iDirect

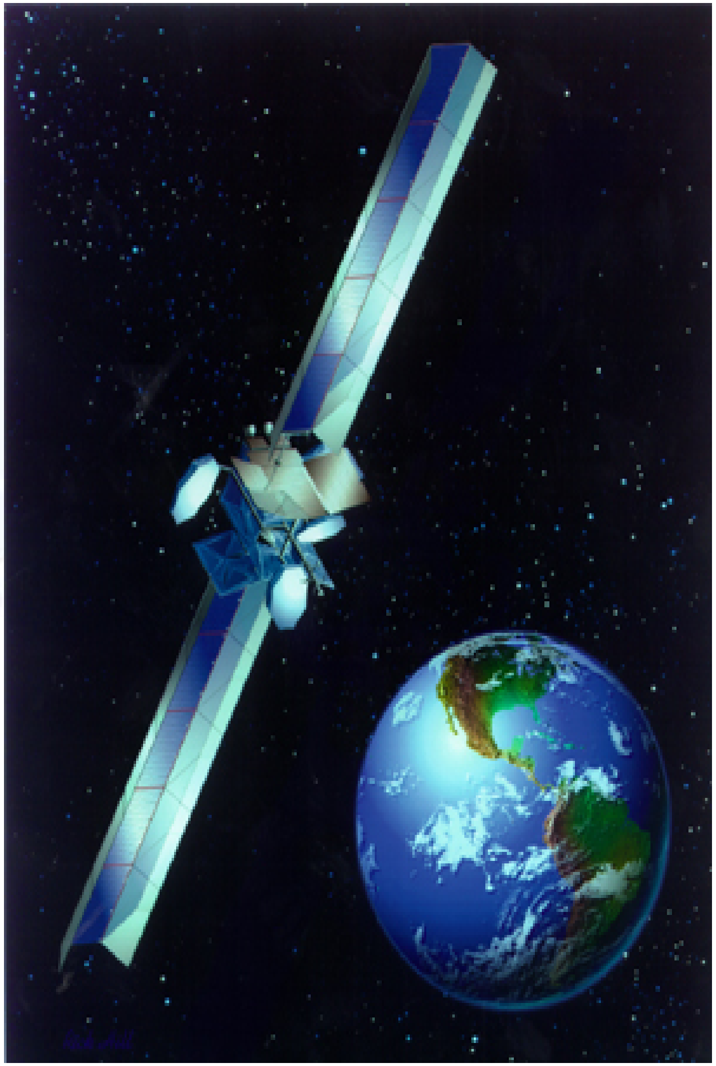
Satellite Communication Concepts

Satellite Communications Concepts - Objectives

- Discuss the advantages of Satellite Communications
- Explain the principals behind the use of Geo-synchronous (GEO) satellites
- Examine a typical satellite link
- Describe the different frequency bands used within a satellite network
- Describe the various components of the satellite network hardware
- Discuss various Satellite Communications terminology

Deciding On Satellite Communications ?

- Geographical Coverage Unsurpassed
- Minimal 'line-of-site' difficulties
- Extremely reliable (99.9% Up time)
- Extremely Reliable Data Broadcast or Multicast
- Single Vendor Typically
- Easy Remote Site Deployment
- Supports multiple applications:
  - Streaming Video & Audio applications
  - Data applications
  - Voice applications; Voice Over IP



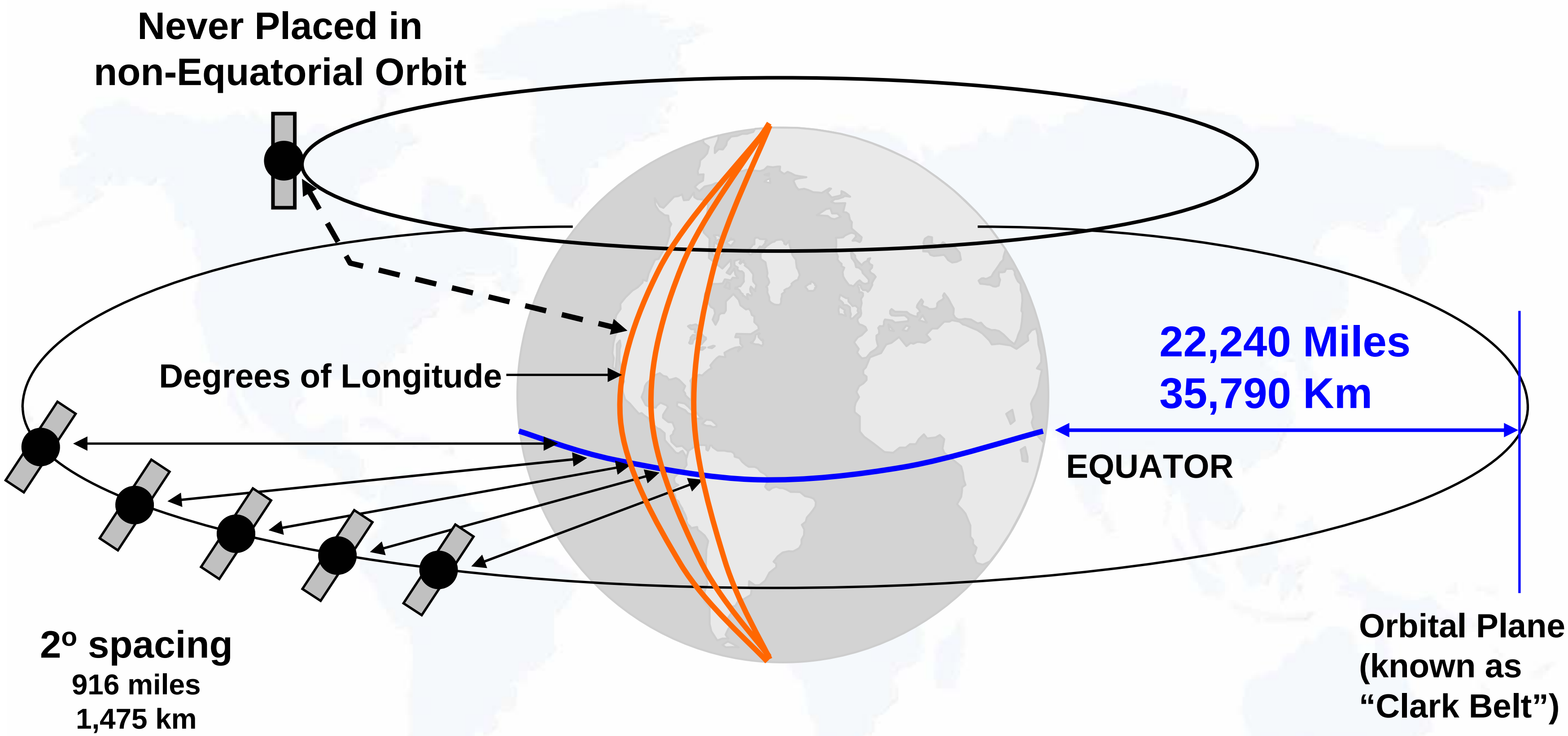
Why Satellite Communications ?
Added Advantages

- Ideally suited for point-to-multipoint and large distributed networks
- Capable of asymmetrical bandwidth
- A single point of management allows for easier traffic analysis/management
- Operational Low Bit Error Rate (BER); typically >10-8 (iDirect >10-9)
- Capable of simultaneous delivery of data to an unlimited number of remotes
- Independence from typical telephone infrastructure
- Private Network capabilities

Satellite Orbits

- Geographically-synchronous Earth Orbit (GEO)
  - Orbital period = Earth's rotation (23h 56m 4sec)
  - Orbit directly over equator – 0^{o} Latitude
  - Orbital position measured by degrees of Longitude
  - Satellite orbit would weave figure-eights around a point on the ecliptic when viewed from the ground
- Alternatives are:
  - Medium Earth Orbit (MEO)
  - Low Earth Orbit (LEO)
  - Polar Orbit, using the North/South Pole as reference

Geosynchronous Earth Orbit (GEO)



Orbital Circumference:	164,870 miles 265,490 km
Orbital Velocity:	6,870 mph 11,060 kph

ALL Geosynchronous Satellites are Geostationary, meaning they orbit in fixed positions over the EQUATOR (0º Latitude). Therefore, position is determined & reported in LONGITUDE.

Speed of Light
186,282 mps
299,762 kms

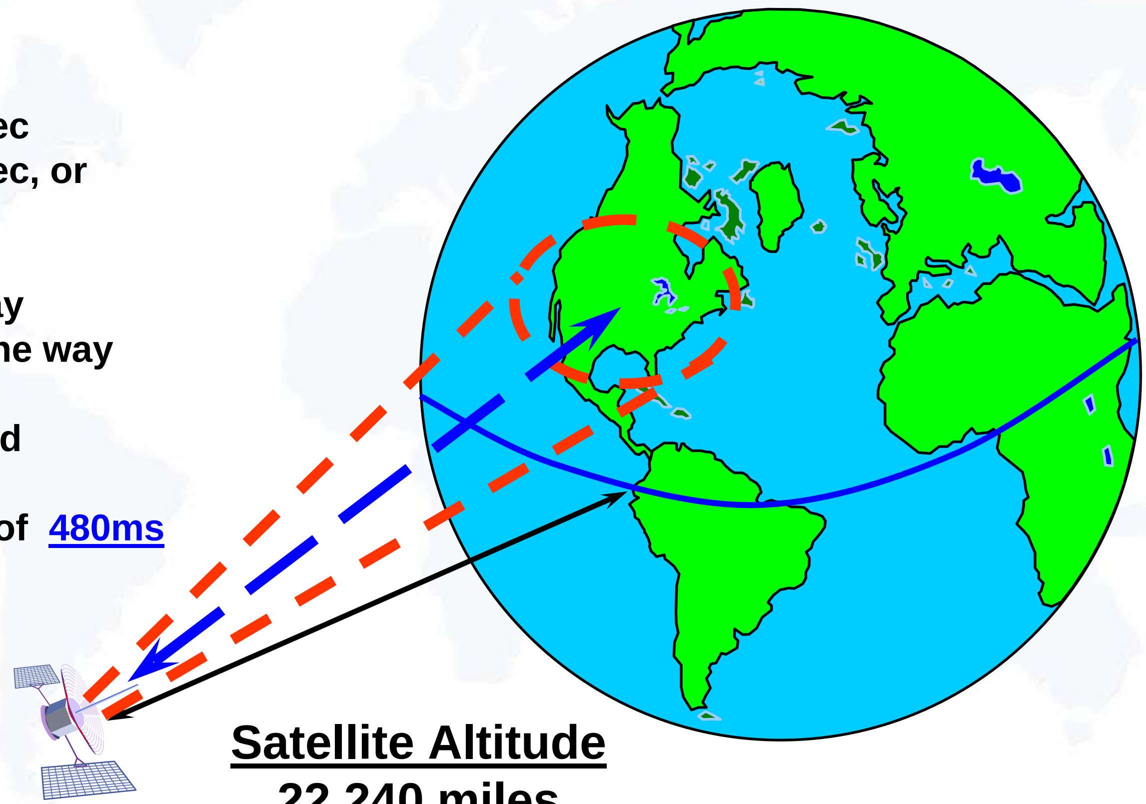
Therefore:
22240/186282 = .119sec
35,790/299762= .119sec, or

120ms	Uplink delay
+ 120ms	Downlink delay
240ms	Total delay, one way

Delay for both Outbound and Inbound (IP 'Ping') Total Round-trip Delay of 480ms

GeoSynchronous Orbit

Propagation Delay



Satellite Altitude
22,240 miles
35,790 Km

Frame Start Delay (FSD)

Each earth station location has a unique distance from a geostationary satellite based on its Geographic (GEO) Location

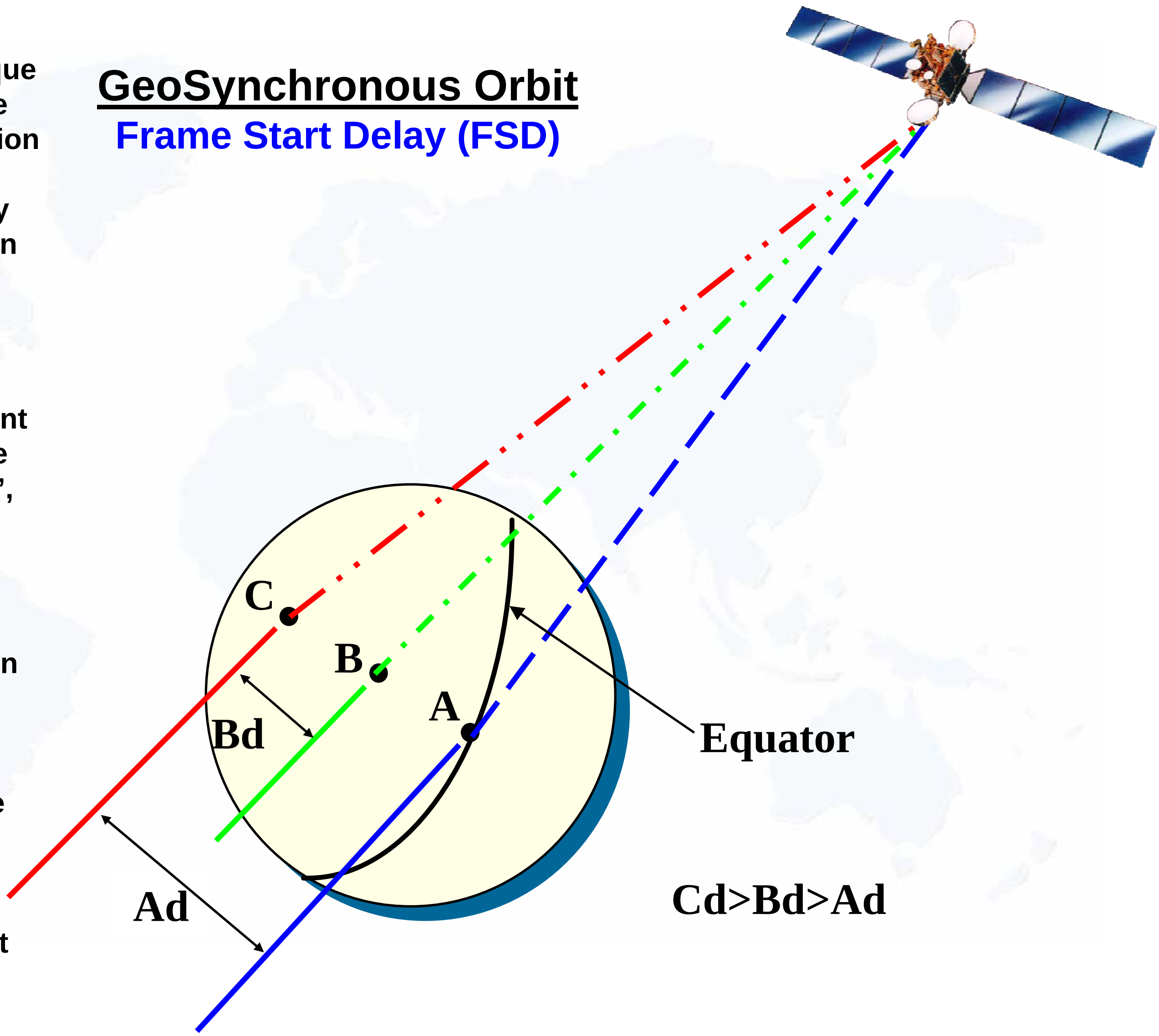
Each sites GEO Location is a uniquely physical position on the earth, given in geographic coordinates as degrees, minutes and seconds of Latitude & Longitude in a given hemisphere

Location 'A' is found to be at a different distance from a geostationary satellite (closer in this case) than site 'B' or 'C', therefore, for synchronized timing, it must be delayed 'longer'.

A unique Frame Start Delay (FSD) is required for each earth station location

The FSD is calculated based on three factors: the GEO Location of the teleport, the satellite & the remote site

The FSD is that transmission delay associated with an earth station geo-location such that the signal arrives at the satellite timed to eliminate interference with other earth stations

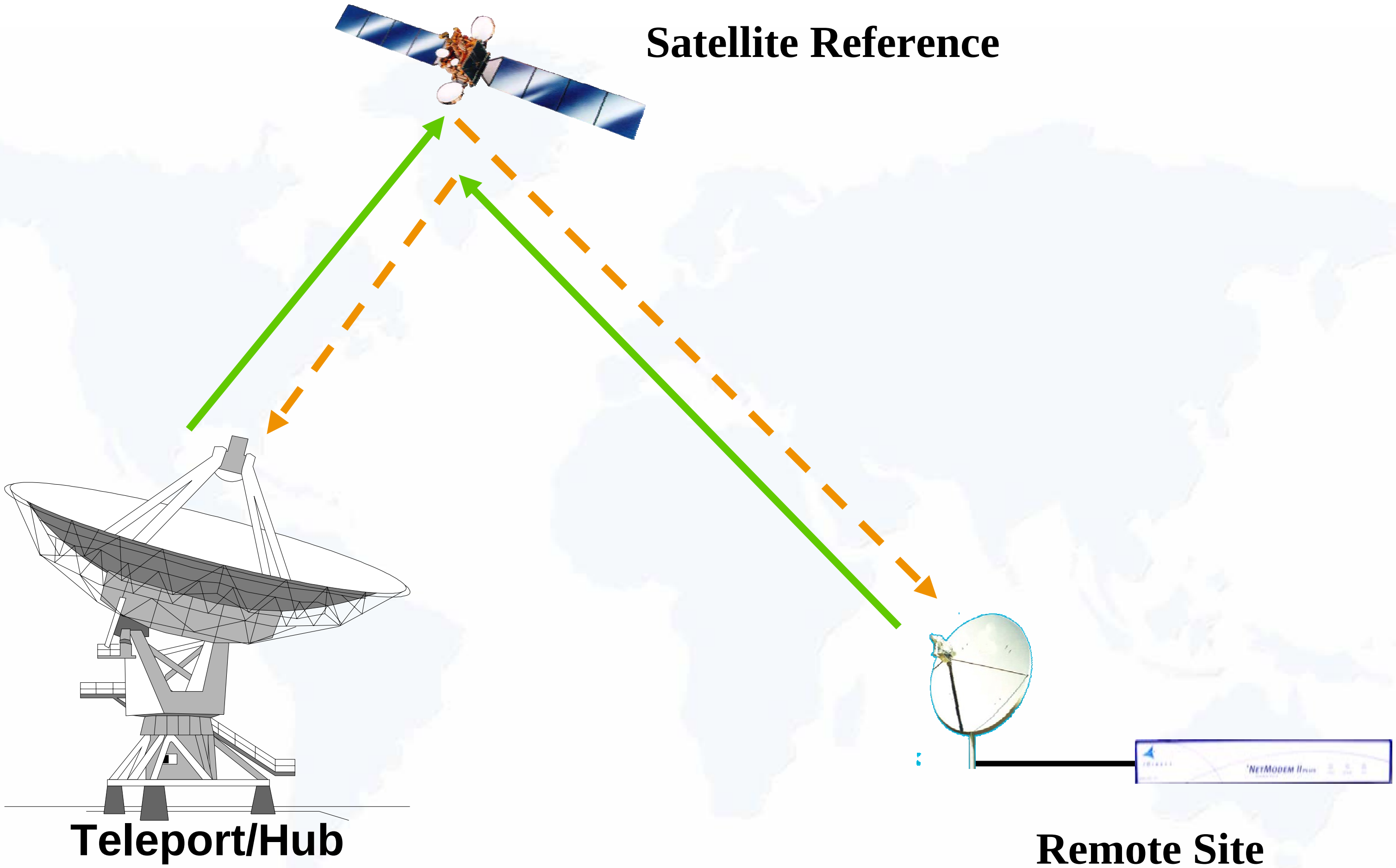


Terms to Remember

- Uplink
  - Transmission path from teleport/earth station to satellite
- Downlink
  - Transmission path from satellite to teleport/earth station
- Outbound Channel, aka Outroute or Downstream
  - Signal from the Hub to the Remote
    - Outbound Uplink (Hub to Satellite)
    - Outbound Downlink (Satellite to Remote)
- Inbound Channel, aka Inroute or UpStream
  - Signal from the Remote to the Hub
    - Inbound Uplink (Remote to Satellite)
    - Inbound Downlink (Satellite to Hub)

(Outbound and Inbound signals typically use the same satellite & transponder)

