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The Evolution of Satellite Communications (Satcom) Antennas

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Outline

- A Bit of Early History
- Some Terminology - Jargon
- Basic Satcom Geometry – Orbits and Coverages
- Key Antenna Properties for Satcom
- Survey of Modern Antenna Terminals
- Challenges for New Satcom Systems
- Takeaways

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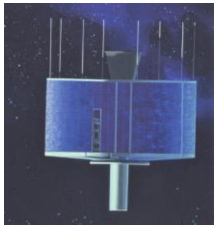
Early Days

- Comsat's early Earth Station Antennas were large, 30 m (~ 100 feet) steerable reflectors
- The early system concept was that of small, low power (weak) satellites in low earth orbit (LEO)
- Large antennas that could track the moving satellites and capture the weak signals would be needed



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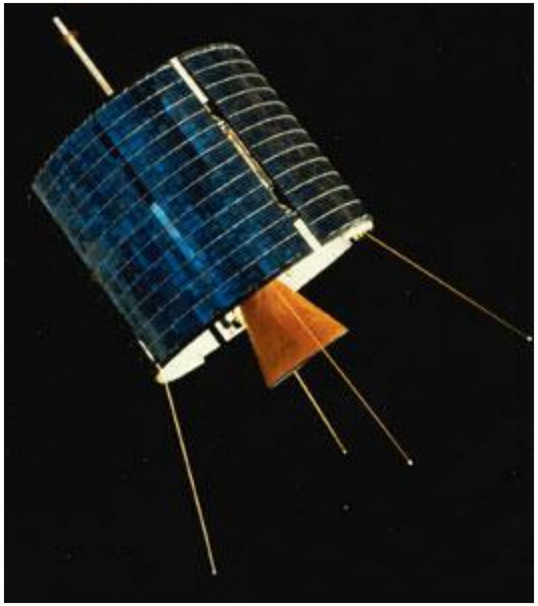
Early Days and Early Bird



- But Comsat decided to take a chance on a system of geostationary earth orbit (GEO) satellites
- Early Bird or Intelsat I was launched in April 1965 and it set the course of commercial satellite communications (Satcom) developments for years to come
- Decades later we are now renewing interest in low earth orbit satellites - but let’s first pause and discuss basic terminology

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Each Technical Area Has Its Own Jargon

Gradient Index Lens

Gain

LEO

EIRP

Aperture

Dielectric Constant

Elevation

Phased Array

G/T

Beamwidth

MEO

VICTS

Wavelength

DBF

Nadir Angle

Polarization

Phase Shifter

GEO

Beam

Time Delay

A Recent Gift from My Grown Granddaughter

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- **A remembrance gift about jargon from when granddaughter Angela was about 6 years old I was trying to explain satellites.**
- **She asked this brilliant question when I blithely used the word “signal”**

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Satcom Bands and Frequencies

Band	Up/Down GHz	Up/Down Wavelength cm
C	6/4	5/7.5
Ku	14/12	2.1/2.5
K	29 Up	1
Ka	19 Down	1.6
V	60	0.5

Signal quality is proportional to an antenna's effective aperture size *in square wavelengths*

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GEOMETRY

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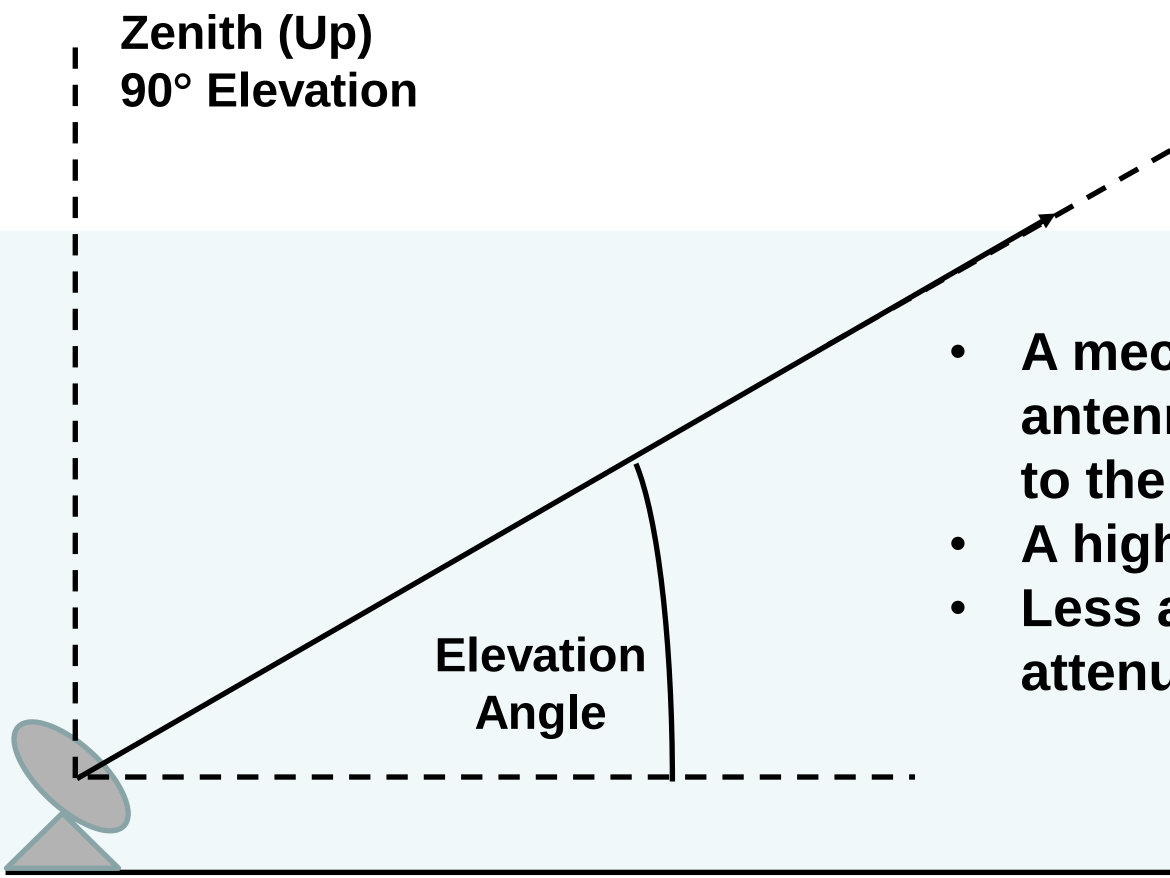
Earth Terminal Elevation Angle



