Inside the World of Communications Satellites

From Integration to Orbit: An Insider's Perspective

A Presentation to KARS

By Fred Richardson, AB7IJ

A Quick Personal Introduction

- Member of KARS since 2022 - Living in Boerne (Champion Heights)
- Married to Joyce since 1973 - we have 4 married children and 14 grandchildren
- First Licensed in New Jersey in High School as WN2ZUM (Novice) / WB2ZUM (General)
- Inactive after college until 1993 – Re-licensed in WA State as AB7IJ (Amateur Extra)
- Electrical Engineer in Aerospace and Defense industry
  - Satellite Integration and Test and Systems Engineering – Hughes Aircraft Co - El Segundo, CA & TDY in Kent, WA
  - Airborne Early Warning and Control communications suite- Boeing - Kent, WA
  - Satellite In-Orbit Test – Space Systems Loral (now MAXAR Technologies) – Palo Alto, CA
- Retired in Dec 2020 and moved to Boerne in March 2022
- FYI: I am much more comfortable with <u>block diagrams</u> than I am with <u>schematic diagrams</u>

Why Satellites Matter to Hams

Satellites extend our communication reach beyond line of sight. A growing number of satellites with Amateur Radio payloads is available for use by hams

Many hams work in aerospace and satellite related fields or follow space missions

Understanding the professional side gives insight into ham satellites

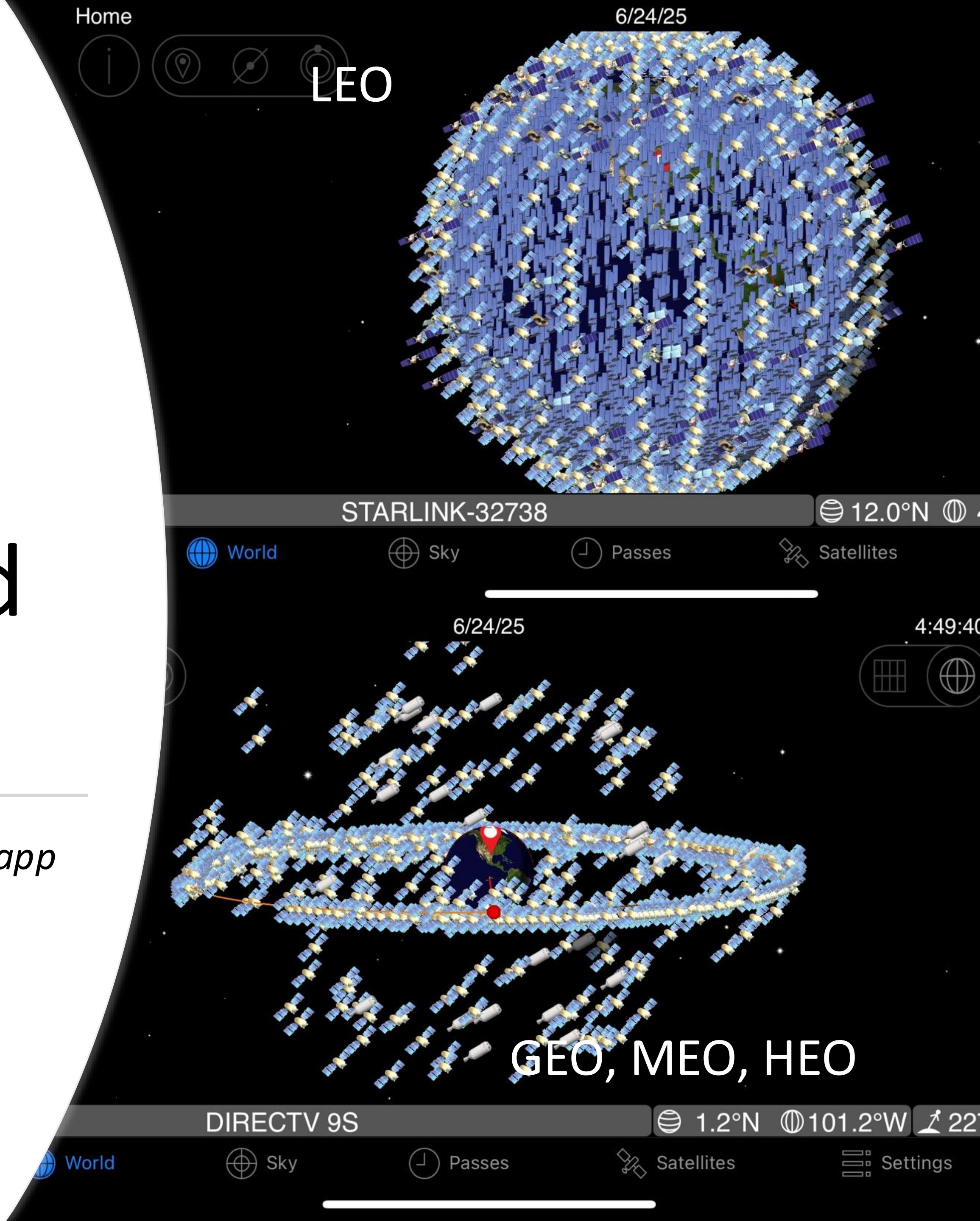
How many satellites are there?

- Total # of Active Satellites: 12,509 as of 2 Sep 2025
- Total # of orbiting objects (active, defunct, rocket bodies, debris): ~15,000
- GEO: (Communications, Weather, GNSS augmentation; Military; **1 Amateur Radio**): 569
- MEO
  - GNSS (Navigation - e.g. GPS): 169
  - O3b (“Other Three Billion” – Broadband data): 28
- LEO
  - Iridium (Voice/Data): 80
  - Globalstar (Voice/Data): 85
  - OneWeb (Voice/Data): 651
  - STARLINK (Internet): 8,140 (Ultimate Plan: 42,000!!!)
  - NOAA (Weather): 23
  - Others (Including ISS): 405
- HEO (Molniya, Tundra, Graveyard): 247 active / ~2,200 inactive
- **Amateur Radio (Mostly LEO): 104. . . Welllll, not really – Stay Tuned**

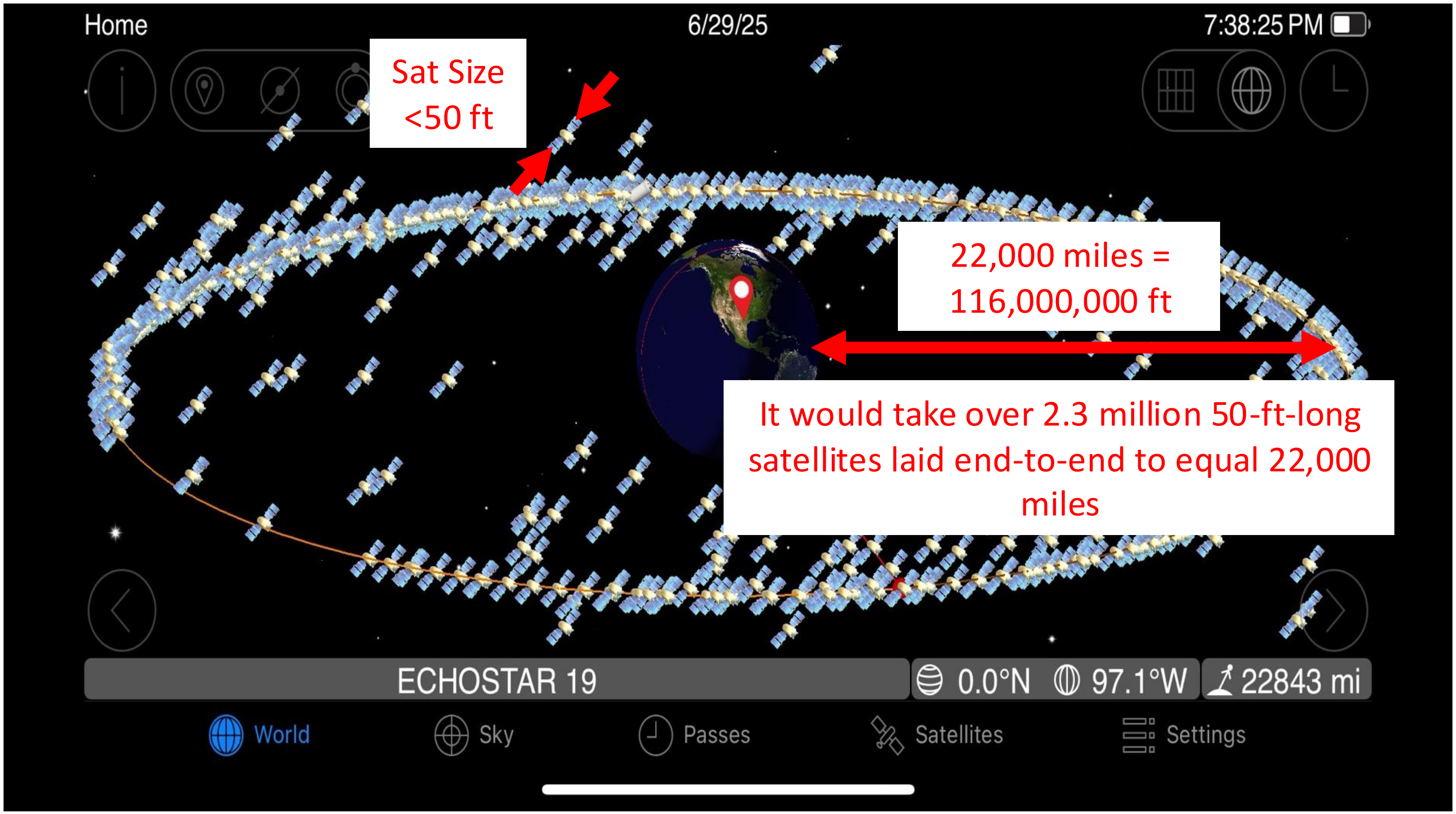
*Information derived from **GoSatWatch** app & **CelesTrack** web site*

THAT Many? How crowded *is* Space?

Images taken from GoSatWatch app



A quick word about GoSatWatch images



Types of satellites

Classification by MISSON

- **Communications:** Satellite TV, Satellite Radio, Internet Connectivity, Data Connectivity, Enterprise Networks, Telephony, Industrial & Infrastructure Monitoring, Mobile Satellite Services, Military & Government Comm, Amateur Radio
- **Earth Observation:** Weather (GOES); Earth Resources & Environmental monitoring (Landsat); Intelligence; Disaster Response; Mapping Services; Urban Planning; Agriculture (Worldview/Worldview Legion)
- **Navigation** (GPS and GPS Augmentation)
- **Science/Astronomy:** Space Environment, Sun, Stars (Hubble, Jim Webb Space Telescope), Planetary
- **Technology Demo:** R&D; test & demo of new systems (Hitch-hikers; CubeSats)
- **Human Space Flight** – ISS
- **Highly Classified and Sensitive Missions** ("National Assets")

Classification by Orbit Type

- **GEO** – Geosynchronous/Geostationary (22,000 miles altitude / Circular Orbit in the equatorial plane)
- **LEO** – Low Earth Orbit (about 200 to 2000 km altitude – 120 to 1200 miles; usually circular)
- **MEO** – Medium Earth Orbit (about 2000 to 36,000 km altitude; can be circular or elliptical)
- **HEO** – Highly Elliptical Orbit (term often applied to specific types of elliptical orbits with a 63.4 deg inclination to equator)

What Is an Orbit?

- An Orbit is a closed*, curved path an object (satellite) follows around a central body (planet or other massive body)
- A balancing act between GRAVITY and the object's INERTIA (velocity)
  - If an object is given sufficient inertia in a lateral direction relative to a planet, its motion will carry it around the planet faster than it falls downwards (due to gravity) toward the planet's surface, and the object will continue "falling around" the planet.
- Kepler's and Newton's laws state that all orbits follow <u>*elliptical**</u> paths

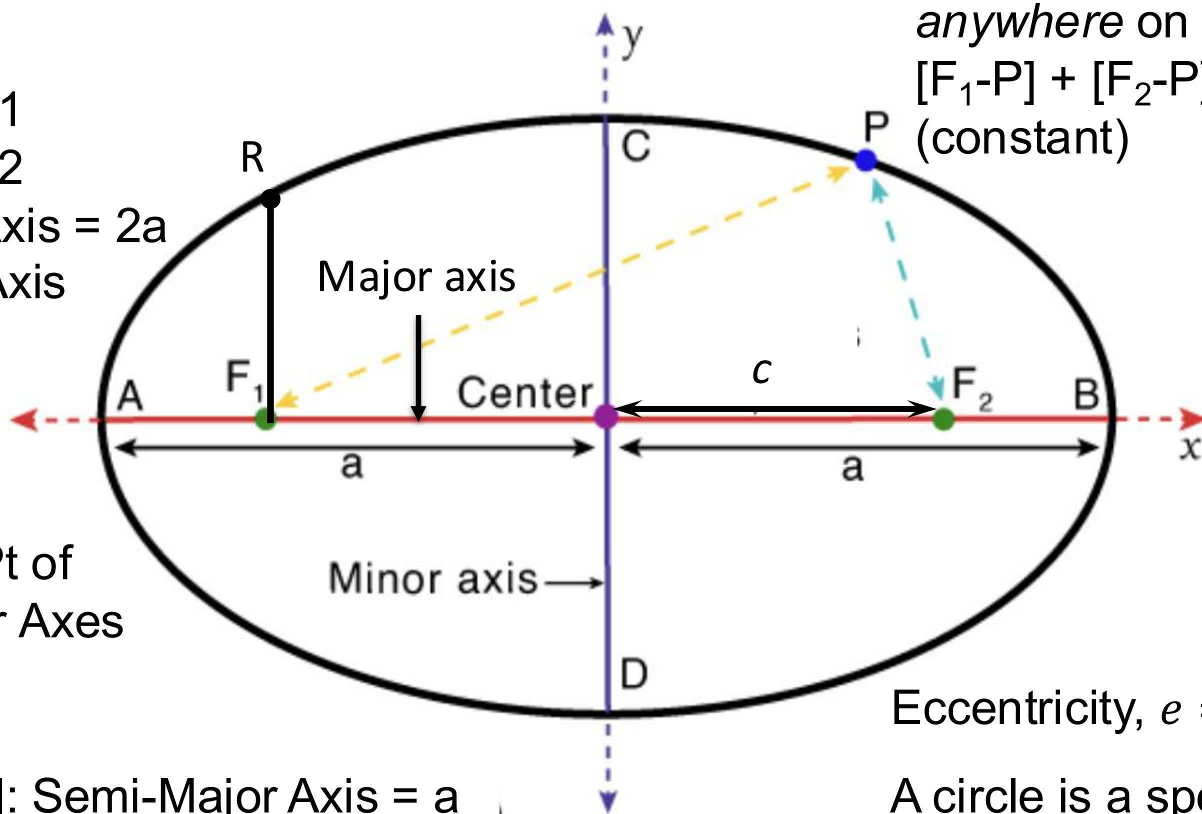
* NOTE: Parabolic and Hyperbolic orbital trajectories ("fly-bys"), in which an object's velocity exceeds "escape velocity" will not be addressed here

What is an Ellipse?

