HiSeasNet Satellite Basics

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LDEO

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Outline

- Key satellite issues
  - Footprints, power, orbits, antennas, bands, polarization, spectrum, etc.
  - Different types of satellite networks/services
  - Economics
- Earth stations
- Data over satellites
  - Operators/Providers, modems, EbNo, routers, etc.
- The future of satellite communications

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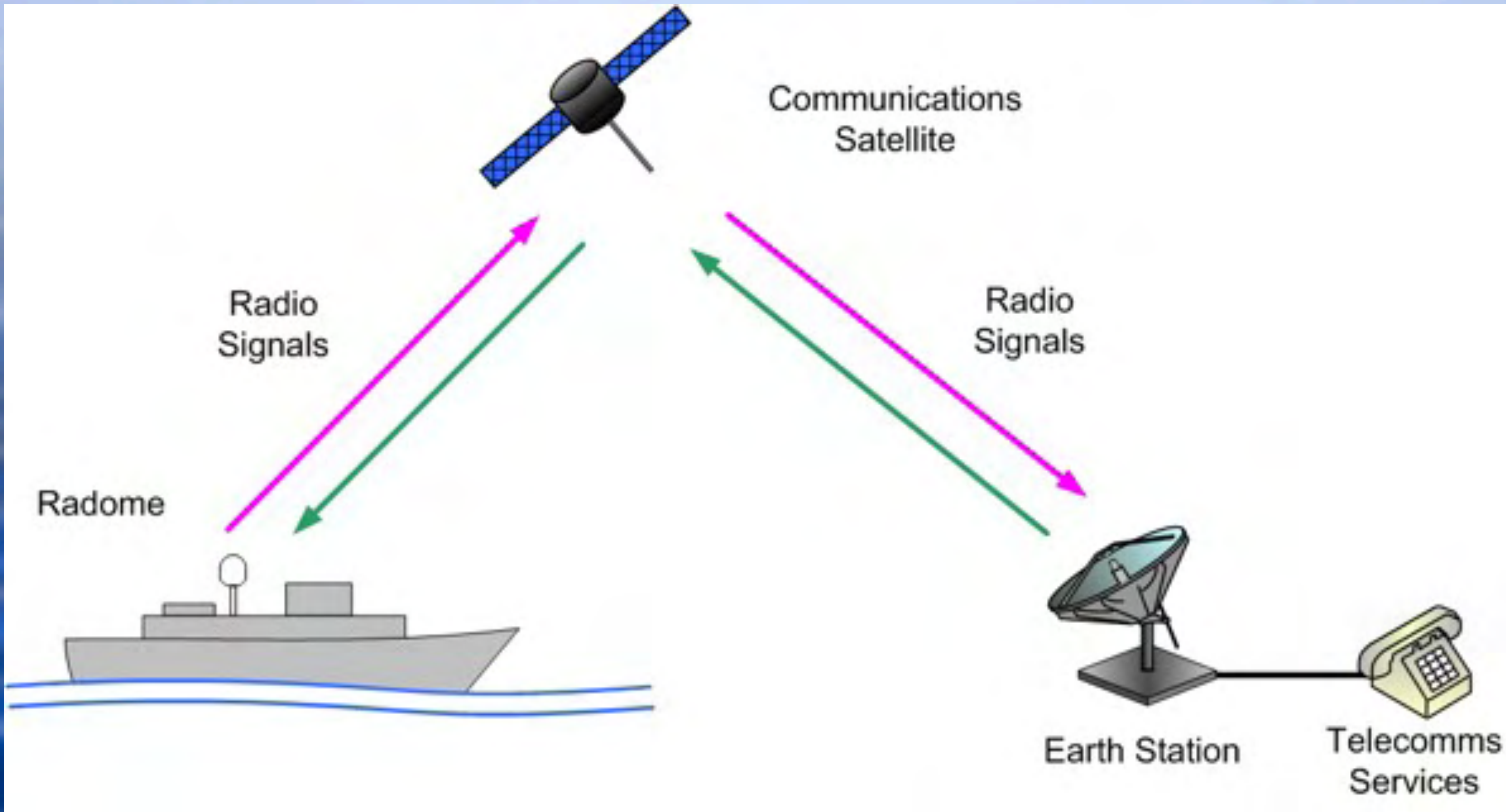
Network Overview



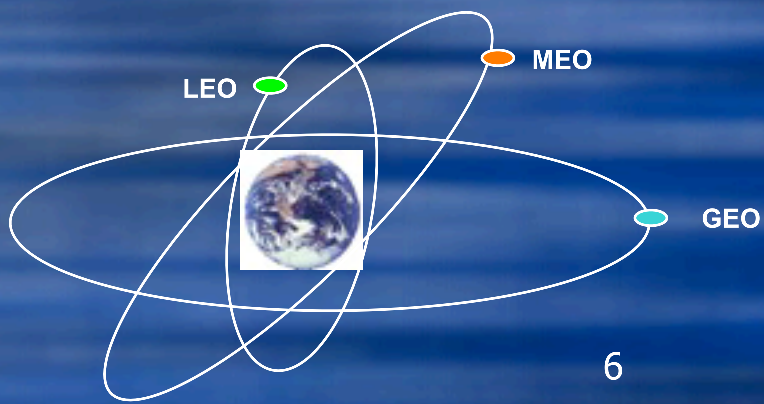
Satellite structure/position

- Satellites currently orbiting the earth represent a wide variety of sizes, shapes and capabilities, each designed for specific purposes.
- Based on function and purpose, they can have Low, Medium, or Geostationary orbits
- The designed purpose dictates what type of orbit they are placed in, frequency band of operation, types of transmissions, power levels emitted and where their signal(s) are directed.
- The different sizes and shapes vary widely, but all satellites have the same basic elements.
- Stabilization, telemetry equipment, and boosters are all used to keep the satellite oriented properly in its specific orbital position.
- Solar panels and batteries are used to power the transmit and receive RF equipment and telemetry systems which are used to track & control the satellites' position.

Types of Satellite Orbits

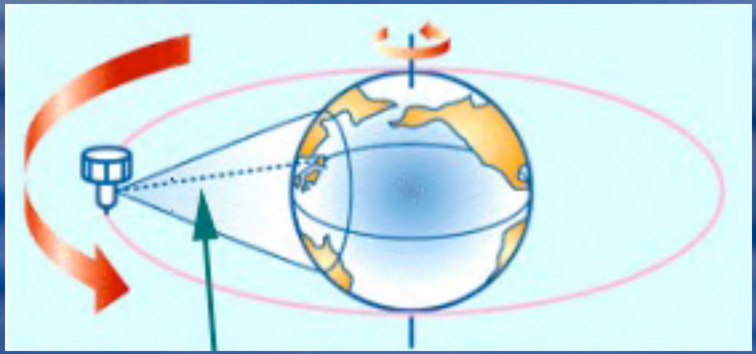
- LEO (Low Earth Orbit)
  - 500 to 1000 miles above the earth
- MEO (Medium Earth Orbits)
  - 8000 miles above the earth
- GEO (Geostationary Earth Orbit)
  - 22,753.2 miles above the earth
- Inclined orbits, Molniya, etc