- **A mechanically steerable antenna can point directly to the satellite.**
- **A higher elevation is better**
- **Less atmosphere and rain attenuation**

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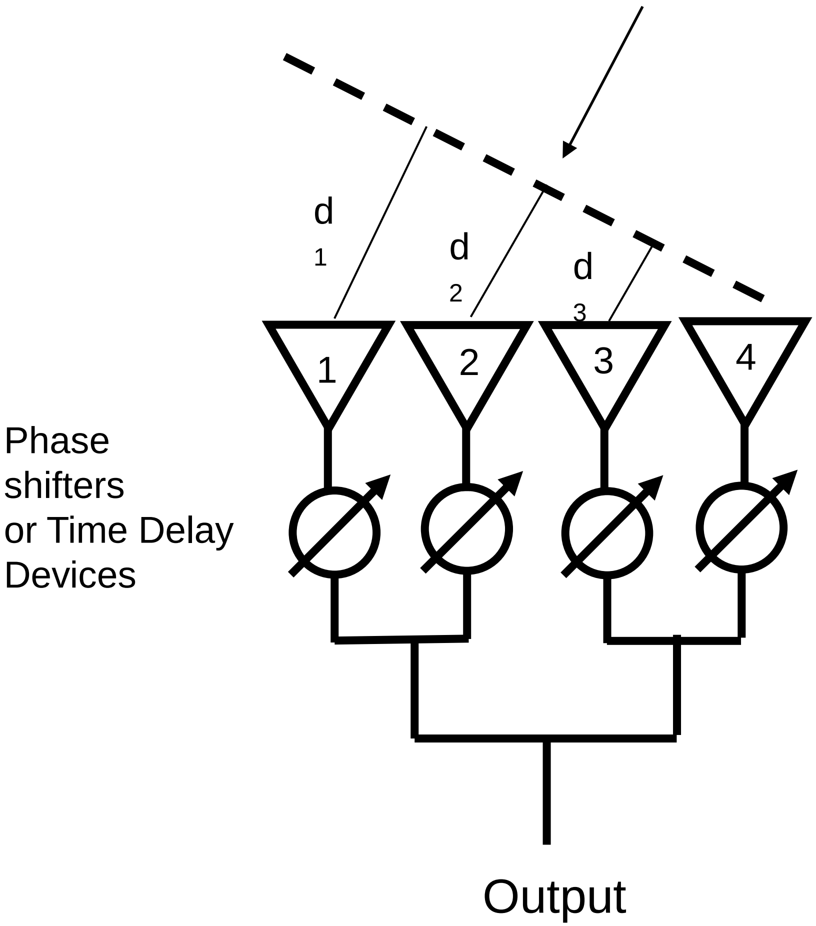
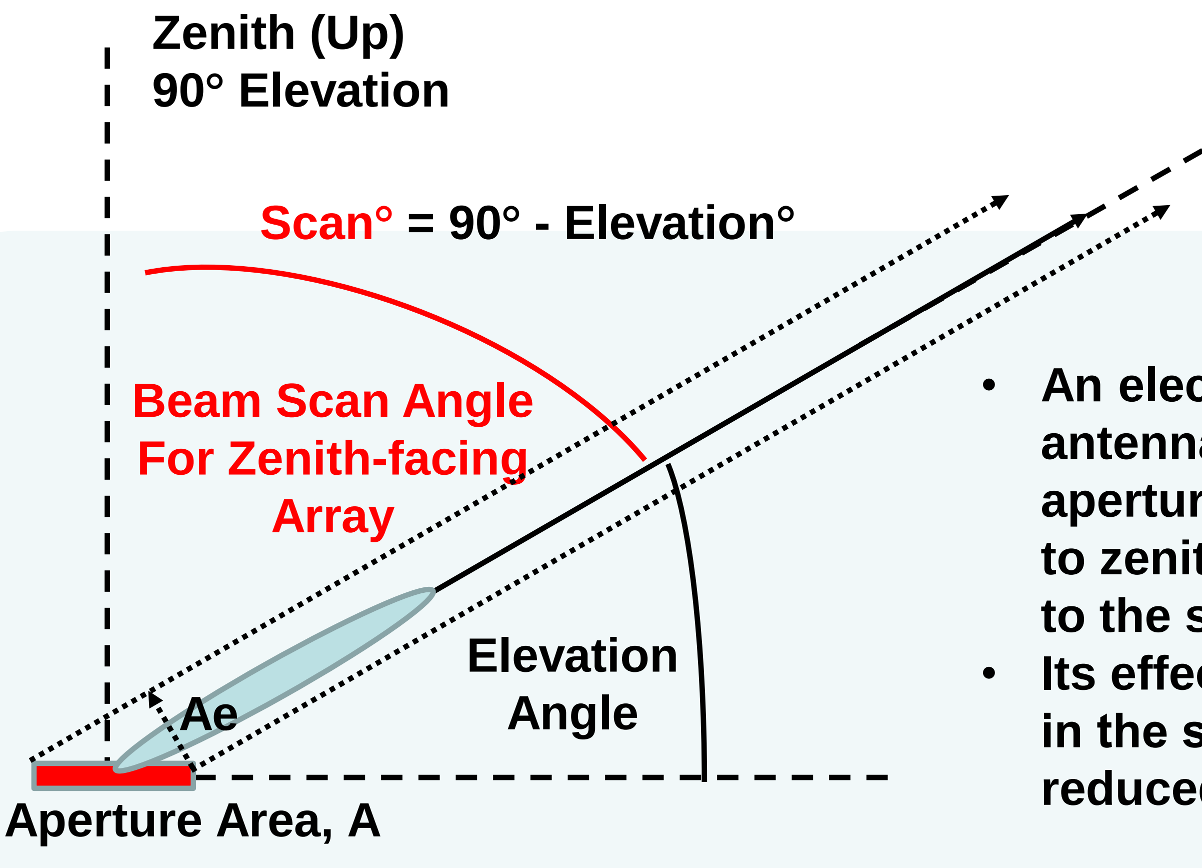
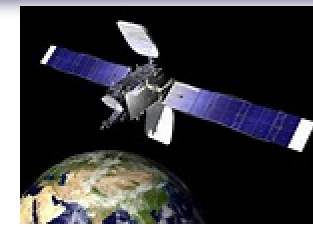
Phased Array