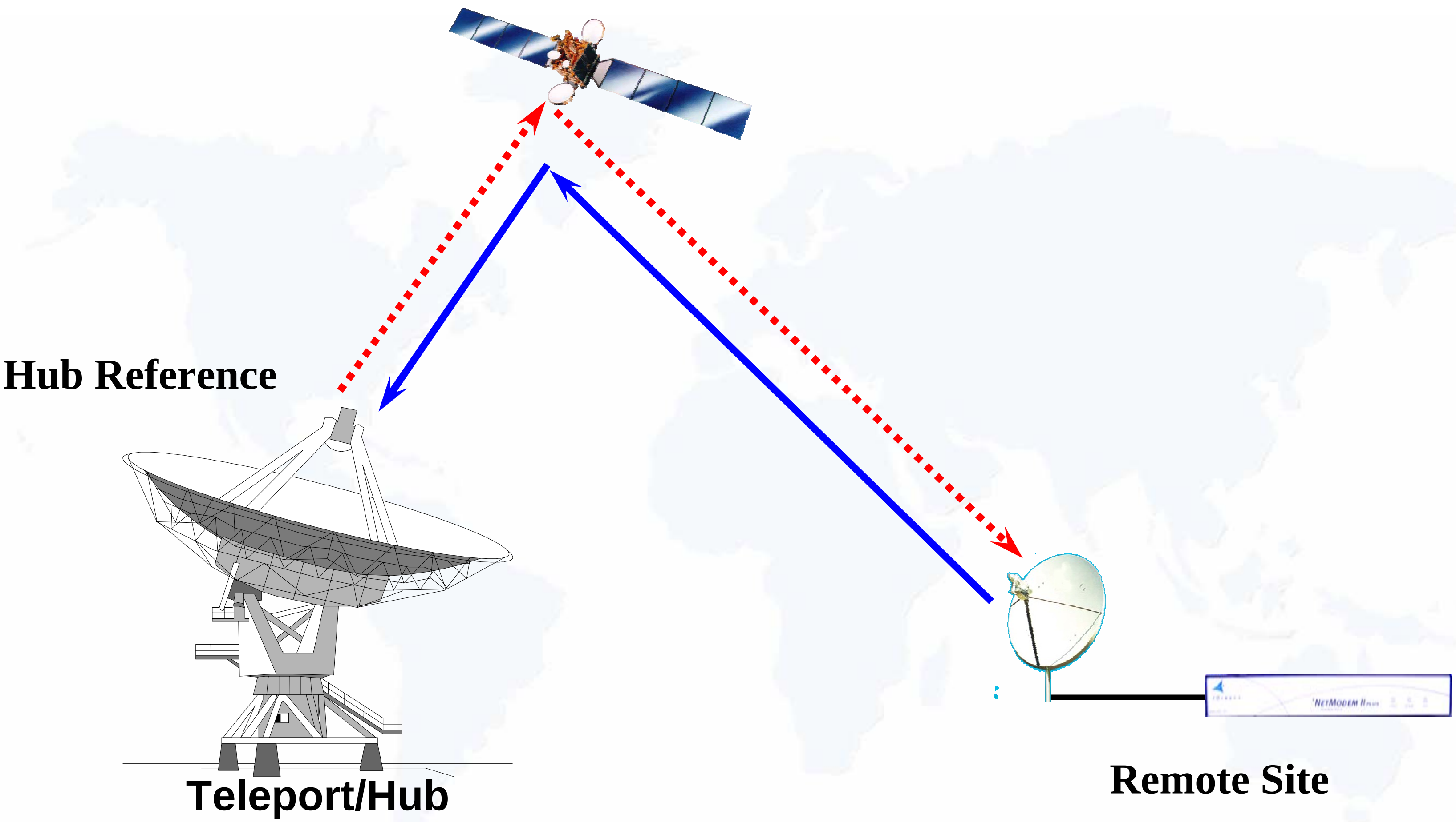
Typical Communications Link



= Uplink (to satellite from earth station)

= Downlink (from satellite to earth station)

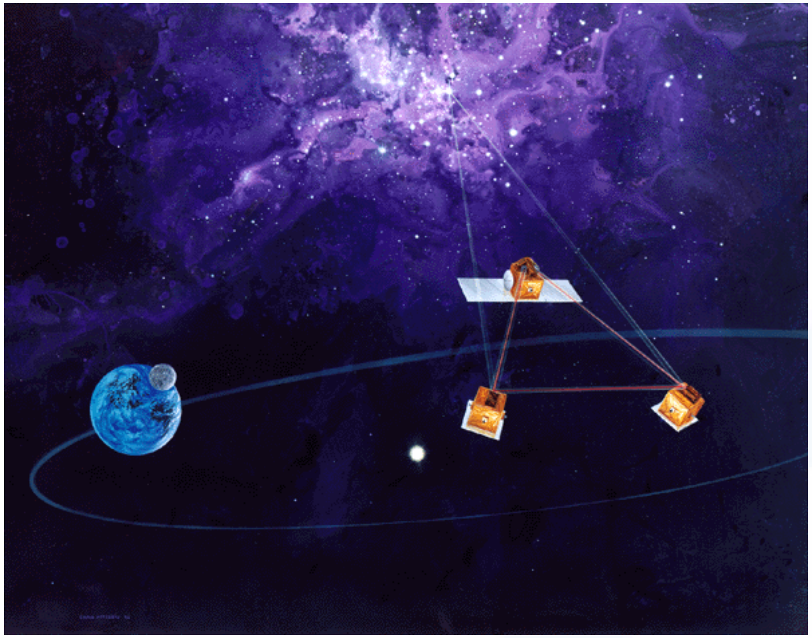
Communications Link Perspective



= Outbound/Outroute/Downstream (from the hub)

= Inbound/Inroute/Upstream (to the hub)

The Satellite - Components



Operational, Guidance & Control Components

- Power System
- Solar Panels
- Propulsion Jets
- Guidance System

Communications Components

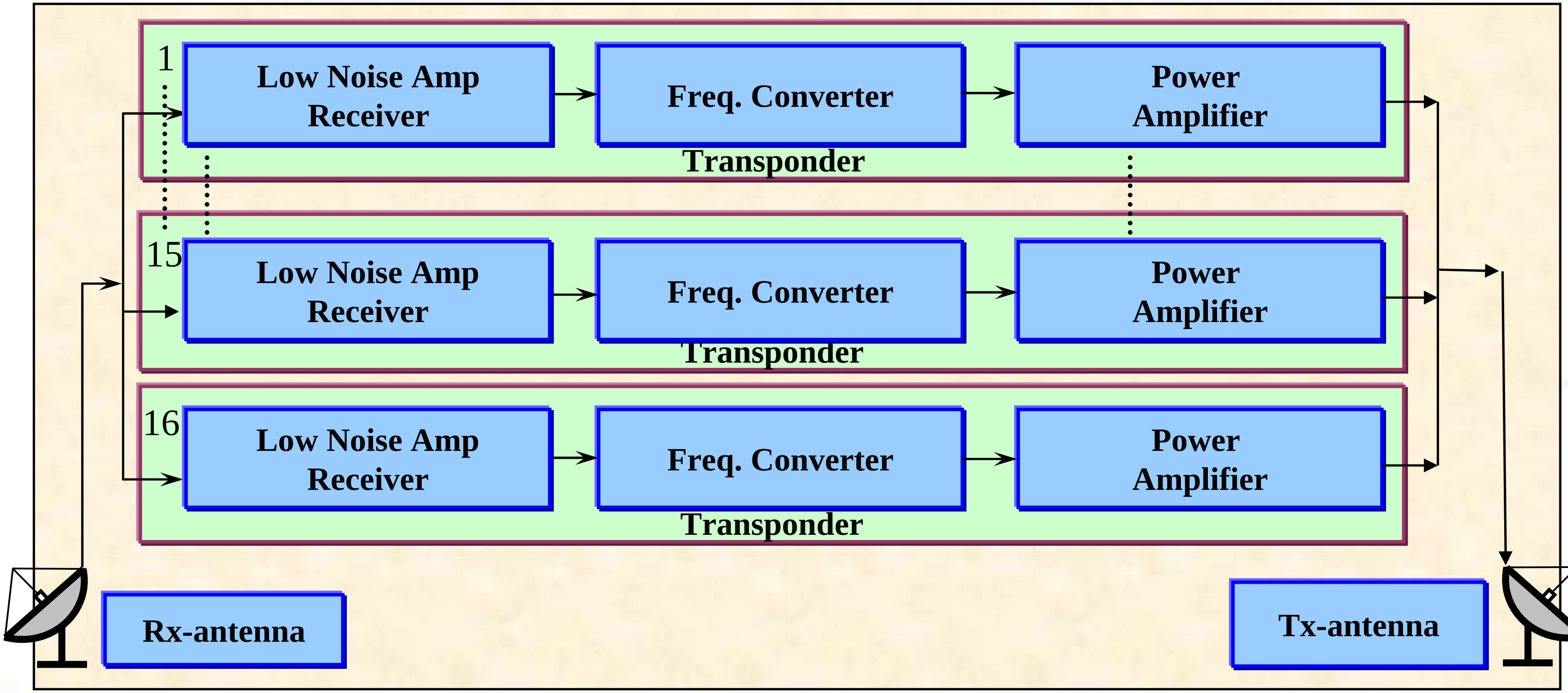
- Antennas
- RF Transmission Equipment
- Transponders/Converters
- Switching & Redundancy Components

The Satellite – Major Components

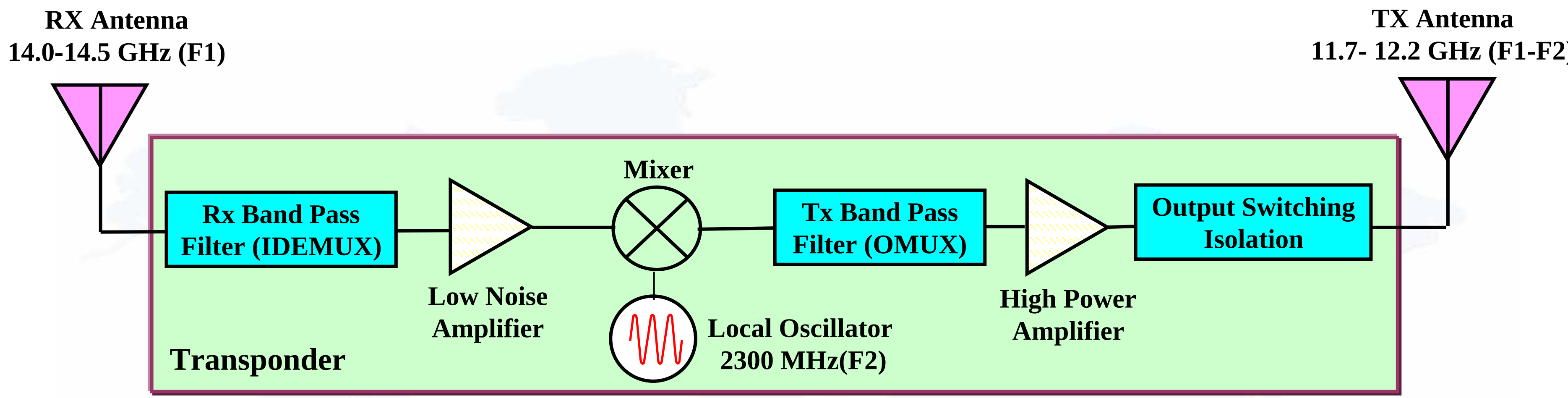
- Antenna - Receive
  - Antenna, divider and Bandpass Filter
  - Bandpass Filter allows only desired signals to pass through
- Amplifier - Receive
  - The Low Noise Amplifier (LNA) increases the power level of the signal
- Transponder
  - A transponder receives the transmission from earth (uplink), amplifies the signal, changes frequency and retransmits the signal to a receiving earth station(s) (downlink)
  - Includes the receiving antenna, a broadband receiver and a frequency converter (also called the Local Oscillator)
- Mixer → Frequency Converter (per transponder)
  - The Mixer is the intermediate step between the receive components and the transmit components
  - Mixing utilizes a known stabilized frequency source called the Local Oscillator (L/O) to translate the received Uplink frequencies to the transmitted Downlink frequencies
- Amplifier - Transmit
  - The High Power Amplifier (HPA) increases the power level of the signal to a level that the Earth Station can receive it
- Antenna - Transmit
  - Antenna, combiner/isolation and frequency Bandpass Filter

The Satellite – Block Diagram

- Receives on Uplink → Translates/Converts → Retransmits on Downlink
- Satellite Capacity is typically 500 MHz divided over many ‘Transponders’
- Transponders of 36, 54 or 72 MHz have been typical



Transponder Block Diagram



Output after mixer

F1-F2	F1 +F2
F1-2F2	F1+2F2
F1-3F2	F1+3F2
F1-4F2	F1+4F4
.	.
.	.
.	.

- Input (Band Pass) Filter (IDEMUX)
- Low Noise Amplifier (LNA) acts as a low power pre-amplifier
- Mixer, or Frequency Down Converter
- Output filter (OMUX)
- High Power Traveling Wave Tube Amplifier (TWTA)
- Output isolation & switching

Typical Satellite Foot Print

EIRP Effective Isotropic Radiated Power

Signal Polarization

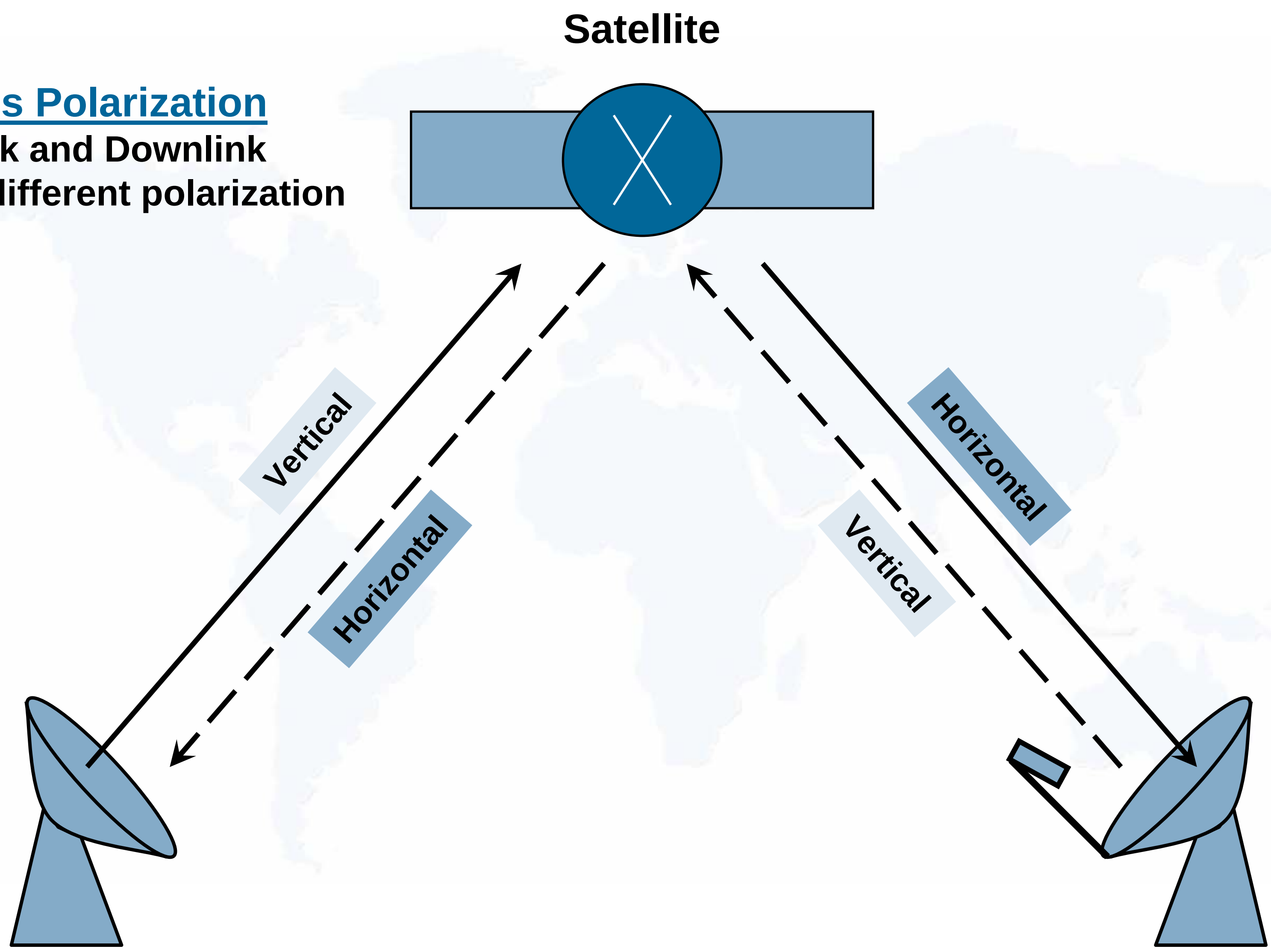
- In electrodynamics **polarization** is a property of waves, such as light and other electromagnetic radiation. Unlike more familiar wave phenomena such as waves on water or waves propagating on a string, electromagnetic waves are three-dimensional, and it is this higher-dimensional nature that gives rise to the phenomenon of polarization.
- Take the case of a simple plane wave, which is a good approximation to most light waves. The plane of the wave is perpendicular to the direction the wave is propagating in. Simply because the plane is two-dimensional the electric vector in the plane at a point in space can be decomposed into two orthogonal components. Call these the *x* and *y* components (following the conventions of analytic geometry). For a simple harmonic wave where the amplitude of the electric vector varies in a sinusoidal manner, the two components have exactly the same frequency. However, these components have two other defining characteristics that can differ. First, the two components may not have the same amplitude. Second, the two components may not have the same phase, that is they may not reach their maxima and minima at the same time in the fixed plane we are talking about.
- Consider first the special case where the two orthogonal components are in phase. In this case the direction of the electric vector in the plane, the vector sum of these two components, will always fall on a single line in the plane. We call this special case **linear polarization**. The direction of this line will depend on the relative amplitude of the two components. This direction can be in any angle in the plane, but the direction never varies.
- Now consider another special case, where the two orthogonal components have exactly the same amplitude and are exactly ninety degrees out of phase. In this case one component is zero when the other component is at maximum or minimum amplitude. Notice that there are two possible phase relationships that satisfy this requirement. The *x* component can be ninety degrees ahead of the *y* component or it can be ninety degrees behind the *y* component. In this special case the electric vector in the plane formed by summing the two components will rotate in a circle. We call this special case **circular polarization**. The direction of rotation will depend on which of the two phase relationships exists. We call these cases **right-hand circular polarization** and **left-hand circular polarization**, depending on which way the electric vector rotates.

Linear Polarization

- In this case the direction of the electric vector in the plane, the vector sum of these two components, will always fall on a single line in the plane. We call this special case **linear polarization**. The direction of this line will depend on the relative amplitude of the two components. This direction can be in any angle in the plane, but the direction never varies.