J-Track 3D Satellite Tracking



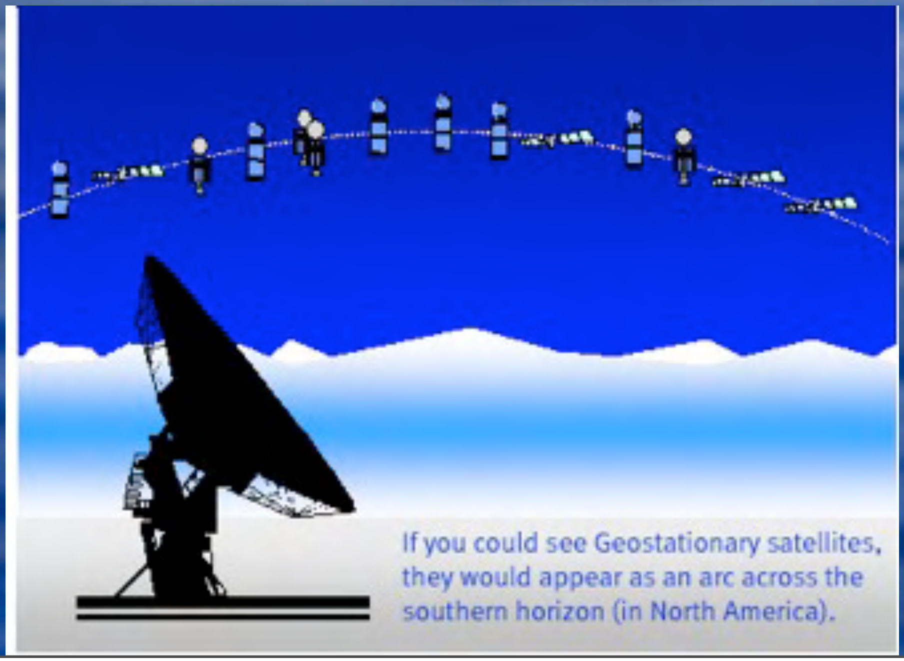
Geosynchronous Orbit

- Clarke Orbit
  - Named after, Arthur C. Clarke, who first envisioned its potential for global communications usage in 1945.
  - Also called a geostationary orbit
- If a satellite is positioned about 22,236 miles above the equator, its rotational speed will match that of the earth and, therefore, appear to remain in a fixed position when viewed from the earth's surface. These satellites are referred to as "Geo-Synchronous" or "Geo-Stationary".
- Many serve a wide variety of communications services including telephone, data, radio and television. These are the satellites that SeaTel antenna systems are most commonly used with.



Geosync Orbit

- They are all in orbit over the Equator (0 degrees Latitude) and so are usually referred to by their "longitudinal" position as often as by their name.
- Starting from 0 degrees longitude increasing in degrees East or West to 180. At these two points a satellite could be called 0.0 degrees East or West, or 180 degrees East or West respectively.
- Satellites move around a little due to solar wind, sun/moon gravity tweaks, etc. Sats have a fixed fuel source to keep them on station



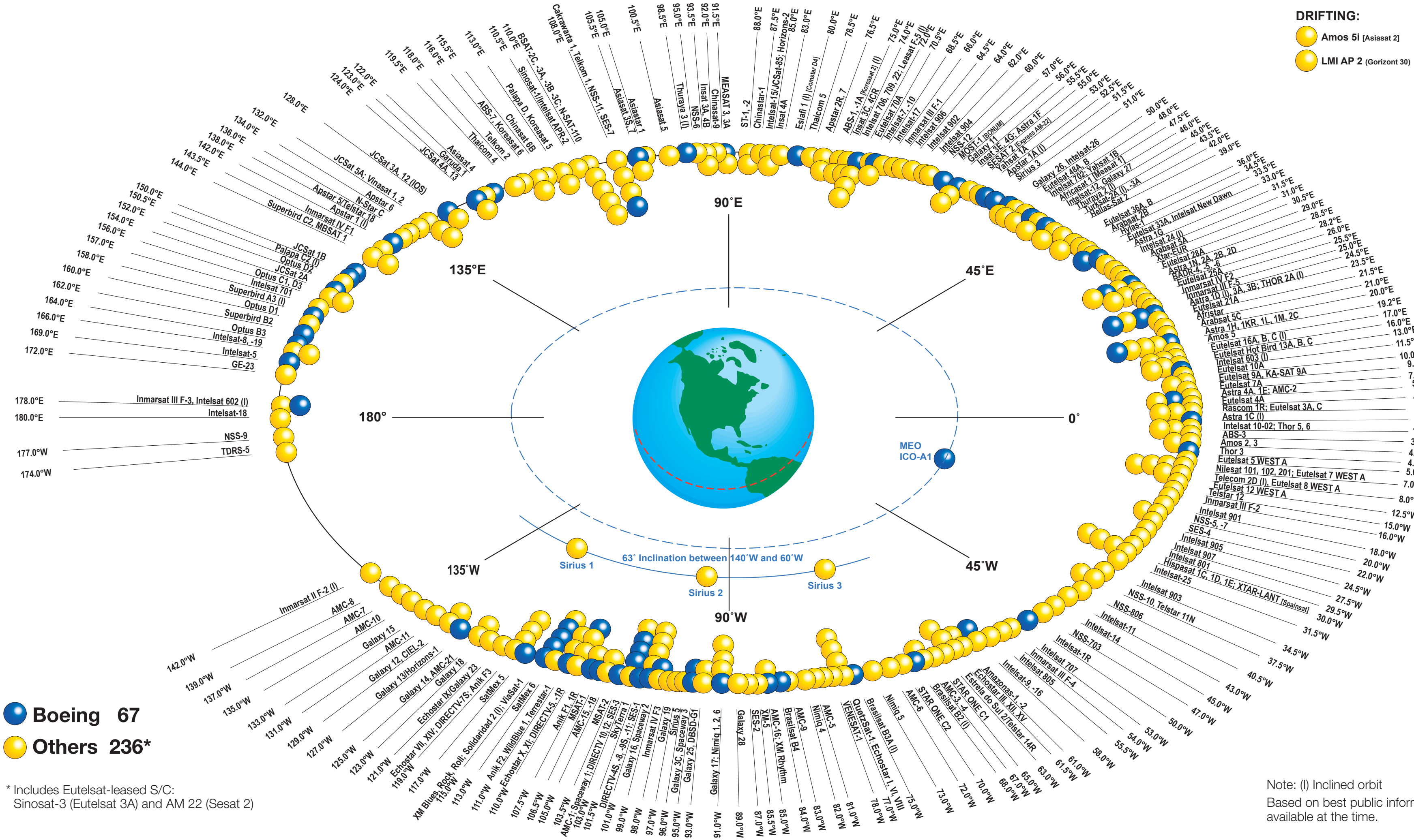
Satellites as relay

- Communication satellites are relay links (repeater) in space. They have very sophisticated antennas & RF equipment
  - They have highly focused antenna patterns (footprints)
  - They can utilize 350 Watts per transponder, more every generation
- They utilize either linear or circular polarization which requires the correctly polarized feed on the ship's antenna
- The ship must be in a strong enough area of the satellite's footprint for antenna system to operate.
- Regardless of the type of signal, they are all relay devices, located in space to re-broadcast their signals to a much larger area than would be possible by local area (TV Station) transmissions.