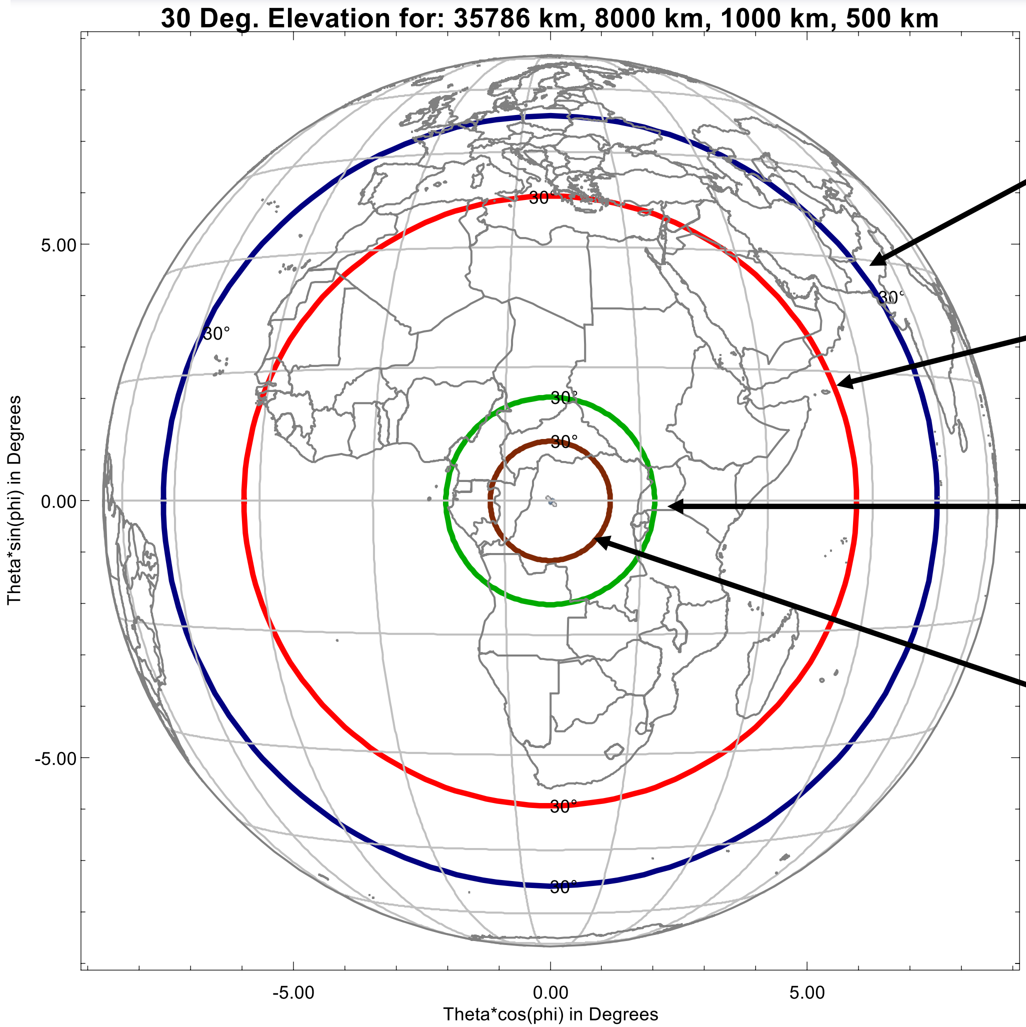
Phased Array Elevation Angle and Effective Area