(A Type of Conic Section)

A: Vertex- 1
B: Vertex- 2
C: Co-Vertex-1
D: Co-Vertex-2
[A-B]: Major Axis = 2a
[C-D]: Minor Axis
F_1: Focus-1
F_2: Focus-2

For point P lying *anywhere* on the ellipse:
$[F_1\text{-}P] + [F_2\text{-}P] = 2a$
(constant)



Center: Mid-Pt of Major & Minor Axes

[Center-A]: Semi-Major Axis = a
[Center-C]: Semi-Minor Axis

Eccentricity, $e = c/a$

A circle is a special case of an ellipse with F_1 & F_2 both at the Center
Thus c=0 and e=0

A *WHAT???*

A: Vertex- 1
B: Vertex- 2
C: Co-Vertex-1
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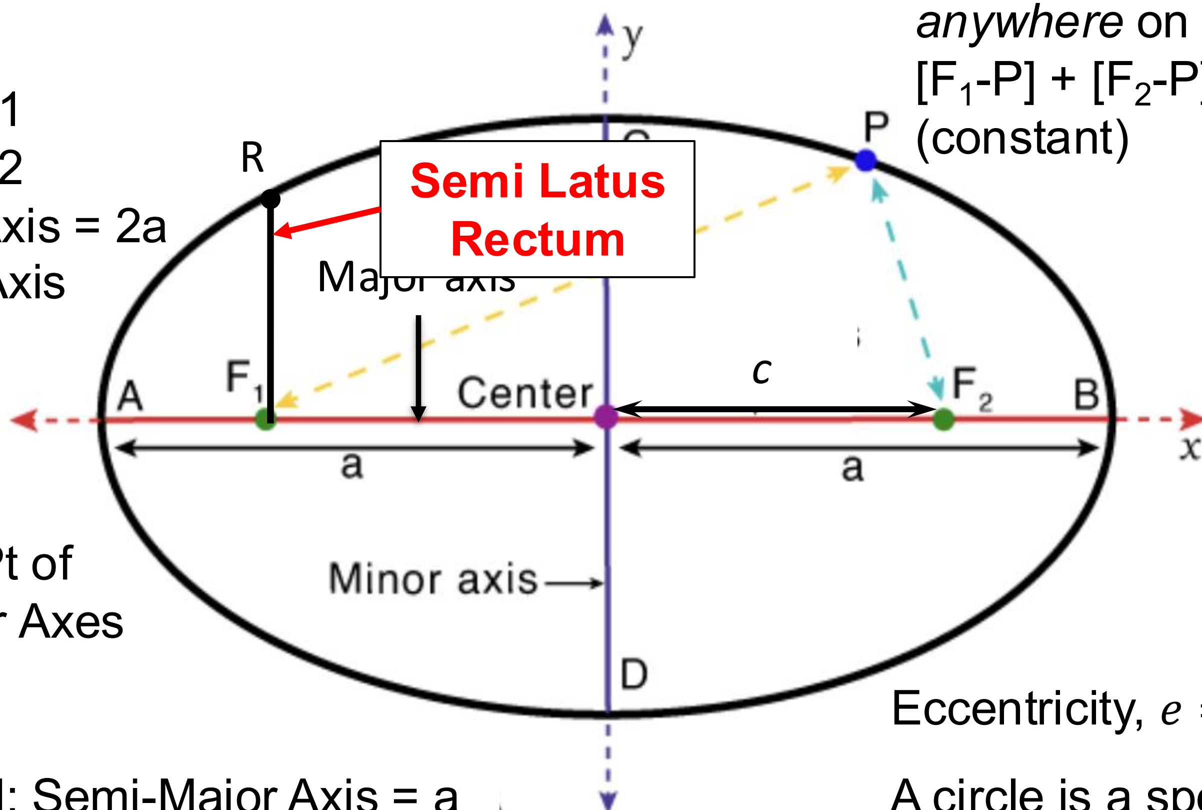


For point P lying *anywhere* on the ellipse: $[F_1\text{-}P] + [F_2\text{-}P] = 2a$ (constant)

[Center-A]: Semi-Major Axis = a
[Center-C]: Semi-Minor Axis

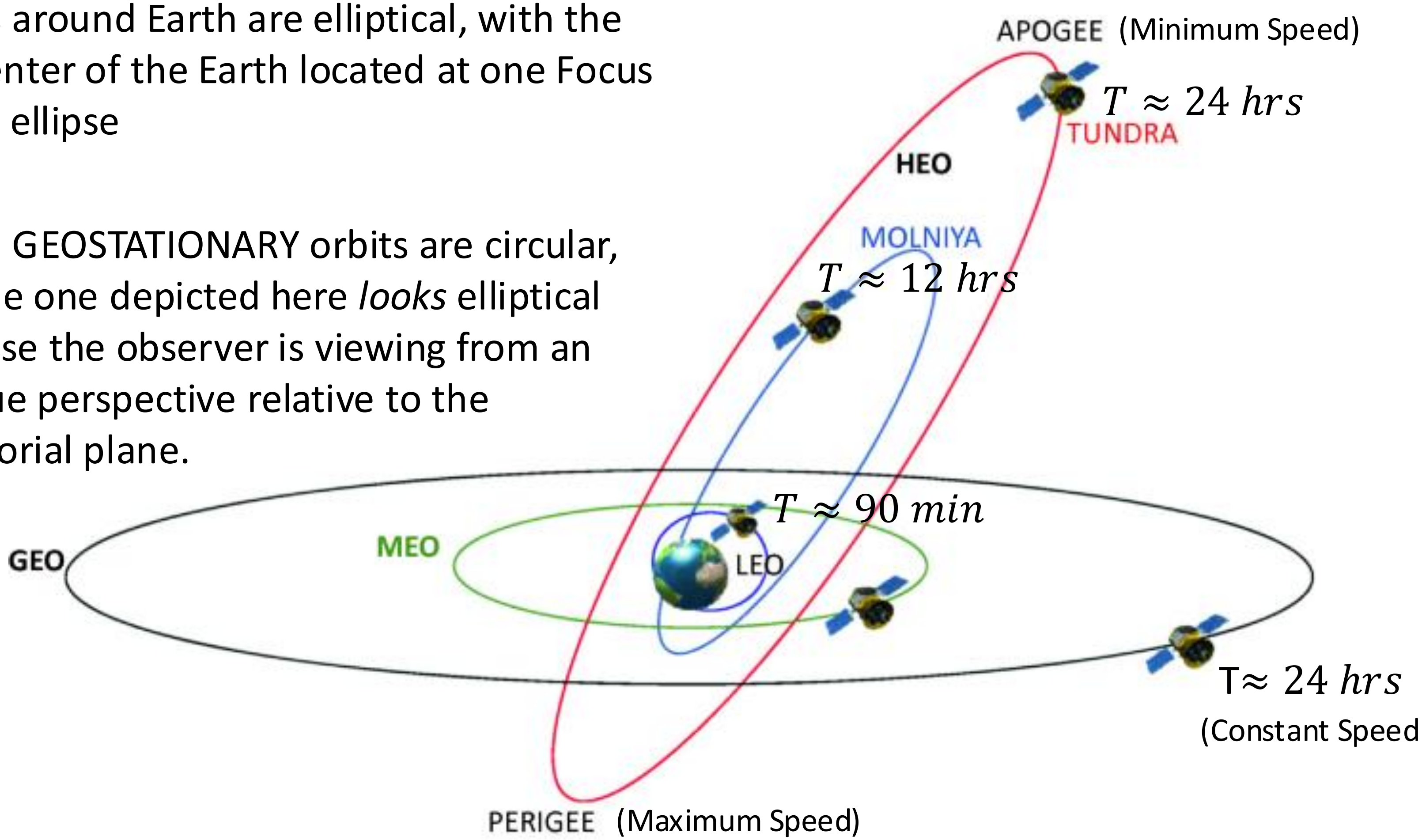
Eccentricity, $e = c/a$

A circle is a special case of an ellipse with F_1 & F_2 both at the Center; c=0 thus e=0

Orbit Types Visualized

Orbits around Earth are elliptical, with the the center of the Earth located at one Focus of the ellipse

Note: GEOSTATIONARY orbits are circular, but the one depicted here *looks* elliptical because the observer is viewing from an oblique perspective relative to the equatorial plane.



Orbital Elements

- **Orbital elements** are the parameters required to uniquely define a specific orbit in space and time
- In general, eight parameters are necessary to unambiguously define an arbitrary orbit.
  - Two to describe its size and shape (ellipse)
  - Three to describe the orientation of the plane of the orbit and the orientation of the orbit on that plane.
  - One to describe the speed of orbital motion
  - Two to describe the position of the orbiting satellite around its orbit as a function of time
- In practice, only six parameters need to be explicitly specified for orbits around the Earth

Classical Keplerian Elements

Assumptions

- Earth Orbit – Earth's gravitational constant assumed
- Reference Plane: Earth's Equatorial Plane
- Reference Direction: Direction to a specific point on the "celestial sphere" – Defines zero "Longitude"
- Time Reference: "Epoch" – Date/Time at which time dependent satellite parameters apply

Six Keplerian Elements

- Semi-Major Axis, a (km) - Size
- Eccentricity, e (ratio) - Shape
- Inclination, i (deg) – Angle between Ref (Equatorial) Plane and Orbit Plane
- RAAN, Ω (deg) – Angle between Ref Direction and Ascending Node (Right Ascension of the Ascending Node)
- Argument of Perigee, ω (deg) – Angle between Ascending Node and Perigee (Periapsis)
- Mean Anomaly, γ (deg) – Angle between Perigee and the "mean" position of the satellite at Epoch

6 Main Orbital Parameters

a semi-major axis

e eccentricity

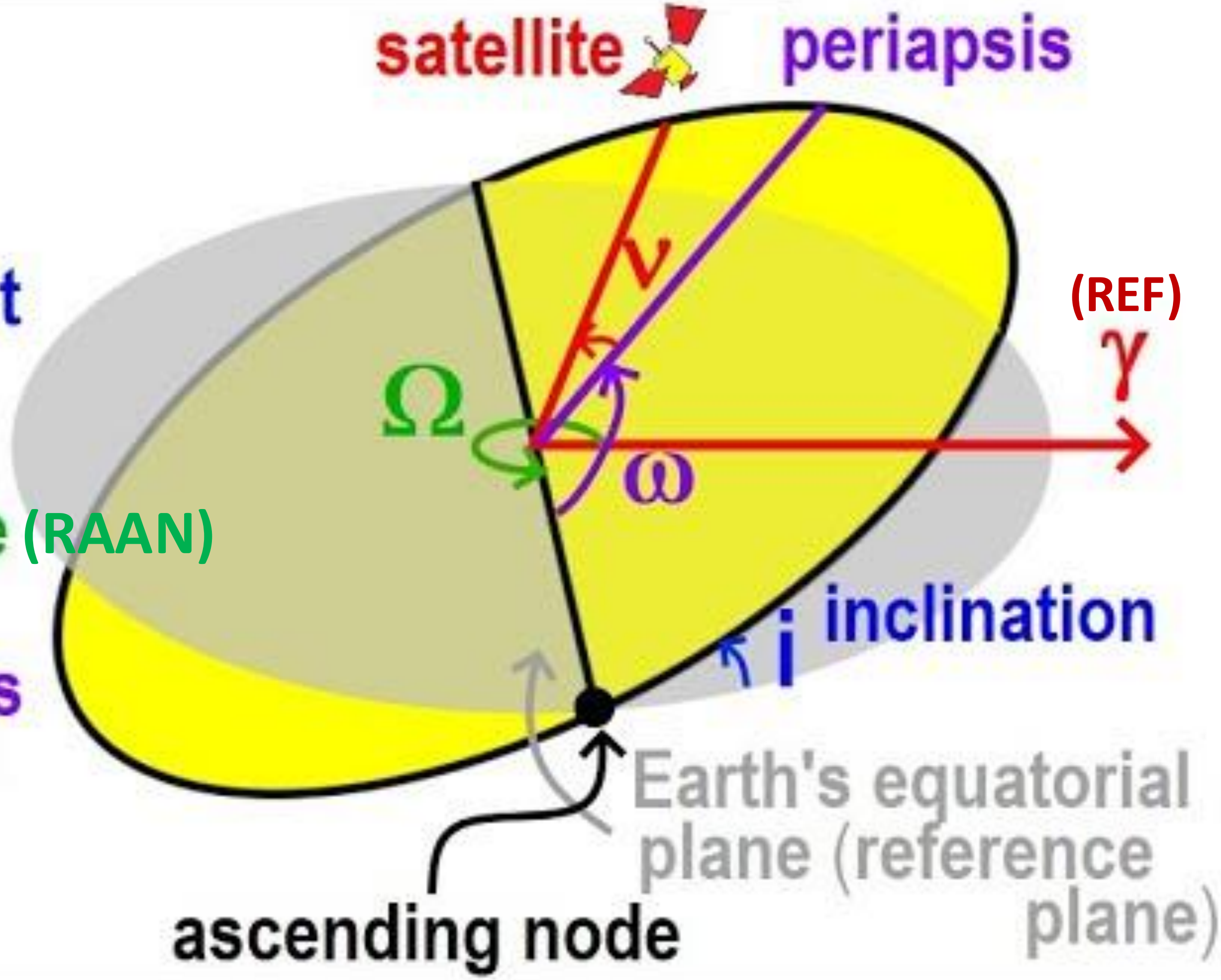
i inclination of orbit (tilt)