Satellite Orbital Spacing

- In the simplest form 3 satellites would be required to provide global coverage, with each satellite illuminating about 42% of the earth's surface.
- As time has passed, the number of satellites in Geosynchronous orbit has increased to the present population of more than 230 satellites.
- The satellite positions are regulated by multi-national organizations which use illumination area, frequency allocation and polarity usage to plan satellite positioning (for each type of services) in such a way as to provide for the greatest number of satellites possible without interfering with each other.
- Good planning and co-operation (among satellite operators and users alike) are required to achieve the goal of locating the satellites 2 degrees apart from each other in longitudinal position.

Commercial Communications Satellites
Geosynchronous Orbit



* Includes Eutelsat-leased S/C:
Sinosat-3 (Eutelsat 3A) and AM 22 (Sesat 2)

Note: (I) Inclined orbit
Based on best public information available at the time.

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Satellite Design

- Solar panels for power
- Antennas for communications
  - Configurations, spectrum, amplifiers, fuel, footprints, often fixed at launch
- Intelsat 18 (similar to IS-23 for our AOR)
  - 180deg W, POR coverage
  - Ku-band and C-band transponders

Satellite RF Equipment

- Each satellite has redundant receive and transmit equipment capable of operating in its assigned frequency band(s).
- Satellites can employ multiple antennas, so they can have switching equipment that will direct selected transponder outputs to a particular antenna.
- Multiple antennas provide multiple or "spot" beam footprints
- Better control of bandwidth used by each transponder = more transponder channels within each frequency band.
- Some bands (like Ku-band) have even been split into multiple sub-bands because they are now being used so efficiently.
- Modern satellites have 32+ transponders which are capable of transmitting C and Ku Band simultaneously at high power levels (150-250 Watts).

The Satellite Antenna

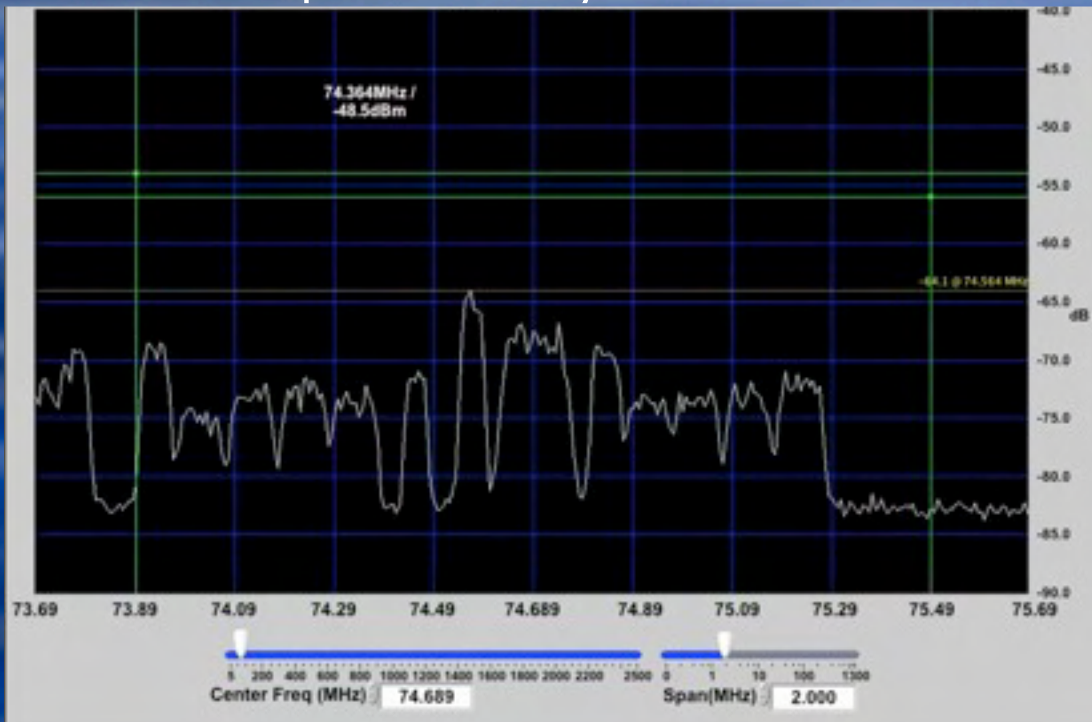
- Sophisticated satellite antenna designs provide highly focused illumination patterns that are called footprints.
- Some of these illumination patterns are shaped to fit the geographic area of coverage.
- Focusing and shaping the beam concentrates the transmitted energy into the footprint of the desired area of coverage without wasting any of it elsewhere.
- This increases the overall receive level (Effective Isotropic Radiated Power -EIRP) throughout the footprint pattern, allowing smaller (lower gain) dishes to be used in receive only systems.
- Some of these antennas provide very wide coverage allowing them to receive from, or transmit to, an area equal to about 40% of the earth's surface (global beams) …at the cost of power and thus antenna size

Uplink and Downlink

- The satellite itself is a relay device, receiving and re-transmitting signals.
- Transmitted signals originate from an Earth Station, or in special cases, another satellite.
- These **uplink** signals are received at the satellite on one frequency, routed to the on-board conversion & transmission equipment, and transmitted as the **downlink** signal at a different frequency.
- Transmissions from earth use higher frequencies while transmissions from satellites use lower frequencies. First satellites had limited power and lower frequencies have less attenuation (loss).
- The received and transmitted signals may use the same antenna and be using the same area of coverage (footprint). This UP-DOWN link is called a "single hop". Some signals require multiple satellites and are know as "double hops"
- An "Earth Station", can be fixed or mobile. A fixed station is one which does not move (stationary position) and a mobile station is one which is capable of changing position (ie.. a news van, or a HiSeasNet ship).

Satellite Carriers

- The data from a satellite signal is wrapped up in these little bumps in the spectrum
- Taller bumps are easier to lock onto, have for fade margin
- Wider bumps have more data
- When you increase a bump's width without changing power, the height comes down
- Best seen with a spectrum analyzer



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Satellite Frequency Bands

- The next slide gives Uplink and Downlink frequencies of the Satellite Bands.
- A wide band of frequencies is shown in the next slide.
  - It is important to note that frequencies used by other electronic systems may interfere with the satellite system. CB, TV UHF & VHF and especially navigational radars are examples of possible interference sources.
- Several sub-sands maybe in use within what is commonly called C & Ku bands.
- Certain sub-band usage may be restricted to a given geographic area in an effort to extend the maximum number of satellite signals in that area while minimizing interference.