- An electronically steerable antenna (ESA) usually has its aperture pointing straight up to zenith and scans its beam to the satellite
- Its effective aperture area, Ae, in the satellite's direction is reduced: Ae=Acos(scan)

View from GEO Altitude: 30° Minimum Elevation Contours from Sats at Indicated Altitudes



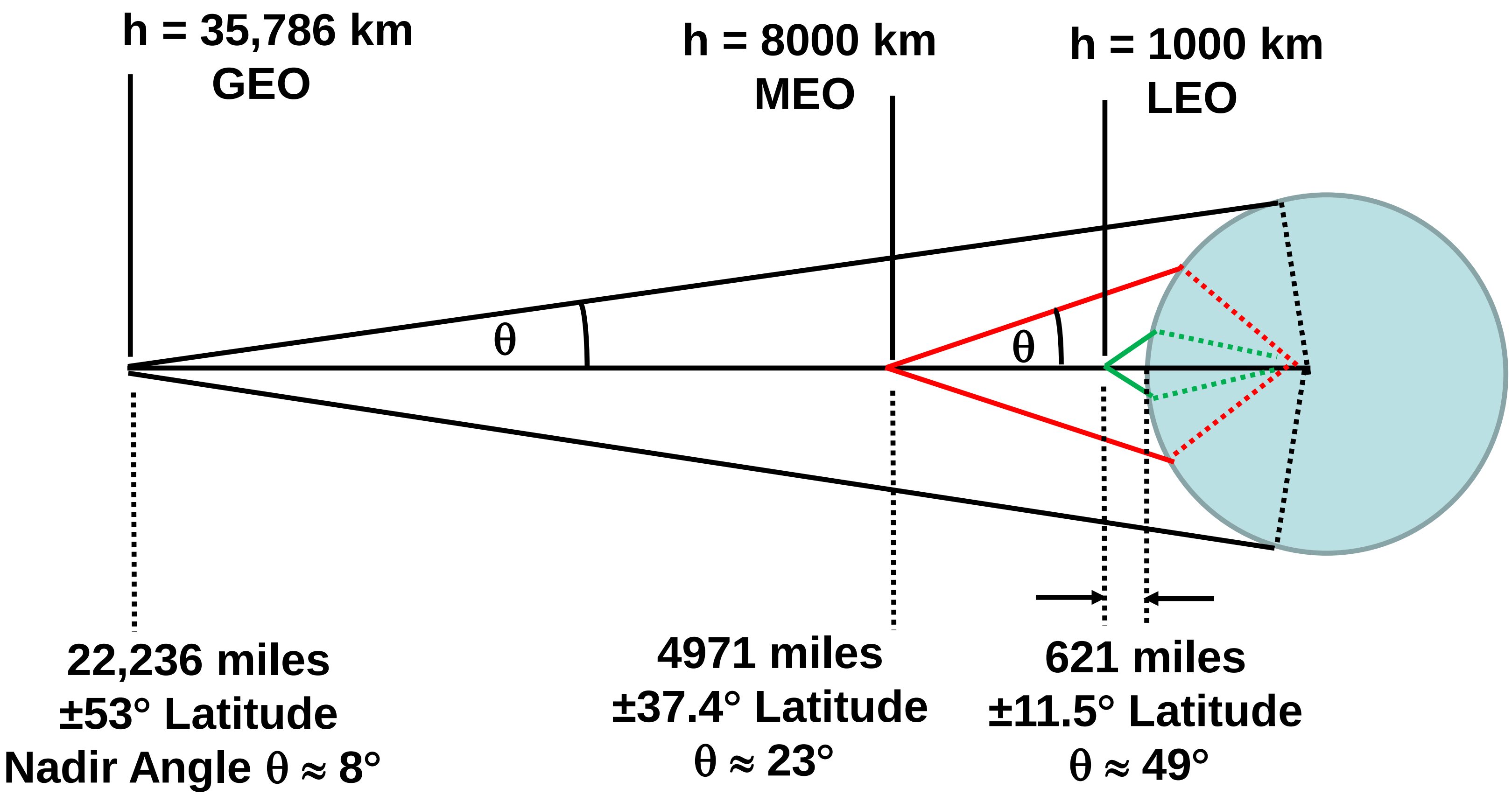
35786 km (GEO)
20% of Earth Area

8000 km (MEO)
10% of Earth Area