Cross Polarization (XPol)

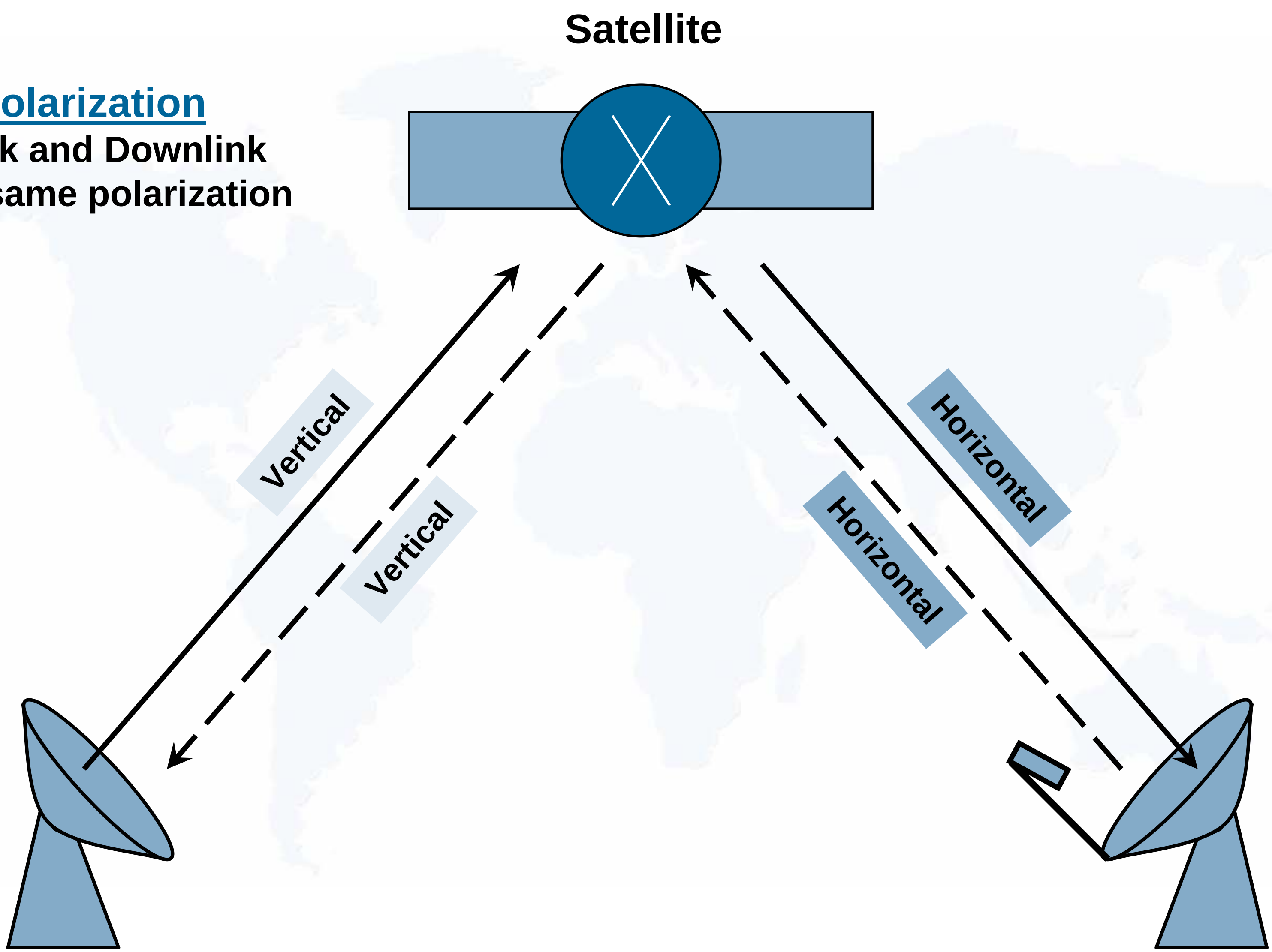
Cross Polarization
Uplink and Downlink
Use different polarization



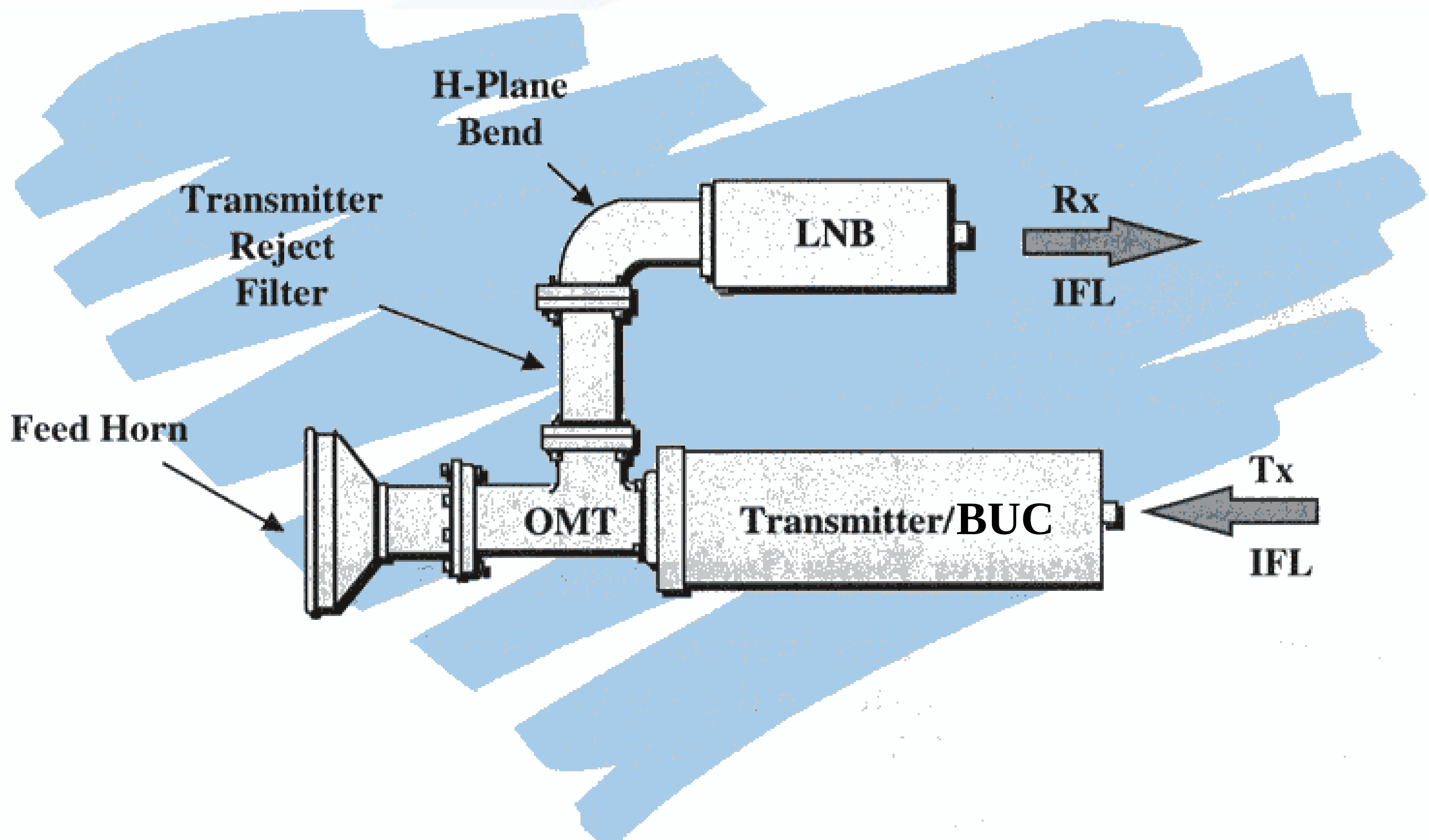
Coincident Polarization (CoPol)

Co Polarization

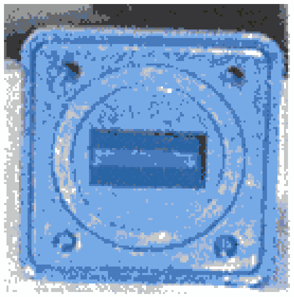
Uplink and Downlink
Use same polarization

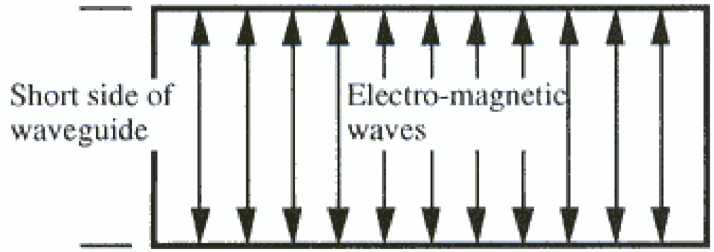


VSAT Feed Assembly

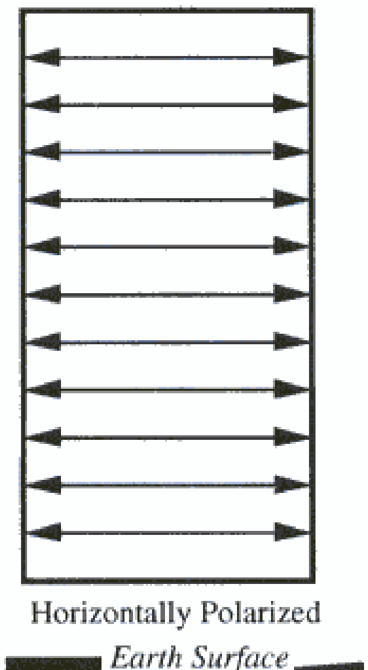


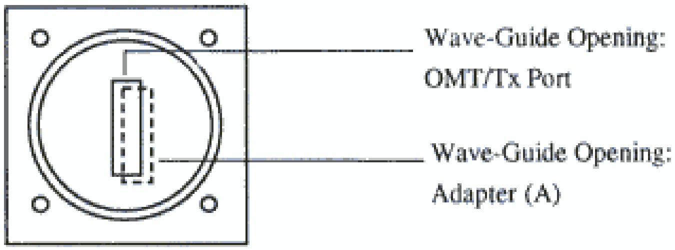
BUC	Block Up Converter
LNB	Low Noise Block (Down Converter)
OMT	Orthogonal Mode Transducer
Orthogonal	Relating to or composed of right angles. Having a set of mutually perpendicular axes



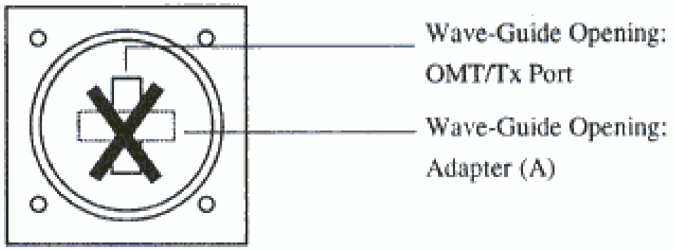


Physical Horizontal Position = Vertical Polarization





Correct Waveguide to Component Orientation



Incorrect Waveguide to Component Orientation

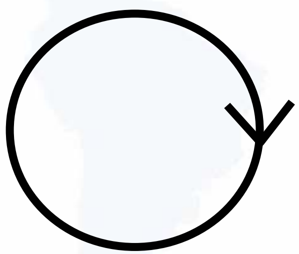
Circular Polarization

- In electrodynamics circular polarization of electromagnetic radiation is polarization such that the tip of the electric field vector at a fixed point in space describes a circle. The magnitude of the electric field vector is constant.
- A circularly polarized wave may be resolved into two linearly polarized waves, of equal amplitude, in phase quadrature and with their planes of polarization at right angles to each other.
- Circular polarization may be referred to as *"right-hand"* or *"left-hand,"* depending on the direction in which the electric field vector rotates.

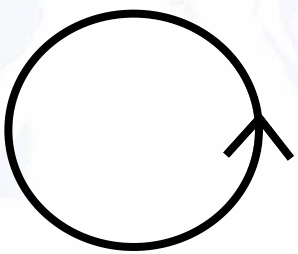
Circular Polarization

- Satellite Capabilities are 500 MHz for each Polarization (Right hand and Left hand)

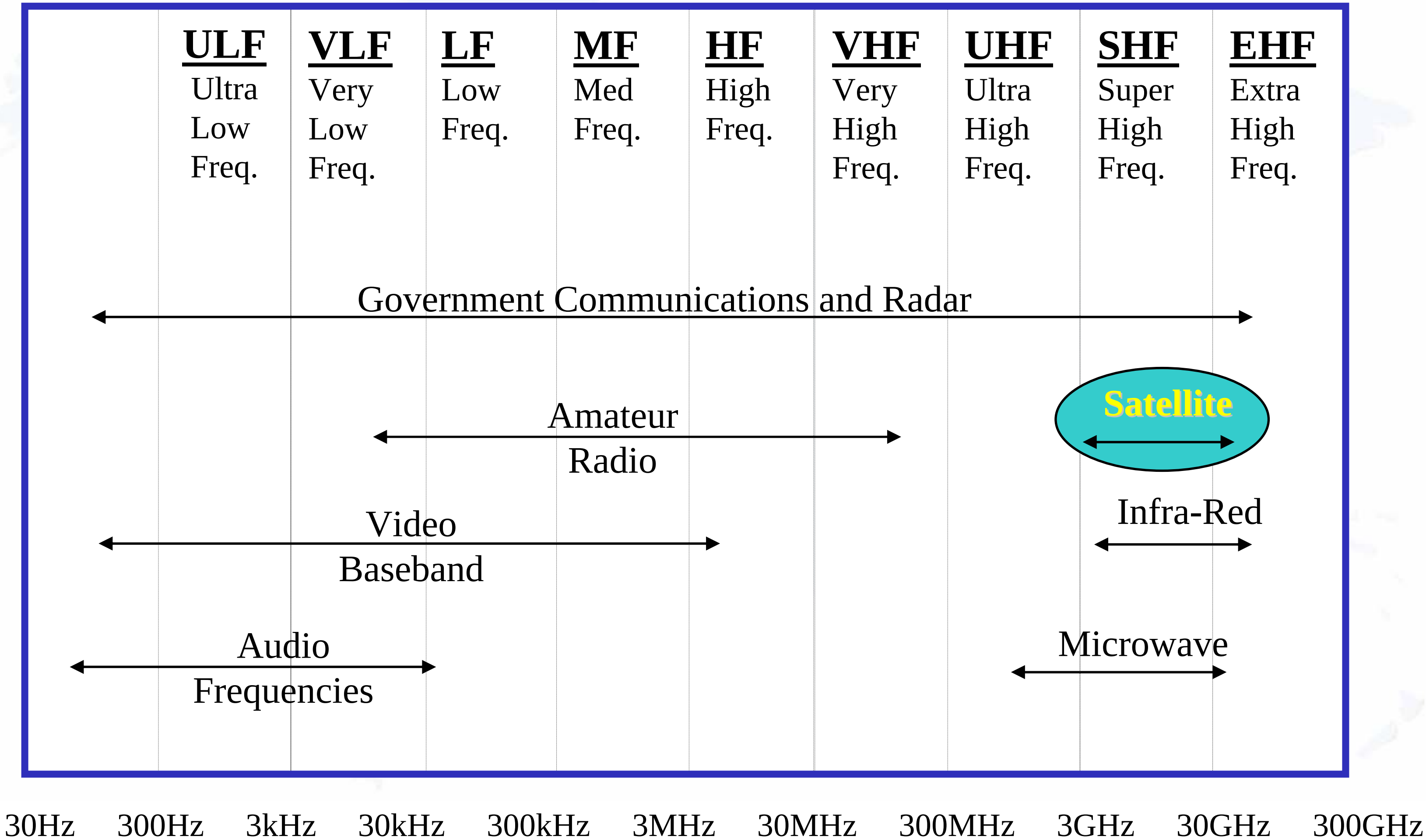
Right Hand Circular Polarization



Left Hand Circular Polarization



Satellites Frequencies used within the Frequency Spectrum



Satellite Link Frequencies

L BAND FREQUENCY

Domestic US Frequency (MHz)	International Frequency (MHz)
950	950
1450	1700

Ku BAND FREQUENCY

Up Link Frequency (MHz)	Translation Frequency (MHz)	Down Link Frequency (MHz)
14000	Varies	11700
14500	X	12200

C BAND FREQUENCY

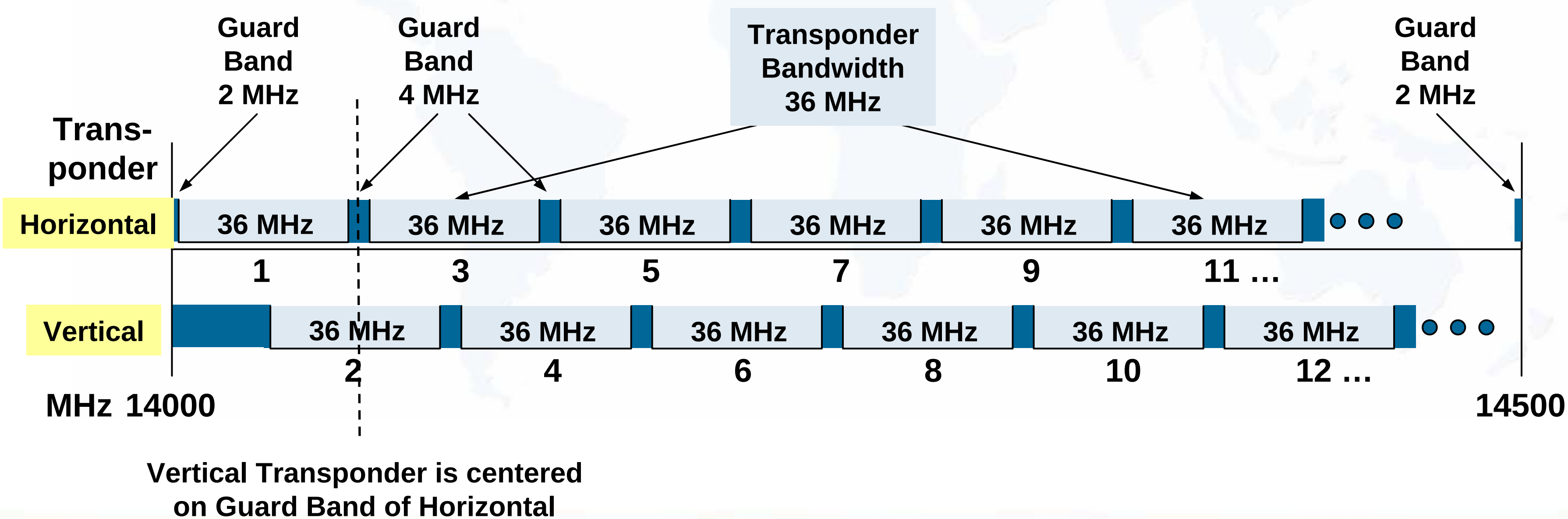
Up Link Frequency (MHz)	Translation Frequency (MHz)	Down Link Frequency (MHz)
5925	(Varies)	3700
6425	X	4200

Ka BAND FREQUENCY

Up Link Frequency (MHz)	Translation Frequency (MHz)	Down Link Frequency (MHz)
27500	Varies	11700
30500	X	20700

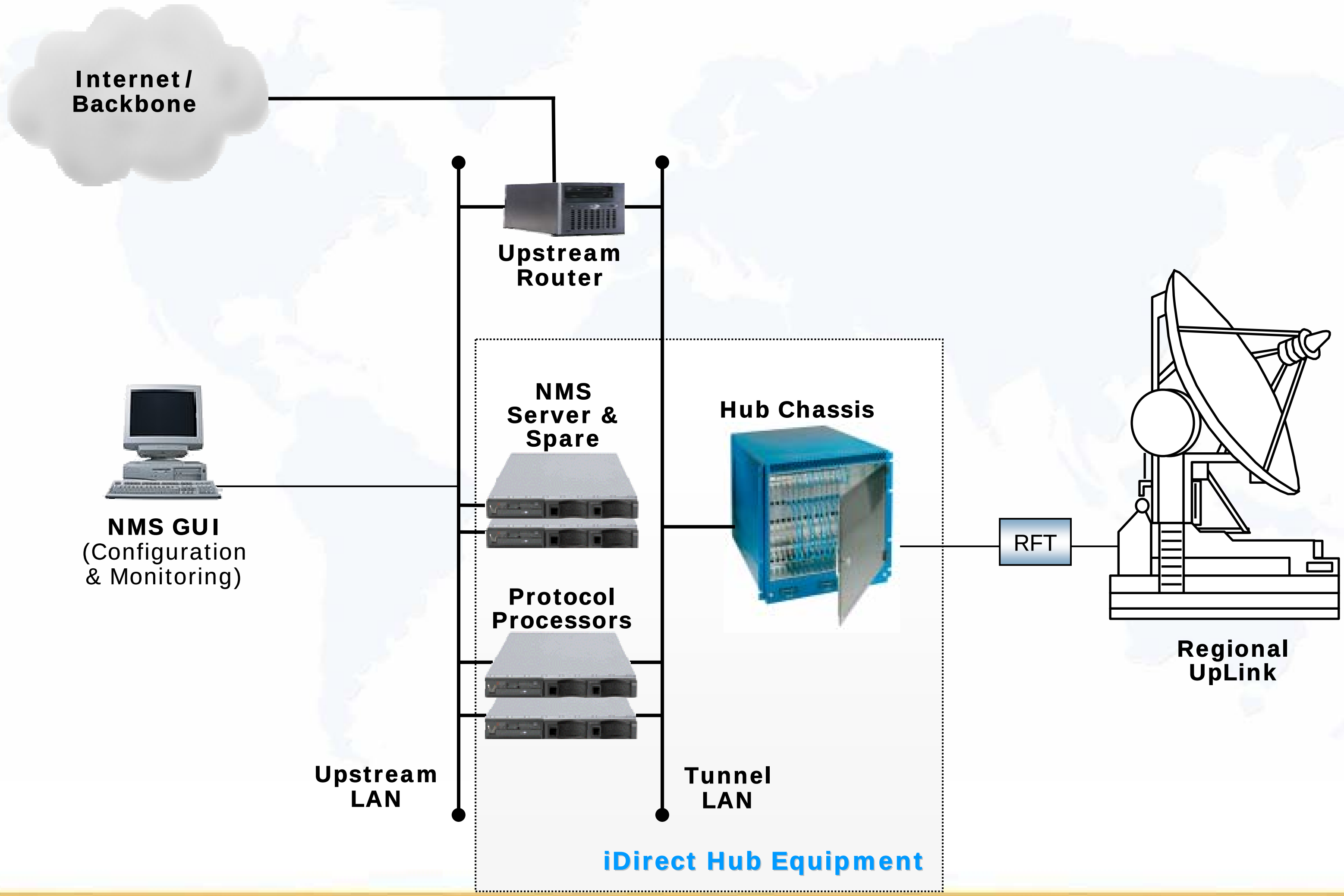
Overview – Satellite / Transponder Bandwidth

- Satellite Capacities are
  - 500 MHz Vertical Polarization
  - 500 MHz Horizontal Polarization
  - Divided into bands using Transponders
- Ku Band
  - 14000 MHz to 14500 MHz (Uplink)
  - 11700 MHz to 12200 MHz (Downlink)
- Transponder Bandwidth is generally one of following: 27 MHz, 36 MHz, 54 MHz, 72 MHz
- Transponders for Vertical and Horizontal Polarization

