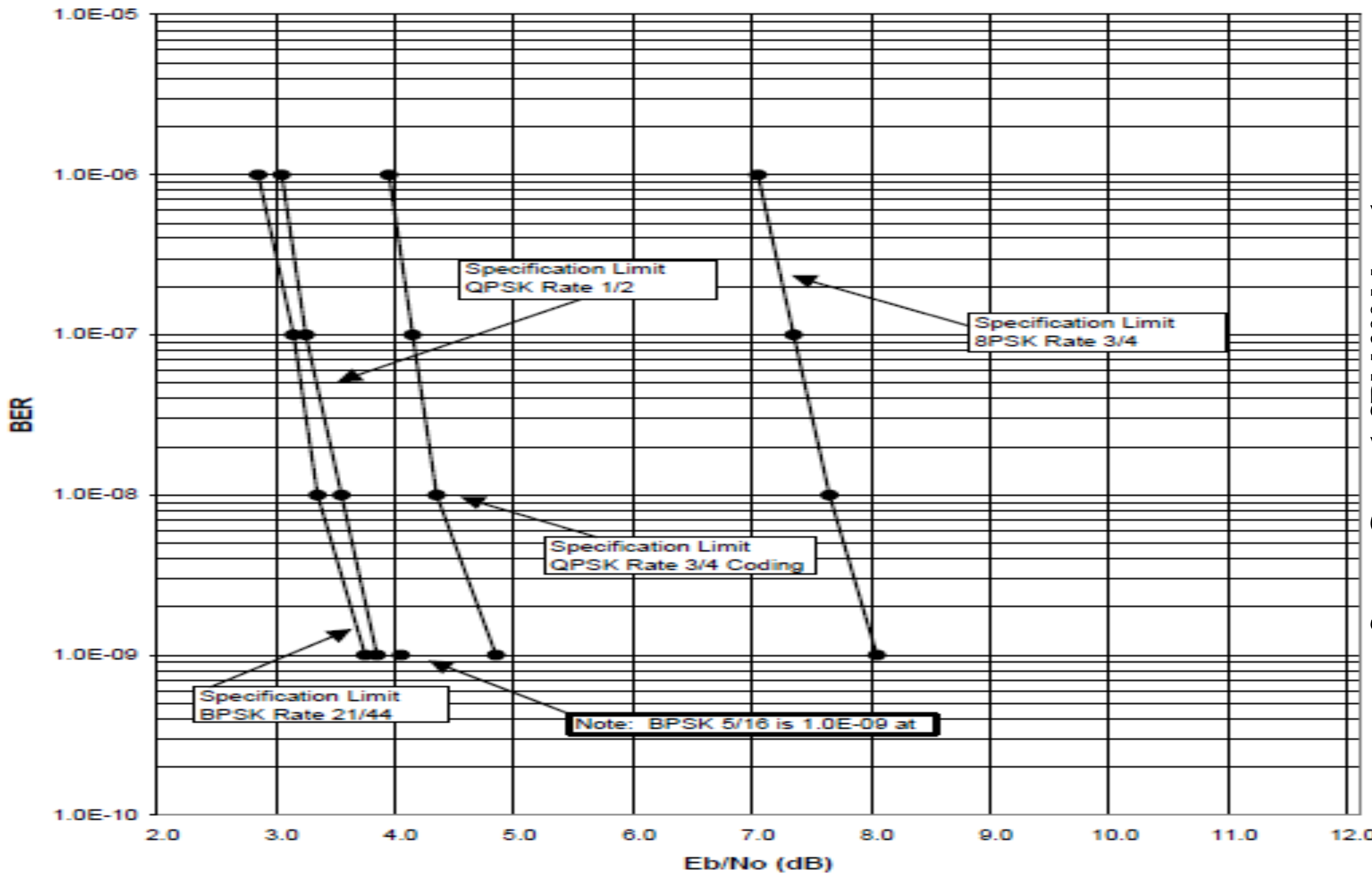
Why use 8 PSK modulation?

Mode	Eb/No at BER = 10^{-6}	Eb/No at BER = 10^{-8}	Spectral Efficiency	Symbol Rate	Occupied Bandwidth for 1 Mbps Carrier
QPSK Rate 1/2 Viterbi (see Note 1)	6.0 dB	7.2 dB	1.00 bits/Hz	1.0 x bit rate	1190 kHz
BPSK Rate 21/44 Turbo	2.8 dB	3.3 dB	0.48 bits/Hz	2.1 x bit rate	2493 kHz
BPSK Rate 5/16 Turbo	< 4.0	< 4.0 dB	0.31 bits/Hz	3.2 x bit rate	3808 kHz
QPSK / OQPSK Rate 1/2 Turbo	3.0 dB	3.5 dB	1.00 bits/Hz	1.0 x bit rate	1190 kHz
QPSK / OQPSK Rate 3/4 Turbo	3.9 dB	4.3 dB	1.50 bits/Hz	0.67 x bit rate	793 kHz
8-PSK Rate 2/3 TCM and RS (IESS-310) (see Note 2)	6.1 dB	6.6 dB	1.82 bits/Hz	0.56 x bit rate	666 kHz
8-PSK Rate 3/4 Turbo	7.0 dB	8.0 dB	2.25 bits/Hz	0.44 x bit rate	529 kHz

Source: Comtech SDM 300 Manual

- Spectral efficiency – Globally, telecommunications regulatory agencies are all pushing for more efficient modulation schemes
- 8PSK has a spectral efficiency of 2.25 bits/Hz. This comes at the price of a higher Eb/No requirement: 8dB vs. 5dB for OQPSK

QPSK vs 8 PSK modulation



Source: Comtech SDM 300 Manual

Why use 2.3 vs. 2.4 GHz?

- The 2.3 GHz amateur band (10 MHz segment) is adjacent to NASA's existing S-band downlink allocation (2.29-2.30 GHz)
- Its comparatively easy to build frequency agile RF circuits to operate in both 2.29 and 2.3 GHz segments
- Fewer strong (local) interferers, in comparison to 2.4 GHz
  - However, the spectrum from 2.310 to 2.390 GHz is allocated to direct satellite radio broadcast

Servers & Connectivity

- Servers:
  - Redundant power supplies
  - Redundant hard drives
  - Multiple load-balanced, redundant Ethernet ports
- Connectivity:
  - Redundant broadband connections
  - Local storage cache capability in case broadband link is lost

Software & Control

- Web based user interface
- Based on CentOS/Apache platform
- All ground stations linked to Grand Forks, North Dakota control center

Assessment of Proposed Solution – CubeSat Mission

- Low cost
  - Can just buy time on network, commensurate with needs
  - Or can build ground station and contribute to network
  - Ground station can be higher quality, due to equipment provisioning model
- High reliability
  - SLA & monitoring means that problems will be repaired quickly, prevents prolonged outage
  - Higher-grade equipment and spare parts reduces outage time

Assessment of Proposed Solution – CubeSat Mission (cont.)

- Potential for student involvement
  - On-campus operations centers provide employment and training for undergraduates
  - Limited equipment needs:
    - Computers
    - High-speed Internet link
- Potential for integration with space operations class / curriculum
- Provides an opportunity for student involvement prior to full-fledged launch of spacecraft program

Conclusions & Future Work

- The proposed network represents a new paradigm for small satellite ground station services
- Hardware has been acquired to build three ground stations
- Immediate work will focus on building the ground stations (land has been acquired in Colorado, other locations being sought)

References & Acknowledgements

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Thanks &
Any Questions

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