(Right Ascension)

Ω longitude of ascending node (RAAN)

ω argument of the periapsis

ν mean anomaly of epoch



Reporting Orbital Elements: *Element Sets ("Elsets" or "Keps")*

Purpose

- Enable users on the ground to properly point ground antennas to satellite (or simply to know where to look to catch a glimpse of a visible satellite)
- Support mission ops planning such as station keeping or orbit trim maneuvers

Report Format – Two-Line Element Sets (TLE's)

- Widely recognized standard format used by NASA, NORAD, and others, including ARRL

Decoding a TLE

ZCZC SK58
QST de W1AW
Keplerian Bulletin 58 ARLK058
From ARRL Headquarters
Newington, CT, July 25, 2025
To all radio amateurs

SB KEP ARL ARLK058
ARLK058 Keplerian data

Special thanks to AMSAT-NA (AMSAT.ORG) for the following Keplerian data.

Decode 2-line elsets with the following key:
1 AAAAAU 00 0 0 BBBBB.BBBBBBBB .CCCCCCCC 00000-0 00000-0 0 DDDZ
2 AAAAA EEE.EEEE FFF.FFFF GGGGGGG HHH.HHHH III.IIII JJ.JJJJJJJJKKKKKZ
KEY: A-CATALOGNUM B-EPOCHTIME C-DECAY D-ELSETNUM E-INCLINATION F-RAAN
G-ECCENTRICITY H-ARGPERIGEE I-MNANOM J-MNMOTION K-ORBITNUM Z-CHECKSUM

Mean Motion
- Number of Orbits per Day
- Used to **derive Semi-Major Axis**

Launch Info: Launched 1974; 89th successful launch of 1974; piece B

0 AO-7
1 07530U 74089B 25206.54527303 -.00000029 00000-0 10583-3 0 9999
2 07530 101.9944 211.3000 0012486 36.0796 94.9552 12.53690402319586
0 ISS
1 25544U 98067A 25206.42513046 .00012218 00000-0 22104-3 0 9996
2 25544 51.6348 117.5476 0002053 115.0064 245.1138 15.50086892521092

Orbital Period

- Newton's laws of motion and gravitation state that the period of an orbit – the time it takes for a satellite to complete one revolution around the central body – is a function of the size of the orbit
  - The larger the semimajor axis (or radius of a circular orbit), the longer the period

    Specifically: $T = 2\pi\sqrt{\frac{a^3}{GM}}$

    Where:

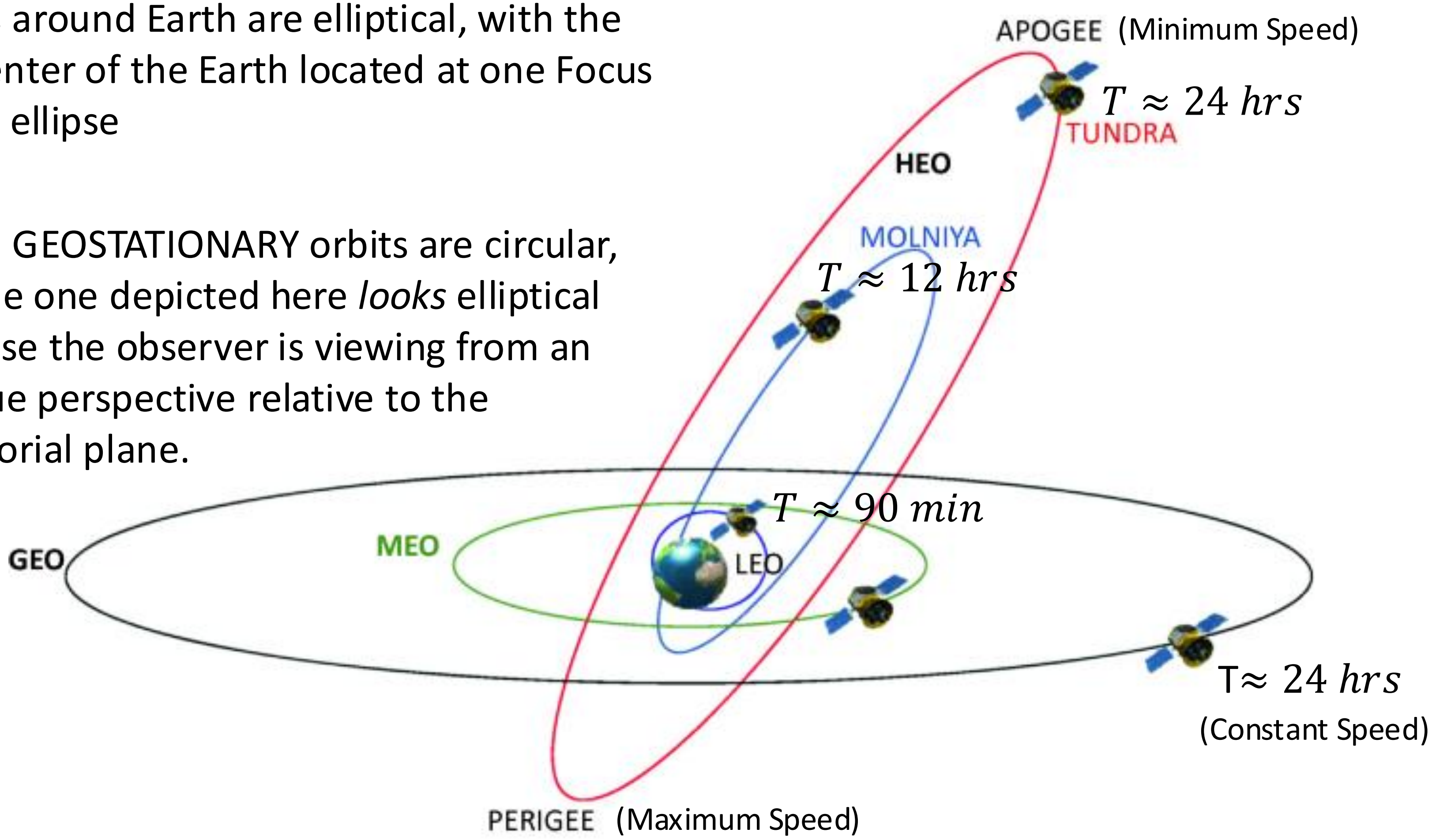
    $T = Period$
    $a = Semimajor\ Axis$
    $G = Gravitational\ Constant$ of Central Body
    $M = Mass\ of\ Central\ Body$

    - LEO: $\approx 90\ to\ 120\ min$
    - GEO: $\approx 24\ hrs$
  - This also means that the closer a satellite is to the central body, the faster its orbital speed

Orbit Types Visualized

Orbits around Earth are elliptical, with the the center of the Earth located at one Focus of the ellipse

Note: GEOSTATIONARY orbits are circular, but the one depicted here *looks* elliptical because the observer is viewing from an oblique perspective relative to the equatorial plane.



Orbit Determination

- Elsets gradually grow “stale” due to orbit perturbations and must be periodically updated
- Determination of a satellite’s orbital elements by measurement of its range, range rate, and angular position over time from specific locations on Earth’s surface
- NORAD tracks orbits of thousands of orbiting objects using radar, and publishes elset results
- Satellite operators track their satellites’ orbits using their closed-loop ranging systems and highly directional ground system antennas

Where can TLEs be found?

- Obtaining TLEs
  - GoSatWatch app
  - celestrack.org web site
    - See next slide
  - Amateur Radio satellites
    - ARRL Keplerian Bulletins
    - Amsat.org web site

CelesTrak.org Elsets

NORAD GP Element Sets
Current Data

Current as of 2025 Sep 04 14:07:32 UTC (Day 247)

A New Way to Obtain GP Data (aka TLEs)

TLE/3LE | 2LE | OMM XML | OMM KVN | JSON | JSON PP | CSV

Supplemental GP Data

Special-Interest Satellites	
Last 30 Days' Launches	
Space Stations	
100 (or so) Brightest	
Active Satellites Oldest | Docked	
Analyst Satellites	
Russian ASAT Test Debris (COSMOS 1408)	
Chinese ASAT Test Debris (FENGYUN 1C)	
IRIDIUM 33 Debris	
COSMOS 2251 Debris	
Weather & Earth Resources Satellites	
Weather	
NOAA	GOES
Earth Resources	
Search & Rescue (SARSAT)	Disaster Monitoring
Tracking and Data Relay Satellite System (TDRSS)	
ARGOS Data Collection System	
Planet	Spire
Communications Satellites	
Active Geosynchronous Movers	
GEO Protected Zone	GEO Protected Zone Plus
Intelsat	SES
Eutelsat	Telesat
Starlink	OneWeb
Qianfan	Hulianwang Digui
Kuiper	Iridium NEXT
Orbcomm	Globalstar
Amateur Radio	SatNOGS
Experimental Comm	Other Comm
Navigation Satellites	
GNSS	
GPS Operational	GLONASS Operational
Galileo	Beidou
Satellite-Based Augmentation System (WAAS/EGNOS/MSAS)	
Navy Navigation Satellite System (NNSS)	
Russian LEO Navigation	
Scientific Satellites	

Active Geosynchronous

Current as of 2025 Sep 04 14:07:32 UTC (Day 247)

Latest GP (TLE format) Data

Element Set Age (days)						
0–5	5–10	10–15	15–20	20–25	25–30	> 30

Show 25 entries Search:

International Designator	NORAD Catalog Number	Name	Period (minutes)	Inclination (degrees)	Apogee Height (km)	Perigee Height (km)	LAN (deg E)	Latest Data	GP Age (days)
1988-091B	19548	TDRS 3	1,436.07	12.82	35,938	35,634	-48.8		0.52
1989-077A	20253	FLTSATCOM 8 (USA 46)	1,436.23	12.50	35,803	35,775	125.5		0.73
1990-079A	20776	SKYNET 4C	1,436.11	13.43	35,814	35,760	33.3		0.66
1991-054B	21639	TDRS 5	1,435.99	14.11	35,833	35,736	-167.5		1.12
1993-003B	22314	TDRS 6	1,436.07	14.18	35,832	35,740	-45.7		0.36
1993-056A	22787	UFO 2 (USA 95)	1,436.13	11.80	35,800	35,775	28.7		0.66
1994-009A	22988	USA 99 (MILSTAR-1 1)	1,436.12	17.19	35,794	35,780	-90.0		0.75
1995-003A	23467	UFO 4 (USA 108)	1,436.11	9.67	35,803	35,770	172.3		0.48
1995-035B	23613	TDRS 7	1,436.19	13.50	35,827	35,750	89.0		0.75
1995-060A	23712	USA 115 (MILSTAR-1 2)	1,436.08	13.97	35,794	35,778	-120.0		0.69
1996-020A	23839	INM							
1996-053A	24307	INM							
1996-070A	24674	INM							
1997-050A	24936								
1997-065A	25019								
1998-006B	25153	INM							
1999-009B	25639	S							
1999-053A	25924								
1999-063A	25967	UFO							
2000-016A	26107								
2000-024A	26356	USA							
2000-034A	26388								
2000-059A	26554								
2000-065A	26575								
2000-067A	26580								

Notes:
- * Drifting > 0.1°/day (drift rate shown in parent
- ⓘ Link to additional information
- Link to custom search query for related news,
- Link to table for SupGP (TLE format) data (if
- Link to raw GP (TLE format) data
- ⓘ and in the International Designator column
- Link to plot of longitude of the ascending node

