Crash Course on Satellite Communications

Lexington Computer and Technology Group

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Topics

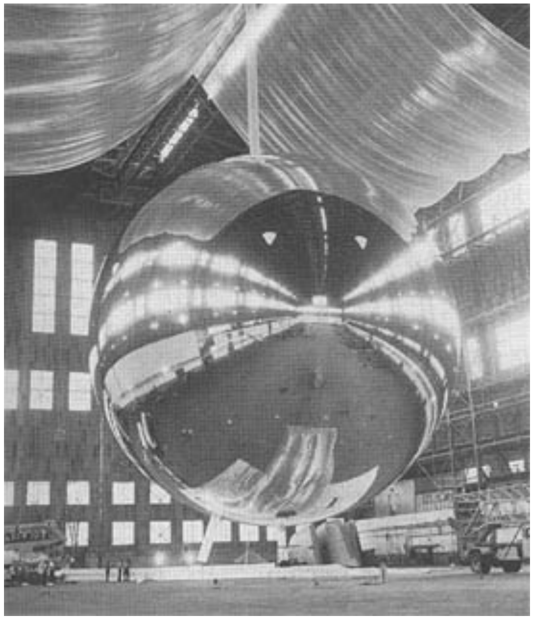
- Early history of communications satellites
- Various types of orbits
- International regulation and governance of communications satellites
- Ground station equipment
- Factors affecting the performance of a satellite link
- ARPA Packet Satellite Network Projects
- VSAT Networks

A Brief History

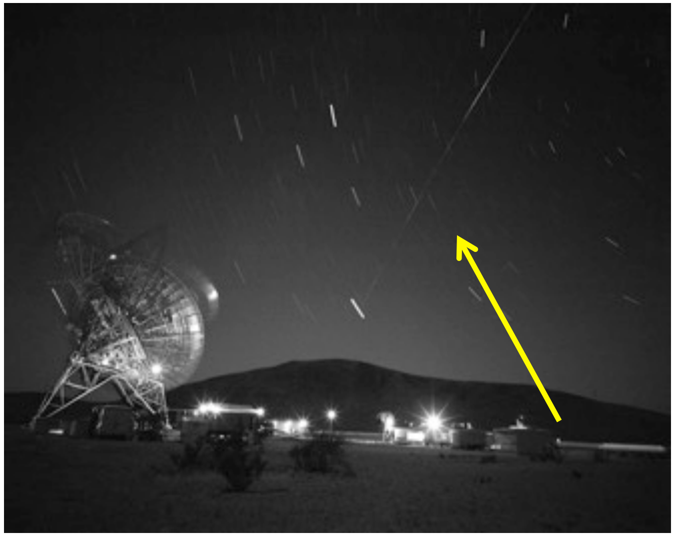
- Arthur C. Clarke proposed geostationary orbit satellites for television and microwave communications in the Feb. 1945 issue of Wireless World
- John Pierce brought together five Bell Labs innovations from the 1940s and 1950s to implement Clarke's vision:
  - High power traveling wave tube amplifiers (TWTA)
  - Ultra low noise cryogenically cooled maser*-based receive amplifiers
  - Photovoltaic solar cells
  - Transistors
  - Information Theory (improving communications in the presence of noise)
- After Sputnik and Explorer I, John Pierce proposed a couple of steps:
  - Echo I – a 100 foot Mylar balloon to passively reflect microwave signals
  - Telstar – an active microwave repeater

* Microwave Amplification by Stimulated Emission of Radiation

Echo 1 – Launched Aug. 12, 1960

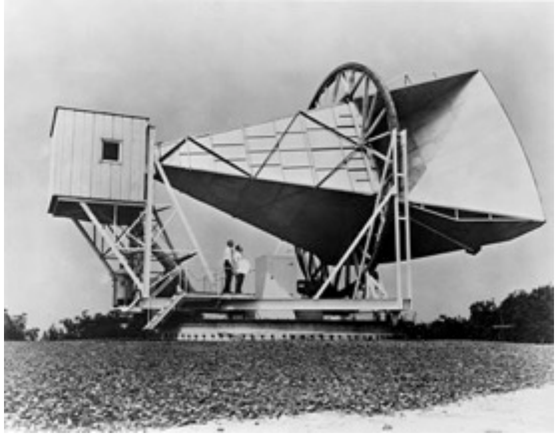


Reflective Mylar
Weight: 146 lbs
Diameter: 100 ft
Orbit: Eccentric/Inclined
- Apogee: 1046 mi
- Perigee: 947 mi
- Inclination: 47.2°
- Orbital Period: 118.3 min



View of Echo 1 passing over JPL Golstone, CA tracking transmit Earth Station

Carried a pre-recorded speech by Pres. Eisenhower and first satellite phone call between Holmdel, NJ and Goldstone, CA



Bell Labs Crawford Hill, Holmdel, NJ
Maser-enabled tracking receive Earth Station

Later used by Arno Penzias and RW Wilson to detect 3° Big Bang background radiation

Telstar – Launched Jul. 10, 1962

President Kennedy Press Conference transmitted live to Europe via Telstar

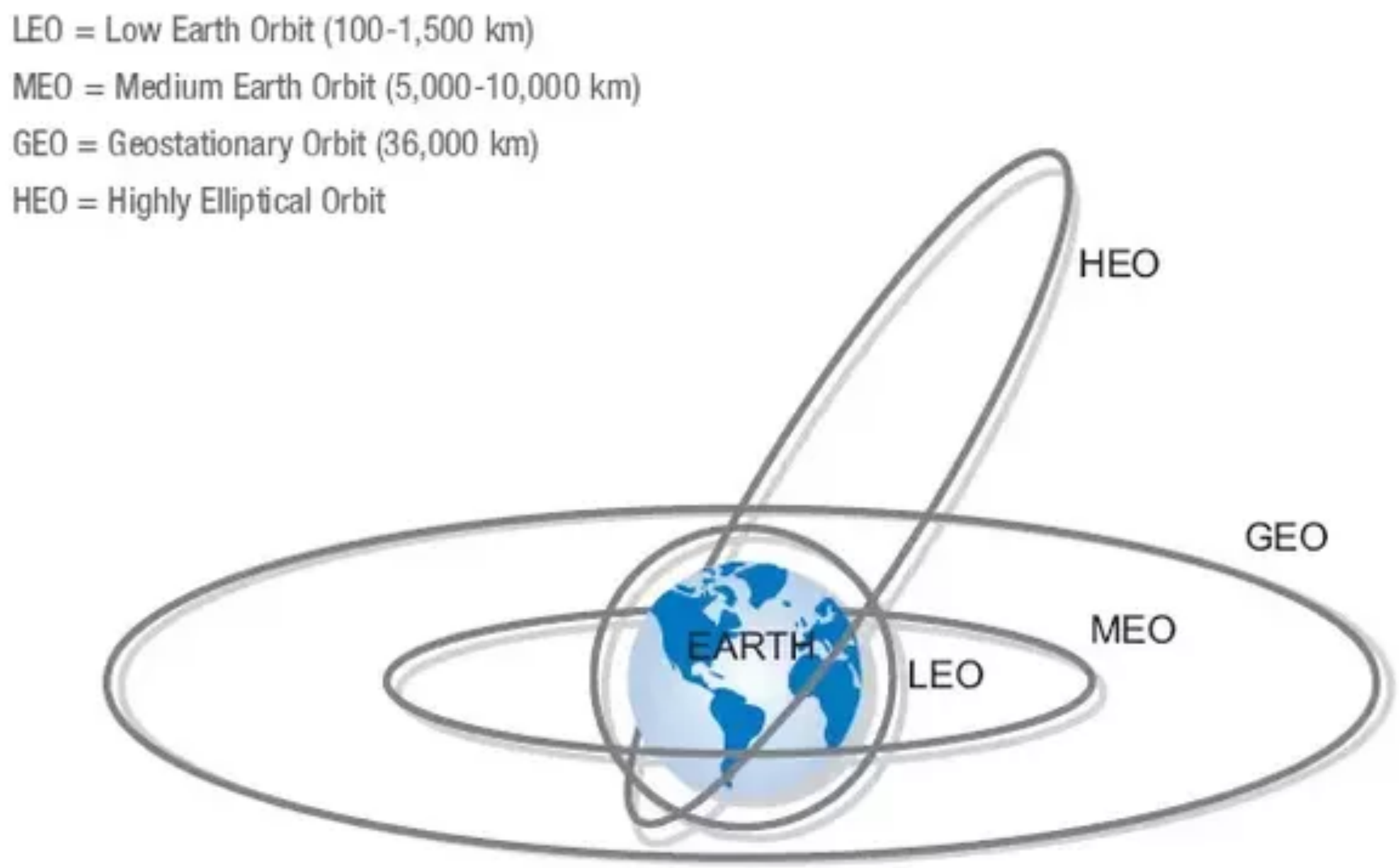
Giant Horn Antenna, Andover, ME

Weight: 377 lbs   Diameter: ~3 ft
Orbit: Eccentric/Inclined
- **Apogee: 592 mi**
- **Perigee: 3687 mi**
- **Inclination: 44.8°**
- **Orbital Period: 2.5 hours**