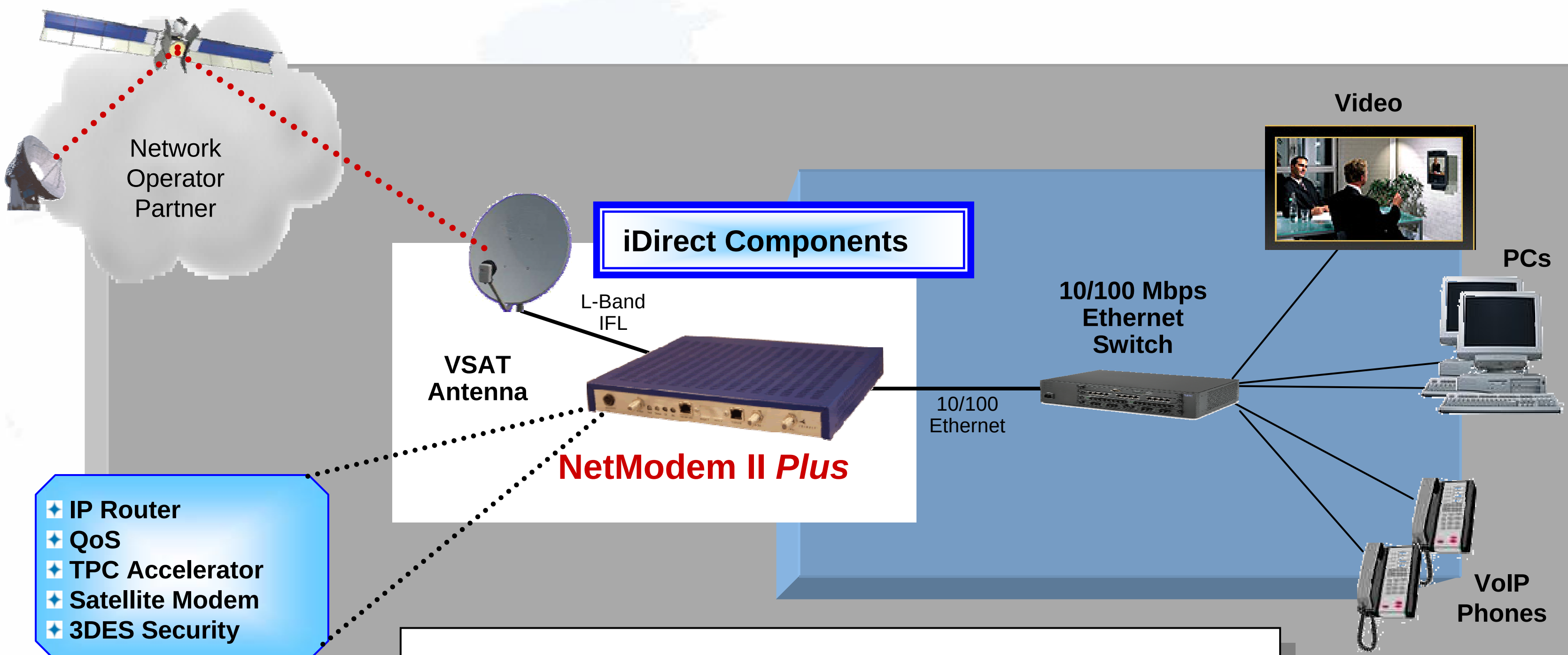


iDirect Typical Hub Configuration

iDirect Hub Chassis used by Network Operators to Share NetModem Services and Connect NetModems to the Internet

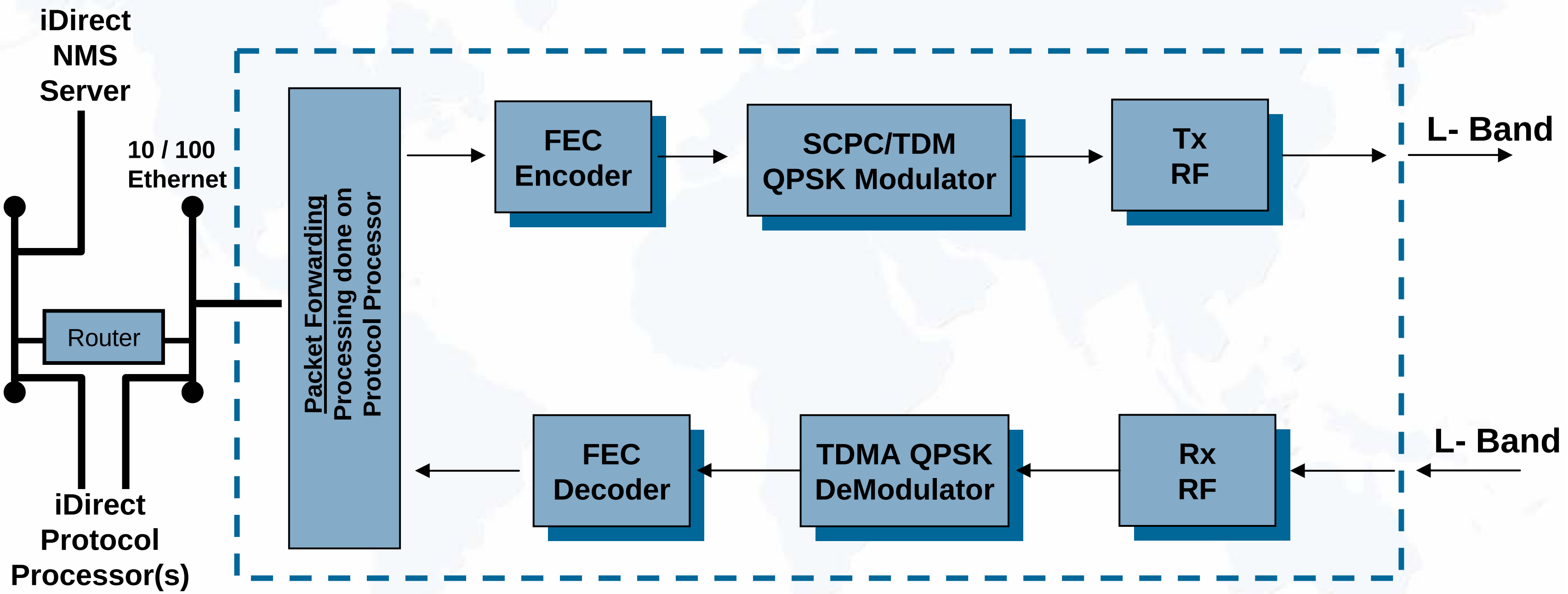


Typical Remote Site Configuration



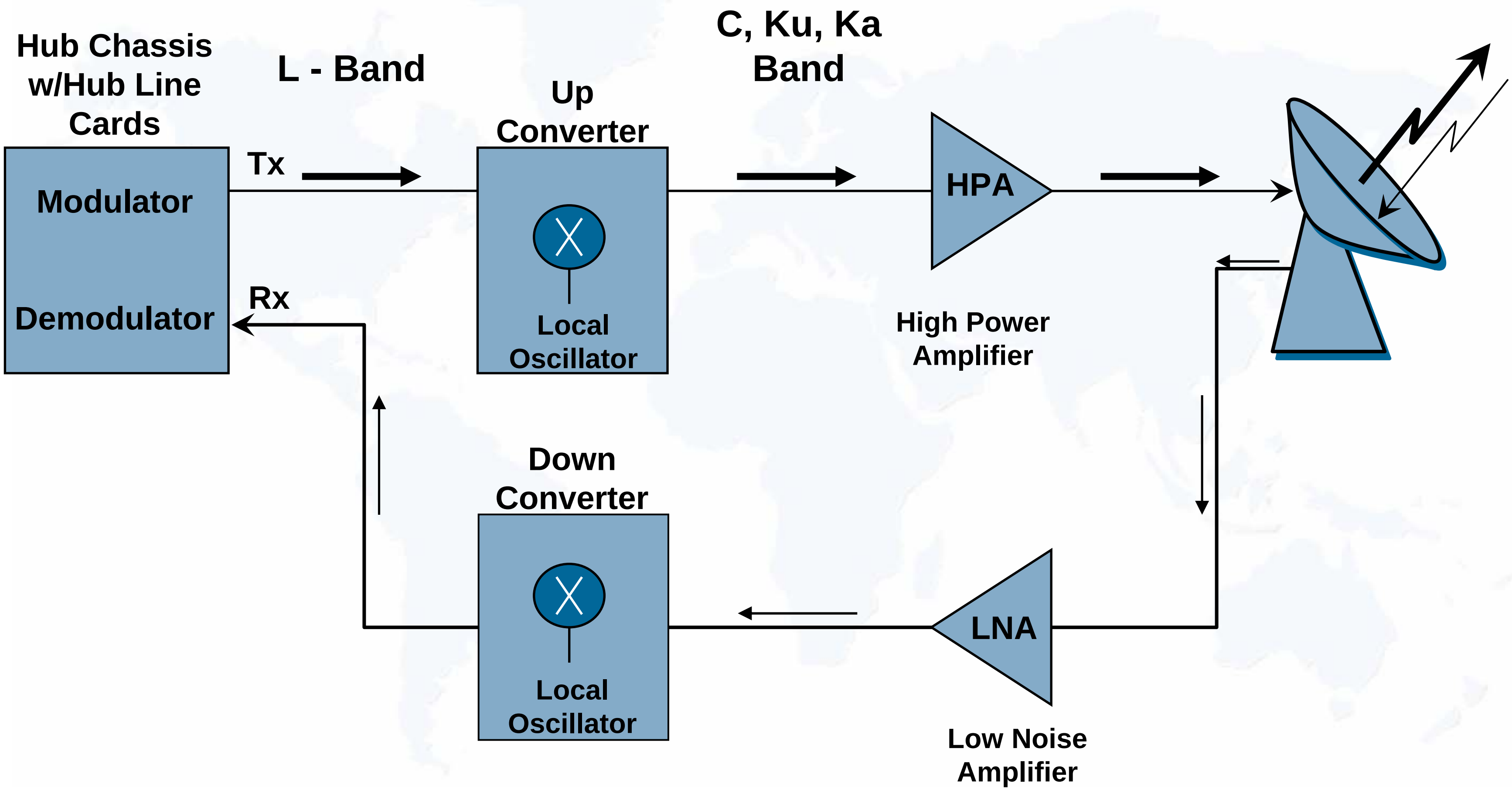
Simple Deployment…

- Integrated, single box connection to the LAN
- No power needed at VSAT Antenna
- Centrally Managed
- Enable Broadband Connectivity!

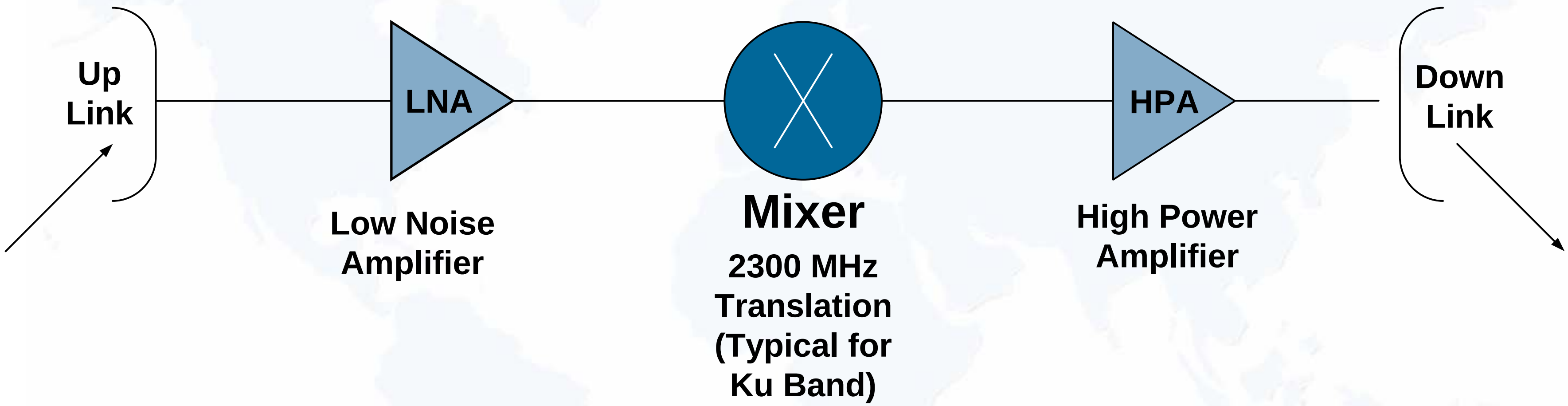


FEC	Forward Error Correction
SCPC	Single Channel Per Carrier
TDMA	Time Division Multiple Access

Overview - Hub Teleport Components



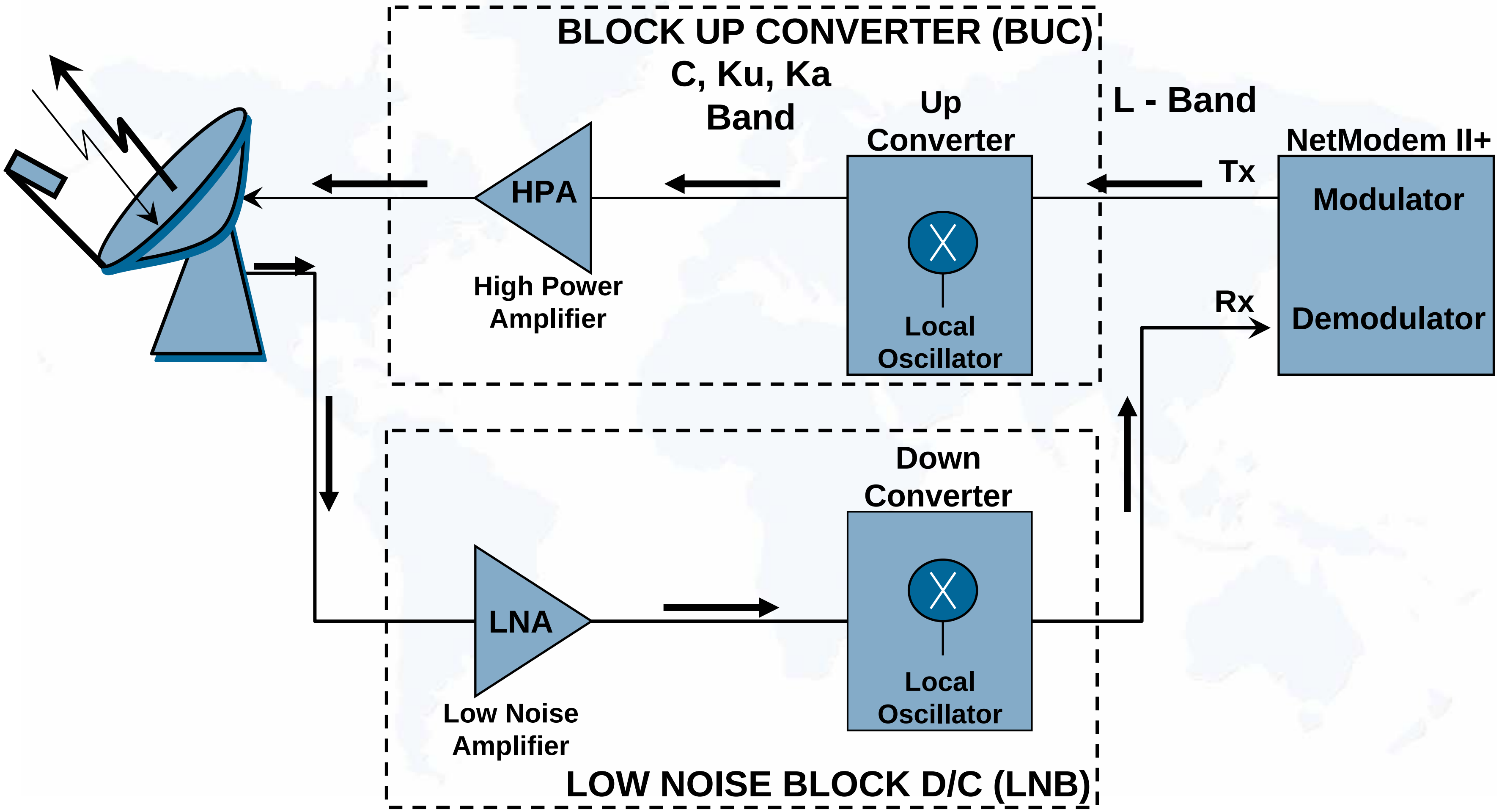
Ku Band (Domestic)



Ku Band Domestic US Frequency

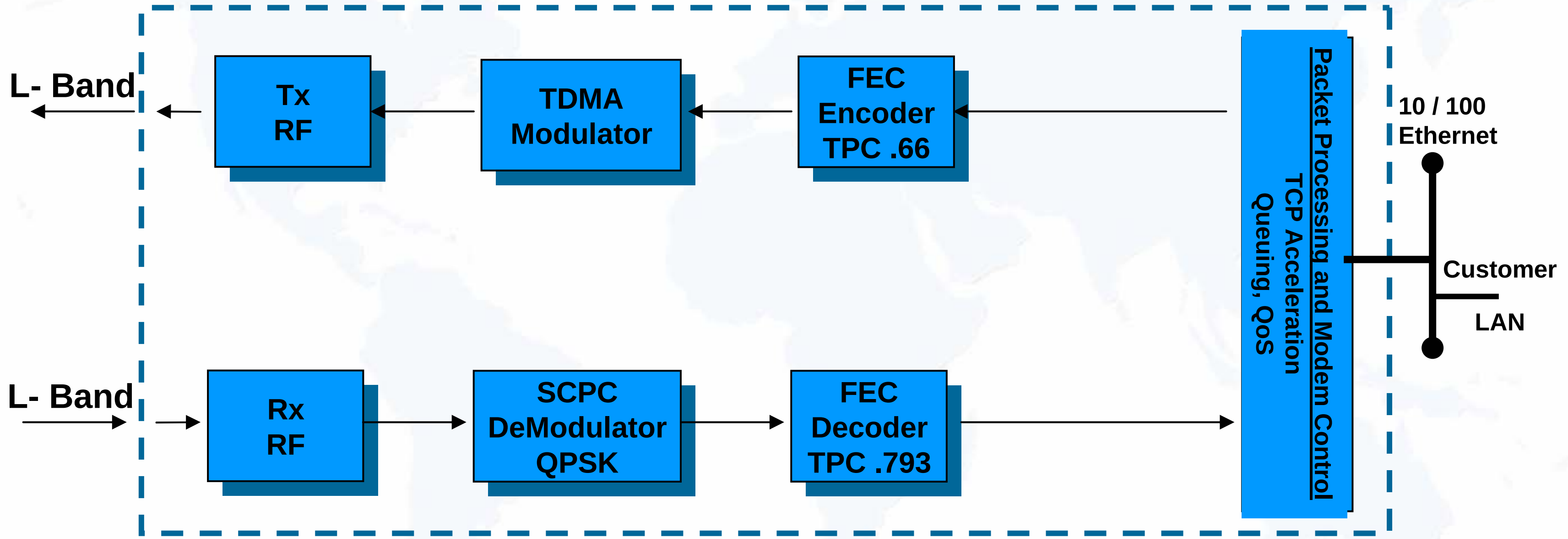
Up Link Frequency (MHz)	Translation Frequency (MHz)	Down Link Frequency (MHz)
14000	2300	11700
14500		12250