Showing 1 to 25 of 569 entries

```
TDRS 3
1 19548U 88091B   25247.09350105 -.00000292  00000+0  00000+0 0  9998
2 19548  12.8209 342.8836 0036015 341.8771   3.5795  1.00273419122518
FLTSATCOM 8 (USA 46)
1 20253U 89077A   25246.88454434 -.00000362  00000+0  00000+0 0  9992
2 20253  12.5017 352.8687 0003264 180.8075 253.4896  1.00262706257693
SKYNET 4C
1 20776U 90079A   25246.95807553  .00000133  00000+0  00000+0 0  9993
2 20776  13.4342 351.7513 0006433 242.8948 126.9200  1.00270626128026
TDRS 5
1 21639U 91054B   25246.49016484  .00000092  00000+0  00000+0 0  9994
2 21639  14.1062 355.8768 0011603 238.9308 117.0492  1.00279297124832
TDRS 6
1 22314U 93003B   25247.25451616 -.00000289  00000+0  00000+0 0  9995
2 22314  14.1763 359.1608 0011018 185.9232 204.4150  1.00273953119545
UFO 2 (USA 95)
1 22787U 93056A   25246.95729552  .00000130  00000+0  00000+0 0  9994
2 22787  11.7962   5.0797 0003008 219.5096 132.0495  1.00269390115679
USA 99 (MILSTAR-1 1)
1 22988U 94009A   25246.86238044 -.00000194  00000+0  00000+0 0  9998
2 22988  17.1892  30.7683 0001694 163.6659   9.2427  1.00270441 30086
UFO 4 (USA 108)
1 23467U 95003A   25247.12846295 -.00000018  00000+0  00000+0 0  9994
2 23467   9.6706  14.1369 0003921 153.9507  33.9711  1.00270670112080
TDRS 7
1 23613U 95035B   25246.86771227 -.00000230  00000+0  00000+0 0  9990
2 23613  13.4964 350.1481 0009020  97.2521 297.2007  1.00264943110382
USA 115 (MILSTAR-1 2)
1 23712U 95060A   25246.92772740 -.00000014  00000+0  00000+0 0  9996
2 23712  13.9674   5.8376 0001895 152.6389  38.7979  1.00272897 30016
INMARSAT 3-F1
1 23839U 96020A   25247.13288296  .00000082  00000+0  00000+0 0  9999
2 23839  10.0013  49.1896 0007663 135.1076  41.3238  0.99996454107390
INMARSAT 3-F2
1 24307U 96053A   25247.03858922 -.00000069  00000+0  00000+0 0  9990
2 24307   9.2041  56.7722 0006622 104.9170 275.0375  0.99975708106067
INMARSAT 3-F3
```

What do you do with them?

For sky watching – where and when to look for visible satellites (mostly LEO orbits)

Heavens Above web site; GoSatWatch app

Lots of other resources for this – Elsets are transparent to the user

For ground antenna pointing angles (Az/El) and Tracking

Real-time tracking: Gpredict (Win, Mac, Linux); SatPC32 (Win)

Direct-to-Home (e.g. DirecTV, Dish) fixed dish pointing to GEO: www.dishpointer.com or resources provided by the DTH provider

GEOSTATIONARY SATELLITES

The GEO Sweet Spot

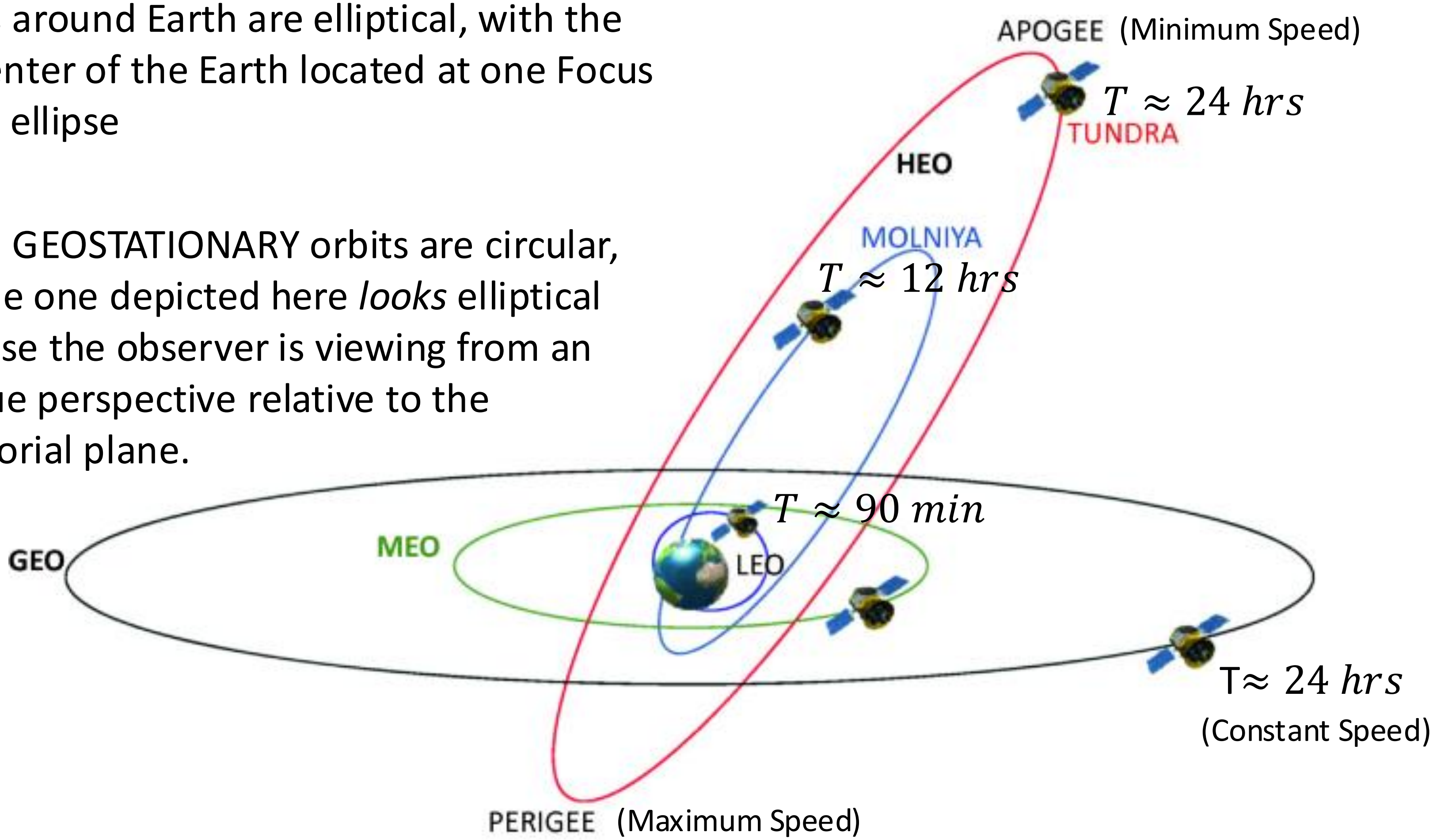
- "GEO" usually means GEOSTATIONARY orbit, but can also refer to GEOSYNCHRONOUS orbit
- GEOTATIONARY Orbit (First proposed by Arthur C. Clarke)
  - Circular (Eccentricity close to 0)
  - Equatorial Orbit Plane (Inclination close to 0)
  - Orbit period = 23hrs, 56mins, 4sec (Mean Motion close to 1.0027) – corresponds to 1 SIDEREAL day
  - Satellite's position in the sky is almost a fixed point
  - Ideal for continuous coverage (TV, broadband, QO-100)
  - RF footprint = wide coverage zone – approximately 40% of the earth's surface is visible from GEOSTATIONARY
- GEOSYNCHRONOUS orbit:
  - Orbit Period = 23hrs, 56mins, 4sec
  - Satellite returns to the <u>same spot in the sky</u> at the <u>same time each day</u>
  - Example – Tundra Orbit (HEO) as in first 3 Sirius Satellite Radio sats
- All GEOSTATIONARY orbits are also GEOSYNCHROUS, but not vice-versa

Orbit Types Visualized

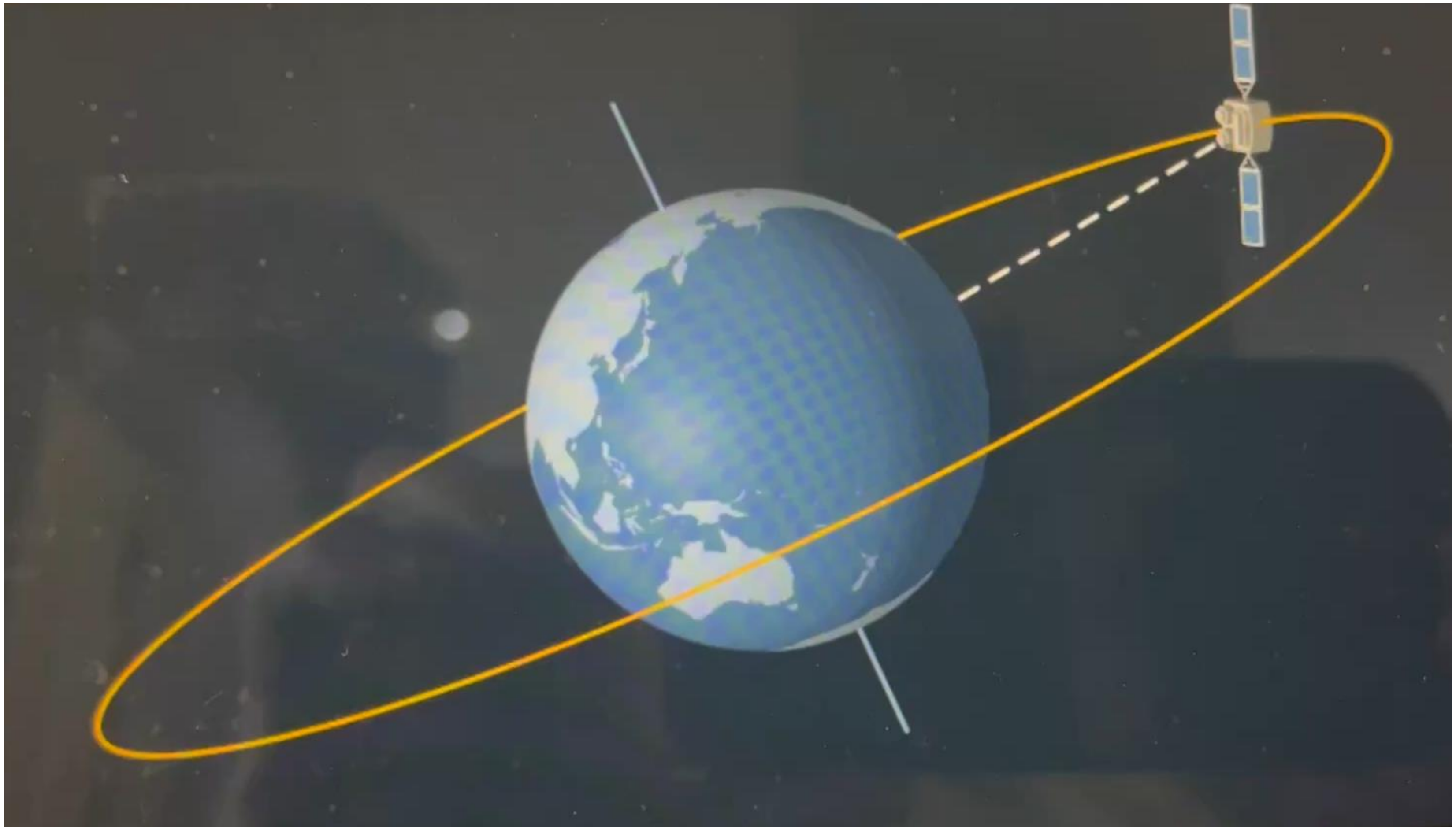
There is an excellent video on YouTube that illustrates several of these orbit types
https://www.youtube.com/watch?v=PZAkiXNJIqc - **Scott Manley**

Orbits around Earth are elliptical, with the the center of the Earth located at one Focus of the ellipse

Note: GEOSTATIONARY orbits are circular, but the one depicted here *looks* elliptical because the observer is viewing from an oblique perspective relative to the equatorial plane.



GEO Orbit Animation



Getting from Here. . .