Transmission Time (US-EUR): 20 min
Uplink: 6 GHz
Downlink: 4 GHz
Bandwidth:
- **1 Television Channel**
- **500 telephone channels**

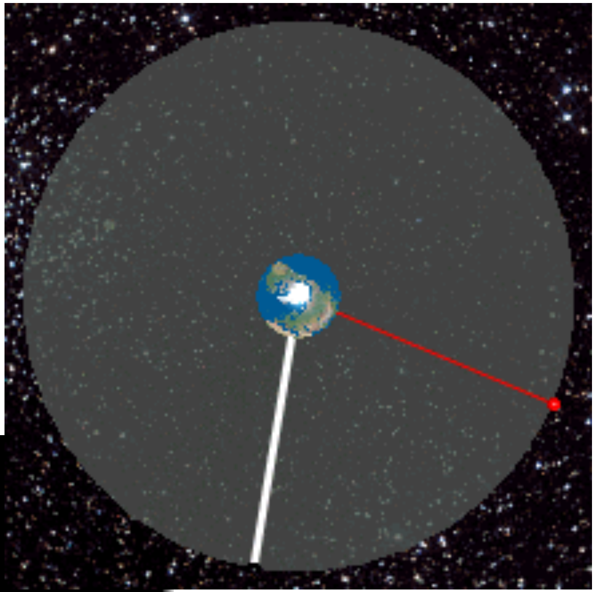
Arthur:
26m Parabolic Antenna at Goonhilly Downs, Cornwall, UK

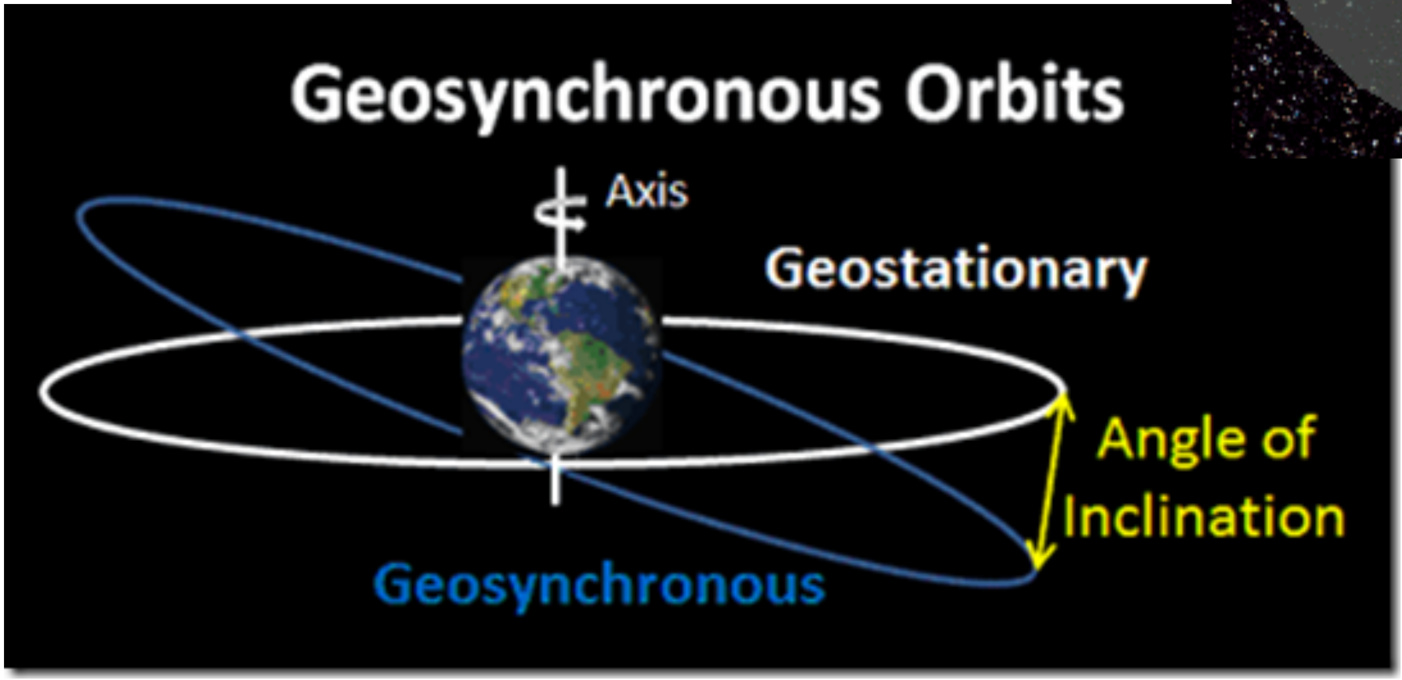
Orbits


LEO = Low Earth Orbit (100-1,500 km)
MEO = Medium Earth Orbit (5,000-10,000 km)
GEO = Geostationary Orbit (36,000 km)
HEO = Highly Elliptical Orbit
HEO
GEO
MEO
LEO
EARTH

Geosynchronous vs. Geostationary Circular Orbits

**35,786 km or 22,236 mi.
above Earth's surface**





Syncom 2 – Launched Jul. 26, 1963
First Geosynchronous Orbit Comms Satellite

Syncom 2:

Built by Hughes Aircraft

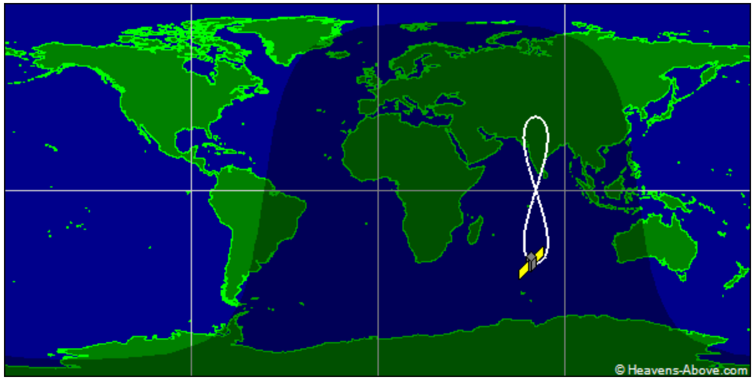
First geosynchronous communications satellite – 33° orbit inclination

71 cm in diameter x 39 cm height

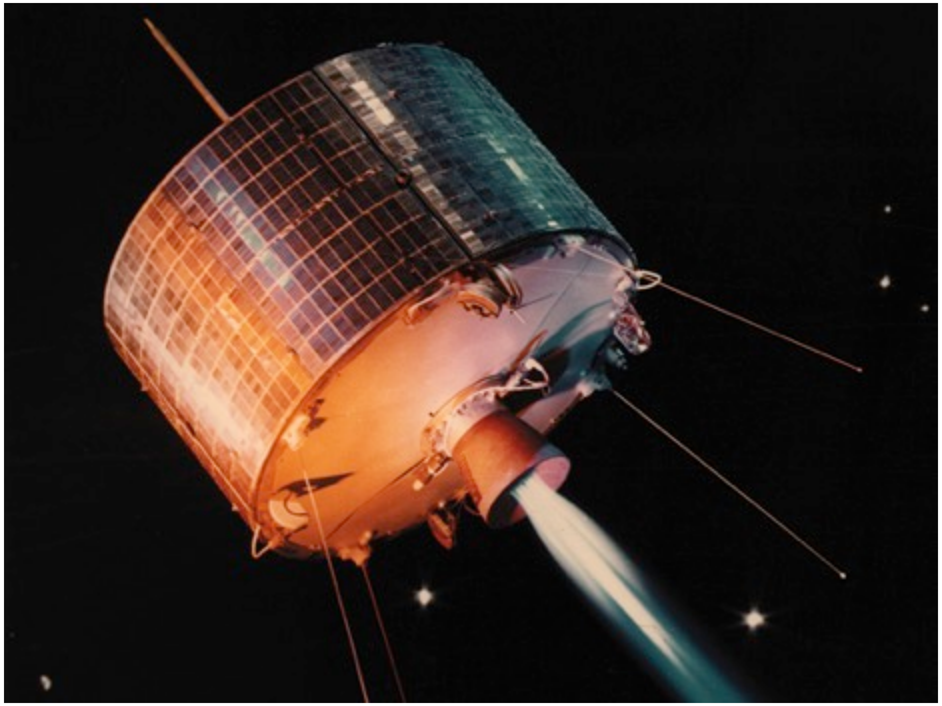
68 kg with fuel at launch

Syncom 3:

First satellite in geostationary orbit 0° inclination



Syncom 2 motion as seen from Earth due to inclined orbit

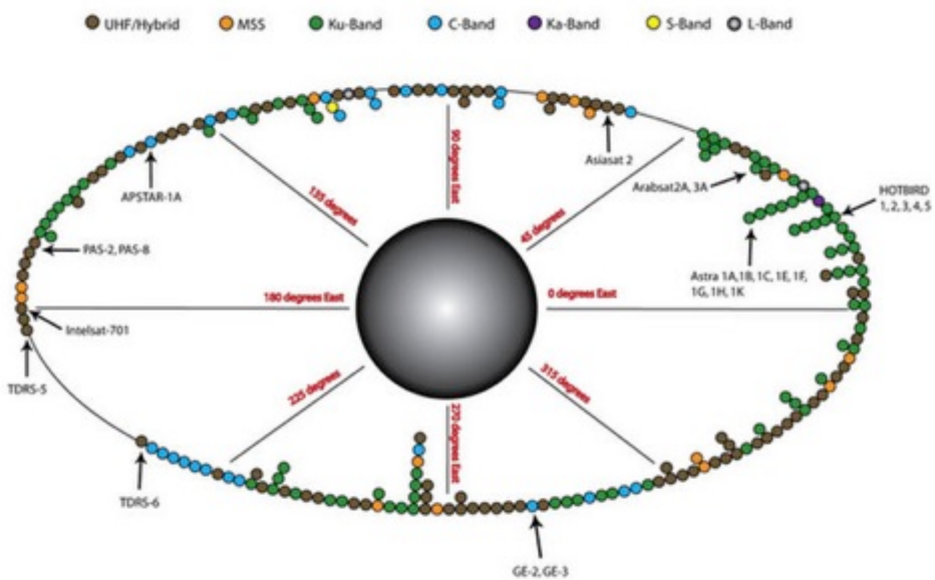


Communications Satellite Governance: 1962 - 2001

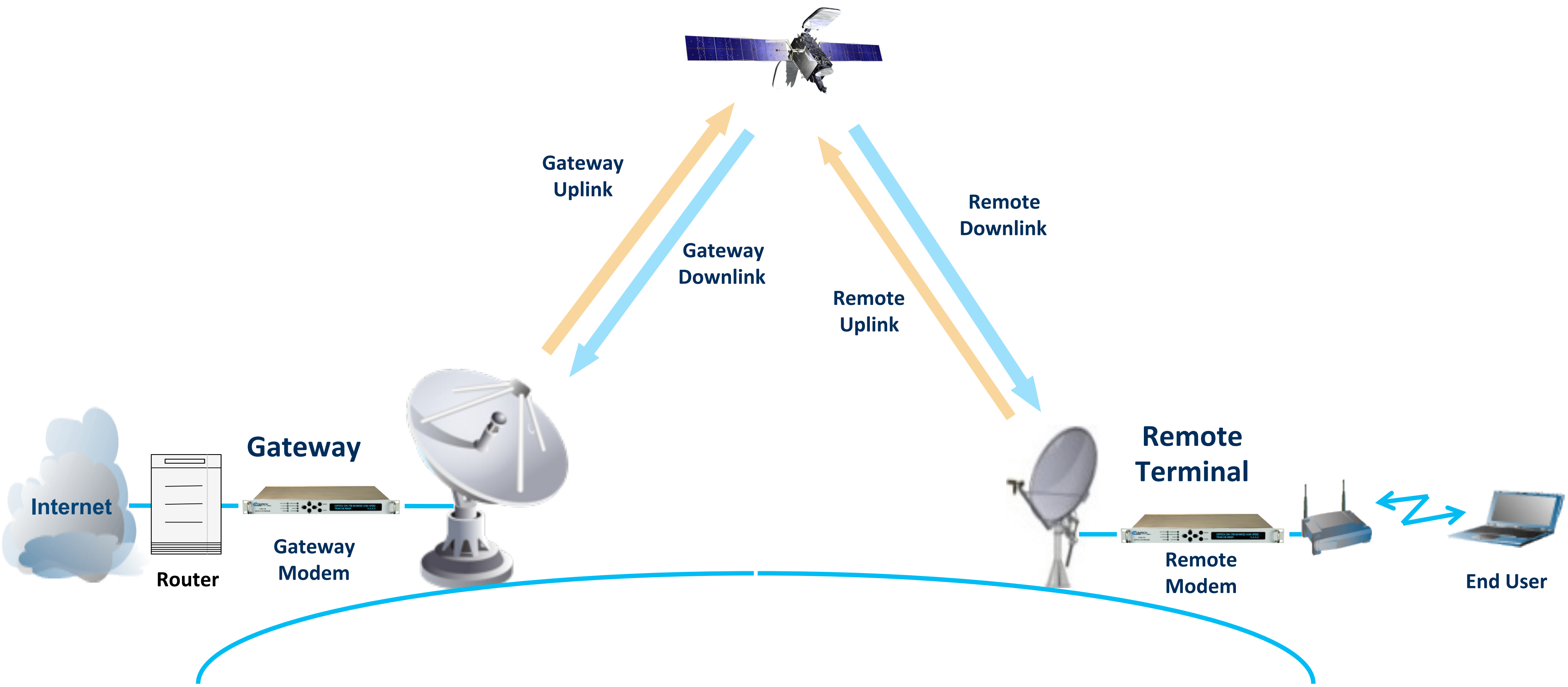
- Most countries had a national telephone company (PTT)
- Following successful launch of Telstar by Bell Labs & NASA, Congress set up the Communications Satellite Corporation (COMSAT)
- COMSAT helped create Intelsat under the auspices of the UN in 1964 and launched the Early Bird satellite in 1965 (became Intelsat I)
- Intelsat helped standardize satellites and ground station equipment
- Commercialization of space by Satellite Business Systems (MCI/IBM), PanAmSat and others in late 20th Century led to the privatization of Intelsat in 2001 (and divestiture of some of its satellites)
- Today, Intelsat is the largest satellite operator followed closely by SES which bought up a number of satellites that were divested by Intelsat and also satellites owned by GE/RCA

International Telecommunications Union (ITU)

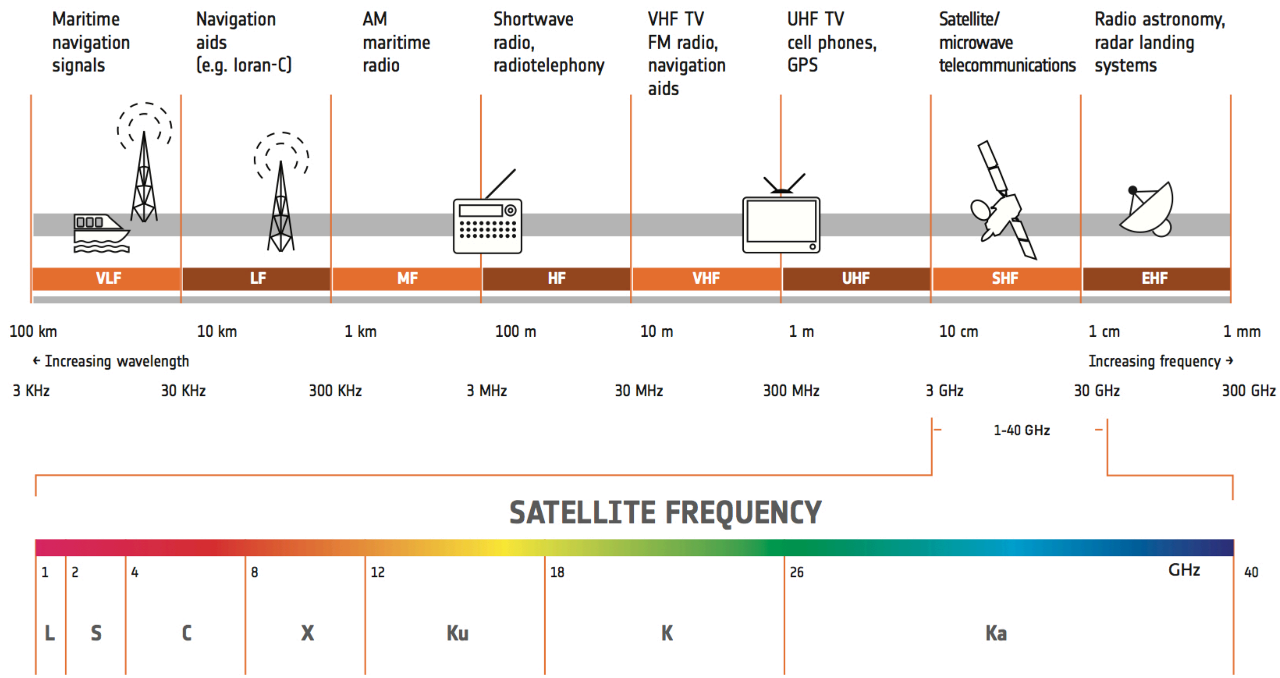
- Originally formed in 1865 to coordinate international telegraph communications and brought under UN administration in 1947 coordinates
- ITU is responsible for satellite frequency and orbital slot de-confliction
- Intelsat, SES, and various government and quasi-government organizations own and operate most of the satellites providing Internet, private data and television services