Standard Satellite Frequency Bands

Band	Uplink Freq (GHz)	Downlink Freq (GHz)
C-Band	5.9-6.4	3.7-4.2
Ku-Band	14.0-14.5	11.7-12.2
Ka-Band	27.5-31.0	18.3-18.8 19.7-20.2

- Ku-band has many sub bands that are used differently in different places

Rain Fade Attenuation

Rain Fade is the common term for Rain Attenuation. This attenuation (or signal strength loss) is caused by the absorption of the satellite signals by heavy rain.

Below is a chart that shows typical attenuation based on rain rate with the subject antenna set to a 30 degree elevation angle

Rain Attenuation (dB) at 30deg				
Rain Rate (mm/h)	4 GHz	6 GHz	12 GHz	14 GHz
5	.1	.15	1.6	1.8
10	.11	.80	2.0	2.9
15	.12	1.4	2.6	5.0
20	.13	1.6	3.3	6.8
25	.14	1.8	4.1	8.0
30	.15	2.0	5.0	9.2
35	.16	2.4	6.0	10.4
40	.17	2.8	7.0	11.8

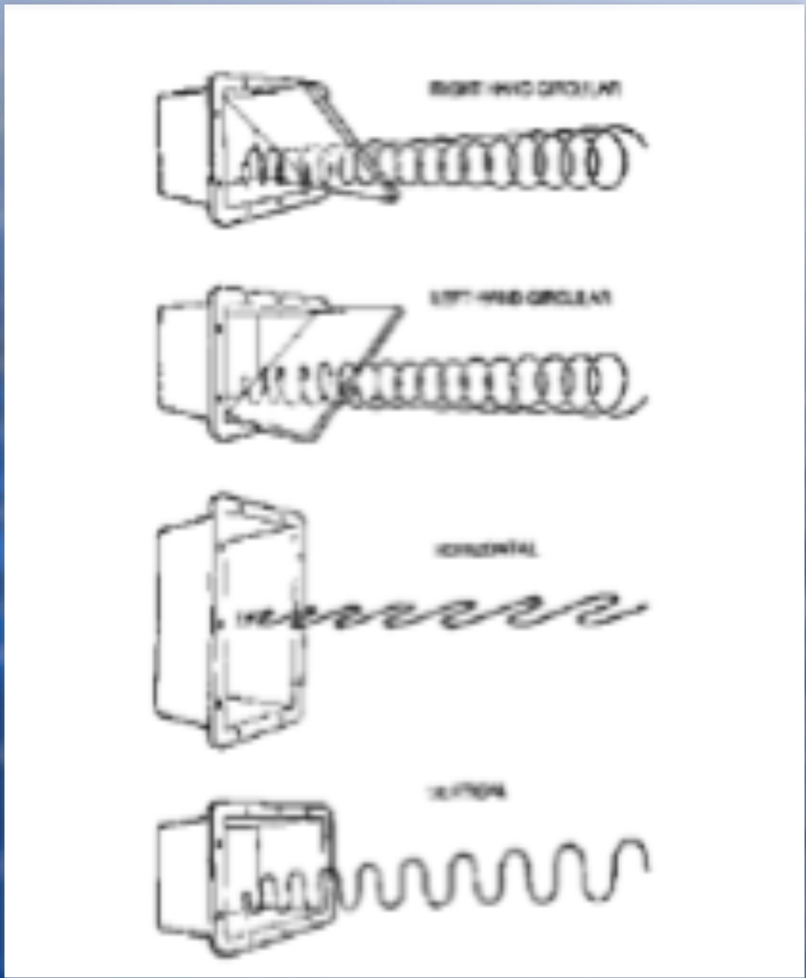
Frequency Band Pro/Con

- C-Band Frequencies
  - Advantages:
    - Wide footprint coverage
    - Minor rain fade issues
  - Disadvantages:
    - Requires larger antennas
    - Requires larger SSPA
    - Affected by terrestrial interference (TI) = more rules/regulation
    - More work to obtain a TX License
- Ku-Band Frequencies
  - Advantages
    - Requires smaller antennas for a focused beam
    - Requires smaller SSPA
    - Less interference problems (farther from other bands) = less regulation = easier to obtain a TX license
  - Disadvantages
    - Big rain fade issues
    - Smaller footprint, not global

Satellite Polarization

- Frequency polarization is a technique designed to increase the capacity of the satellite transmission frequency.
- In linear cross polarization schemes, half of a satellite's transponders transmit their signals to earth in vertically polarized mode; the other half of the satellite's transponders transmit their signals in horizontally polarized mode.
- Although the two sets of frequencies overlap, they are 90 degree out of phase, and should not interfere with each other.
  - Sometimes they do interfere, so we have to adjust antenna feed to isolate "Cross-Pol interference"
- For both satellites and earth stations the normal configuration is to transmit in one polarization and receive in the opposite polarization.

Satellite Polarization - Linear and Circular



- Linear polarization
  - Horizontal or vertical
  - Cross-pol vs co-pol (Tx/Rx in same or different polarity)
- Circular polarization
  - Right or left
- Antenna feed must match satellite transponder
- Must isolate signal to one polarity to avoid interference with other polarity

Satellite Frequencies and Transponders

A Transponder contains a block of frequencies on a satellite. Typical bandwidth is 40MHz per transponder (36MHz usable - 2 MHz of guard band on each side). Some Ku-Band transponder are 54MHz & 72MHz.

Rx (MHz)	11720	11760	11800	11840	11880	11920	11960	12000	12040	12080	12120	12160
Tran.	1	3	5	7	9	11	13	15	17	19	21	23
V												

Rx (MHz)	11740	11780	11820	11860	11900	11940	11980	12020	12060	12100	12140	12180
Tran.	2	4	6	8	10	12	14	16	18	20	22	24
H												

Tx (MHz)	14020	14060	14100	14140	14180	14220	14260	14300	14340	14380	14420	14460
Tran.	1	3	5	7	9	11	13	15	17	19	21	23
H												

Tx (MHz)	14040	14080	14120	14160	14200	14240	14280	14320	14360	14400	14440	14480
Tran.	2	4	6	8	10	12	14	16	18	20	22	24
V												