. . . To Here

Thor-7 Launch Operations

Guiana Space Centre, French Guiana

- Thor-7 Satellite Transport to Launch Base (Left)
- Ariane-5 Launch Vehicle On-Stand with Thor-7 (Center)
- Liftoff! (Right)

From Launch Site to GEO via GTO

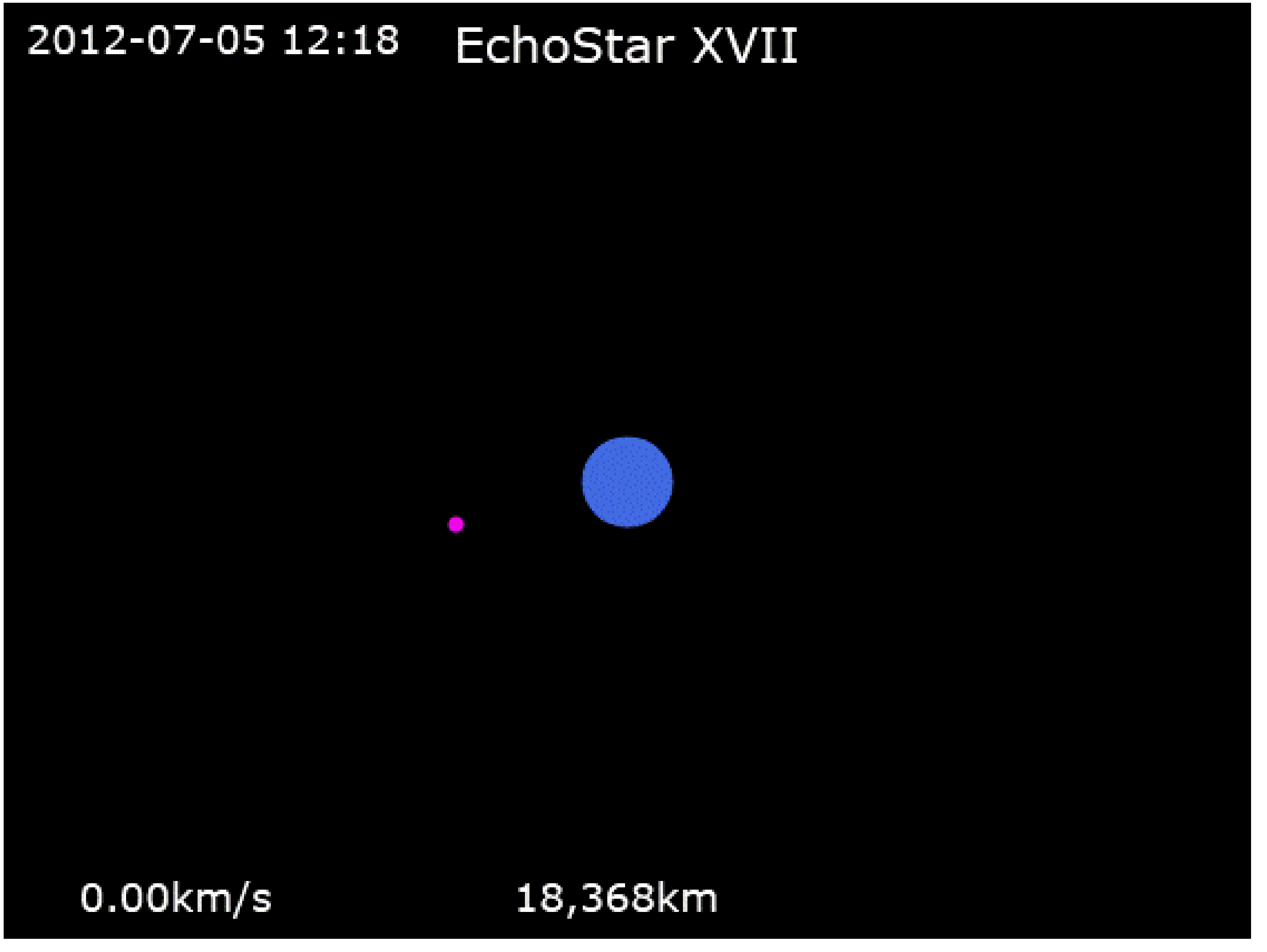
- No, not a Pontiac muscle car; GTO = Geostationary Transfer Orbit
- Launch Vehicle upper stage deploys satellite into a highly elliptical, intermediate orbit
  - Perigee of a few hundred miles altitude
  - Apogee of 22,236 mi altitude = GEO altitude
  - Inclined orbit (usually) - determined by launch base latitude
  - Satellite deployment marks end of Launch Ops
  - Sets up a fuel-efficient transition to GEO orbit
- Satellite Mission Ops team then initiates “Orbit Raising” Ops to achieve the intended GEO orbit

Orbit Raising

- Mission Ops conducted from the Mission Control Center (MCC) by the Mission Team
  - Mission Director, Flight Directors, Ops Engineers, Mission Specialists
  - Per Pre-planned, detailed Mission Sequence
  - Network of Tracking Stations providing:
    - Telemetry, Tracking and Command (TT&C)
    - Coverage for key orbit raising events
- Key events – for bi-prop propulsion system
  - Initial acquisition of telemetry signal; health assessment
  - Solar array deployment – Power Positive
  - Attitude control via bi-prop RCS thrusters
  - Orbit Determination
  - Apogee Maneuver Firings (AMFs) – typically 3 to achieve GEO – uses Main Satellite Thruster
  - Trim Maneuver Firing (TMF) – to position the satellite "in the box" – Uses smaller RCS thrusters
  - Wheel Spin-up/Establish Wheel Mode attitude control
  - Deployment of Communications Repeater Antennas
  - Approximately 10 days to complete
- Ready for In-Orbit Test (IOT) – sometimes called In-Orbit commissioning

Apogee Maneuver Firing

Orbit Raising of Echostar XVII (Jupiter-1)

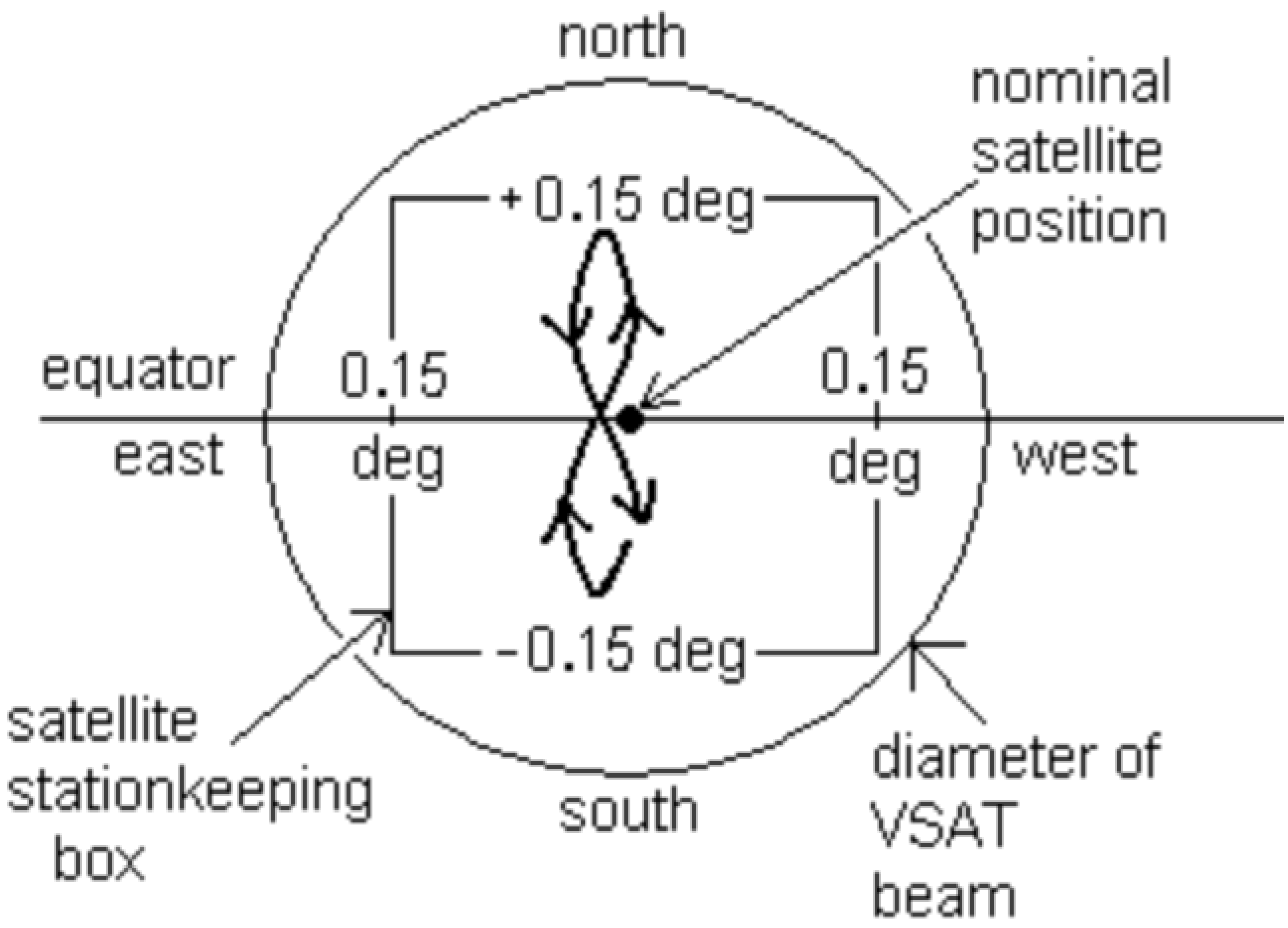


On-Station Operations

Orbit Control – Stationkeeping

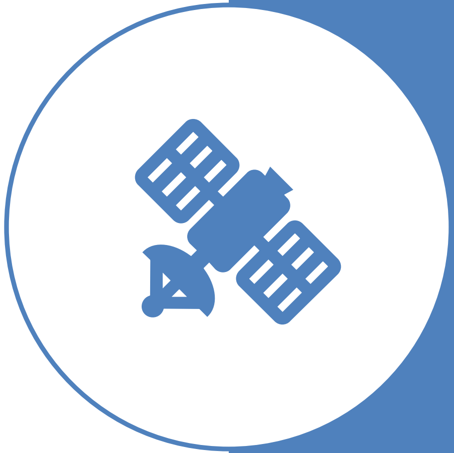
- Various forces act on a GEO satellite that gradually perturb its orbit (and its attitude)
  - Lunar and Solar gravitational fields
  - "Lumpiness" of Earth's gravitational field
  - Solar Wind (high speed charged particles)
  - Solar Pressure (photons)
- These forces gradually change the orbital elements resulting in an oscillating figure-8 movement as well as drift away from its assigned location which grow over time
- If left uncorrected, the satellite's movement will take it outside its assigned "box": N/S and E/W stationkeeping needed
- Use of bi-prop or electric propulsion for corrections
- Stationkeeping fuel budget affects satellite lifespan
- All of this also necessitates regular updating of the TLEs

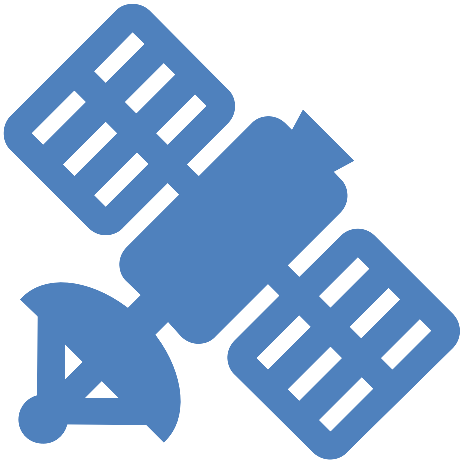
Stationkeeping "Box"



Attitude Control - Pointing

- Satellite Attitude is crucial for maintaining correct antenna pointing and solar array orientation
- Most GEO satellites use 3-axis stabilization
  - Momentum wheels (spinning flywheels) for storage and adjustment of angular momentum in all 3 axes.
  - Gyros or Star Trackers to detect small attitude changes
  - Closed-loop control system to modulate momentum wheel speed (angular momentum) to counteract attitude changes
- Wheel speeds eventually creep up or down towards max or min useful limits: saturation
  - Wheels must be “desaturated” using the RCS thrusters – usually performed autonomously





Satellite Design

Satellite Bus

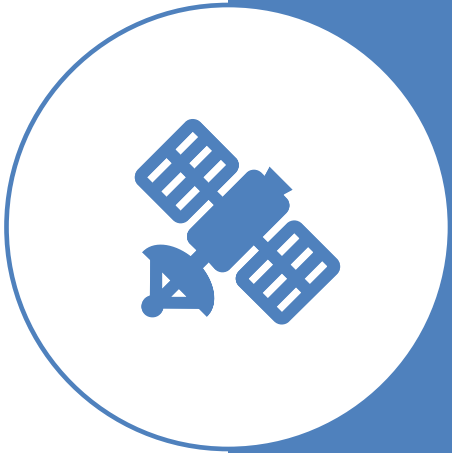
Satellite Payload

Satellite Bus

- Perform all functions required to support all satellite operations in orbit
- Satellite Bus Subsystems
  - Satellite Structure
  - Power Subsystem – Solar Arrays, Batteries & controllers
  - Thermal Control – Temp sensors, heaters, heat pipes, radiators
  - Propulsion Subsystem – MST, RCS (or electric thrusters)
  - Attitude Control Subsystem
  - Telemetry, Command, and Ranging Subsystem – Command Receivers, Command & Telemetry Processors, Telemetry Transmitters, Antennas
  - Main Satellite Processor

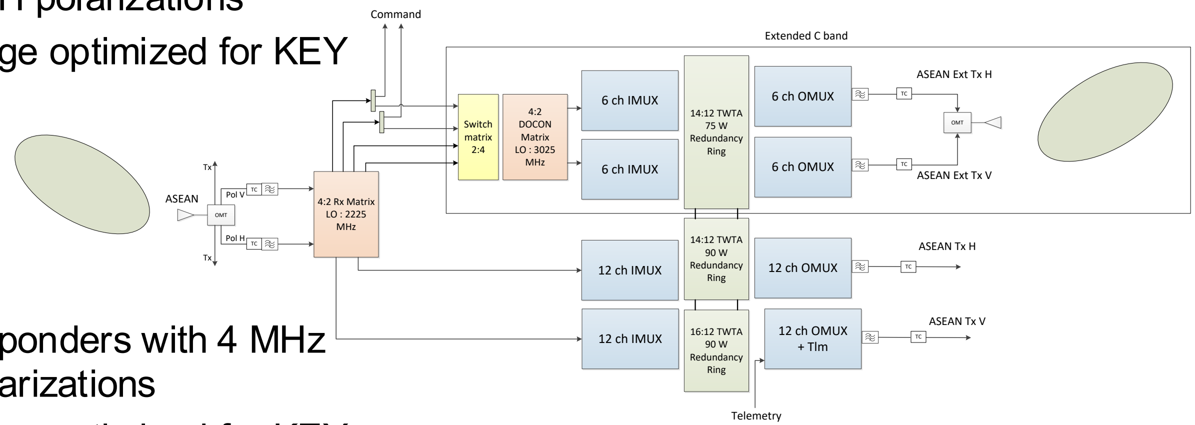
Satellite Payload

- The "Payload" of a communications satellite is usually called a Repeater – there can be multiple repeaters on one satellite
  - C-Band, Ku-Band, Ka-Band Repeaters
  - Repeaters dedicated to specific geographic regions
- Each repeater is comprised of a set of channels called Transponder channels, or simply Transponders
  - Each transponder operates at a unique frequency, and/or antenna polarization, and/or antenna beam
  - Receives an "uplink" signal, translates it to the "downlink" frequency, amplifies it, and re-transmits
- Antenna feeds and Reflectors provide the required receive and transmit coverage beam patterns
- Repeater components include Low Noise Amps (LNAs) and/or Receivers, Downconverters, Upconverters, Linearizing Amps, Travelling Wave Tube Amps (TWTAs) and/or Solid-State Power Amps (SSPAs), filters, multiplexers, redundancy, switching