The Signal Path: From Earth to Space and Back to Earth

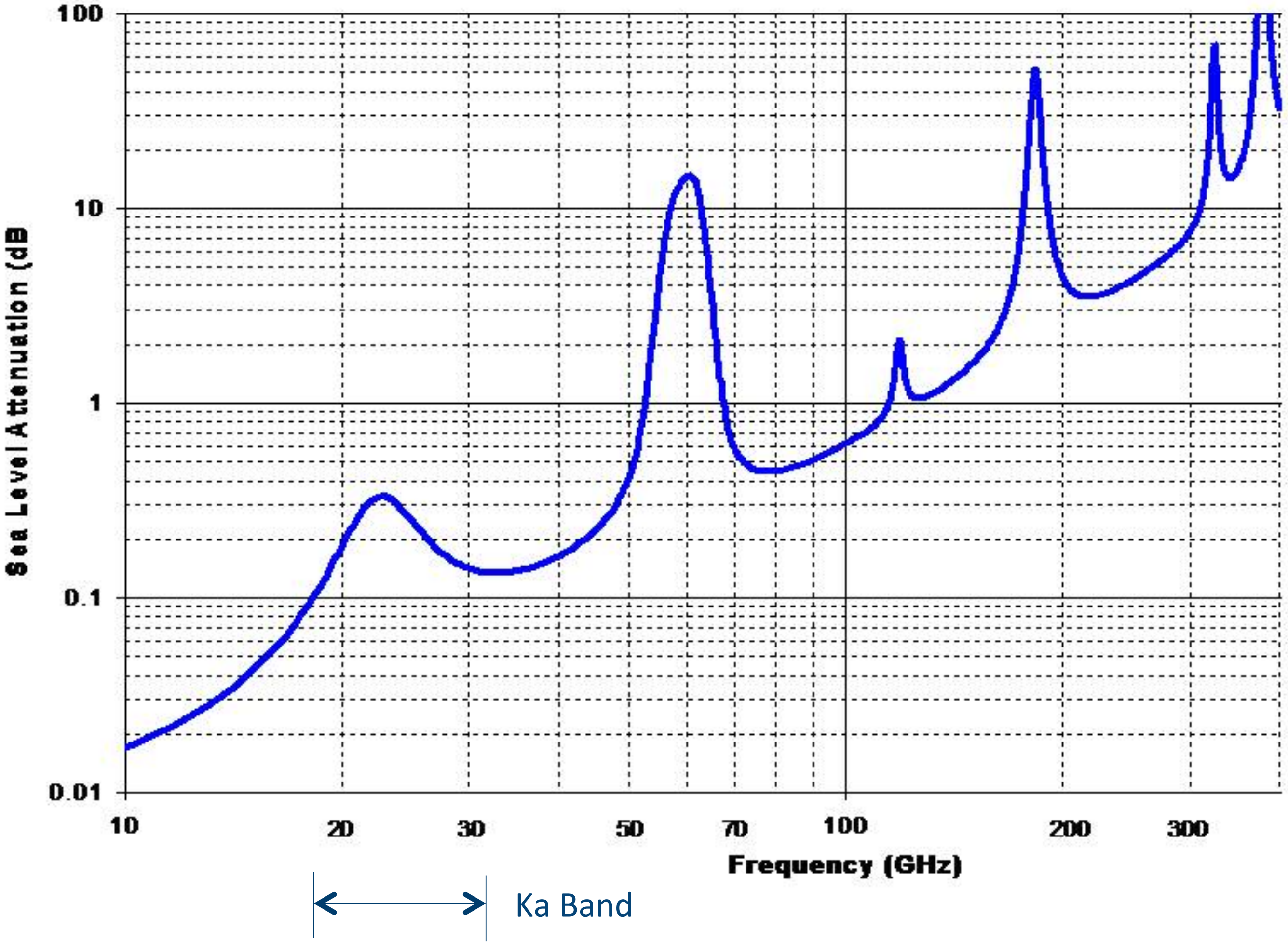


Frequencies Used in Satellite Communications

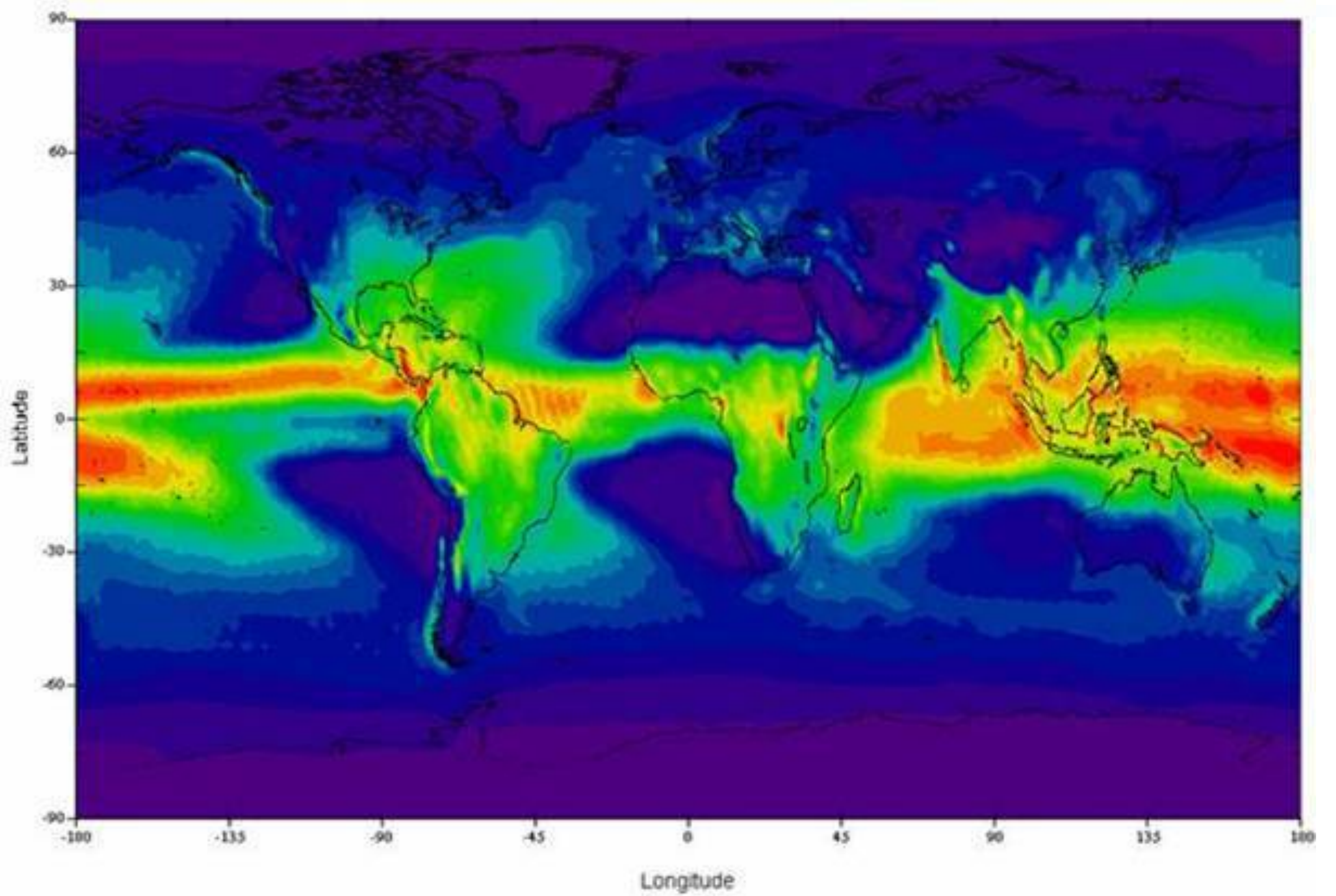


- Satellite communications typically utilize a lower frequency for the downlink (from space to ground) and a higher frequency for uplink (ground to space). For example:
  - C band: 6 GHz for uplink and 4 GHz for downlink
  - Ku band: 14-15 GHz for uplink and 11-12 GHz for downlink
  - Ka band: 27 GHz – 31 GHz for uplink and 17 – 21 GHz for downlink