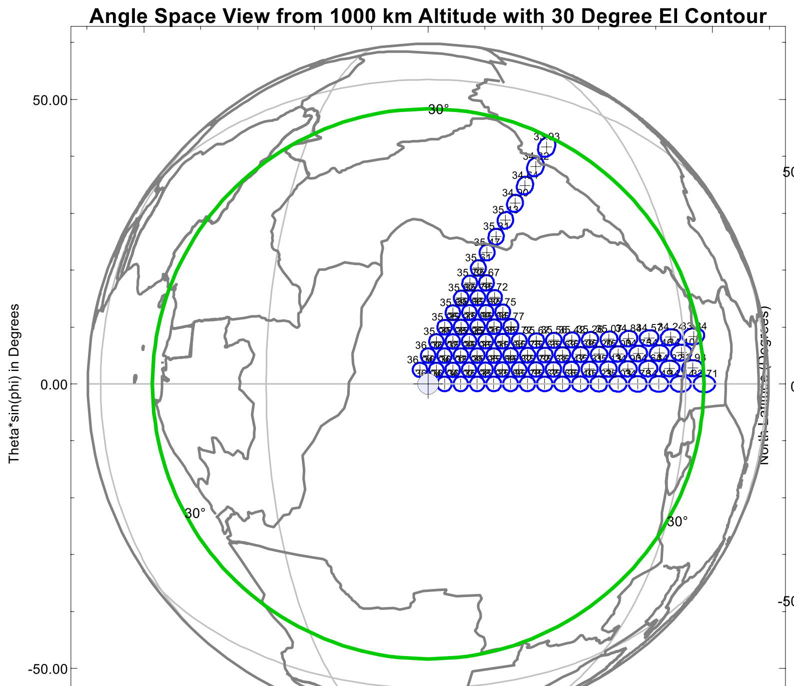
1000 km (LEO)
1% of Earth Area

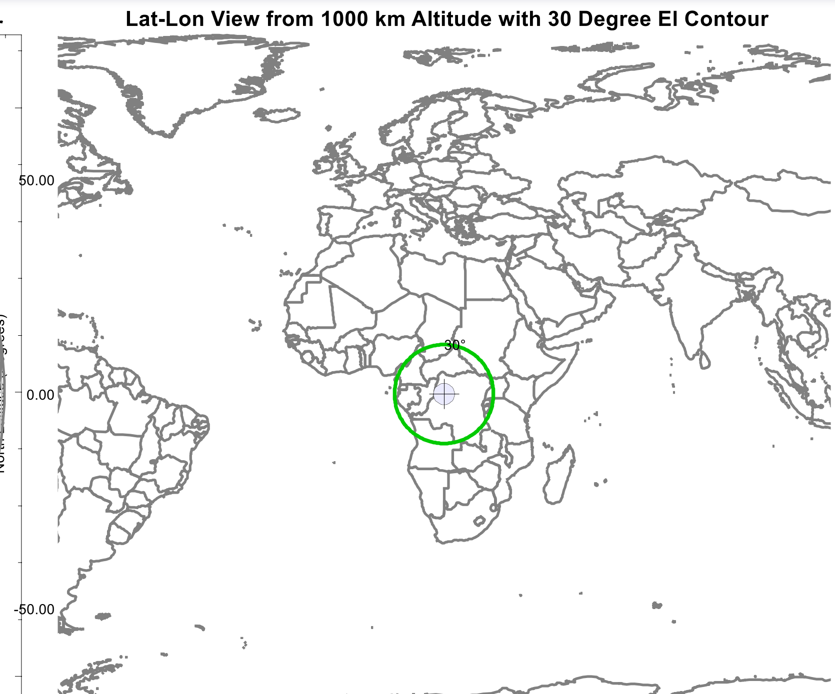
500 km (LEO)
0.3% of Earth Area

Side View of 30° Minimum Elevation Coverage for GEO, MEO and LEO Altitudes



Views of Earth from 1000 km Altitude

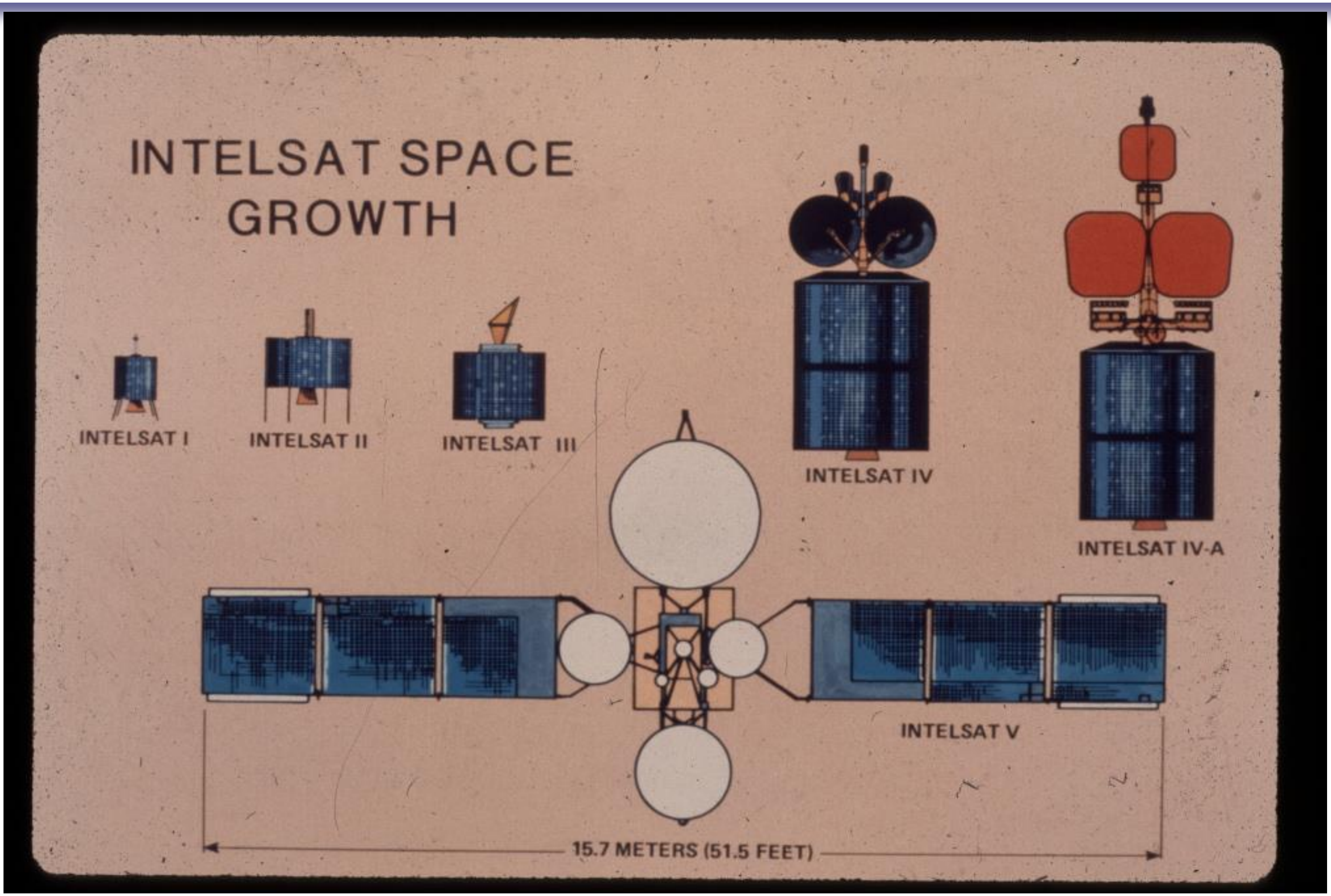




At least 1000 beams from a 50 cm x 50 cm spacecraft array at Ku-band needed to fill the 30° coverage circle.
A few beams are shown here