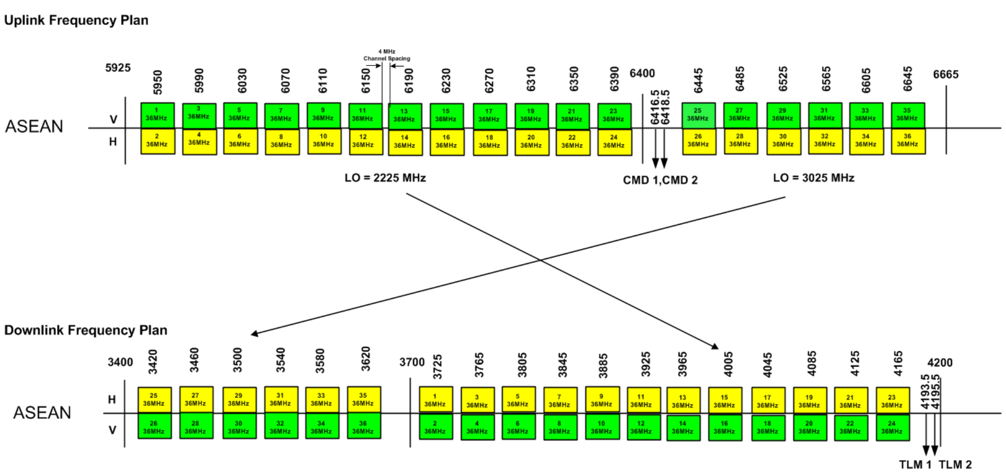


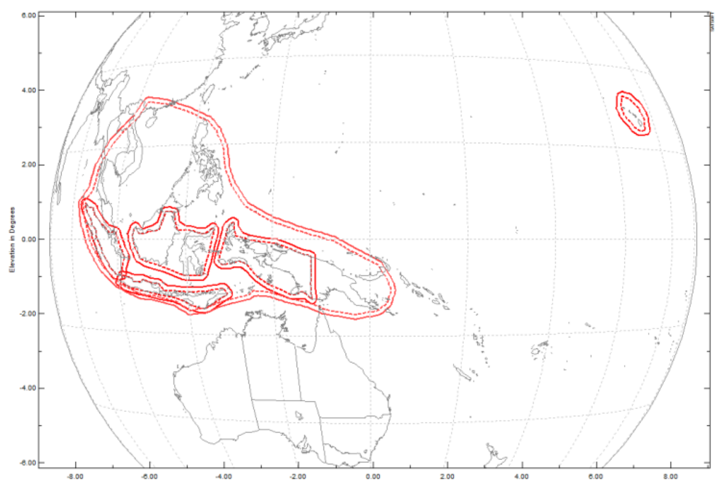
Example C-band Payload Summary Description

- Standard C-band Payload
  - Twenty Four 36 MHz transponders with 4 MHz spacing on V & H polarizations
  - Fixed ASEAN coverage optimized for KEY ISLANDS



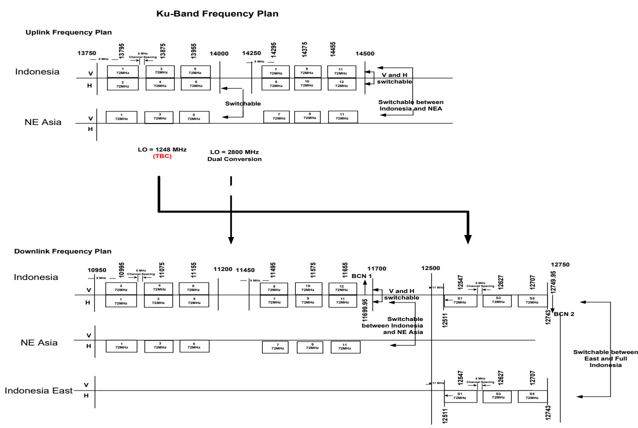
- Extended C-band Payload
  - Twelve 36 MHz transponders with 4 MHz spacing on V & H polarizations
  - Fixed ASEAN coverage optimized for KEY ISLANDS

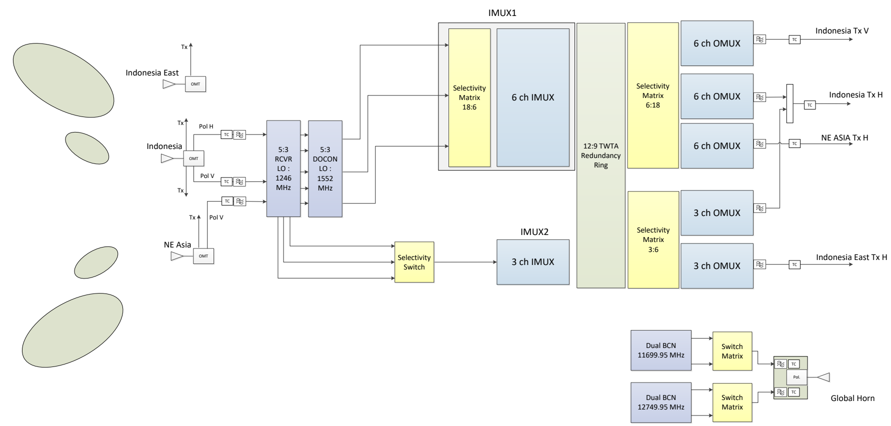




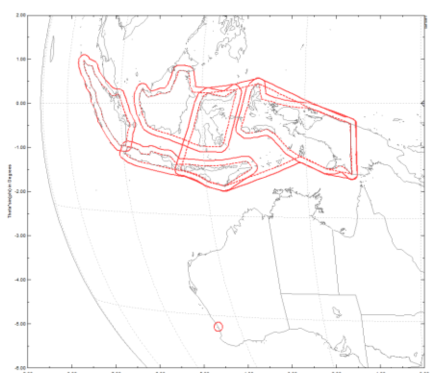
Example Ku-band Payload Summary Description

- Nine 72 MHz transponders with 8 MHz spacing
- Two fixed receive beams from Indonesia and NE Asia
- Three fixed transmit beams to Indonesia, NE Asia and East Indonesia