Attenuation Due to Atmospheric H_2O

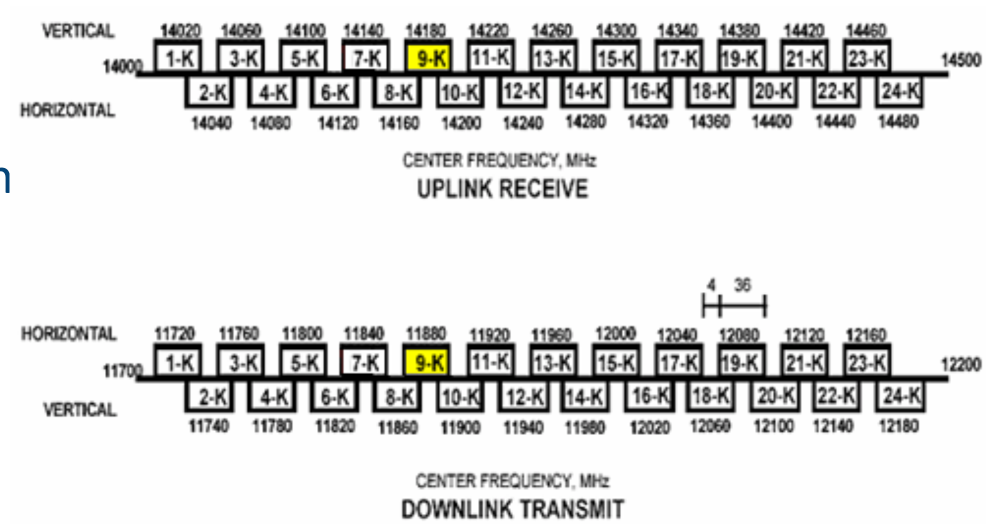


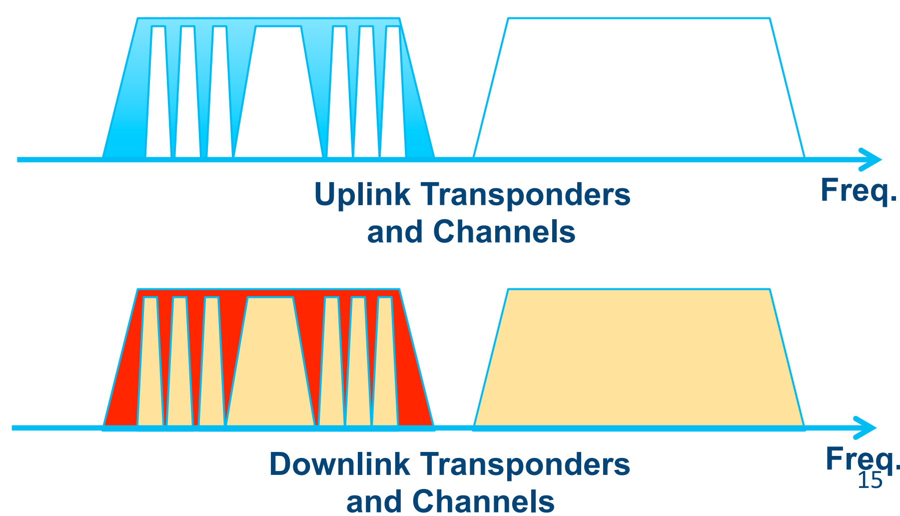
ITU Rain Fade Zones



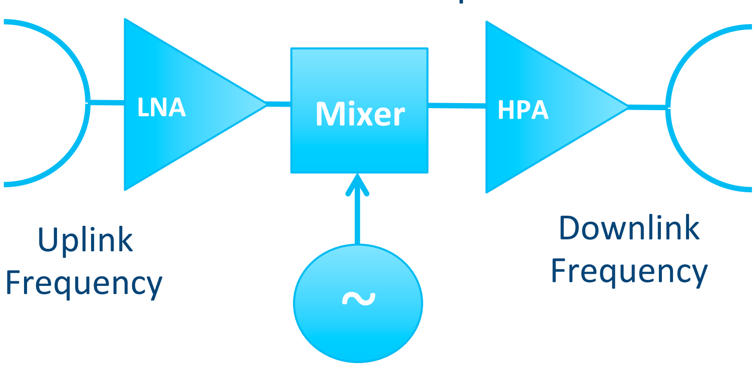
Transponders and Channels

- Typical Ku band satellite has 24 transponders
- Each is 36 MHz wide and spaced with 4 MHz guardbands
- Some have 72 MHz transponders
- Transponders can be divided up into Channels
- Customers can lease a whole transponder or a channel of X MHz