Typical Ku-Band Satellite
Transponder Plan

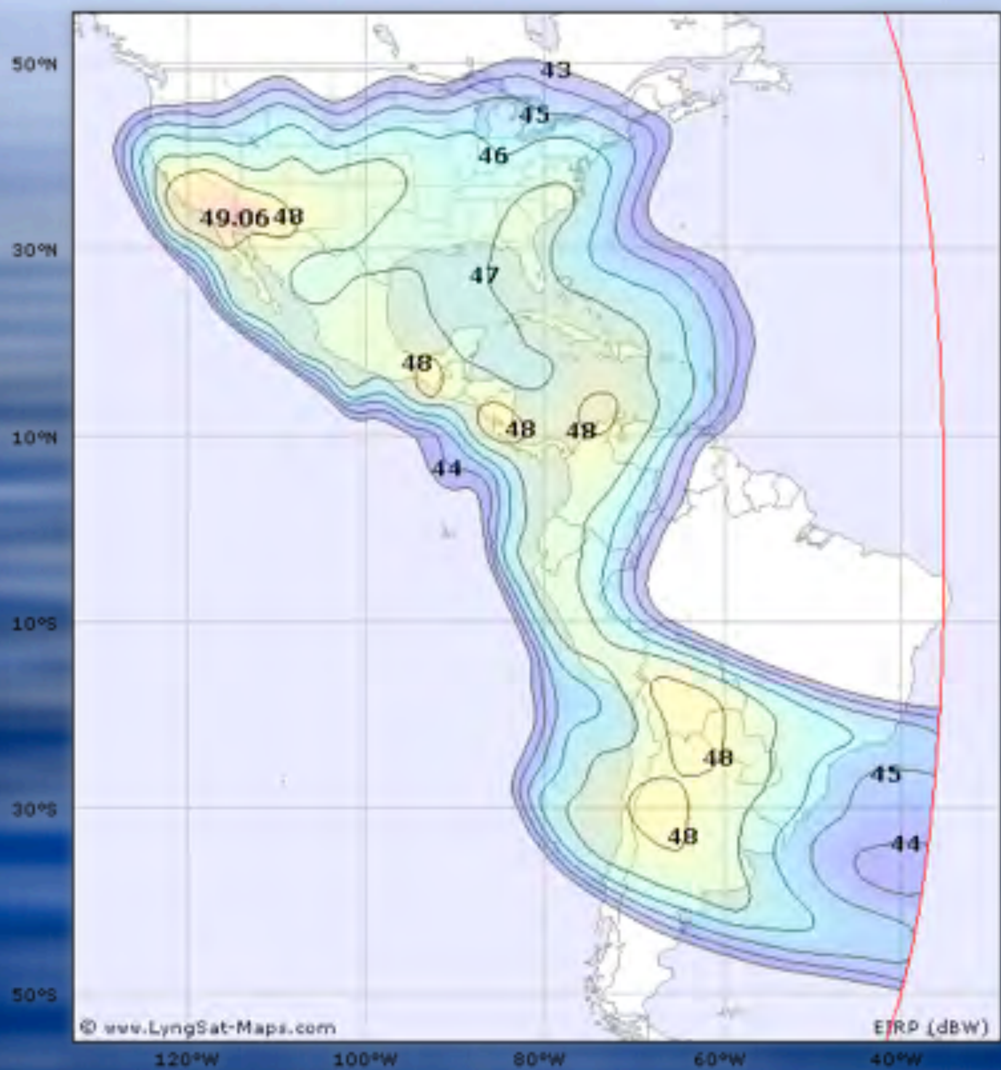
Geo-sync Satellite Summary

- Satellites are relay devices, re-broadcasting signals to a large area on earth (footprint)
- They operate in a variety of frequency bands and can have multiple antennas which allow the transmitted energy to be aimed and focused very accurately in multiple beams.
- The power of each beam dissipates as the area of coverage increases. Contour maps are published by the satellite owners that show the beams' signal strength lessens as the footprint size increases.
- They are in Geo-Synchronous orbit over the Equator, therefore, appear to remain in a fixed position when viewed from the earth's surface.
- Because they are all at 0 degrees Latitude (Equator) they are commonly referred to by their Longitudinal position.
- It is common for a satellite to alternate transponder polarities, (Horizontal & Vertical, or Right & Left hand Circular) to prevent interference of one channel to another, and for adjacent satellites to reverse their transponder polarities.
- Other Electronic Systems may interfere with your Satellite System (CB, TV UHF & VHF and especially Navigational RADARS). Varies with frequency, power, antenna.
- Satellite signals are typically focused, and aimed, at the populated land mass areas of the globe.

Satellite Beam (Footprint)

- The beam pattern of the signal transmitted by the satellite is a function of the antenna being used.
- The pattern is based on the antennas' radiated field pattern when it was tested prior to launch.
- A given amount of power spread over a wide area, such as a Global beam covering 42% of the earth's surface, makes the signal level very weak at all locations within that area.
- A Hemi-beam only covers about 20% of the earth's surface and would have signal levels at least 3dB higher (half the area equals twice the effective power) throughout its coverage.
- Area beams cover about 10%, doubling the power again (another 3dB higher) over a Global beam and Spot beams may be as little as 2% (another 6 dB higher).

Example Footprint



Satellite Footprint Basics

- Transmit power, beam-width, frequency band, and polarization mode are all important factors of the signal transmitted by the satellite.
- The ship's location within the footprint, the overall gain of the system, blockages and atmospheric conditions are the primary factors in the system's ability to receive the signals from a desired satellite.
- Transmit Power
  - The transmit power of some satellites is as little as 8 Watts per transponder. Some newer satellites are capable of 350 Watt transmission.
  - The higher the transmitted power level, the stronger the receive signal will be at any point within the footprint.
- Transmitted Beam Width
  - A fixed amount of power is being transmitted into the footprint area. The larger the area is (wider beam width), the lower the received signal level will be at any given point within that footprint. The smaller (narrower beam width) the footprint area is, the higher the received signal level will be at any point within it.
- Frequency Band and Polarization Type
  - The frequency of the transmission is not as important as the power level or beam-width, but lower frequencies offer a slightly better atmospheric penetration (less attenuation). Circular polarization also offers better penetration of fog and rain (over linear transmissions).