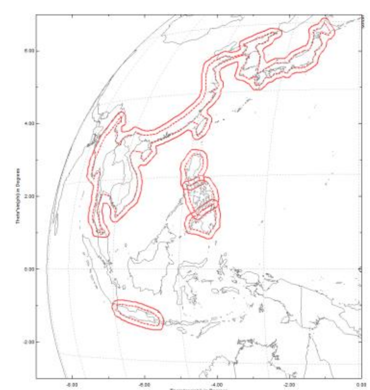




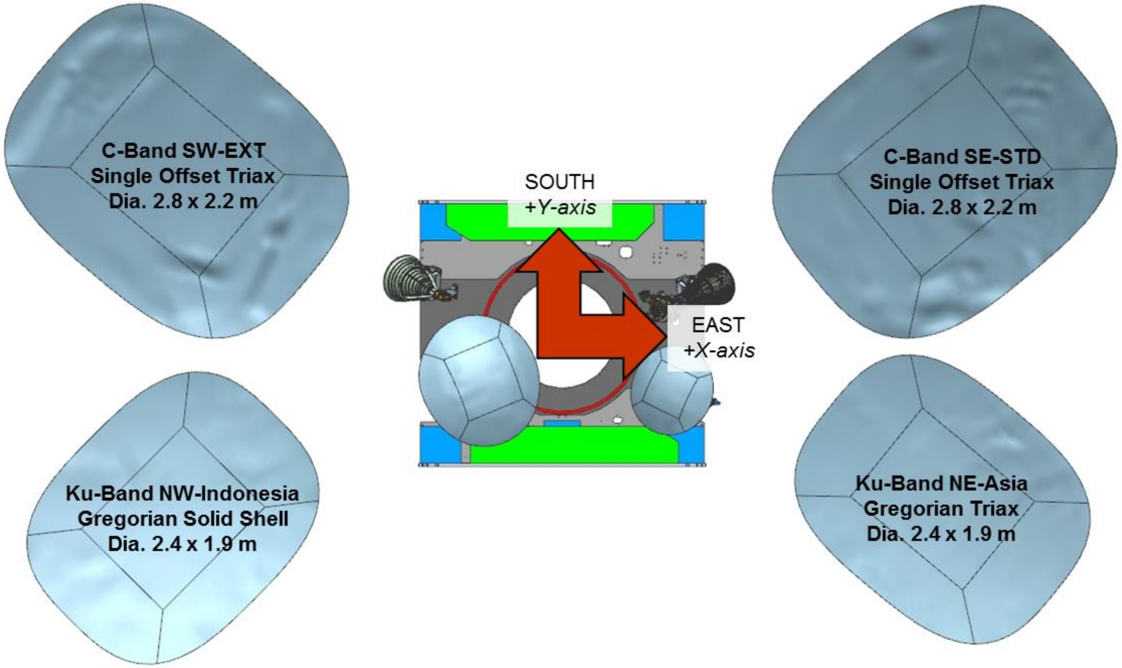
Ku-band Indonesian & East Indonesian



Ku-band North East Asia

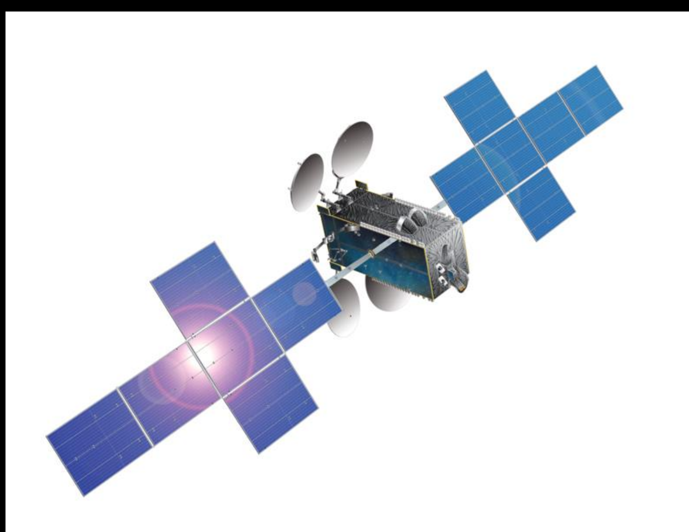


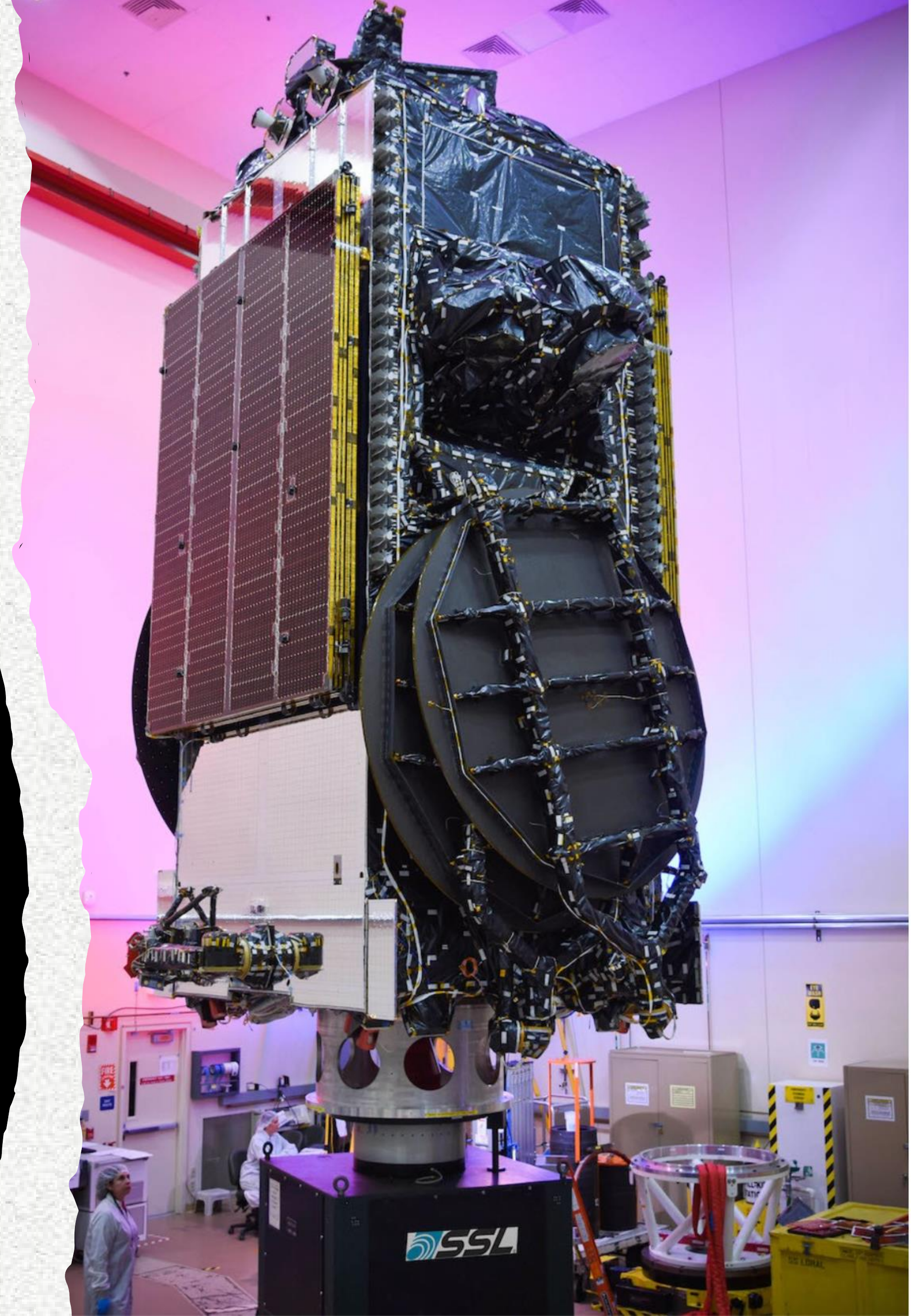
Satellite Antenna Example



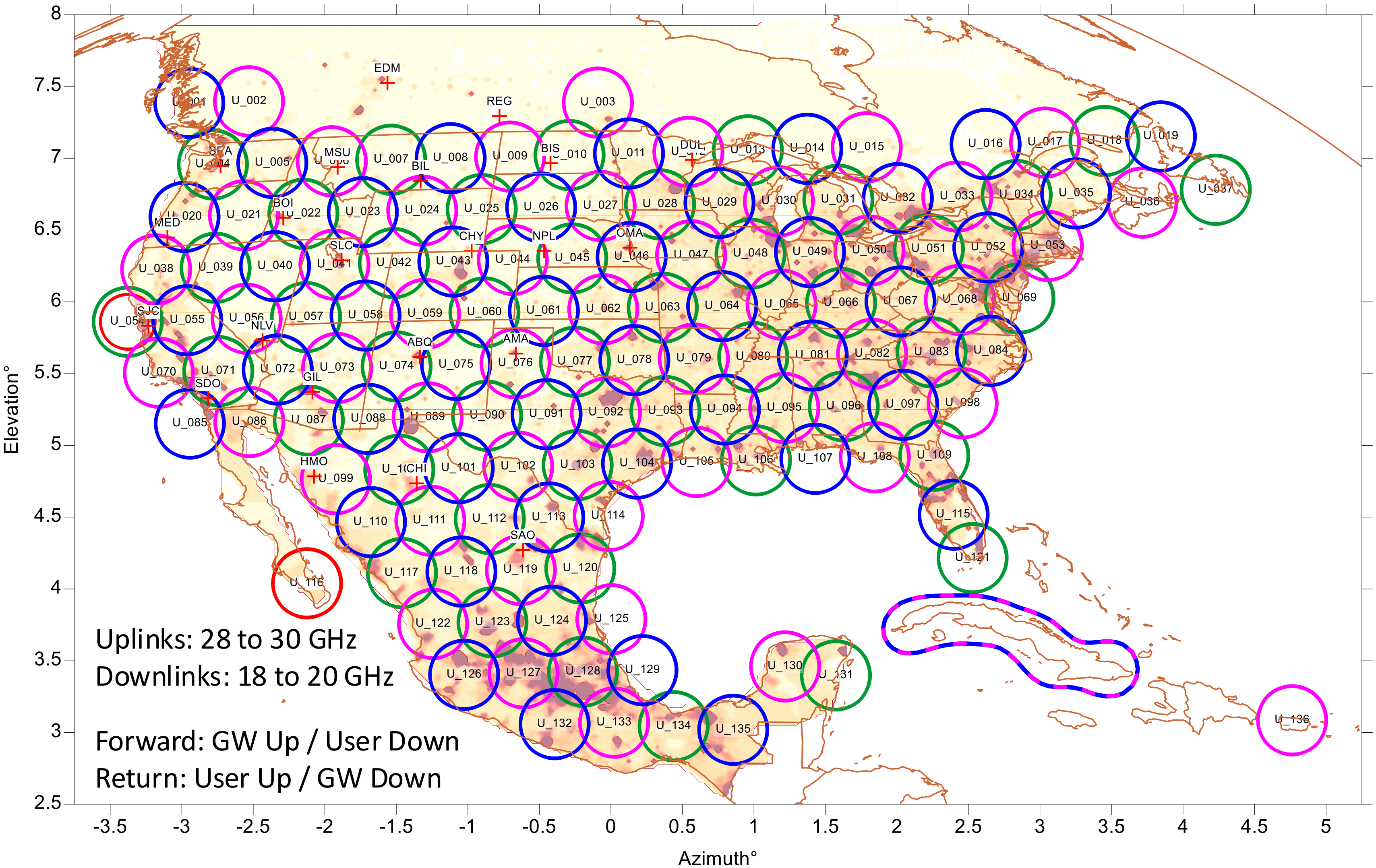
Example
High Throughput Satellite (HTS)

Jupiter-2 (Echostar XIX)
Internet Connectivity





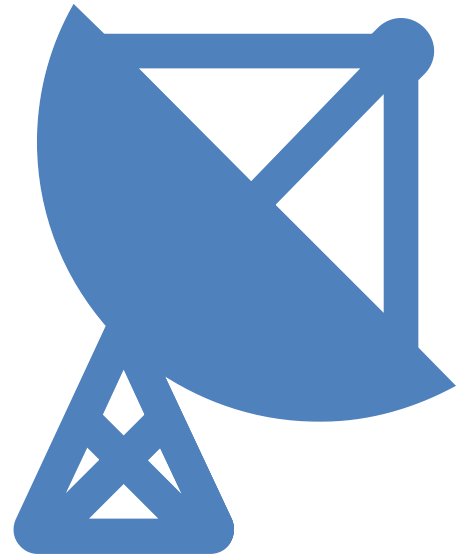
J2 User and Gateway Ka-Band Spot Beam Coverage



Key Communications Payload Performance Parameters

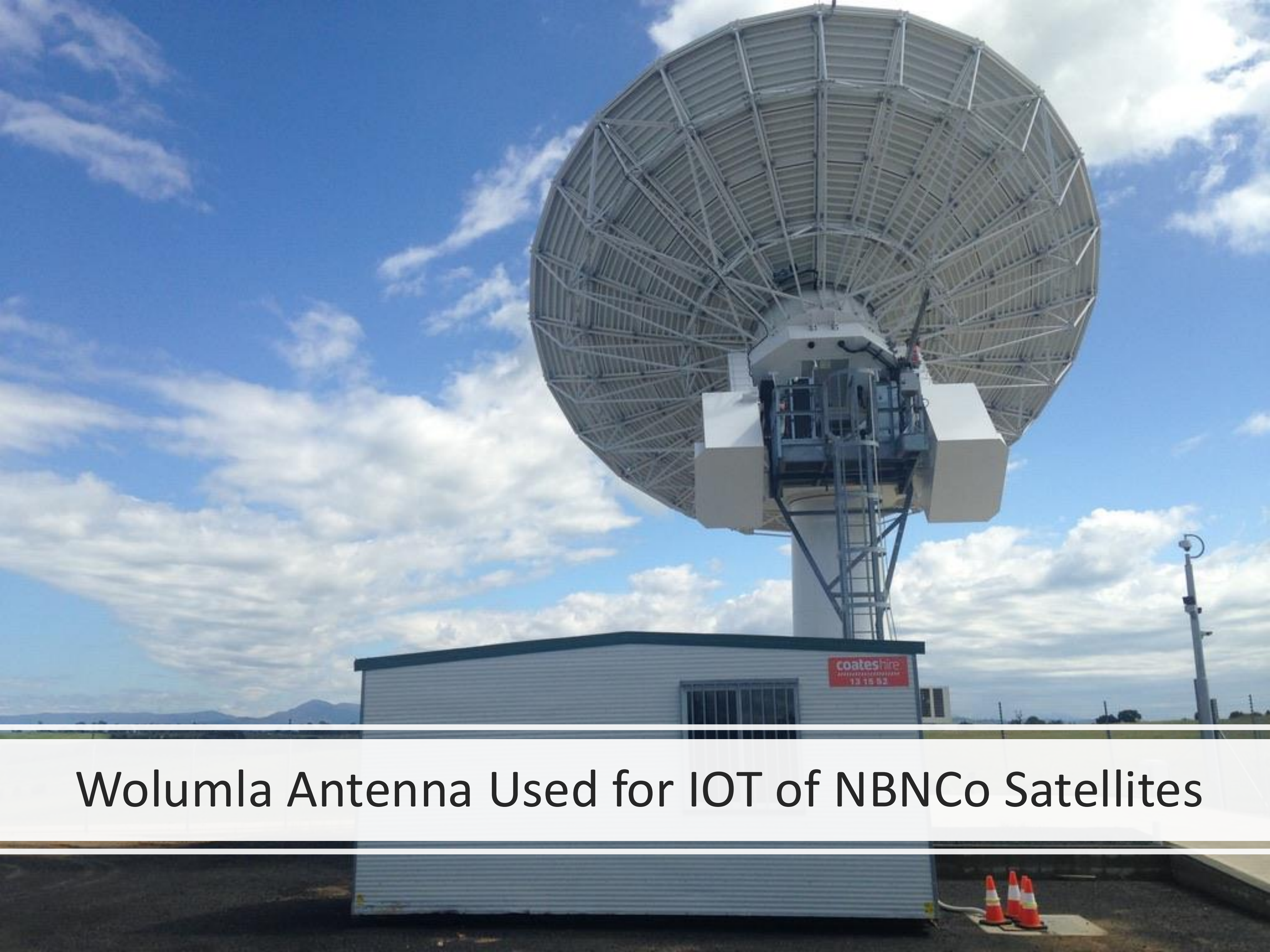
- Receive Figure of Merit: G/T
  - Receive Antenna Gain (G) divided by System Noise Temperature (T)
  - Verification Test: D/L Signal-to-Noise at known U/L
- Saturation Flux Density: SFD
  - U/L signal level (flux density) required to saturate the channel power amp (TWTA)
  - Verification Test: Gain Transfer – D/L level vs U/L
- Effective Isotropic Radiated Power: EIRP
  - Radiated (Downlink) power at saturation
  - Verification Test: Measure D/L power received at ground antenna with U/L signal at saturation
- In-Band Frequency Response
  - Gain flatness across channel passband
  - Verification Test: D/L signal level variation as U/L frequency stepped or swept across the channel passband
- Antenna Patterns:
  - Compliance with specified coverage - Receive G/T & Transmit EIRP
  - Verification Test: Pattern ”cuts” – Azimuth cuts (East/West) and Elevation cuts (North/South)
- For In-Orbit Test S/C attitude is purposely biased and/or slewed in Az & El to point a specific point or points in the antenna pattern at the IOT earth station for above testing

Ground Segment



- Large-aperture, steerable antennas
  - Full Motion (FMA) for GTO & Orbit Raising
  - Limited Motion (LMA) for On-Station Ops and traffic
  - Typically parabolic dish with Cassegrain feed
- High Power Amplifiers (Uplinks): Klystron, TWTA, SSPA
- Low Noise Amplifiers (Donwnlinks): Mounted close to antenna feed
- Calibrated directional couplers near antenna feed for sampling uplink power and injecting calibration signals into downlink for in-orbit-testing & monitoring
- Telemetry, Command, and Ranging processor (e.g. CORTEX)
- Tracking System: Antenna Control Unit, Beacon Receiver, Motors, Motor Drivers, Encoders - Keep antenna pointed to satellite
  - Program Track – Uses current Elsets
  - Step Track – Periodically steps antenna pointing to “re-peak” on D/L beacon
  - Monopulse Track – Continuous closed-loop control using D/L beacon and sum/difference feeds (required for accurate orbit determination)