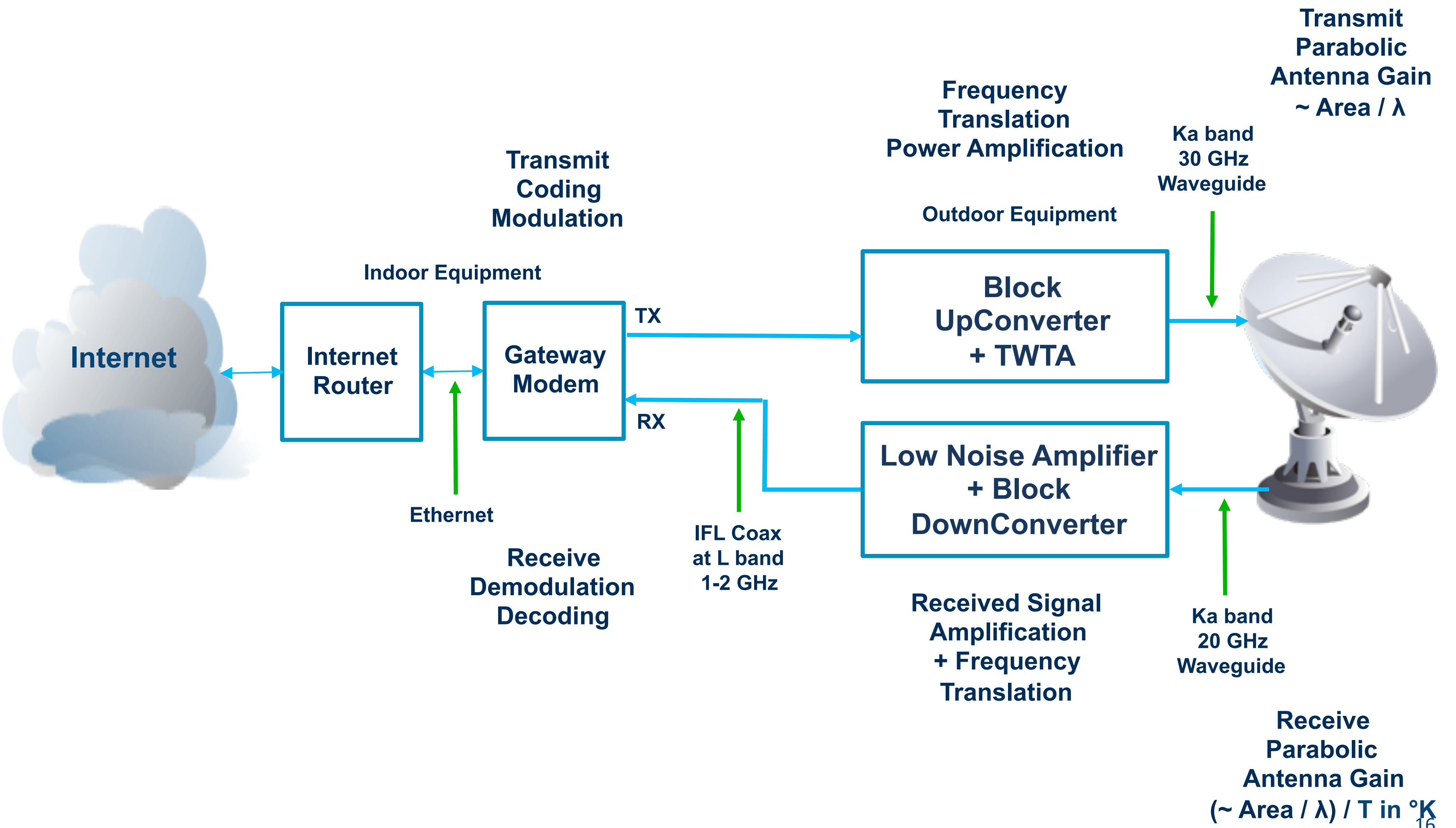




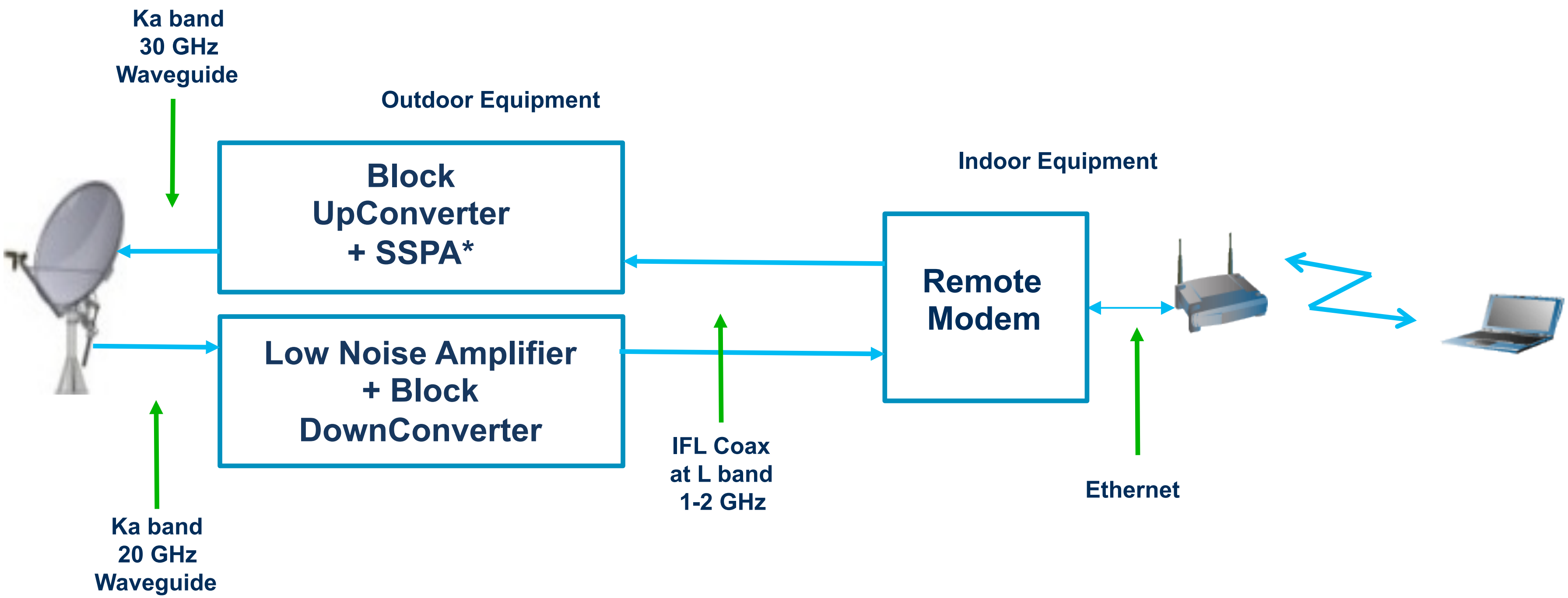
Satellite Transponder



Gateway Block Diagram



Remote Terminal Block Diagram



* SSPA = Solid State Power Amplifier

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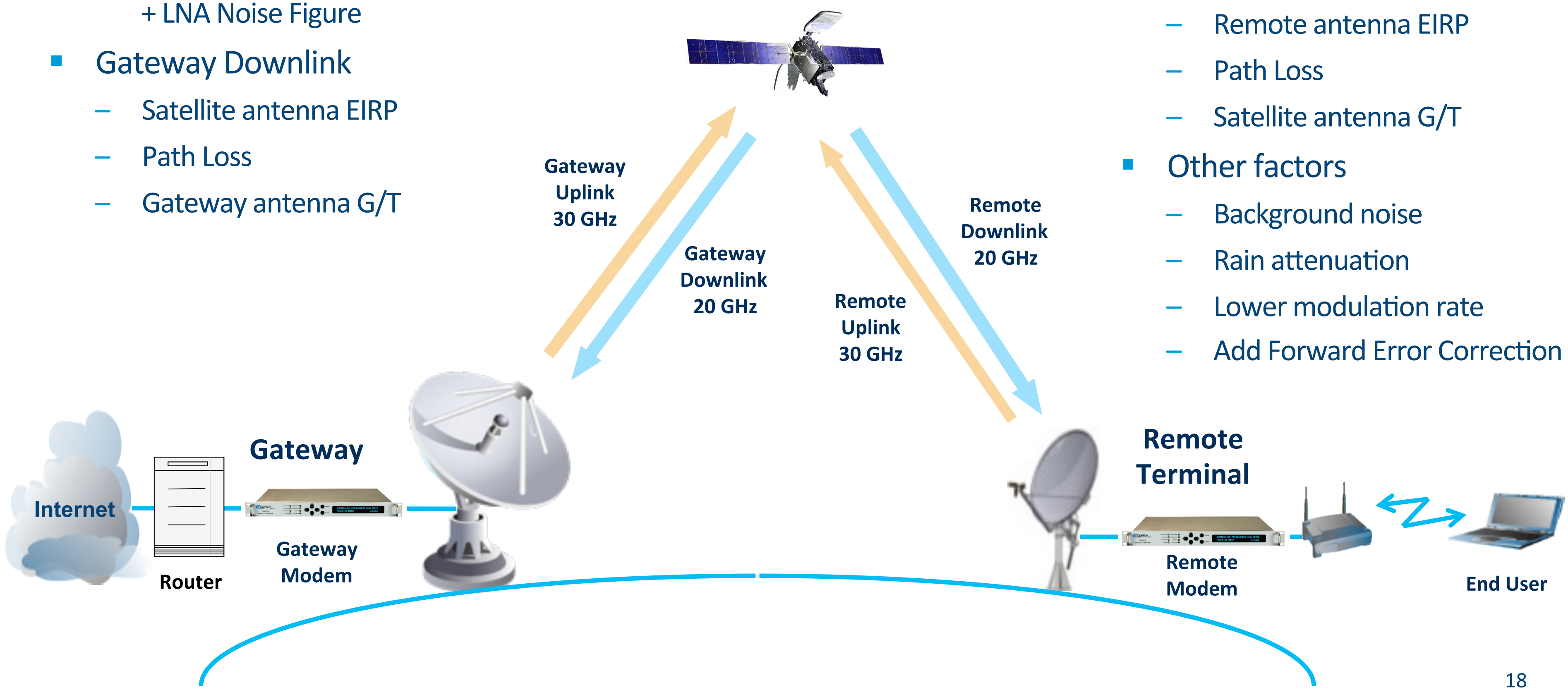
Satellite Link Performance: The Link Budget (calculated in dB)

- Gateway Uplink
  - Gateway antenna (~A/λ) + power amplifier gain: Effective Isotropic Radiated Power (EIRP)
  - Path Loss (signal strength falls off as $1/R^2$)
  - Satellite antenna receive gain (G/T in °K) + LNA Noise Figure
- Gateway Downlink
  - Satellite antenna EIRP
  - Path Loss
  - Gateway antenna G/T
- Remote Downlink
  - Satellite antenna EIRP
  - Path Loss
  - Remote antenna G/T
- Remote Uplink
  - Remote antenna EIRP
  - Path Loss
  - Satellite antenna G/T
- Other factors
  - Background noise
  - Rain attenuation
  - Lower modulation rate
  - Add Forward Error Correction