Overview - Remote VSAT Components



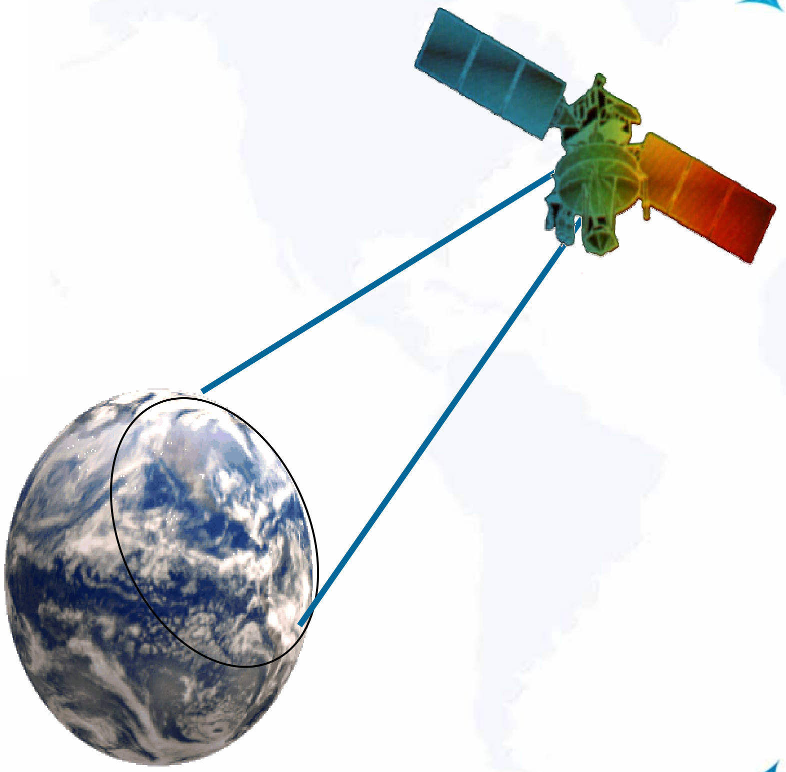
LO **Local Oscillator**

NetModem II+



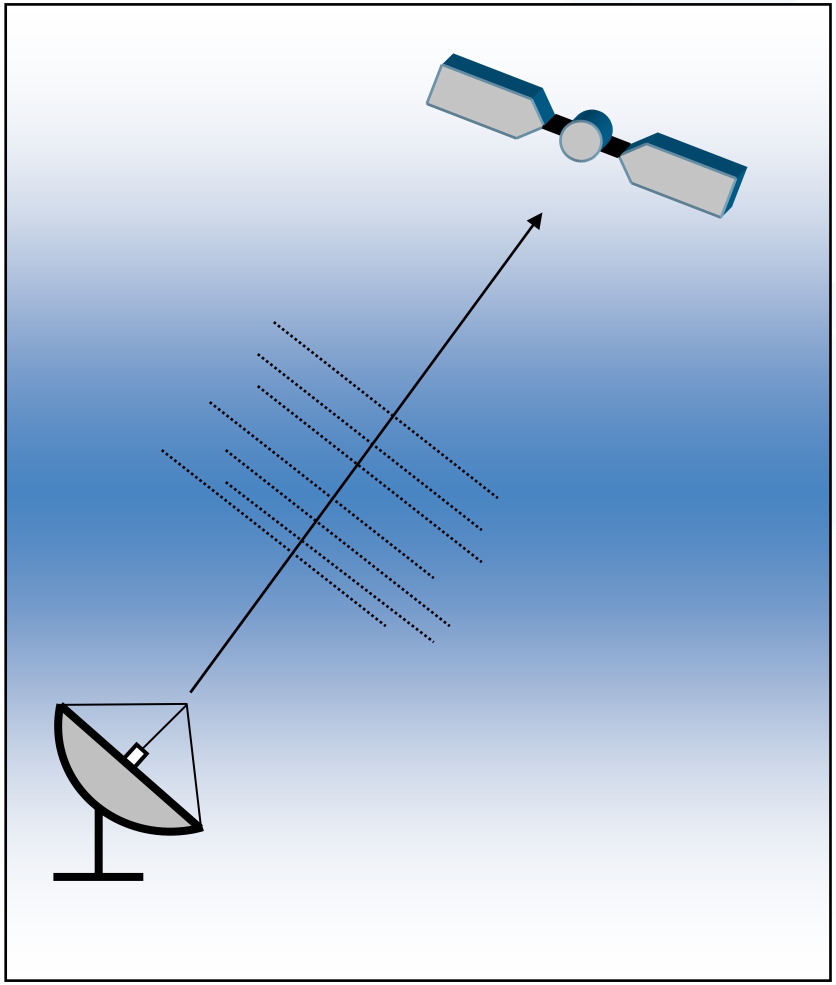
FEC Forward Error Correction
SCPC Single Channel Per Carrier

Link Budget



- The process of correctly sizing uplink and downlink paths
- Takes into account:
  - Established Satellite performance
  - Path Loss (22,300 miles traversing space)
  - Atmospheric effects (weather, ion storms, sunspots, etc.)
  - Frequency bands used (Ku, C, Ka)
  - Hub uplink antenna and amplifier performance
  - Downlink antenna size and receiver noise figure
- Assigns Transponder Uplink & Downlink Frequencies

Link Budget – Rain Margin



- Design for the specified availability
- 99.5% availability will give you about two days of outage per year
- 99.9% will give just 8 hours of outage per year
- Note that for the Hub Outbound Carrier, only the Teleport external Uplink Power Control (UPC) can compensate for rain
- iDirects Hub controls remote site Inbound Carrier power using our Uplink Control Process, or UCP

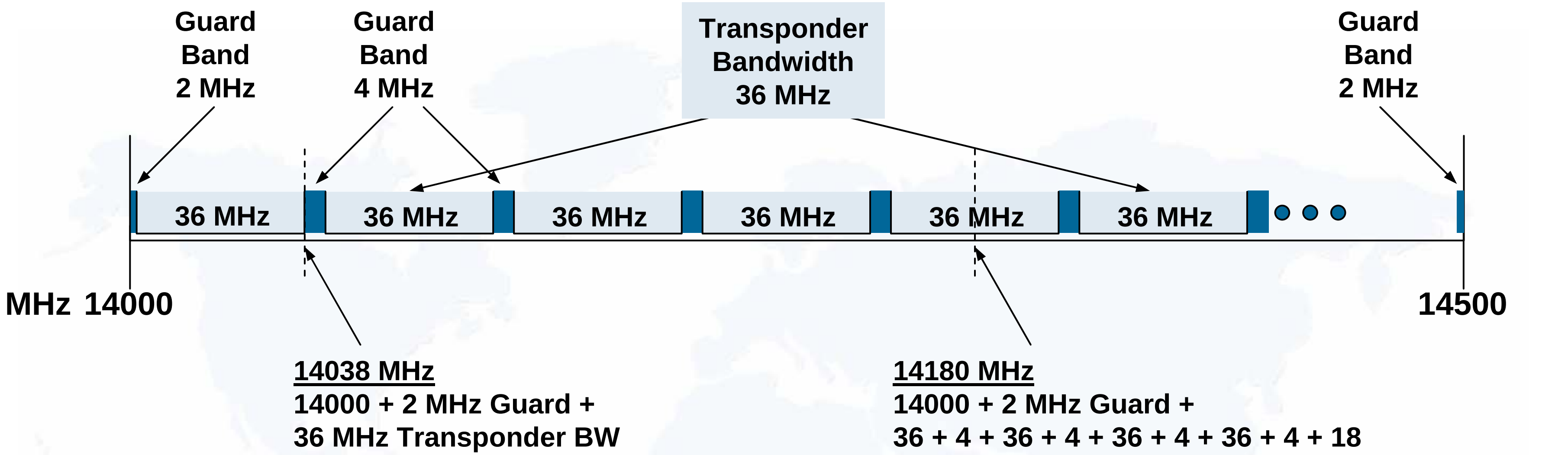
Single Channel per Carrier - SCPC

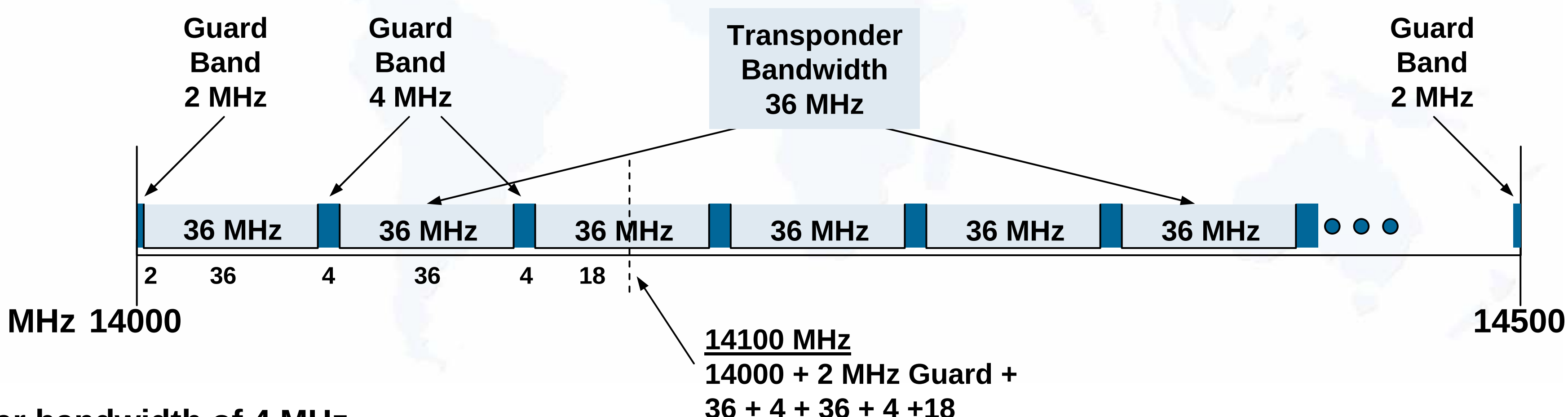
- SCPC is used for economical distribution of broadcast data, digital audio and video materials, as well as for full-duplex or two-way data, audio or video communications. In an SCPC system, user data is transmitted to the satellite continuously on a single satellite carrier. The satellite signal is received at a single location, in the case of a point-to-point system, or at many locations in a broadcast application, providing connectivity among multiple sites.
  - SCPC got its name from the older analog transmission technology, when a single satellite channel could carry only one data carrier

Time Division Multiple Access - TDMA

- A mechanism for sharing a channel, whereby a number of users have access to the whole channel bandwidth for a small period of time (a time slot)
- The difference between time-division multiplexing (TDM) and time-division multiple access is that time-division multiplexing requires users to be collocated to be multiplexed into the channel
  - In that regard, time-division multiple access can be considered as a remote multiplexing technology