At least 300 satellites (green circles) are needed to cover the earth so that any location can be above 30° elevation. Many more if each location must see two or more satellites.

Progresion of Early Intelsat Satellites
Larger Spacecraft Antennas & More Power



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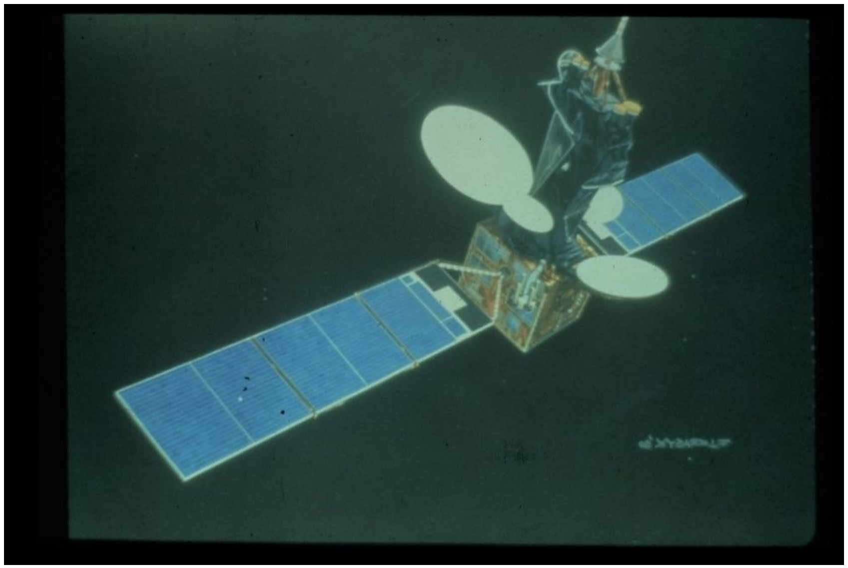
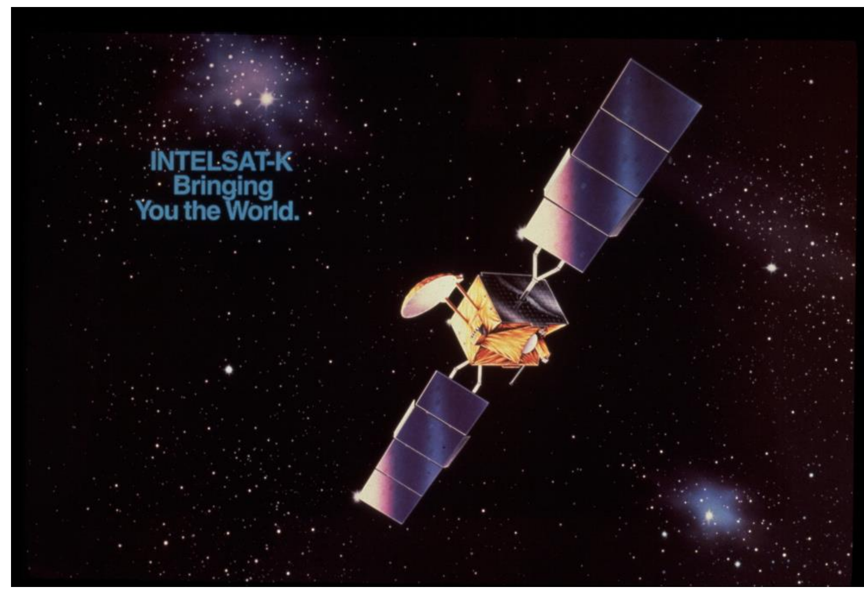
Intelsat V and Intelsat K