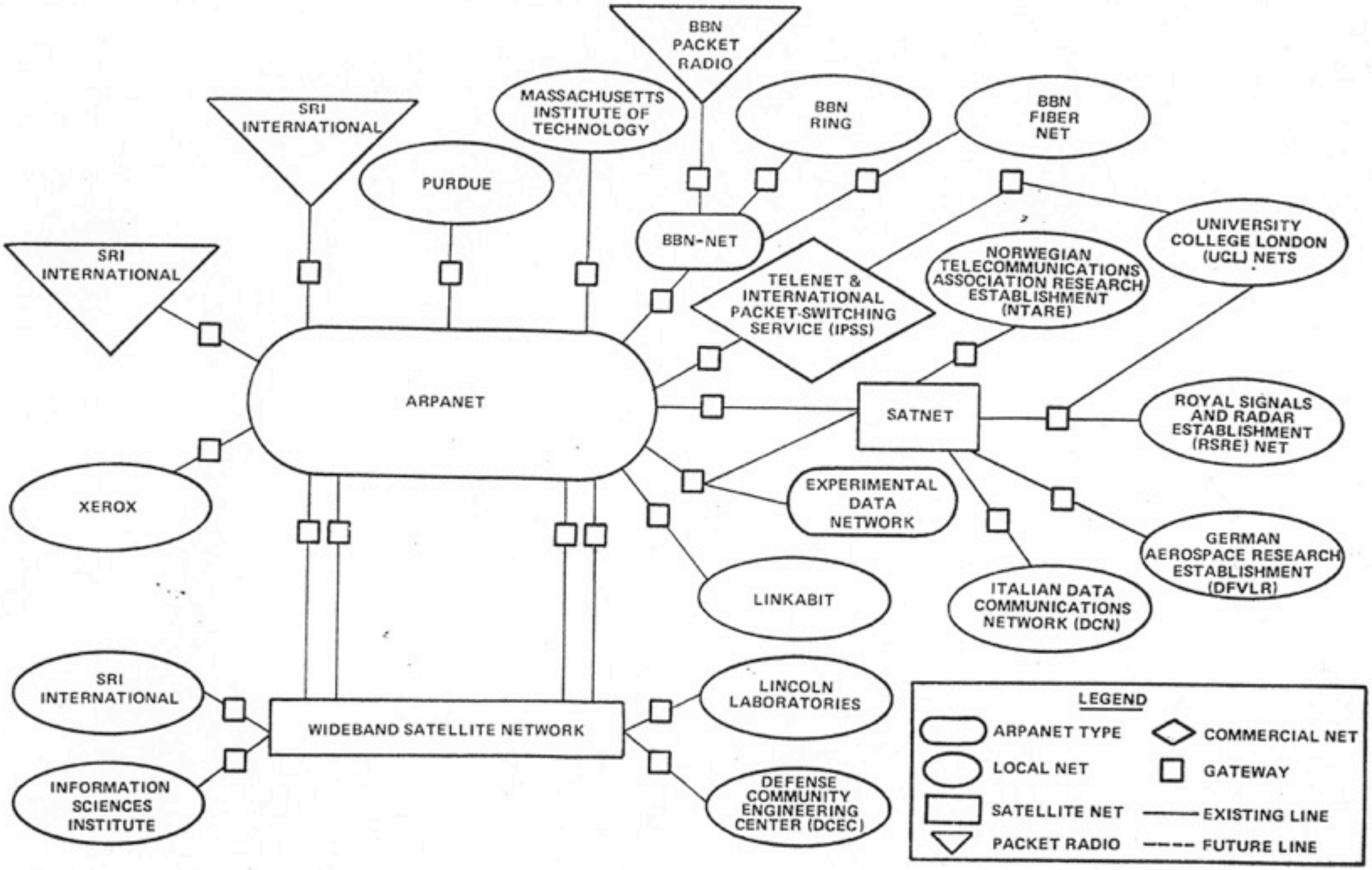


ARPA Packet Satellite Projects

The Beginnings of the Internet in the 1970s

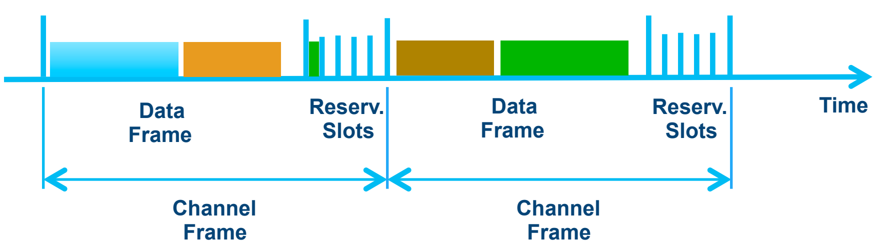
- The ARPANET based on packet switches (IMPs) connected by point-to-point 50 Kbps circuits was up and running
- ARPA wanted to demonstrate that packet switching could also work over local line-of-site radio channels (Packet Radio Networks) and broadcast satellite channels (Packet Satellite Networks)
  - AlohaNet in Hawaii (Norm Abrahamson at Univ. of Hawaii)
  - Packet Radio Network (SRI, BBN, and Collins Radio)
  - Atlantic SATNET (BBN, Linkabit, and COMSAT): 64 Kbps Intelsat Atlantic Ocean Region satellite channel to support for NATO cooperative C^2 exercises
- Wideband Satellite Network: 3 Mbps Westar III/IV channel testbed for:
  - High bandwidth multiprocessor packet switches (BBN Pluribus and Butterfly)
  - Packet voice (VoIP)
  - Multi-site video and multimedia conferencing

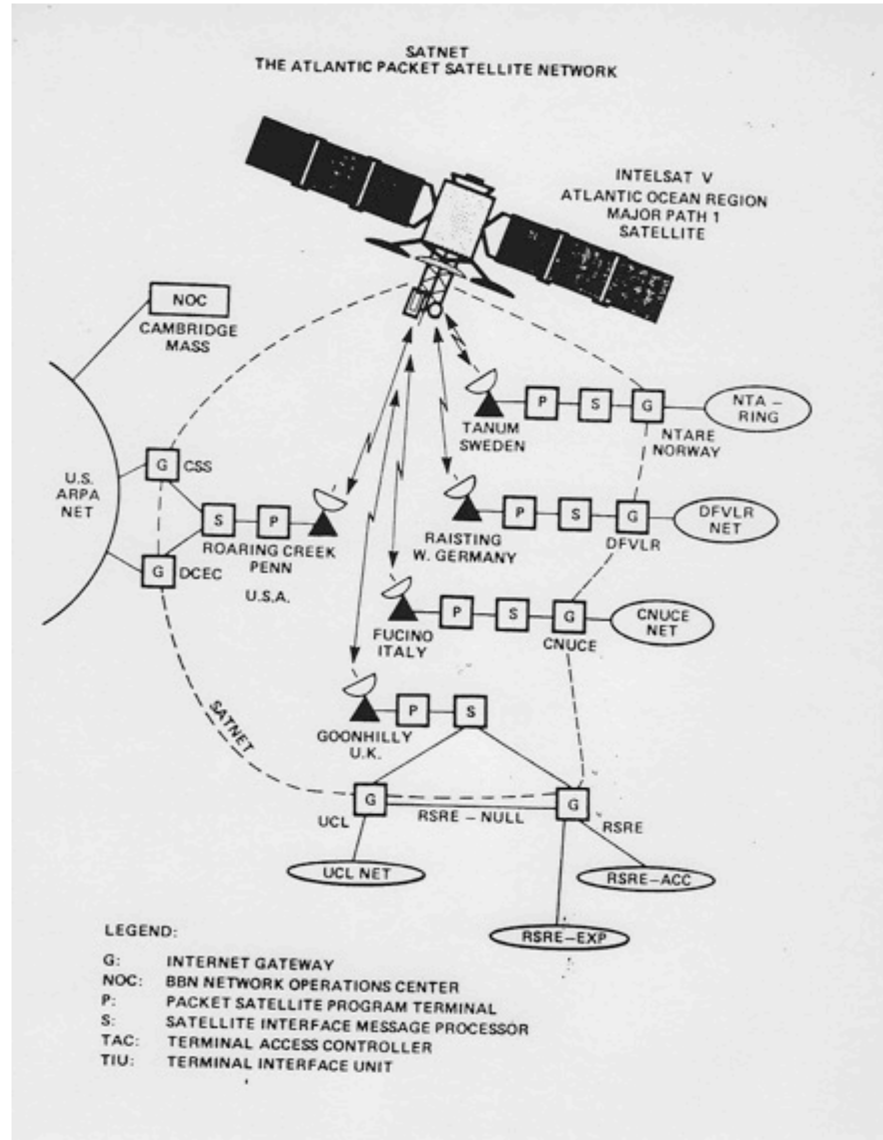
The Interconnection of Diverse Networks by Gateways - 1983



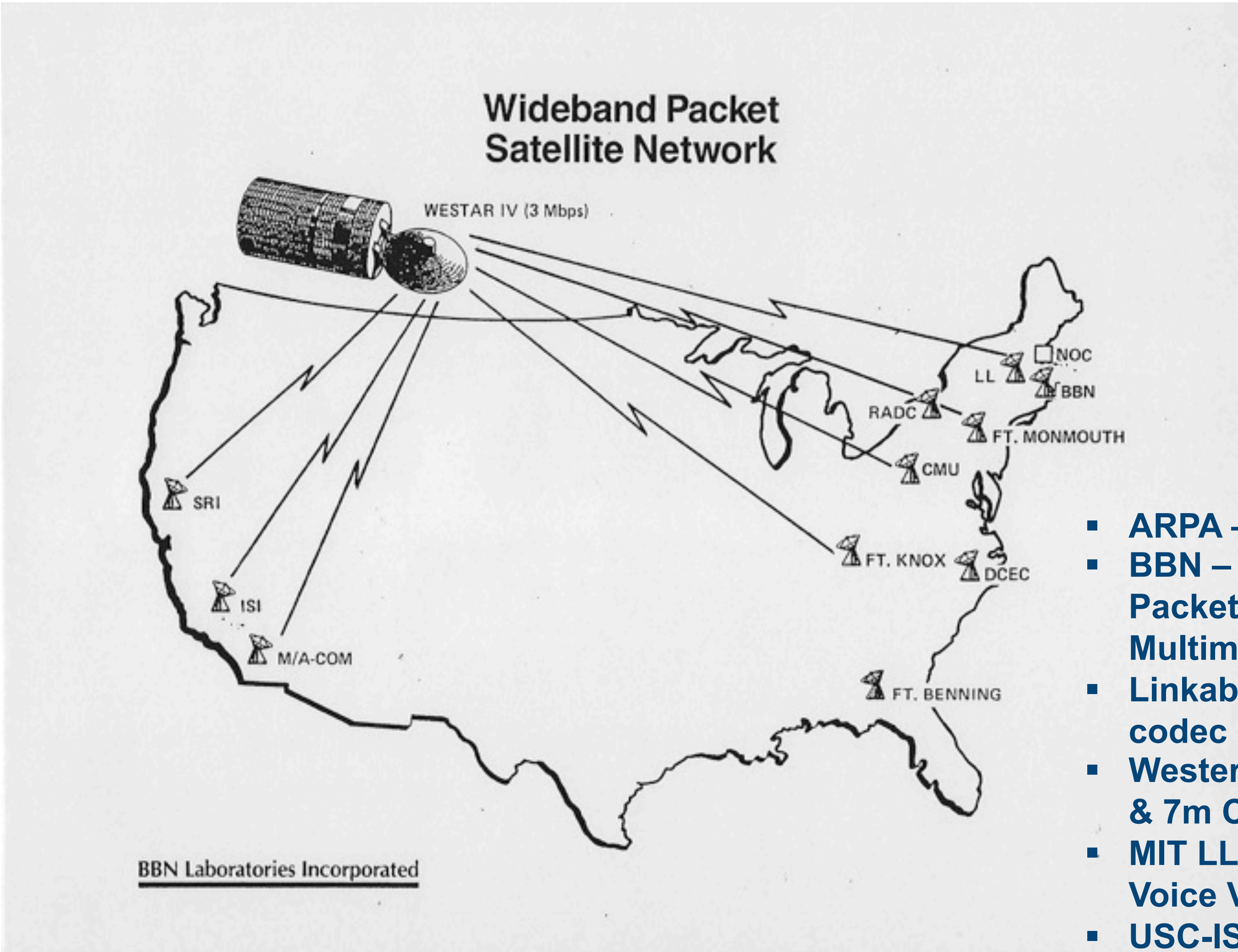
DARPA's Atlantic SATNET
Extending the Internet to Europe: 1977 - 1980