Satellite Frequency Breakdown

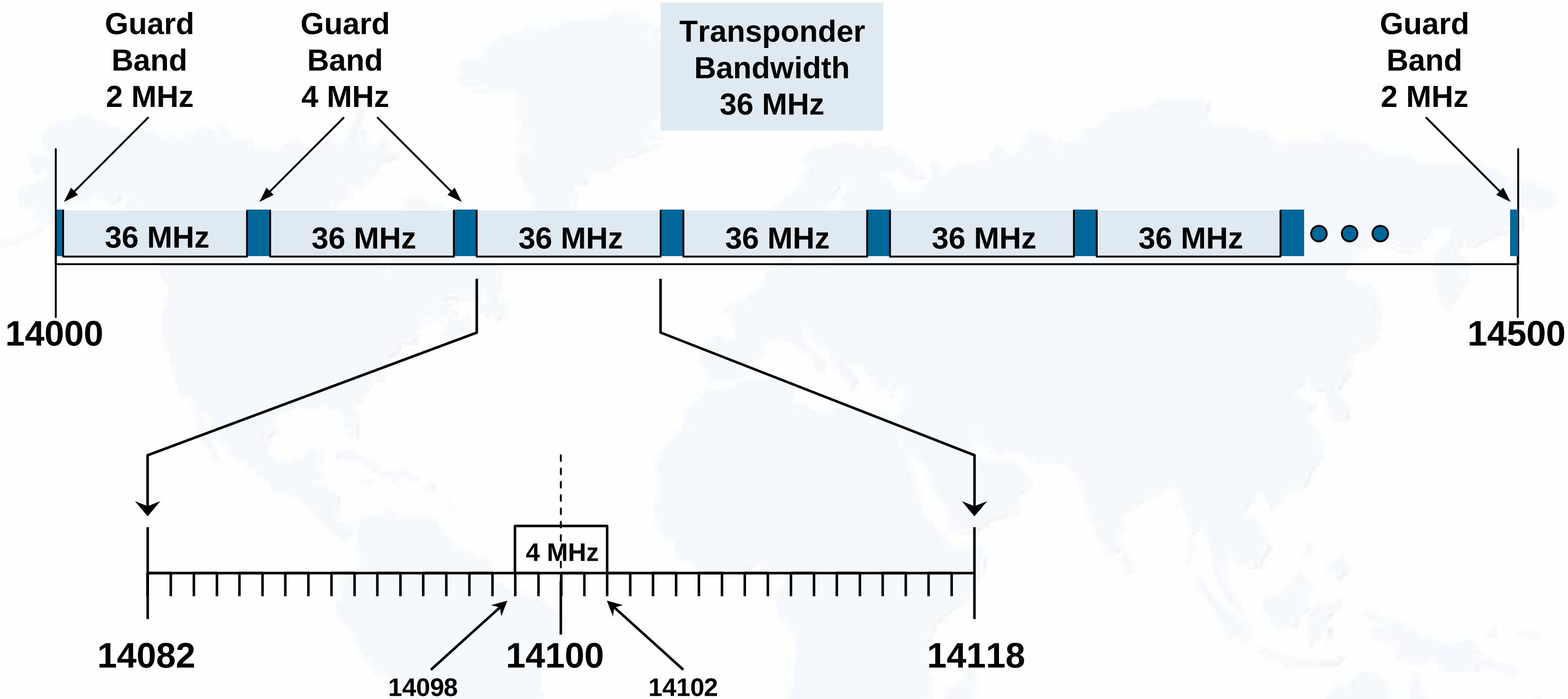




User bandwidth of 4 MHz

Network Operator assigns a transmit frequency of 14.1 GHz to Customer A

Satellite Frequency Assignment

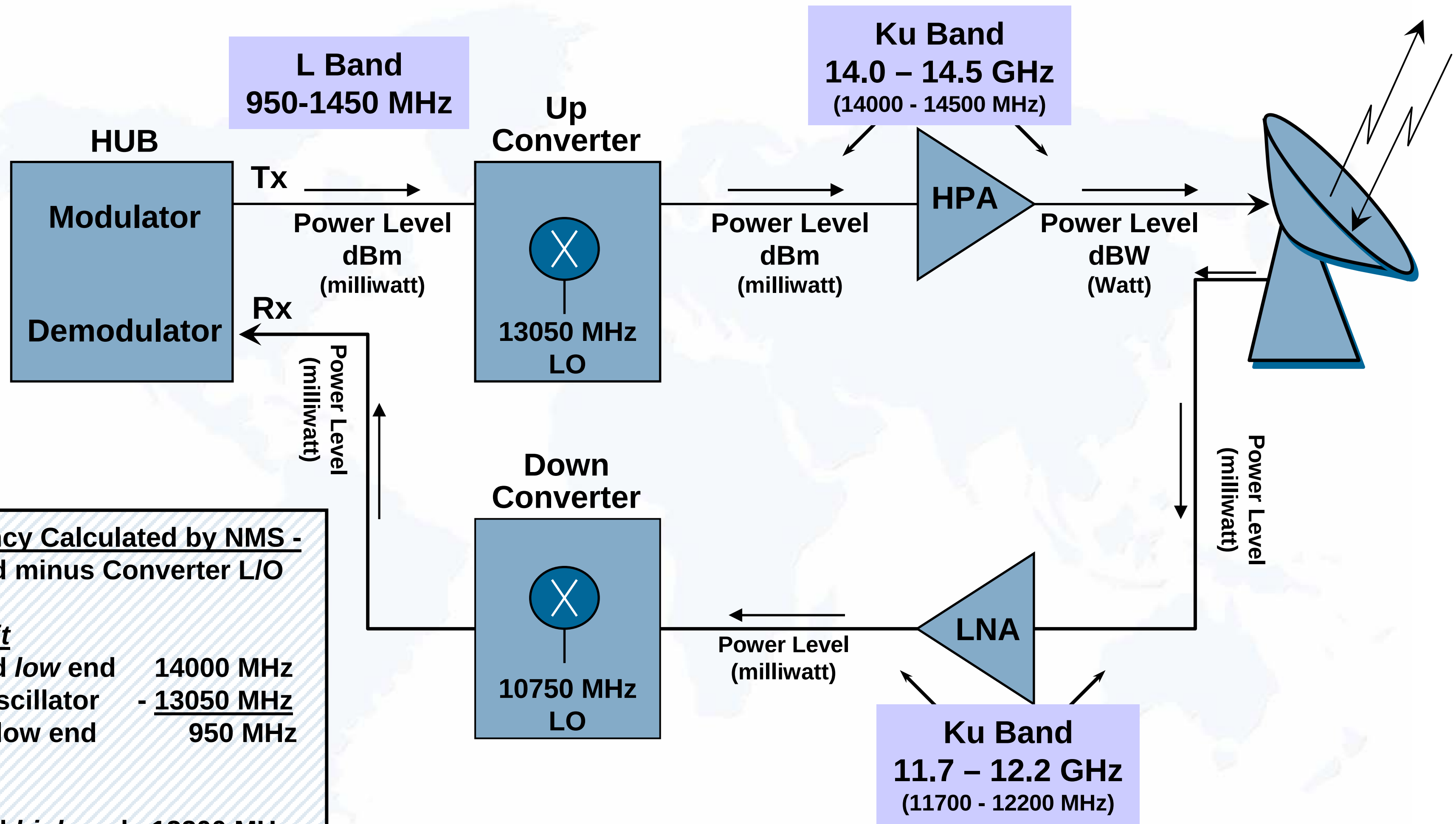


<u>User bandwidth of 4 MHz</u>

Network Operator assigns a transmit frequency of 14.1 GHz to Customer A

Customer Frequency represents the center of the frequency in use

Satellite Up / Downlink Frequencies



Frequency Calculated by NMS -
Ku Band minus Converter L/O

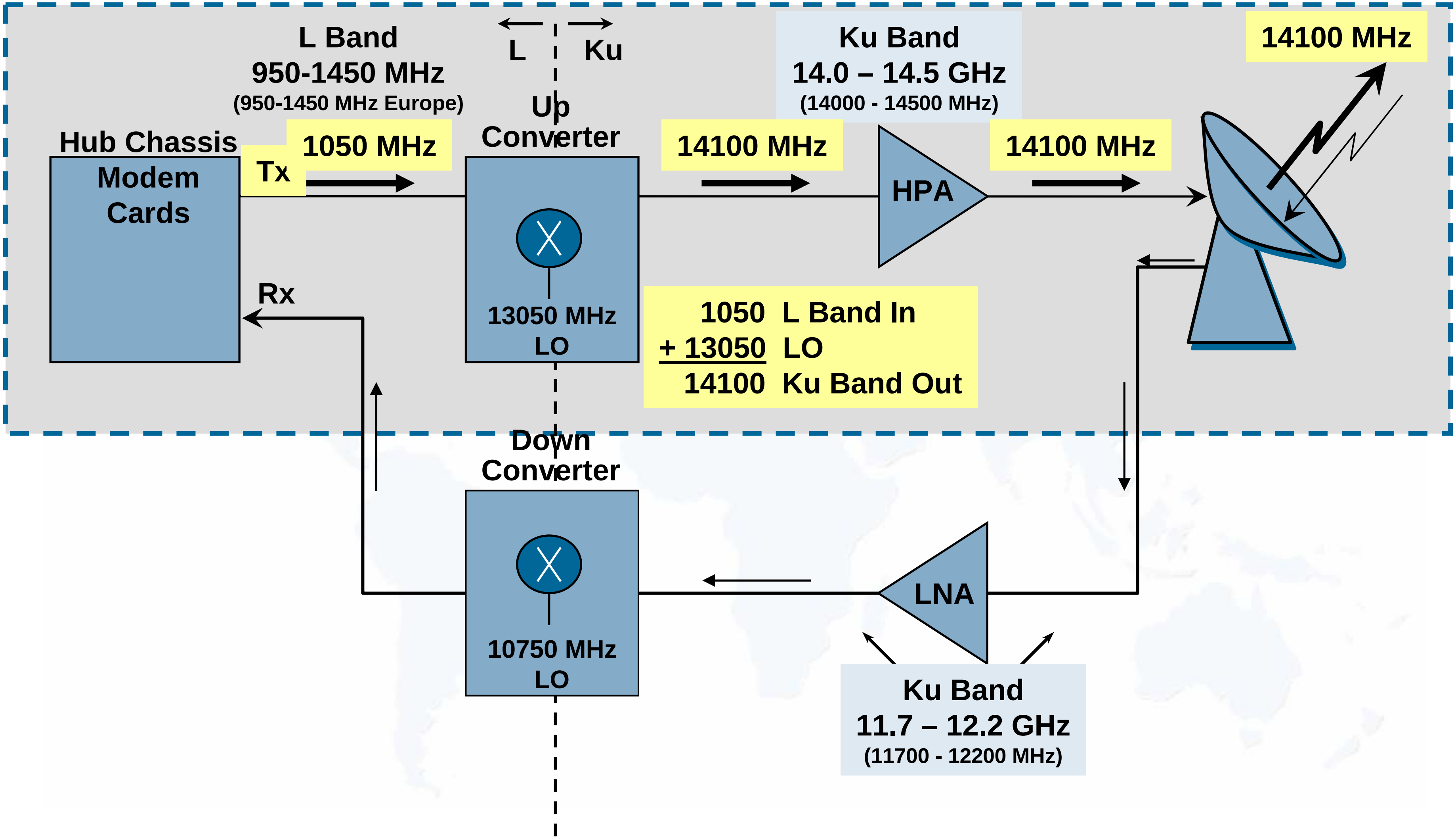
Transmit

Ku Band *low* end	14000 MHz
Local Oscillator	- 13050 MHz
L Band low end	950 MHz

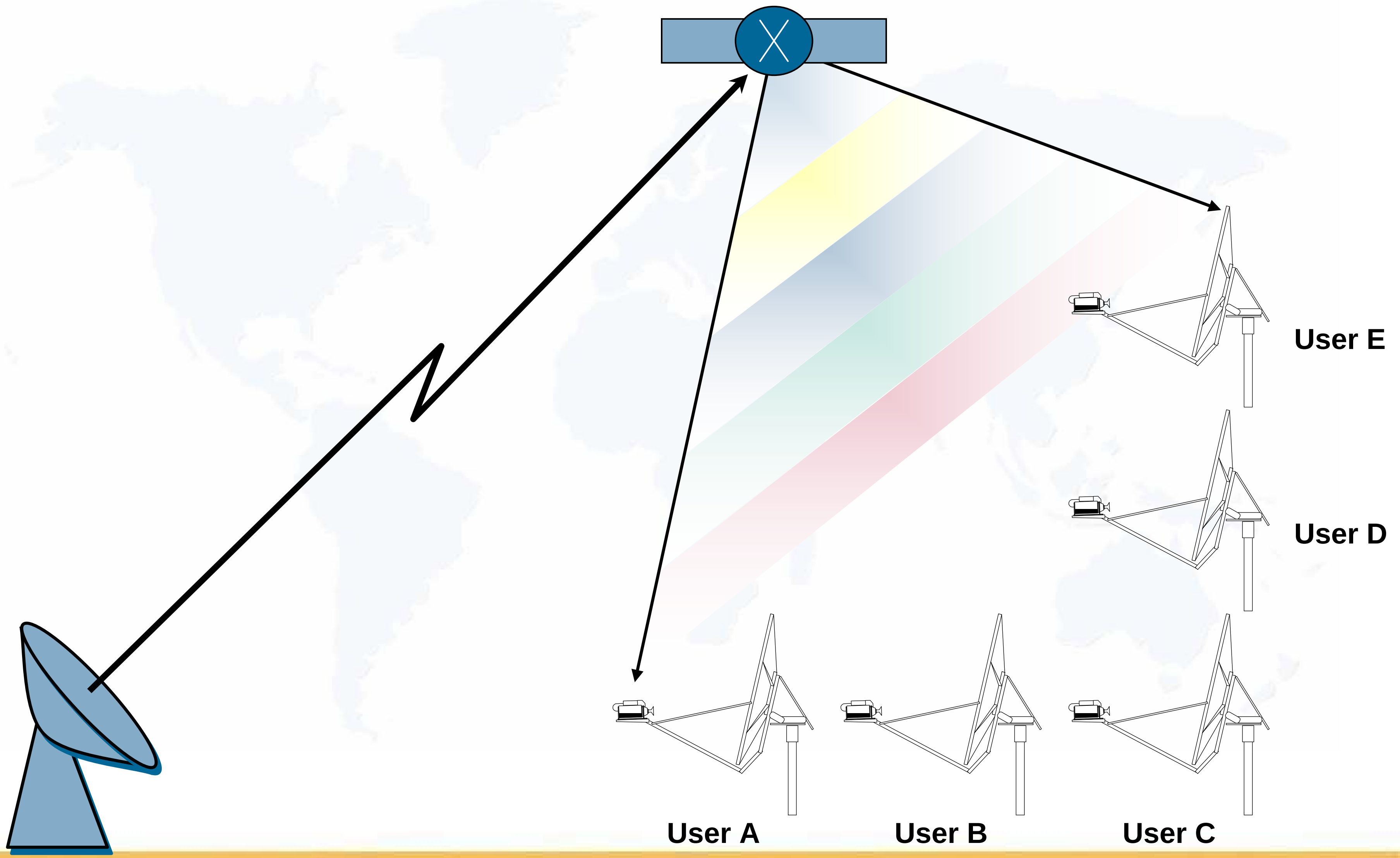
Receive

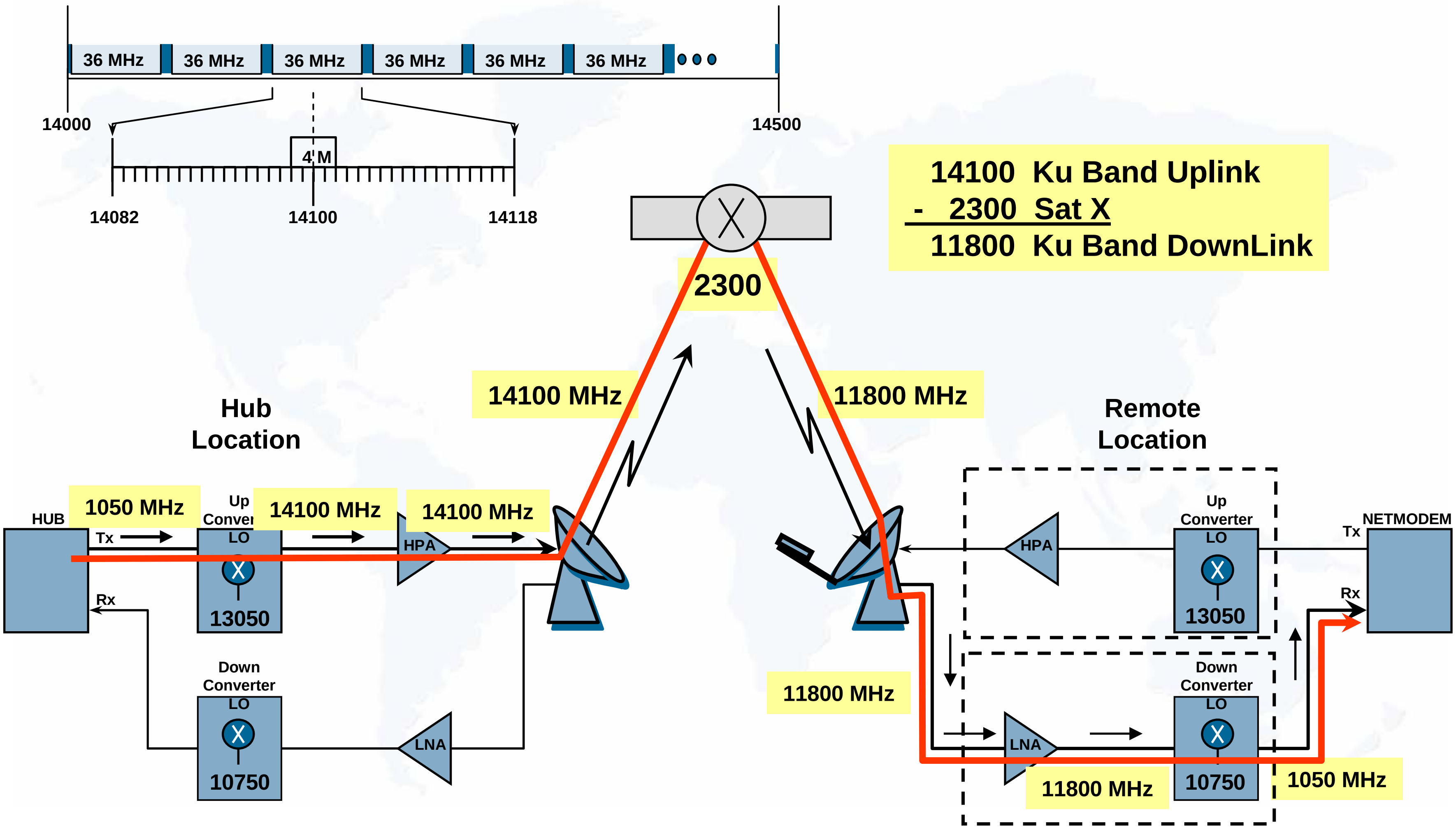
Ku Band *high* end	12200 MHz
Local Oscillator	- 10750 MHz
L Band low end	1450 MHz

Hub Transmit Operation



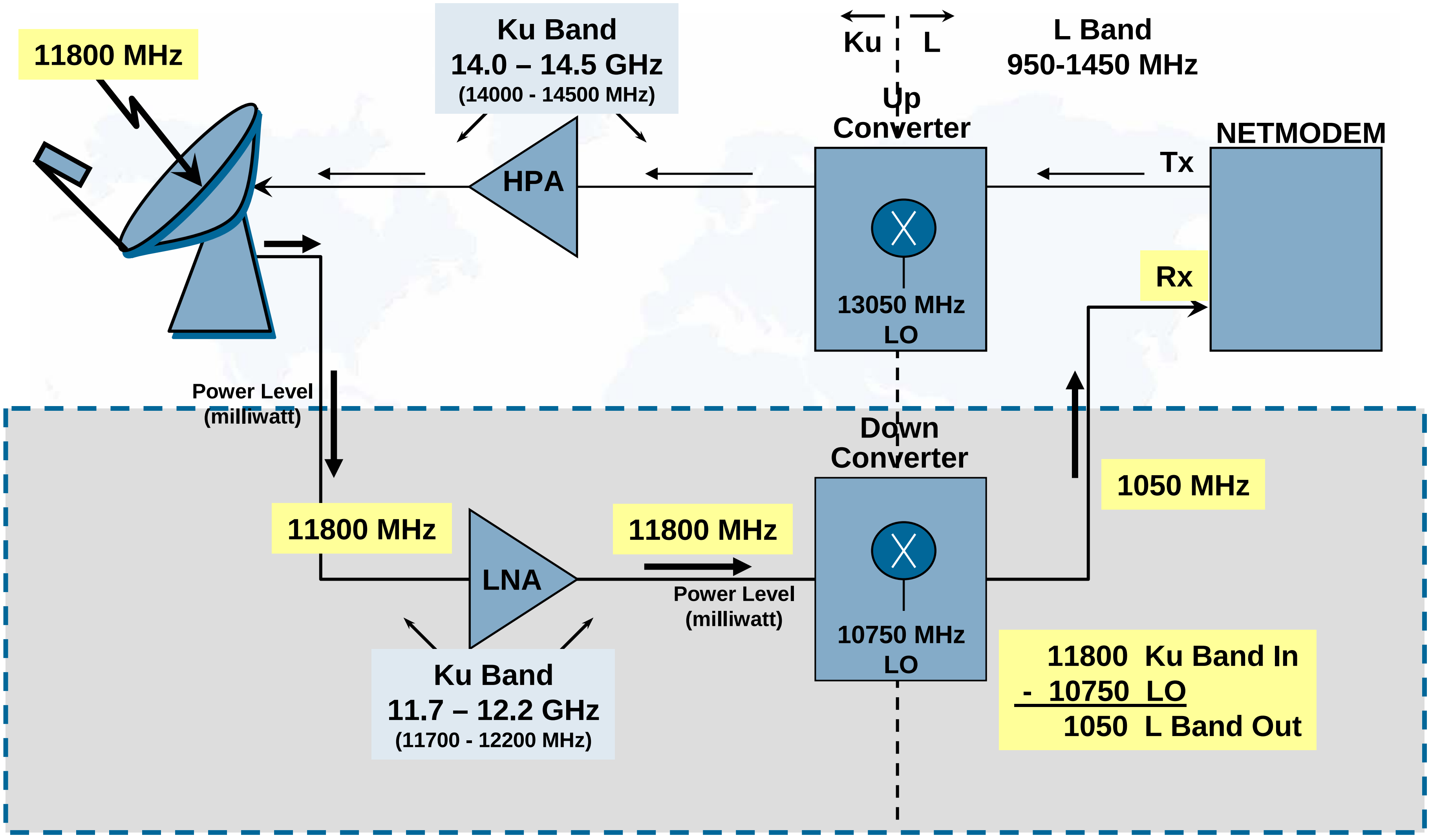
SCPC - Time Division Multiplexing



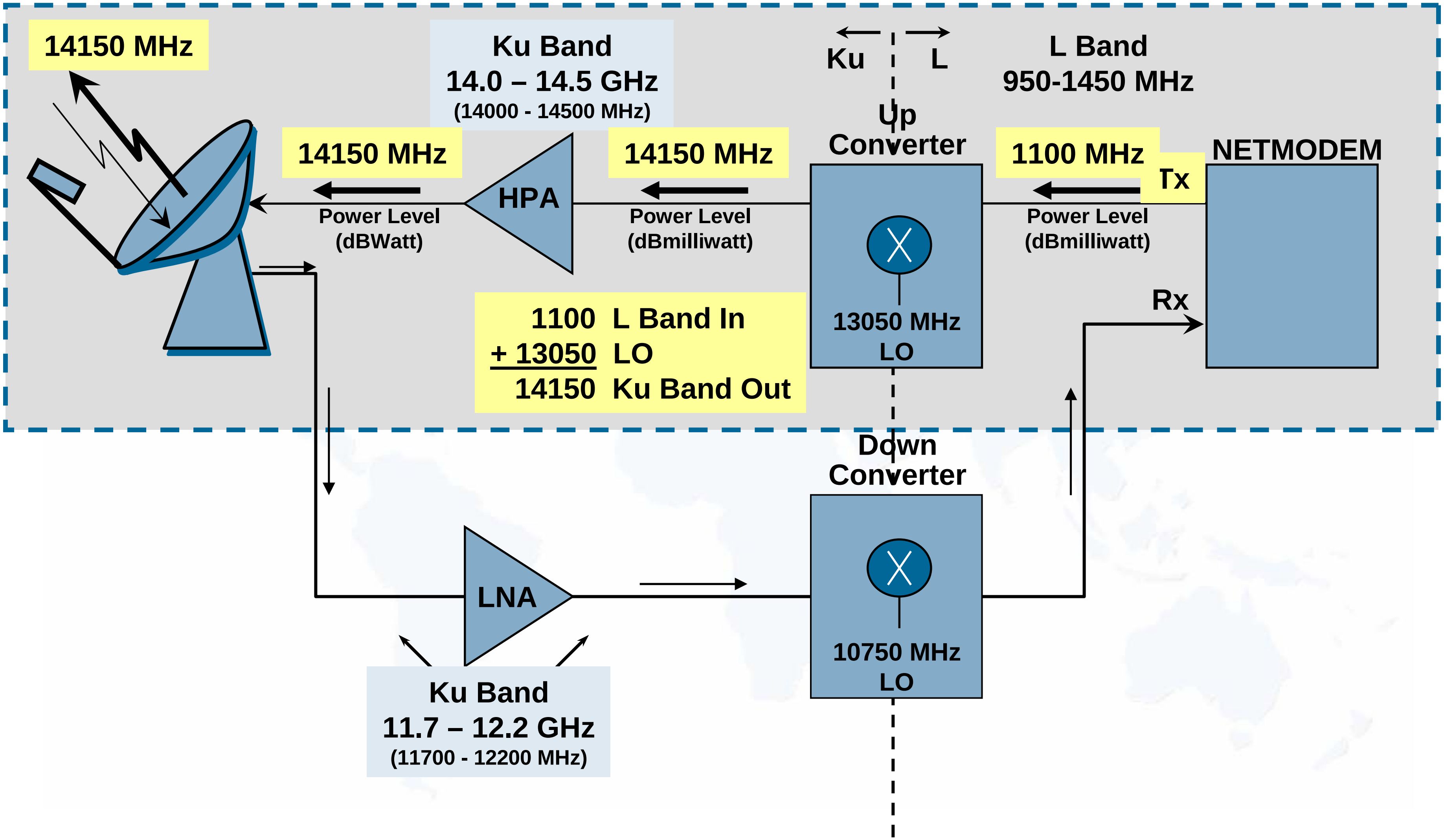


36 MHz
36 MHz
36 MHz
36 MHz
36 MHz
36 MHz
14000
14500
4 M
14082
14100
14118
14100 Ku Band Uplink
- 2300 Sat X
11800 Ku Band DownLink
2300
14100 MHz
11800 MHz
Hub Location
Remote Location
HUB
1050 MHz
Tx
Rx
Up Conver
LO
13050
14100 MHz
HPA
14100 MHz
Down Converter
LO
10750
LNA
Up Converter
LO
13050
HPA
NETMODEM
Tx
Rx
11800 MHz
Down Converter
LO
10750
LNA
11800 MHz
1050 MHz