Example Footprint

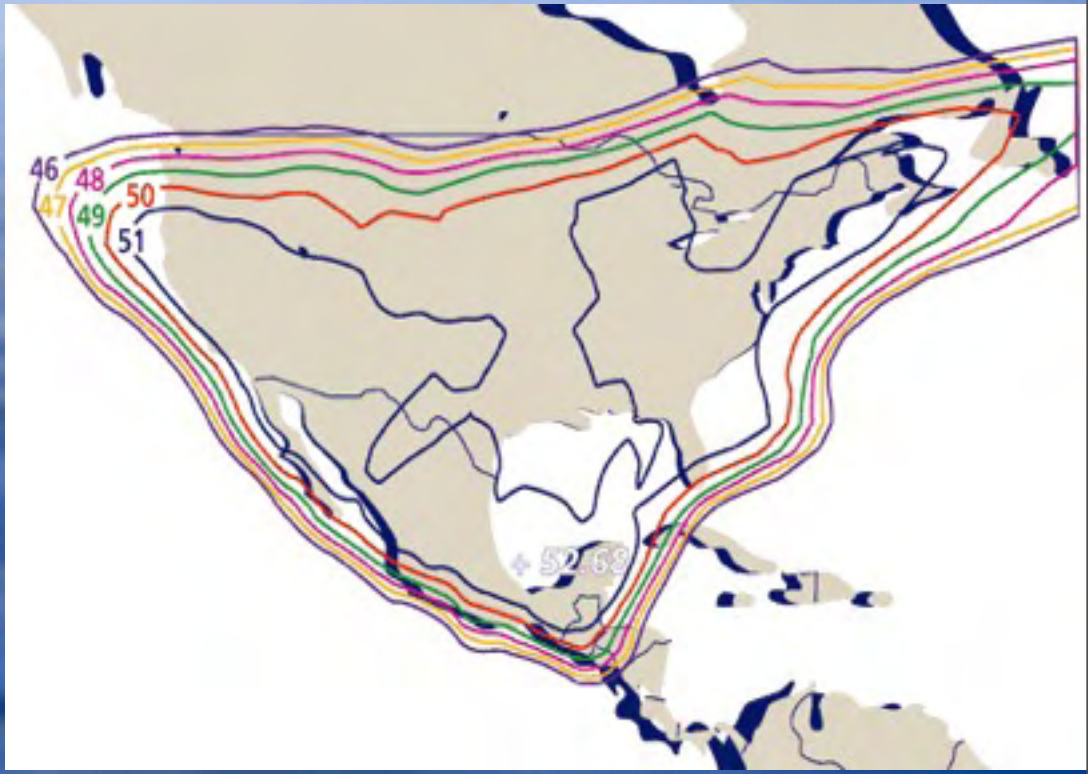
Satellite Footprint Basics

- The signal level of a given footprint is always strongest in the center, decaying (basically in concentric rings) out to the fringes, not necessarily uniform rings
- Even when the ship is in a footprint, the antenna may not be receiving enough signal level for the DAC or the modem to be able to process it properly. Tx power may also be a problem.
- Footprint charts are usually mathematically generated patterns, based on the antennas' performance BEFORE launch, overlaid on pictorial locations of earth. A given satellite can have multiple footprints, with some transponder signals in one but NOT in others.
- In any given satellite footprint, atmospherics change through the day will cause the transponder signal levels to change accordingly.

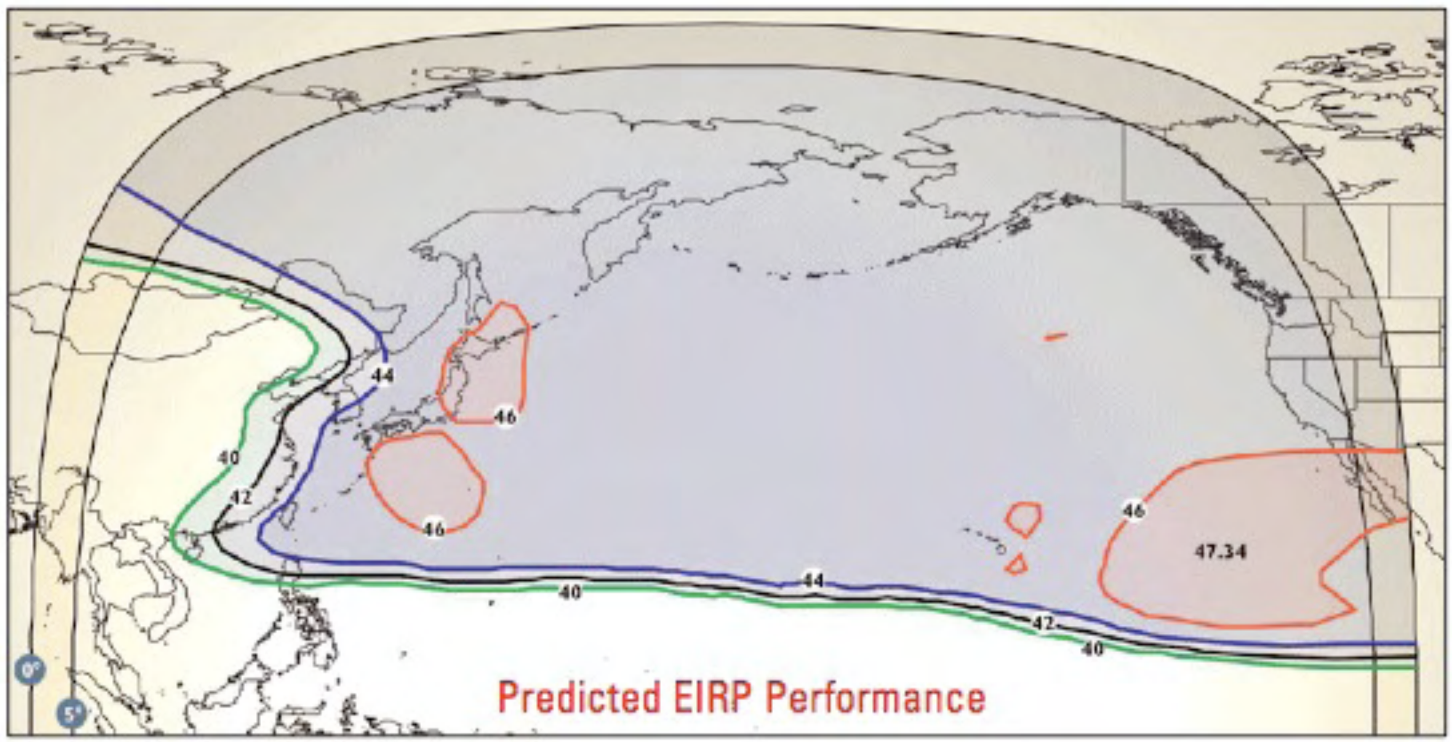
Example Footprint

Satmex 5 - Beam 1 Ku-Band

- Satellite provides Ku-Band service for HiSeasNet ships and other users
- Running out of fuel awaiting SatMex8 replacement
- Operated by SatMex – Mexican company operating 3 satellites geared towards servicing Mexico and N. America
- Beam 1 covers Continental U.S. (including Pacific & Atlantic coasts), Mexico, and Gulf of Mexico
- Located at longitude of 116.8 degrees West (or 243.2 East)
- Shows EIRP Footprint contours (in dBW)
- Note:
  - Decreasing EIRP values from beam center to edge
  - Hot spots
  - Sudden drop at the edge