- Linked UK, Norway, Italy and Germany to the ARPANET in the US
- All sites listen on a common shared 64 Kbps satellite channel and take turns transmitting on that channel
- Distributed control: Priority Oriented Demand Assignment (PODA) to schedule and allocate time on the satellite channel (BBN)
- Burst Modem/Viterbi Coding (Linkabit)



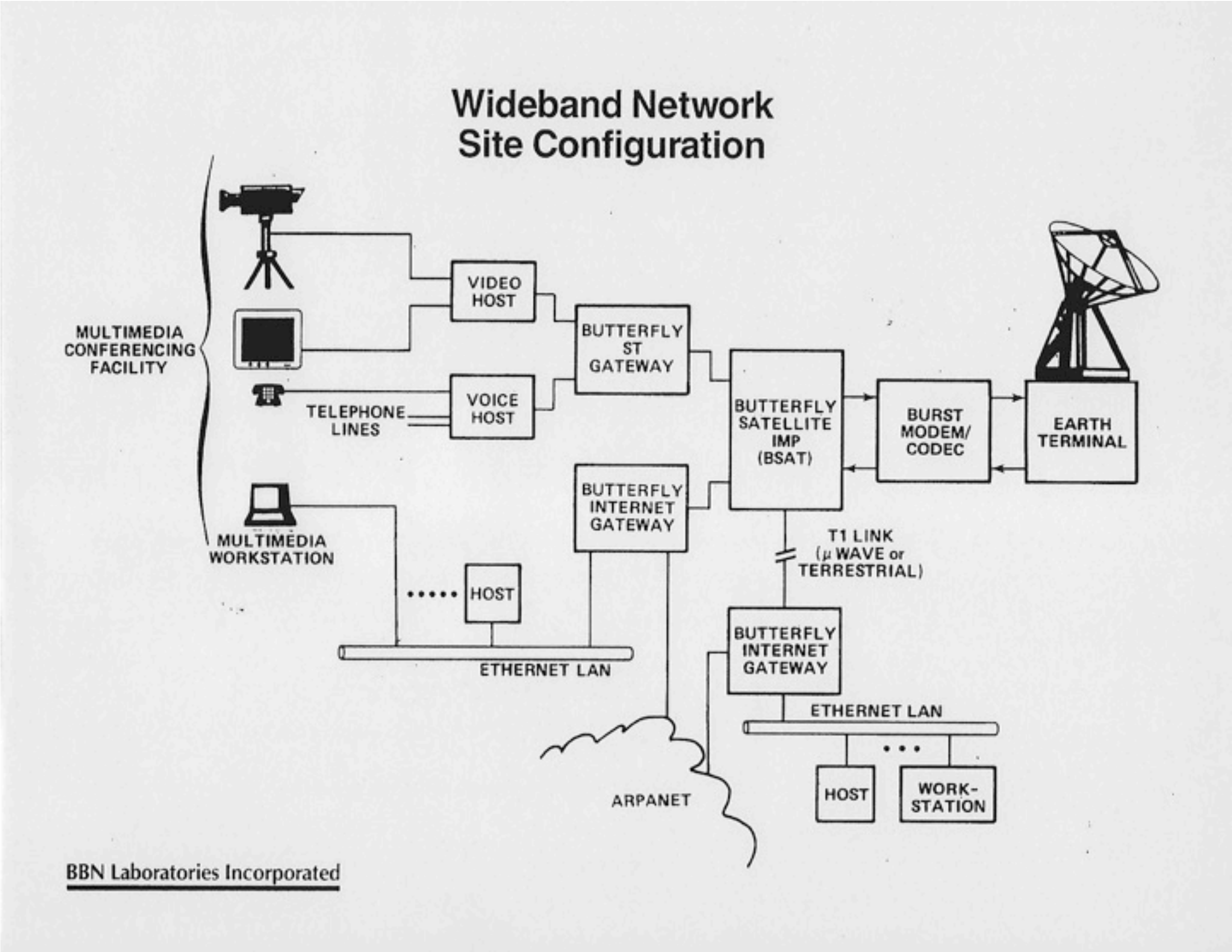


Wideband Satellite Network
3 Mbps Shared Satellite Channel



- ARPA – Systems Integration
- BBN – Satellite Packet Switches, Packet Voice Multiplexers, and Multimedia Conferencing
- Linkabit – Satellite burst modem/ codec
- Western Union – Satellite Channel & 7m C-band Ground Stations
- MIT LL – ST Protocol and Packet Voice Vocoders
- USC-ISI – Video Conferencing

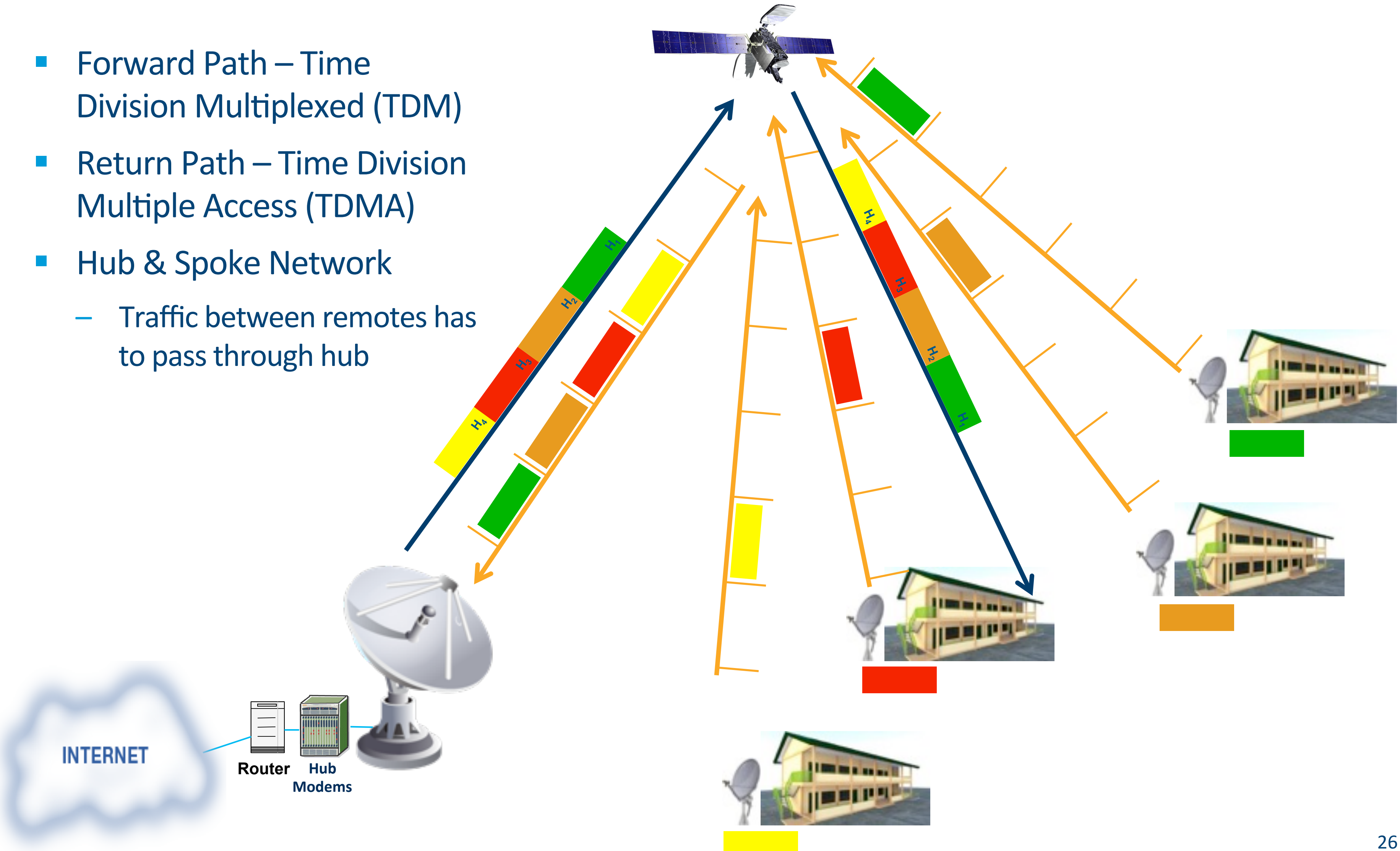
Wideband Net – Typical Site Configuration Voice and Multimedia Conferencing



Wideband Net Packet Voice, Packet Video and Multimedia Conferencing

VSAT Networks

- Forward Path – Time Division Multiplexed (TDM)
- Return Path – Time Division Multiple Access (TDMA)
- Hub & Spoke Network
  - Traffic between remotes has to pass through hub



VSAT Networks in US Today

- Commercial VSAT networks
  - Heavily used for retail inventory and POS terminals
- Consumer Internet Services
  - HughesNet
  - ViaSat Exede
  - $40/mo. (10GB) - $130/mo. (50GB)
  - Terminal + installation ~$300

ViaSat Exede Modem/WiFi Router

Thanks and Questions