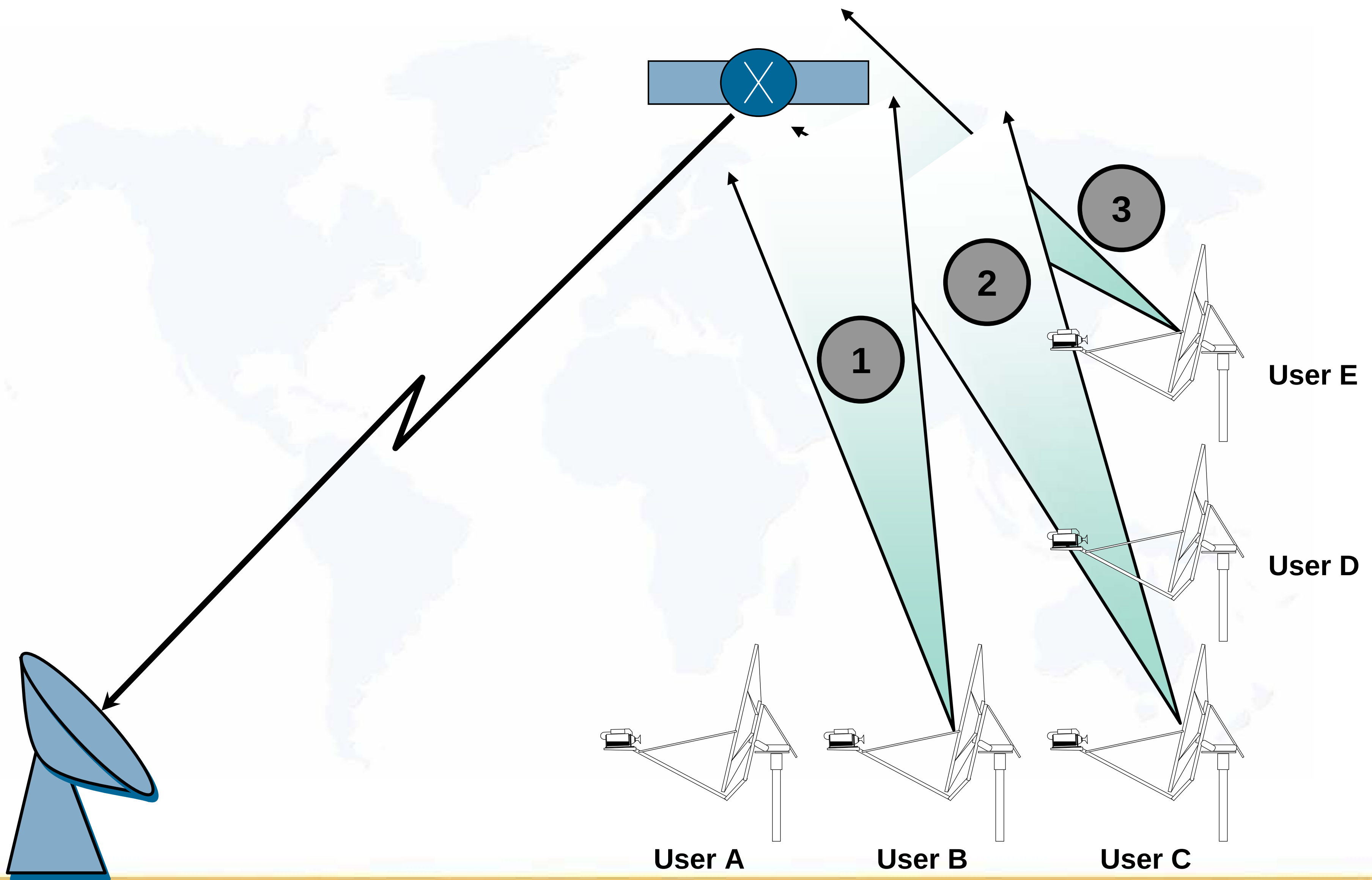
Remote Receive Operation

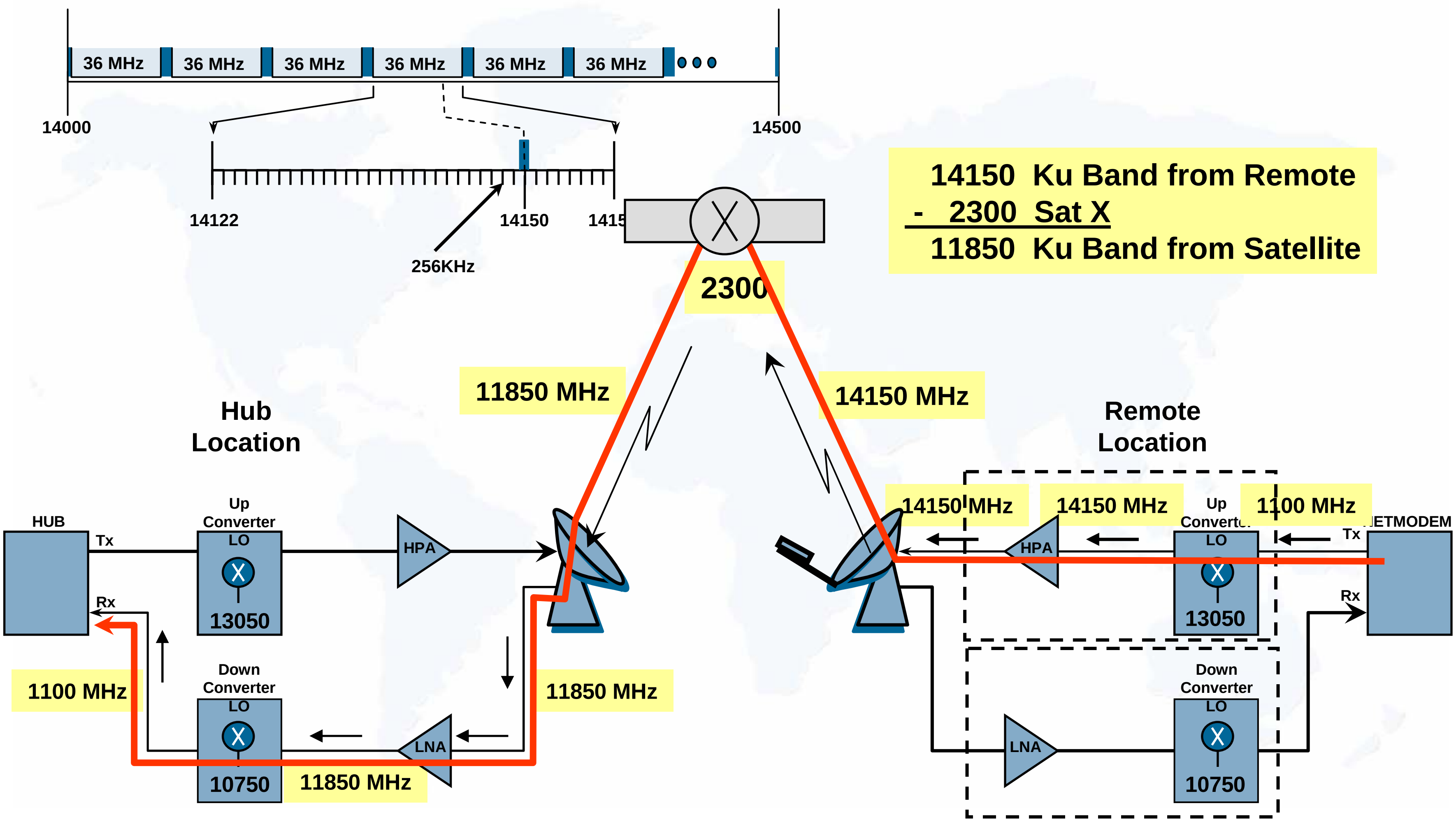


Remote Transmit Operation

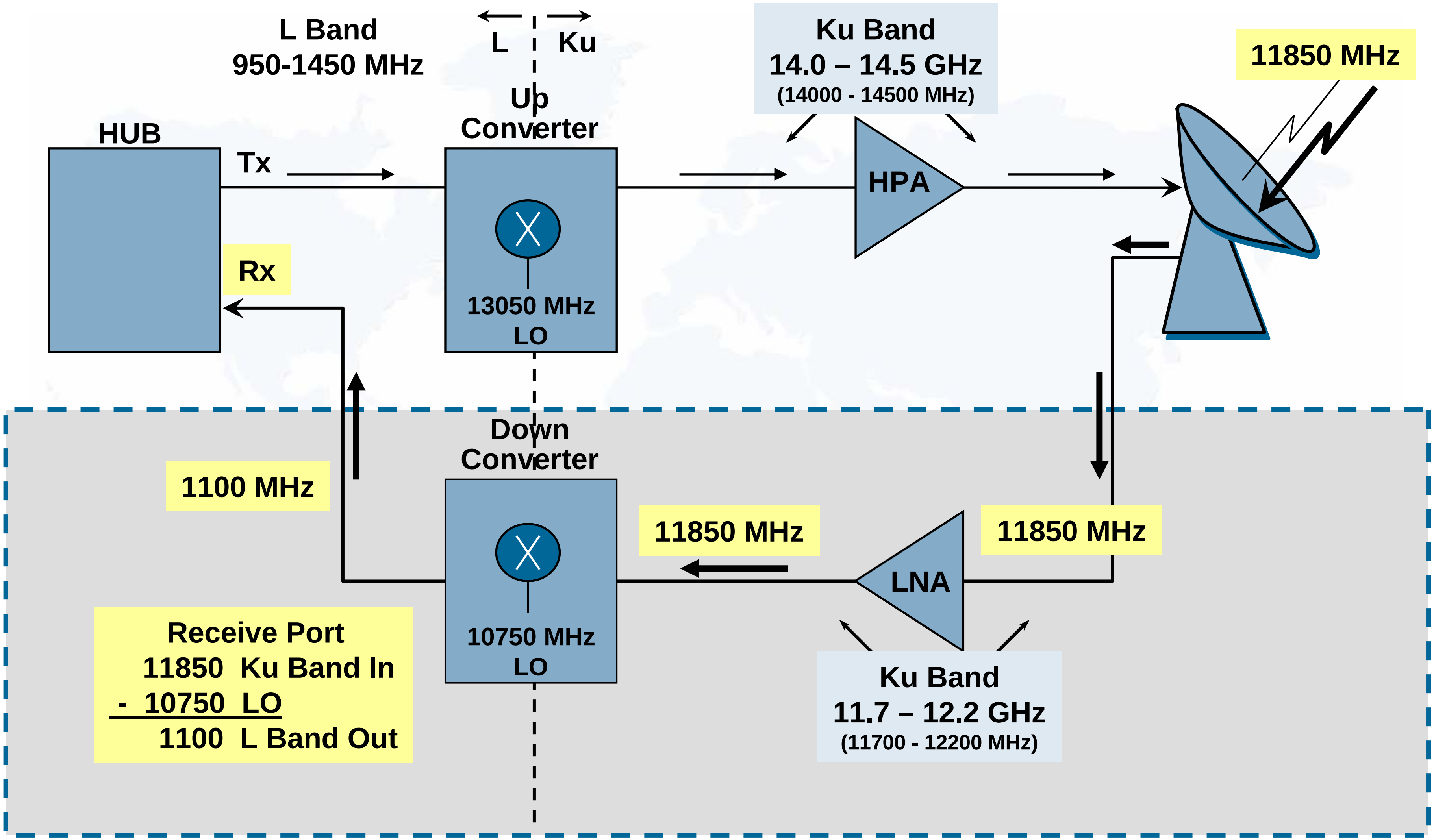


Time Division Multiple Access

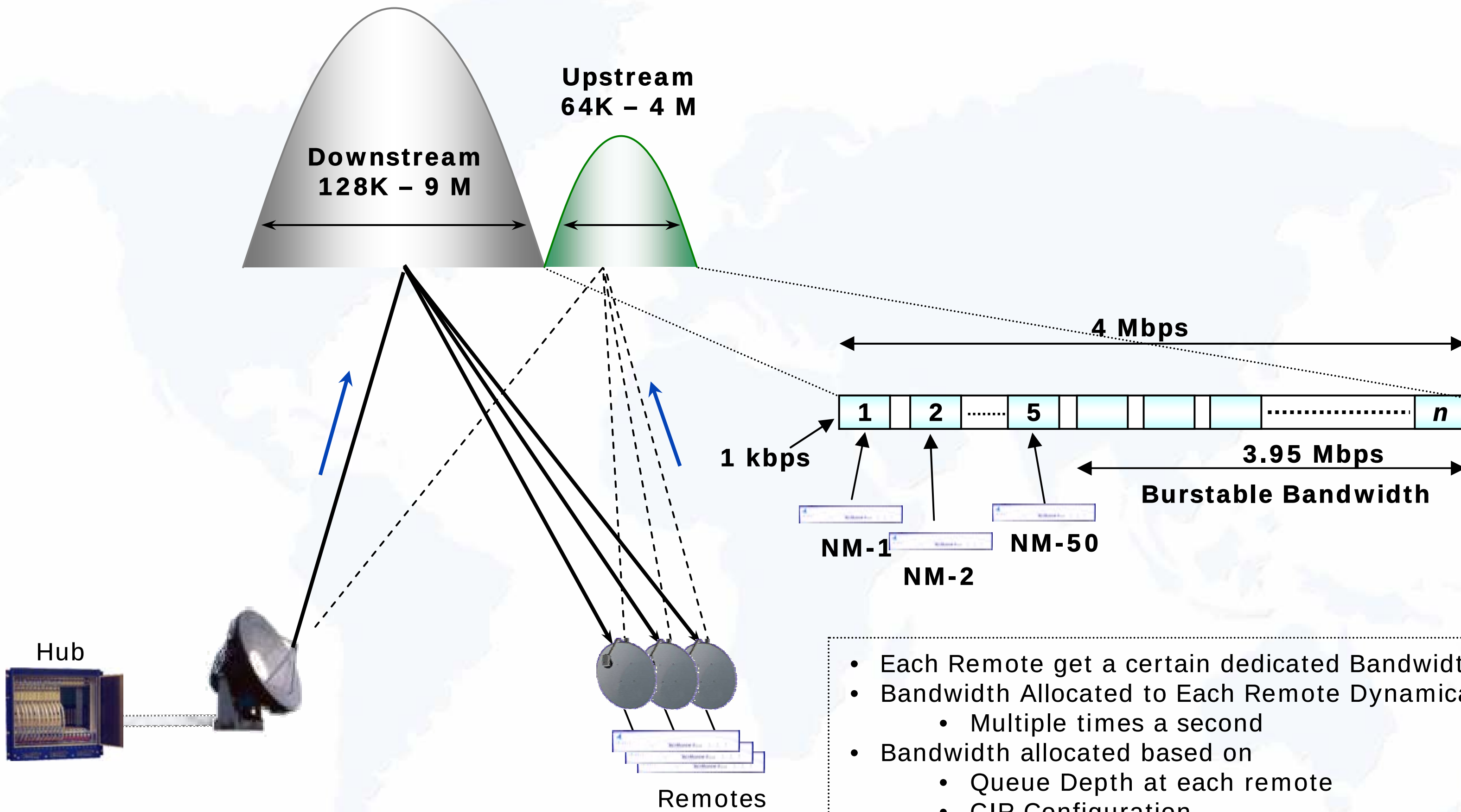



36 MHz
36 MHz
36 MHz
36 MHz
36 MHz
36 MHz
14000
14500
14122
14150
256KHz
14150 Ku Band from Remote
- 2300 Sat X
11850 Ku Band from Satellite
2300
11850 MHz
14150 MHz
Hub Location
Remote Location
HUB
Tx
Rx
Up Converter
LO
13050
HPA
Down Converter
LO
10750
LNA
1100 MHz
11850 MHz
11850 MHz
14150 MHz
14150 MHz
1100 MHz
Tx
Rx
13050
10750

Hub Receive Operation



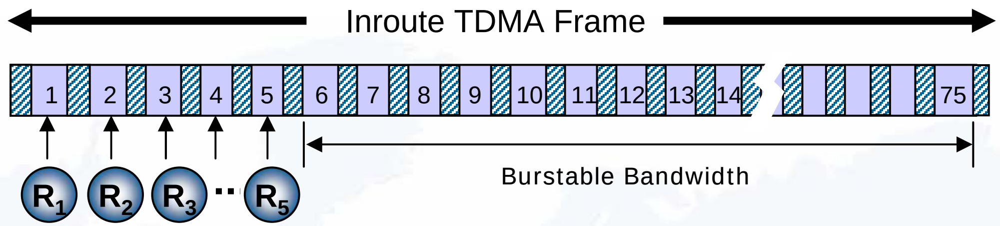
iDirect D-TDMA Network Architecture



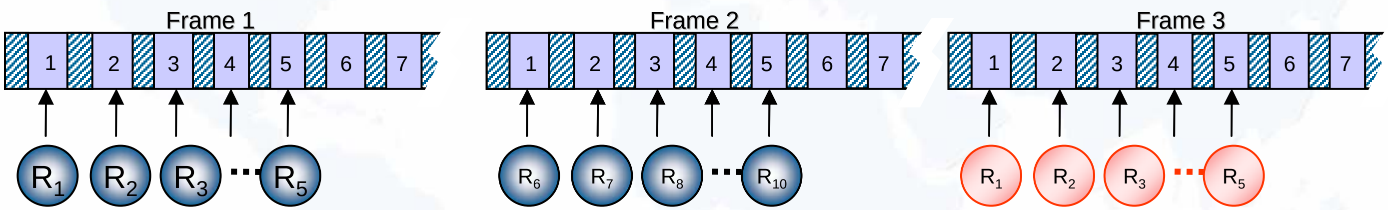
- Each Remote get a certain dedicated Bandwidth
- Bandwidth Allocated to Each Remote Dynamically
  - Multiple times a second
- Bandwidth allocated based on
  - Queue Depth at each remote
  - CIR Configuration
  - QoS/Prioritization Configuration
  - Rate Limiting at each remote

- D-TDMA
  - Deterministic TDMA
  - Technique used to prevention of collisions of remotes transmitting simultaneously
  - Improves throughput by reducing retransmissions

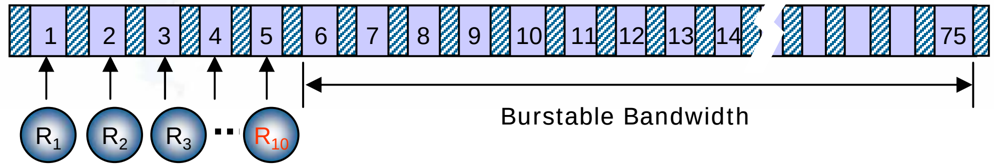
Scheduled Dedicated Timeslot



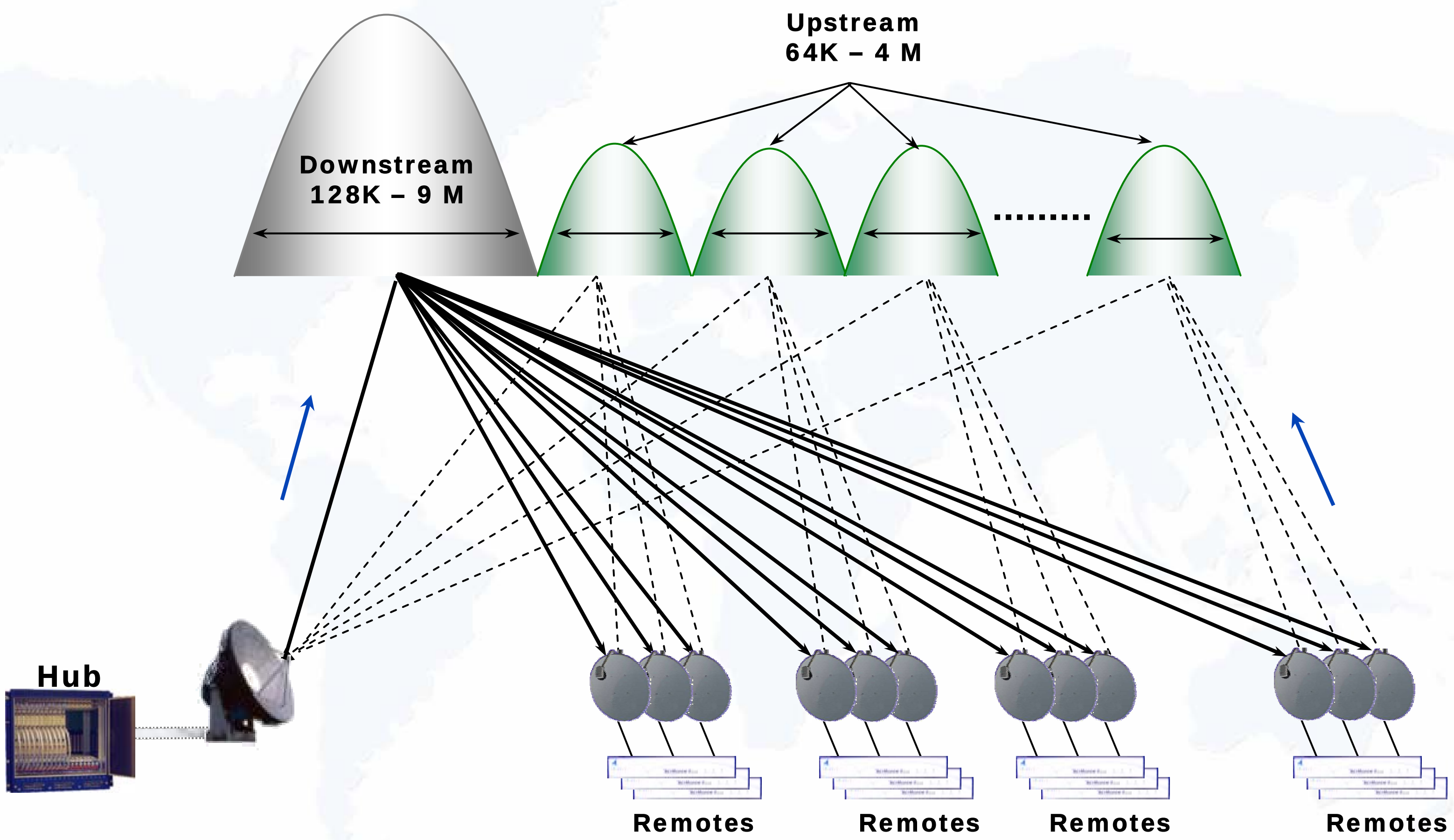
With the default configuration every remote is given a dedicated timeslot, in every frame.
For ex., 5 Remotes using 5 Timeslots, with each remote getting a timeslot every frame.



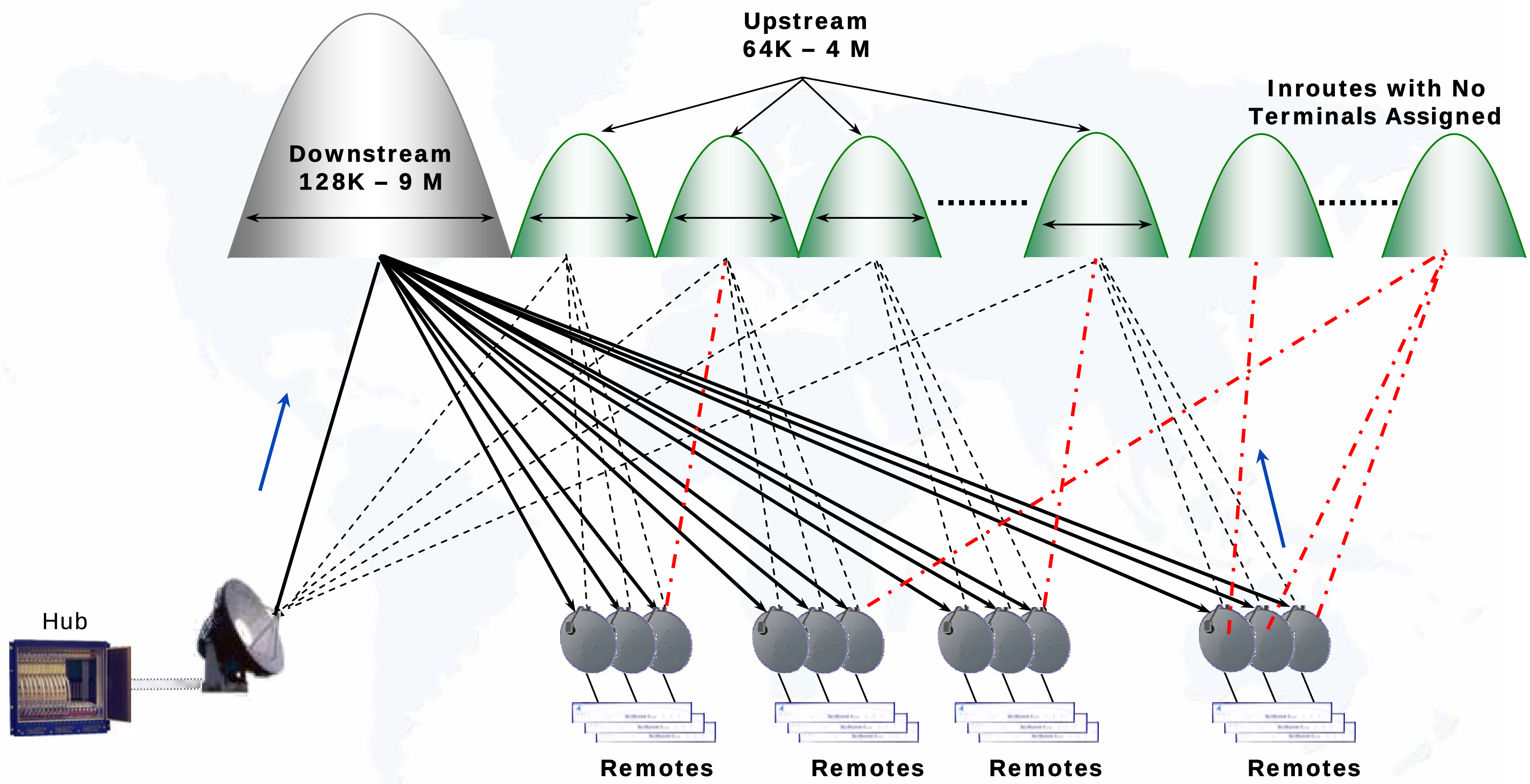
- If a remote is configured to have its dedicated time slot once every 2 frames, then 10 remotes will need only 5 timeslots **(minimum is one time slot every two seconds)**
- This allows one to oversubscribe an inroute at a much higher ratio
- Some example applications would be business continuity and low bandwidth networks that need a guaranteed amount of bandwidth