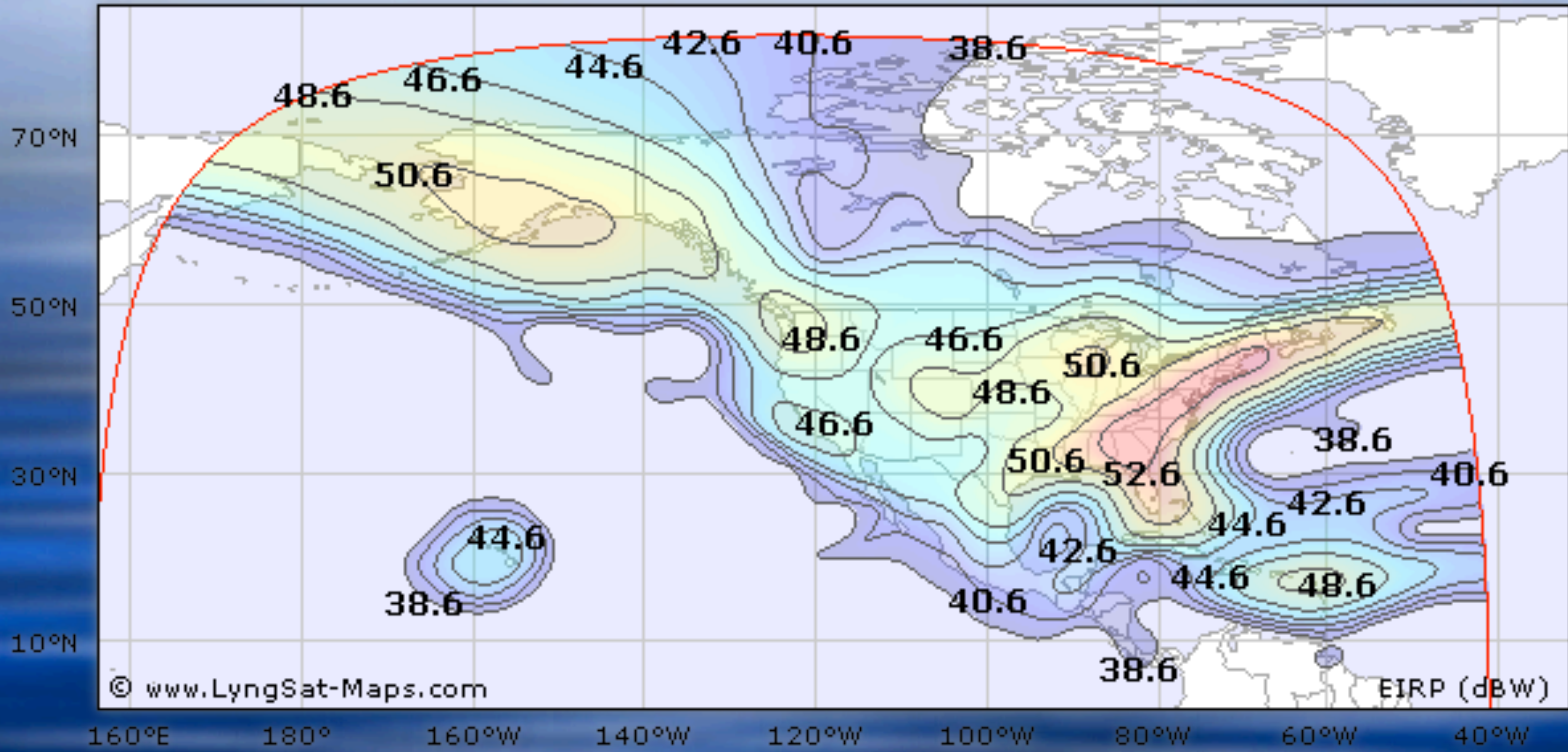


GE-23 Satellite



- Constant ownership change -- Now called "Eutelsat 172A"
- Unusual Ku-band footprint over North Pacific, other wide-ish footprints, too
- Wider beam is weaker and requires minimum 1.5m antenna for efficiency
- No earth station capabilities right now (Look angle from San Diego is 6 deg!)
- Strange co-pol polarization, needs some ship modifications
- Low look angle in US port and coastal waters

Galaxy-18 Satellite



- Hot spots…Why?
- Strong or weak satellite?
- Main purpose?
- What could HSN use it for? What ships?

Satellite Station Keeping

- Even new satellites have a little wiggle in their orbits a little bit
- They need some fuel to keep themselves in a known/fixed box so that fixed antennas can keep generally peaked up
- Satellites are launched with a fixed fuel supply
- If replacement satellite gets delayed, satellites may save fuel by increasing the size of the box and allowing signals to fade more

Solar Outages

- During the year, the sun and satellite move a little bit with respect to each other
- In the Spring and Fall, the sun passes behind GEO satellites enough to cause 5-10 min outages for a few weeks
- Depending on the ship position and look angles, there are 2 opportunities for each day to have outages (Ship and earth station)

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SCPC

- VSAT (Very Small Aperture Terminal...using a focused dish)
- SCPC = Single Channel Per Carrier
- One direction per carrier, fixed data path
- Leased spectrum directly, paid by the month, do what you can with it
- Power limits as to how many carriers you can have
- Simple equipment on ship and at earth station

iDirect

- VSAT based
- Time Division Multiple Access (TDMA) technology
- Lease a big block of spectrum (many MHz)
- Time slice who gets to talk when
  - More time slices, more resolution
  - Give away extra slices if you have them
- Needs expensive earth station gear, special modems
- Doesn’t address wider coverage, just deeper coverage

FBB/BGAN

- L-band technology, less spectrum available, not VSAT
- Small antenna
- Voice and data terminal
- Pay-by-the-byte/minute plans
- Higher latency (1200-1400ms RTT)
- Some flexibility in data path

Iridium

- Truly global coverage, pole-to-pole
- Voice service, too
- Smaller terminals (0.5m, 25lb), lower data rates (136kbps)
- Not all satellites talk back to earth directly
  - Longer delay, possibly frequent handoffs between satellites
- Costly depending on plan
- Next-gen launches are 2015-2017, with data rates of 1.5Mbit (L-band) to 8Mbit (Ka-band)

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Power Equivalent Bandwidth

- With each fraction of a transponder's spectrum comes a fraction of its power
  - Ex: Buy 1MHz on a 36MHz xponder, get 1/36th the power on that transponder
- Bigger antenna = bigger footprint = less power required
- A ship can sometimes use a smaller antenna, but needs more power
  - Ship amp must have the power, and must have leased enough bandwidth to be allowed to use it

Satellite operator's view

- I have only so much capacity in the sky
- How do I make the best use of that capacity?
  - Long term lease for a small chunk? A big chunk?
  - Occasional use? Short term, but more costly...
  - A big block that can get re-sold as a time division block?

iDirect systems

- Aggregated service for many ships
- Can be over-subscribed or under-subscribed...even for the area
- Pay for either a committed information rate (CIR) or a SCPC-like setup

Inmarsat services

- Option 1: Open up a big, efficient pipe and pay by the minute of use
  - Good for bulk data dump, but need to be quick about it
- Option 2: Swap packets in/out all the time, but pay by the byte

HSN Bandwidth Economics

- HSN leases spectrum by the week or month on 1 year or less leases
- Longer leases = cheaper monthly rate
- Short term leases (weeks or months)
  - Usually 30% more for bandwidth
  - Have 1-time setup costs applied ($500-2000)
- Wherever we can, no middle-man or service provider
- Doesn’t get much more bare-bones than HSN
  - Minimal operations staff
  - Equipment maintenance and spares pool
  - Direct SCPC leases (~75+% of the budget)

HSN Additional Satellites

- Sometimes we get bandwidth on different satellites (G-18, IS-906, etc.)
- Requires earth station services (additional monthly cost)
- Requires additional time and engineering for ship and shore
- Multiple ships get even trickier, but are possible

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Earth Stations

- Only need them if you want your data to go somewhere on earth.
- Where signals come out of the sky and hit the Internet and vice versa
- A good station needs:
  - A view of the satellite we are talking on
  - Terrestrial bandwidth/access
  - Big enough antenna and amplifier to sustain carrier(s)
  - Decent enough weather for the band
  - Redundancy in power, data, etc
  - Responsive staff

- Bigger antennas to work with smaller remote stations
- No tracking
- Good access to data network
- Rack of modems and routers