NBNCo Earth Station – Wolumla, NSW, Australia

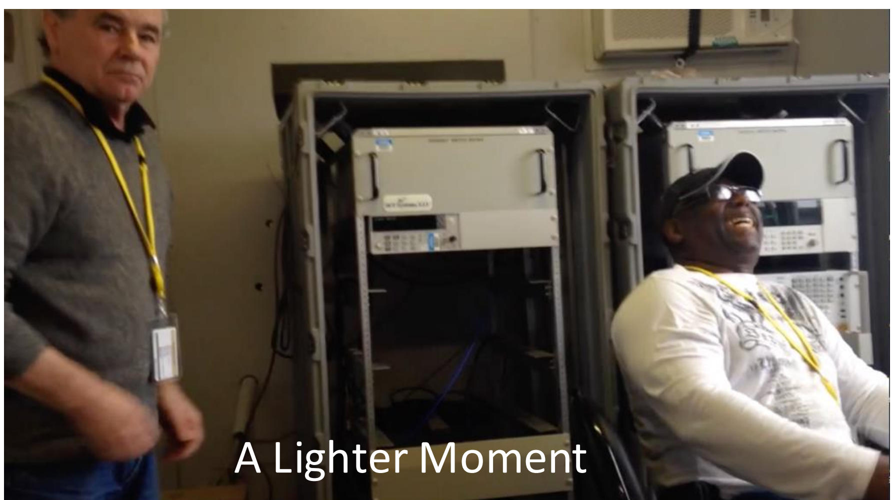


Wolumla Antenna Used for IOT of NBNCo Satellites

The In-Orbit Test Team at Work in Wolumla


IOT Setup Inside the Shelter

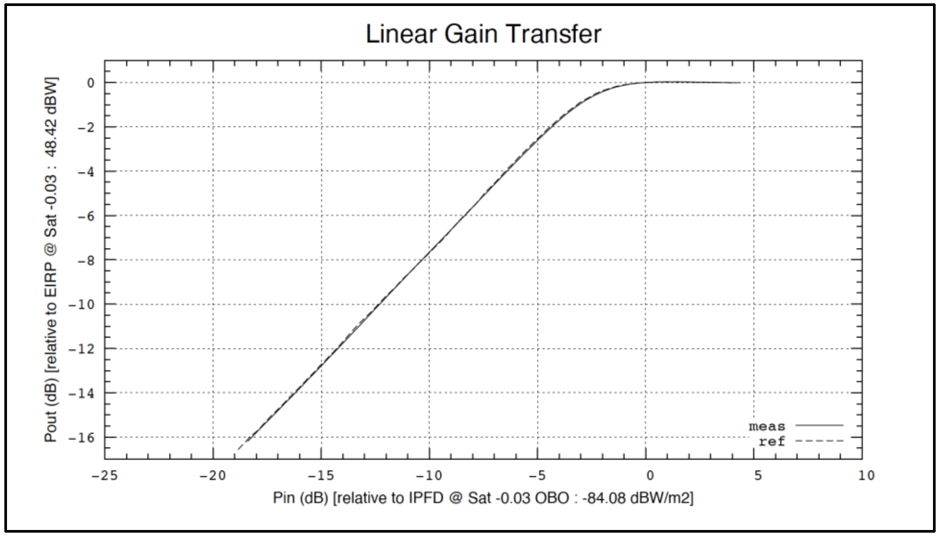

The temporary IOT Shelter

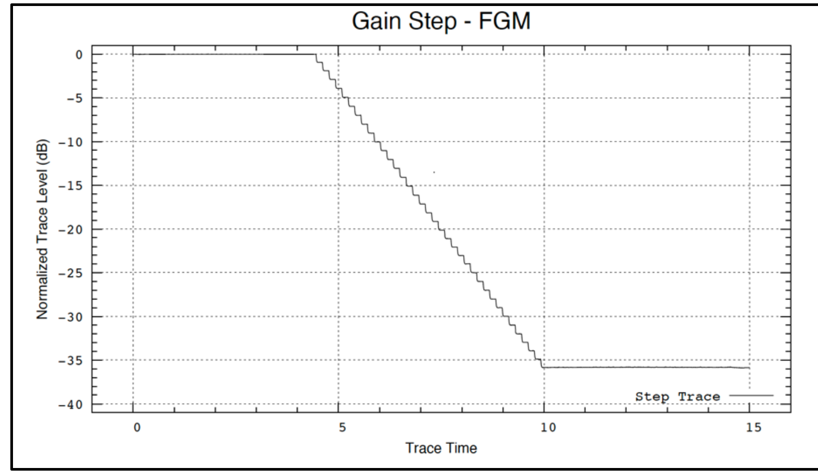

A Lighter Moment

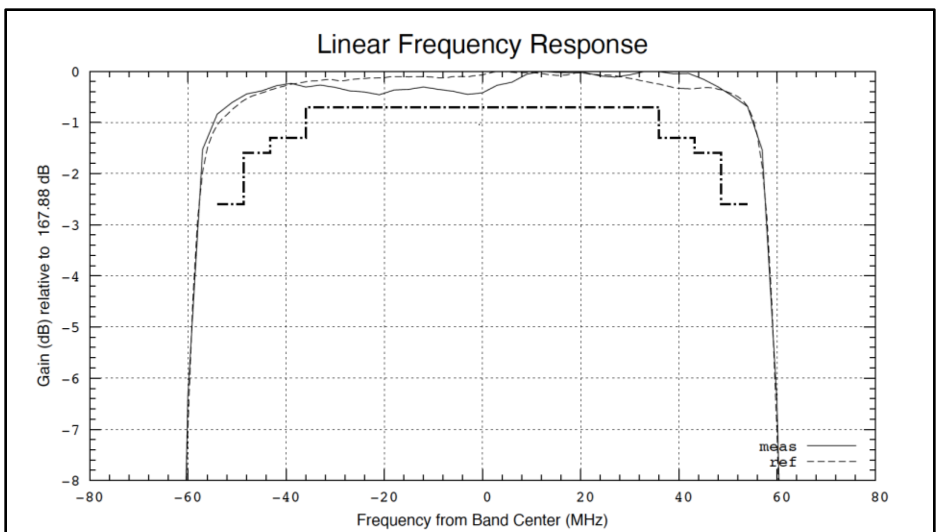

The "Garbage Tip" Next Door

Yours Truly conferring with local propagation experts

Sample Payload IOT Data







Translation Frequency

		Meas	Ref	Delta
Nom UL Freq	:	5985000000.000 Hz	5984205000.000 Hz	795000.000 Hz
Nom DL Freq	:	3760000000.000 Hz	3759205000.000 Hz	795000.000 Hz
Nom Trans	:	-2225000000.000 Hz	-2225000000.000 Hz	0.000 Hz
DL Freq	:	3760000435.020 Hz	3759206032.083 Hz	794402.937 Hz
Tran Freq	:	-2224999564.980 Hz	-2224998967.917 Hz	-597.063 Hz
Delta	:	-435.020 Hz	-1032.083 Hz	597.063 Hz
Delta (PPM)	:	-0.196 ppm	-0.464 ppm	0.268 ppm

Cross-Pol Isolation

TRANSMIT

UPLINK	DOWNLINK		IPFD	EIRP
Co-Pol	Co-Pol	:	-84.14 dBW/m2	48.06 dBW
Co-Pol	Cross-Pol	:	-84.14 dBW/m2	8.46 dBW

TX CROSS-POL ISOLATION : 39.60 dB

RECEIVE

UPLINK	DOWNLINK		IPFD	EIRP
Co-Pol	Co-Pol	:	-94.21 dBW/m2	40.86 dBW
Cross-Pol	Co-Pol	:	-95.12 dBW/m2	-2.13 dBW

RX CROSS-POL ISOLATION : 42.09 dB

Amateur Radio In Orbit

Amateur Radio Satellites: Then and Now
Early OSCAR Satellites

Aug. 1960

Project OSCAR (Orbiting Satellite Carrying Amateur Radio): Brainchild of a group of West Coast Hams; established in Aug, 1960

12 Dec. 1961

OSCAR-1 (Dec 12, 1961; Vandenberg): 10lbs; 145 MHz beacon (“HI” in Morse); 18-day LEO mission

2 June 1962

OSCAR-2 (June 2, 1962; Vandenberg): Similar to OSCAR-1; 18-day LEO mission

9 Mar. 1965

OSCAR-3 (March 9, 1965; Vandenberg): 33lbs; 1-watt, 50kHz transponder; 144.1→145.9MHz; 2 Beacons; 16-day LEO mission (still in orbit)

21 Dec. 1965

OSCAR-IV (Dec 21, 1965; Cape Kennedy): 40lbs; 3-watt, 10kHz transponder; 144 →432MHz; 85-day GTO (failed GEO) mission (re-entered in 1974)

3 Mar. 1969

AMSAT (Radio Amateur Satellite Corp) established March 3, 1969 in Washington, DC

Amateur Satellites: Then and Now AMSAT Phase II and III and Beyond

Phase II

- Higher LEO Orbits; Longer Mission Life
- Various Transponder U/L-D/L Modes and Beacons – 2m, 70cm, 10m
- "Microsats" with store-and-forward digital payloads
- Includes AO-6, AO-7 (still partially operational)

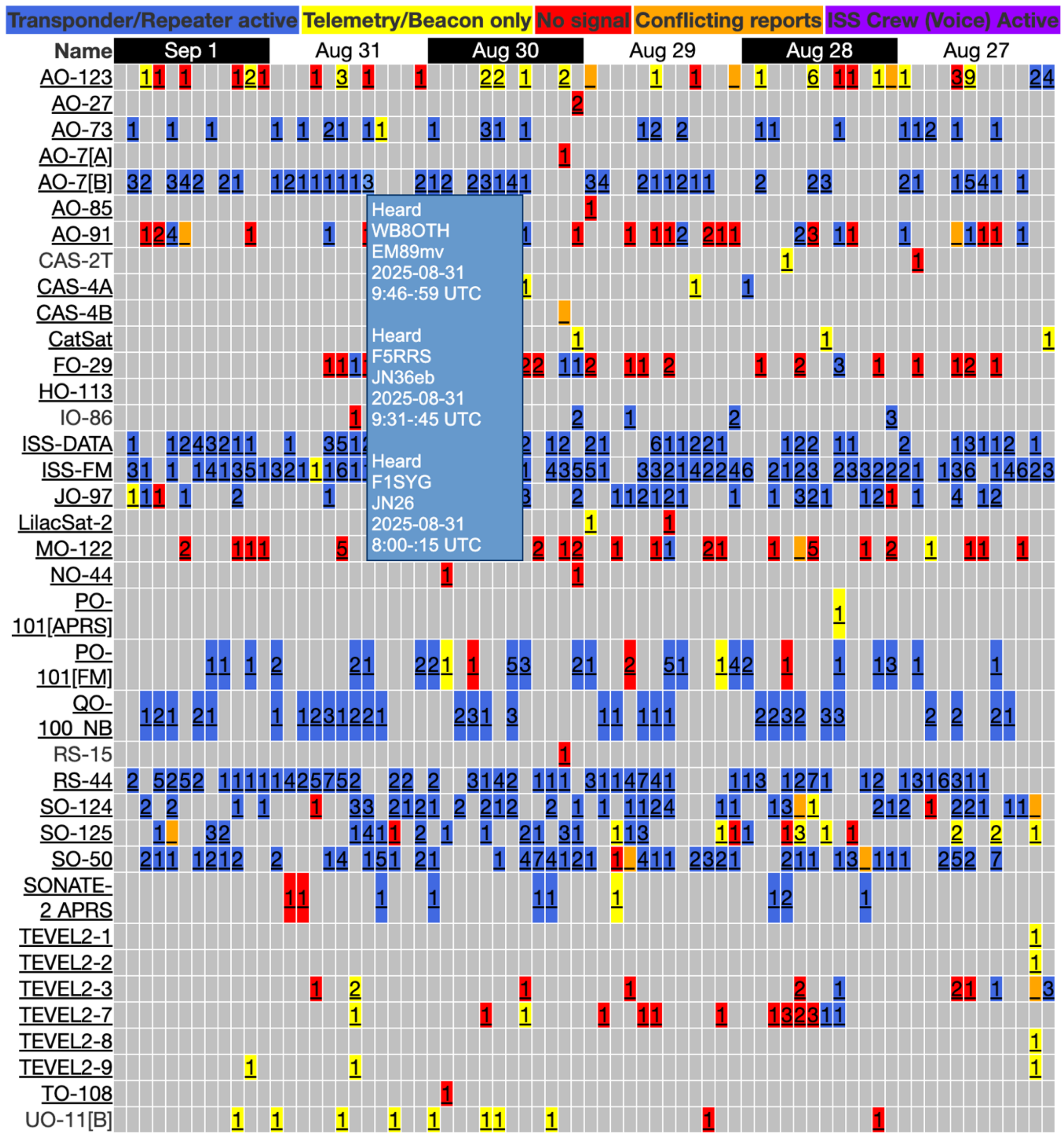
Phase III

- Larger satellites designed for Molnya (HEO) orbits
- More complex payloads

Future Trends

- CubeSats & NanoSats

Currently Operational Satellites (AMSAT Status Page)



RF Challenges for Amateur Satellite Operations

- Doppler shift in LEO
- Satellite tracking
- Frequency coordination (ITU, IARU)
- Link budgeting: ERP, path loss, antenna gain
- Full-duplex operation (e.g., SO-50, QO-100)

How to find more information

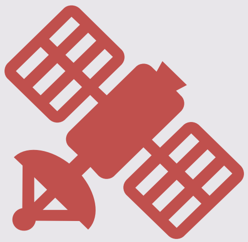
ARRL Publications – Handbook; Operating Manual, etc.

The BEST source by far: AMSAT

https://www.amsat.org/

Closing Thoughts

GEO Comm Satellites vs Amateur Satellites



GEO Comm Satellites

Ultimate Goal: Revenue!

Must meet critical customer functional requirements in order to meet their customers' needs for many years - typically about 18 years

Large, complex, proven robust design, redundancy

EXPENSIVE!!! Customers with very deep pockets.

Drives Competition; innovation among manufacturers

Amateur Satellites

Ultimate Goal: Advancement of the Radio Art (Part 97)

Costs must fall within budgets of very shallow pockets

Drives simplicity, requires compromise, thrives on resourcefulness

- Design resourcefulness
- USER resourcefulness

RF WORLD OF PRO AND AMATEUR SATELLITES SHARES CORE PHYSICS

AMATEUR SATELLITES LET US APPLY AND ENJOY WHAT WE LEARN

YOU DON'T NEED A BILLION-DOLLAR EARTH STATION TO GET ON THE SATELLITES!

Questions & Discussion