Inmarsat Global Xpress K/Ka Band Spot Beam Antennas

SMALL EARTH TERMINALS WITH TRACKING BEAMS

Earth Terminal Trends
Smaller, Cheaper, Low Height, Reliable

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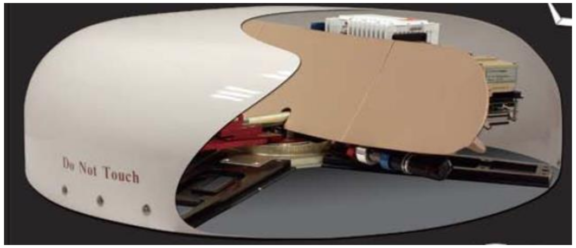
- **Traditional earth terminals** have typically ranged from 5 to 30 meters in size and are almost always mechanically steerable dishes
  - Some fixed torus antennas but these are in the minority
- **Smaller, cheaper, beam tracking terminals are needed for:**
  - Mobile two-way terminals for marine vessels, aircraft, & land vehicles
  - New LEO and MEO satellite constellations
    - Starlink, Kuiper, Telesat, OneWeb, SES mPower et al
- **A low-height physical profile is required for many terminals**
  - Absolutely necessary for aircraft
  - Strongly desired for vehicles for Satcom-on-the-move (SOTM)
  - Desired for appearance on houses, etc.
- **Large deployments – up to millions - require low-cost terminals**
  - Easy installation, no service calls, highly reliable, integrated with other terminal component such as modems, amplifiers, Ethernet interface, etc.
  - Electronically steered antennas (ESAs) with no moving parts

Mechanically Steerable Low-Height Antennas

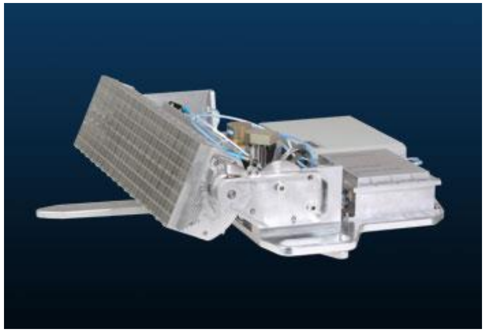
Viasat Global Aero 5520
22 x 94 cm

ThinKom ThinAir Eagle-Ka1000



Commtact MOST

RaySat EagleRay 7000 Live in Action in Oklahoma



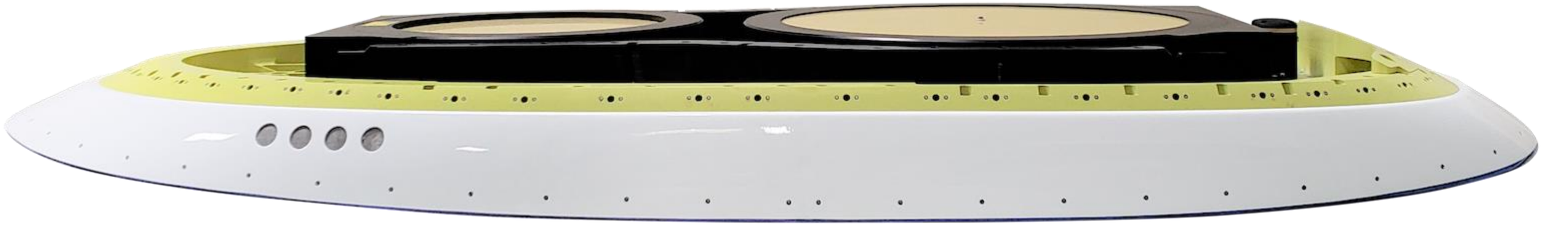
Most cost tens of thousands of dollars

ThinKom VICTS Antenna

- **Variable Inclination Continuous Transverse Stub (VICTS)**
- **Three platters rotate mechanically relative to each other to steer the beam in azimuth and elevation and also control polarization**
- **Linear non-contacting motors assure reliability**
- **One transmit and one receive aperture**
- **One beam per aperture**
- **On 1550 active aircraft for Internet connectivity**

ThinKom ThinAir Falcon-Ku 3030

ThinKom ThinAir Falcon-Ka 2417



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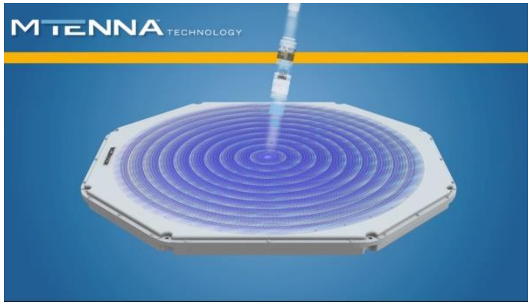
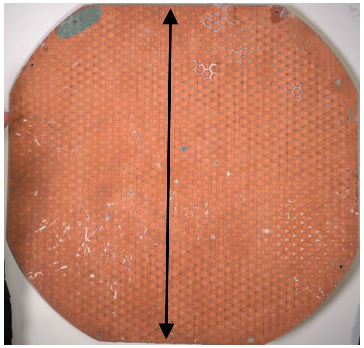
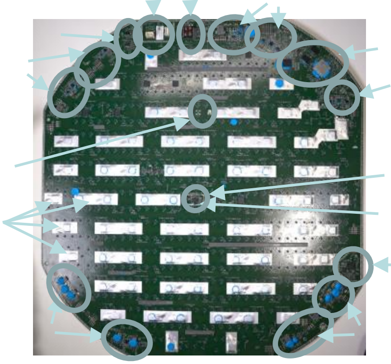
Phased Array Antennas