HSN Earth Station Tour

- Modems
- Routers
- Remote control
- Network

- Antennas
- RF gear
- A/C and power

Intelsat Napa

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Operators vs Providers

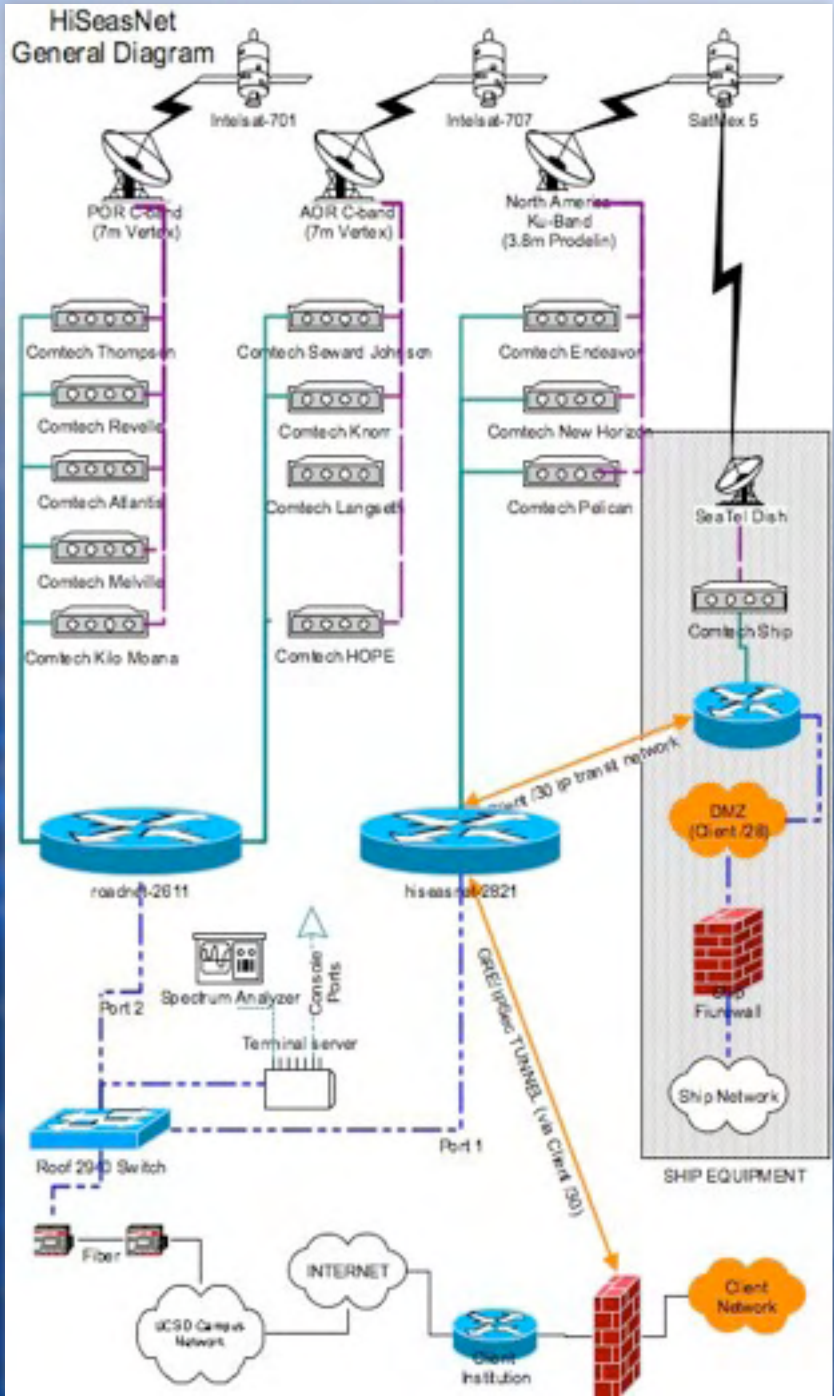
- Just like in the terrestrial world, there are the infrastructure folks and the service folks
- Satellite operators provide a chunk of spectrum/power and let you do what you want with it.
  - SatMex, Intelsat, Inmarsat, SES WorldSkies, etc.
  - Voice? Video stream? SCPC data? TDMA network?
- Service providers do all that Internet magic
  - Downlink to earth, routing, VPNs, email, etc.
- Sometimes the operators also provide services

Hardware

- Beyond the RF gear that pushes energy out the dish, what gear you have below decks depends on what you want to do.
- Satellite Modems do what other modems do: Modulation/Demodulation
- If doing IP, need a router (may be integrated with modem)
- After a router, then what?
- The world is your oyster...

Quality

- Signals get rough around the edges, obstructions, noisy gear, rain fade, etc.
- In order to push good data across, there needs to be enough signal quality and extra information to handle errors in transmission/reception
- EbNo is our measurement: Energy per bit over Noise
- Our modems are good, but we still need an EbNo of about 3.5 or better to push data smoothly
- We can trade EbNo for data rate sometimes ("margin")
  - Stronger signal (more tolerance to problems) with a slower data path.
  - 1/2 the data rate = 3 dB of EbNo



Typical Ship Network Setup

- Fancy tweaks include:
  - Fail over between FBB, 3G, HSN
  - Crypto
  - Acceleration (hidden across the satellite)
  - DHCP for the DMZ

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A time of transition…

- L-band technologies and spectrum may be bottoming out on its price as spectrum is limited
- Ka-band has some wide open spectrum and high capacity, but rain fade and footprint issues
- Ku-band and C-band are still operating mainstays of VSAT comms
- Maritime use is tricky with
  - Stabilized antennas
  - Global range
  - Not near land masses
  - Weather issues

Known Ka-band Systems

- O3b Networks has an MEO system going up later this year
  - Up to 1Gbps speeds, 150ms latency, 1.2-2.2m antennas
  - Spot beams, +45/-45deg latitudes
- Inmarsat GX launching soon, complete in 2015
  - Targeting 50/5Mbps speeds, 60cm Ka- antennas
- Intelsat EpicNG - wide/spot/coding combo of C/Ku/Ka bands
  - Mostly marketing-speak right now, no details
  - Available...eventually/gradually

Ka-Band Good

- More hardware is becoming available for Ka-band, cost is falling
- New technology going up on satellites that is 100x more capacity than Ku-band now (Gigabit beams)
- Much more capacity in the sky should bring prices down
- Ocean areas are sometimes being lit up for aircraft
- SeaTel is working on smaller stabilized antennas for Ka-band, but still 1m-ish

Ka-Band Bad

- Weather fade issues are even worse than Ku-band
- Footprints are often more focused that Ku-band
- Services aren’t up in the sky quite yet
  - Earliest systems up late this year, early next year
  - Complete networks in the next few years

But wait…there's more

- The industry is trending towards service providers for this greater capacity
- Will satellite access be like cell phone access? Cheaper, but less control over the network?
- Time will tell what direction things go, likely some hybrid multi-band solutions for a while
  - C-band in open ocean, Ku- or Ka- while near shore? Need large, multi-band antenna to be efficient at all.
  - Ka- or Ku- in shore, but slow L-band while open ocean? Smaller antennas, but speed limits at sea.

Questions/Issues?

- Any of that make sense?
- What do you want to hear about tomorrow?