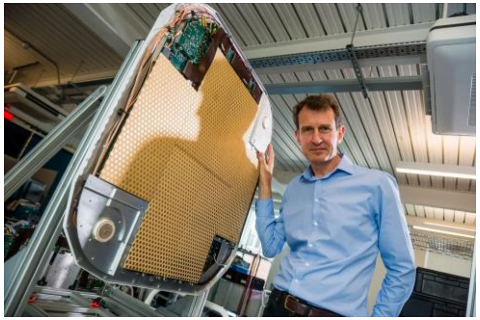


Kymeta Holographic Array



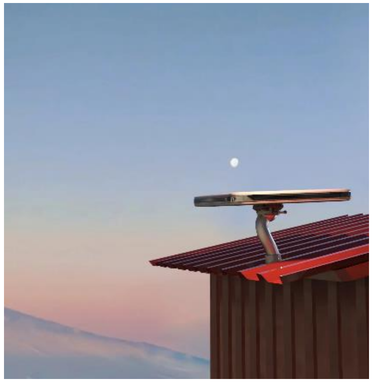


Starlink Terminal ActiveArray Elements ICs



Hanwha-Phasor
Phased Array
Active Electronics

Alcan Phased Array
Liquid Crystal Phasers



Nextenna Phased Array

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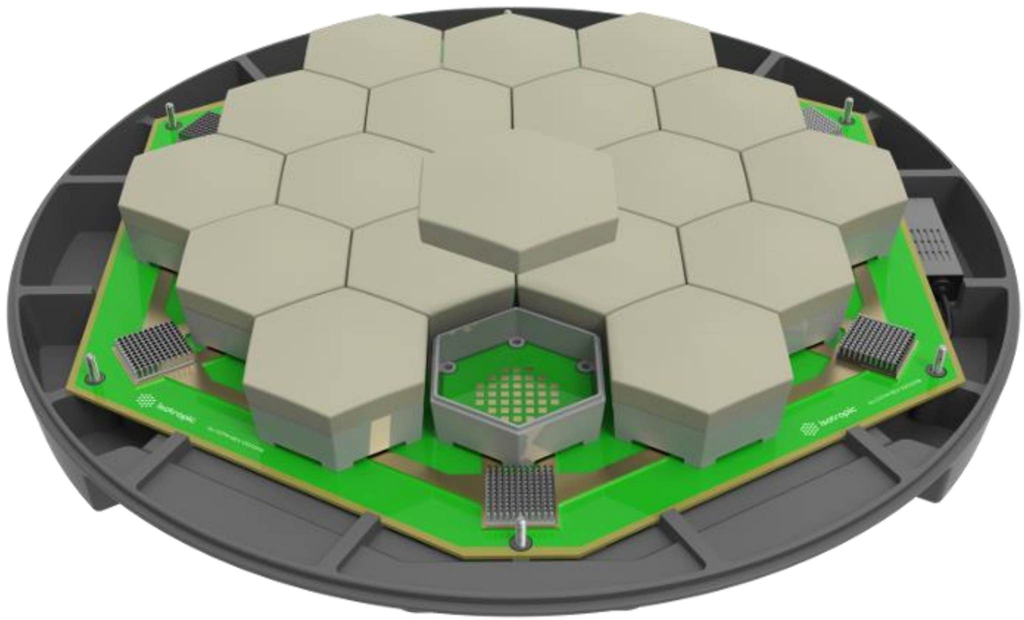
Multiple Beam Arrays

SatixFy
Digital Beamforming (DBF) Array
Multiple Beams
High Power Consumption



Multi-beam arrays can track multiple satellites in LEO, MEO and/or GEO with seamless connections

Isotropic Systems Phased Array of Gradient Index Lenses
Multiple Beams
Lower power than conventional arrays

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Challenges

- **Earth terminal antennas are still too expensive**
- **Starlink**'s first-gen array with > 1200 active elements actually cost > $3,000 and is subsidized so customer pays $500
  - Second gen goal is $1500 actual cost with $500 customer cost
  - Thousands of satellites to have > one sat in view of every terminal
- **Active ESAs** consume high power
  - Almost1 kW for an active aircraft array (Hanwha-Phasor)
  - Multi-beam DBF arrays (SatixFy) consume high power
  - Array of lenses (Isotropic Systems) reduces power on receive
    - Less reduction for transmit
  - Arrays with liquid crystal phasing promise lower power and cost (Nextenna, Alcan, Kymeta) but goal of <$1,000 not yet here.
- **ThinKom VICTS** has low height, low power and good scan but uses mechanically moving parts – but claimed to be reliable

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Takeaways

- Trend is toward millions of small (< 75 cm) integrated terminals
  - Each costing < $1,000 and requiring easy installation
- Innovative solutions include arrays of lenses, phased arrays and digital beamforming (DBF) phased arrays
- Cost, reliability, ease of installation, power consumption and manufacturability goals have not yet been met
- It is not yet obvious which, if any, of the large LEO systems and low-cost terminals will prove viable