Multiple Inbounds per Outbound



Frequency Hopping



Forward Error Correction (FEC)

- A technique for allowing a receiver to correct errors itself, without reference to the transmitter
- It does this by using additional information transmitted along with the data and employing one of the error detection techniques
- The receiver can correct a small number of the errors that have been detected
- If the receiver cannot correct all detected errors, the data must be re-transmitted

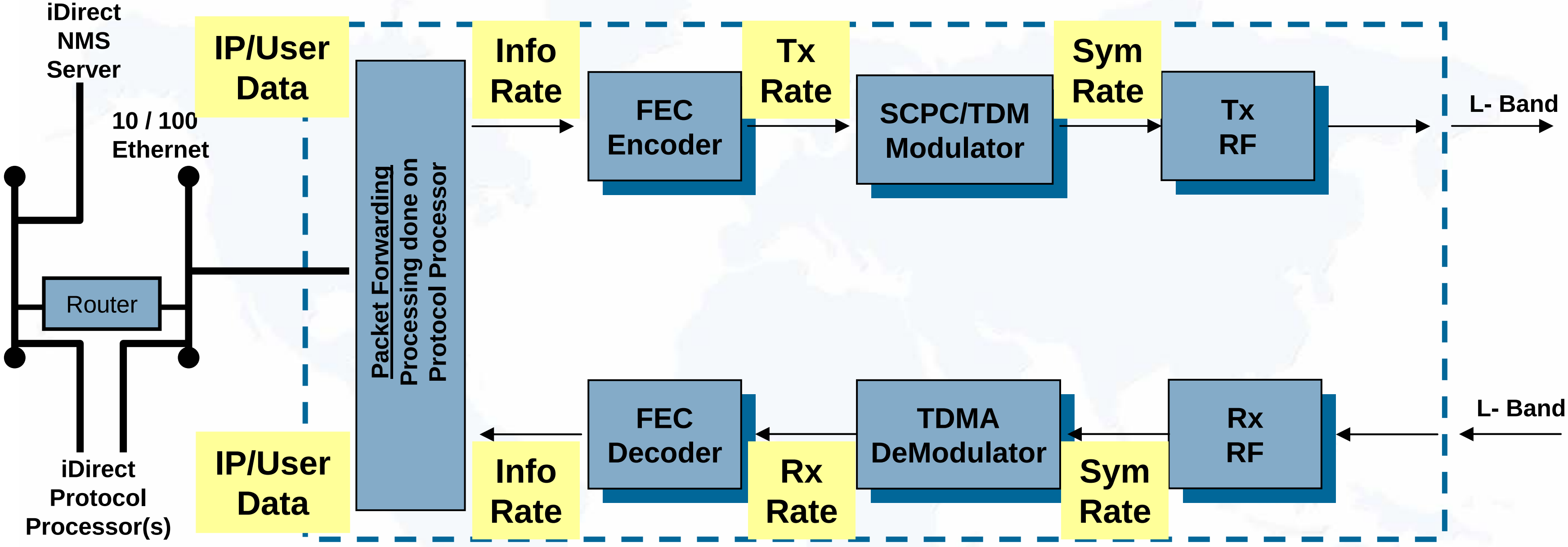
Forward Error Correction

- FEC .793 (Represented fractionally as: 3249 / 4096)
  - A forward correction utilizing .207 overhead bits for each .793 bits of User data
  - Outbound and Inbound carriers
- FEC .66 (Represented fractionally as: 676 / 1024)
  - Inbound carrier only
  - A forward correction utilizing .34 overhead bits for each .66 bits of User data
- FEC .495 (Represented fractionally as: 2028 / 4096)
  - A forward correction utilizing .505 overhead bits for each .495 bits of User data
  - Outbound carrier only

Forward Error Correction

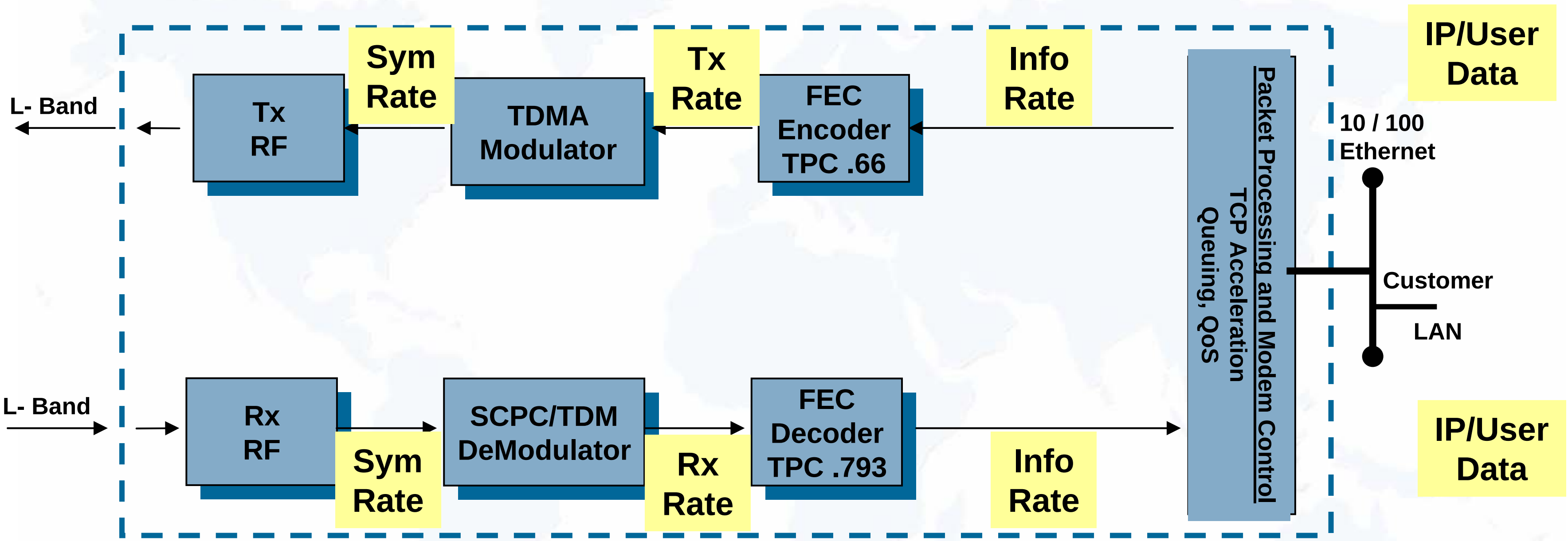
- FEC of .793 or .495 are used in the outbound links (hub to remote)
- FEC of .793 or .66 are used in the inbound links (remote to hub)
- Higher the FEC bits utilized (.505 v .207) provides
  - Higher overhead on satellite links
  - Better the data integrity
  - Smaller the VSAT dish required at the remote
  - Higher FEC bits used the lower the user traffic in the stream
- Info Rate of 6.344Mbps utilizing a FEC of .793 would require a Transmission Rate of 6.344/.793 = 8 Mbps

Hub Line Card



FEC	Forward Error Correction
SCPC	Single Channel Per Carrier
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
Sym	Symbol Rate
Tx	Transmission Rate
Rx	Receive Rate

NetModem II+



FEC	Forward Error Correction
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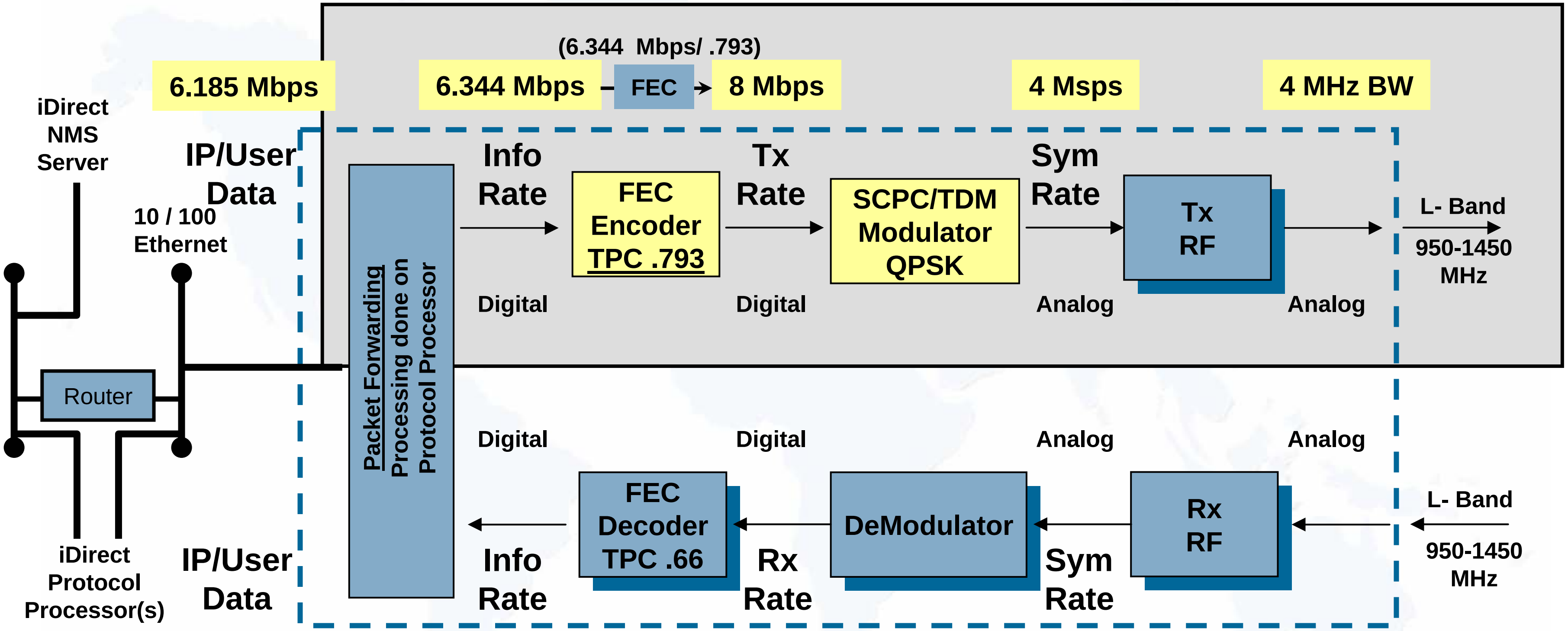
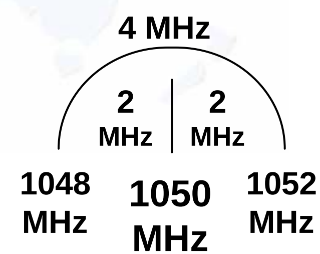
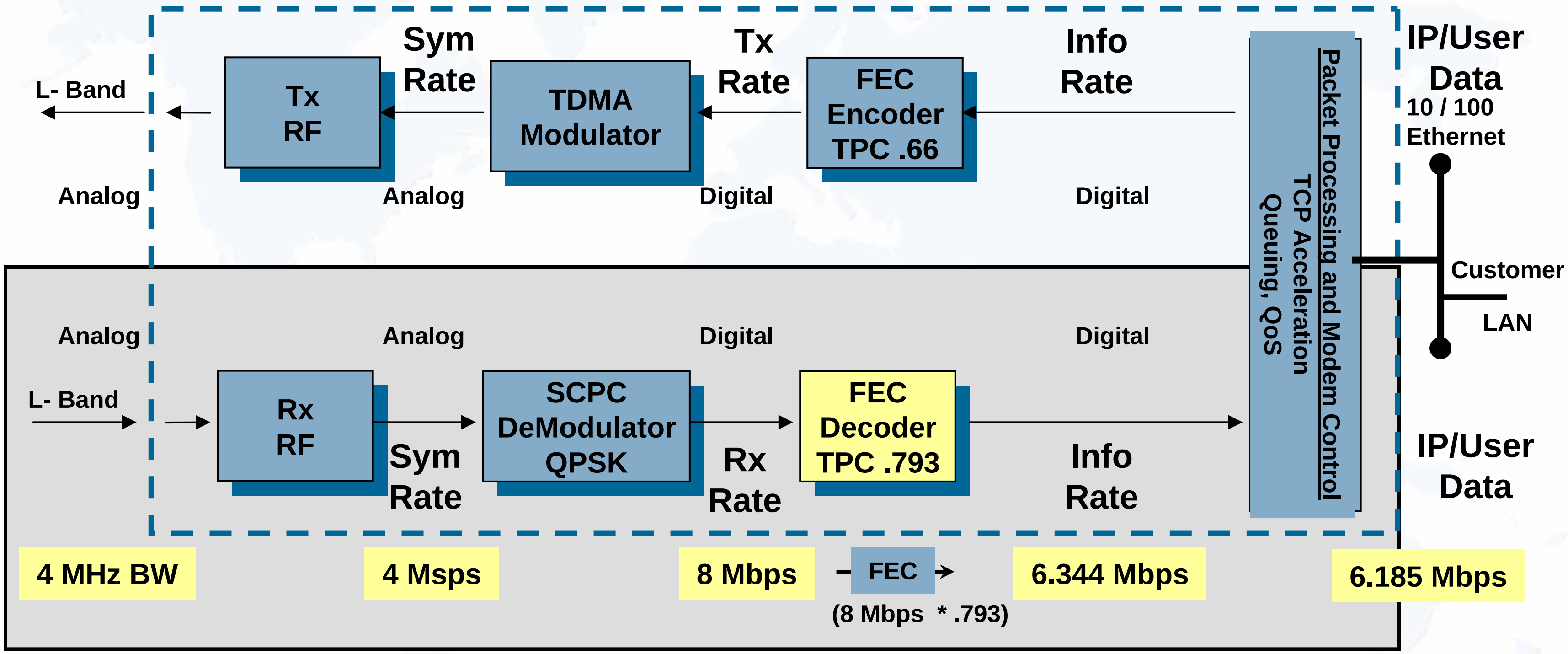
Hub Line Card





FEC	Forward Error Correction
Mbps	Mega (Millions of) bits per second
Msps	Mega (Millions of) symbols per second
SCPC	Single Channel per Carrier
TPC	Turbo Product Code

NetModem II+



FEC	Forward Error Correction
Mbps	Mega (Millions of) bits per second
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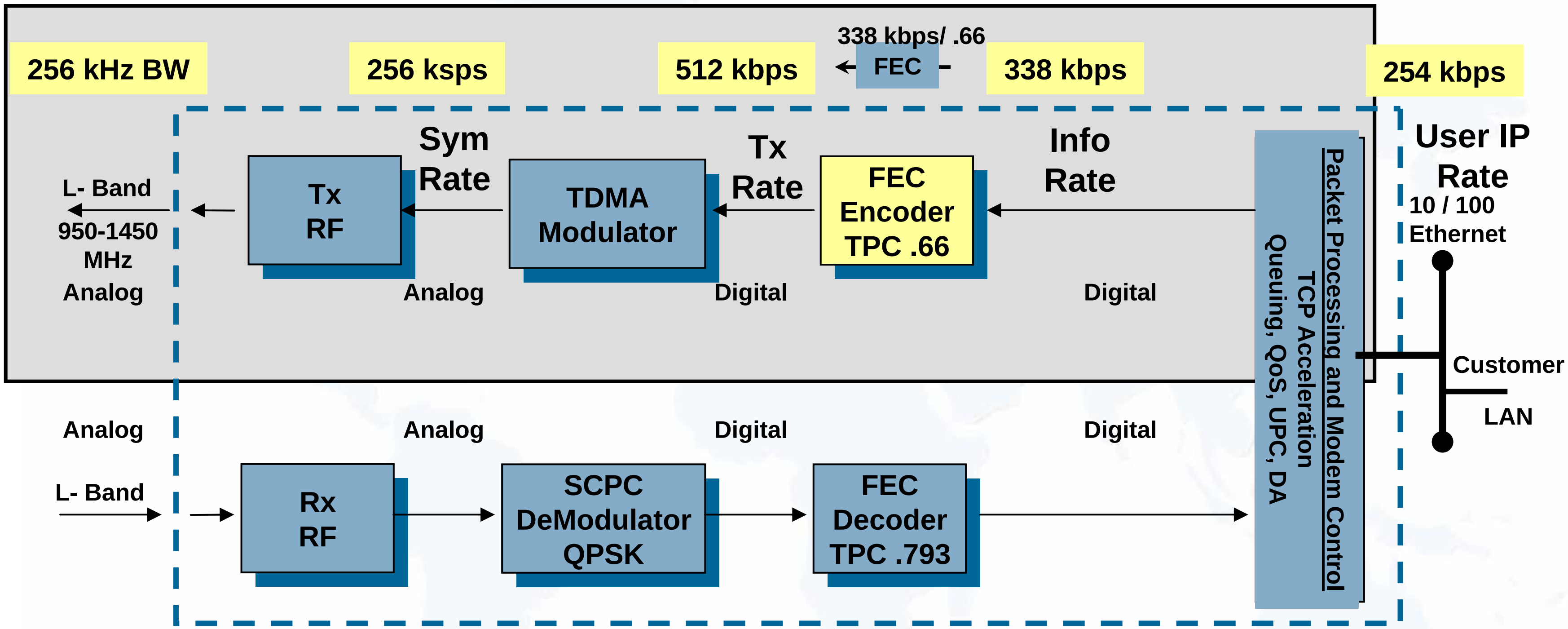
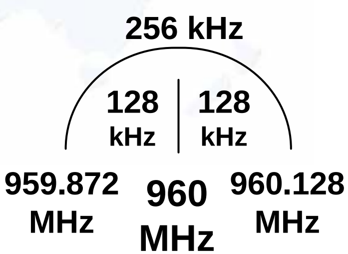
Remote Transmit Operation

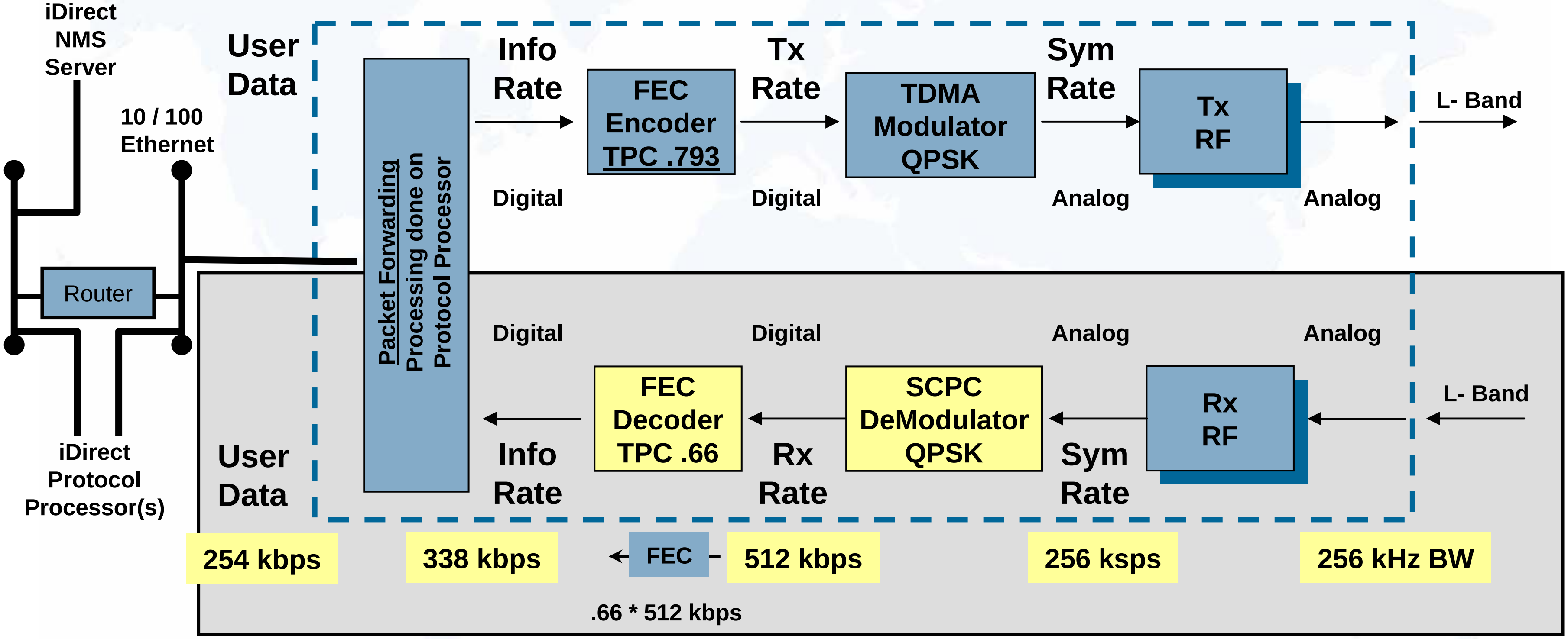
NetModem II+





FEC	Forward Error Correction
kbps	kilo (thousands of) bits per second
ksps	kilo (thousands of) symbols per second
SCPC	Single Channel per Carrier
TPC	Turbo Product Code

Hub Line Card



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kbps	kilo (thousands of) bits per second
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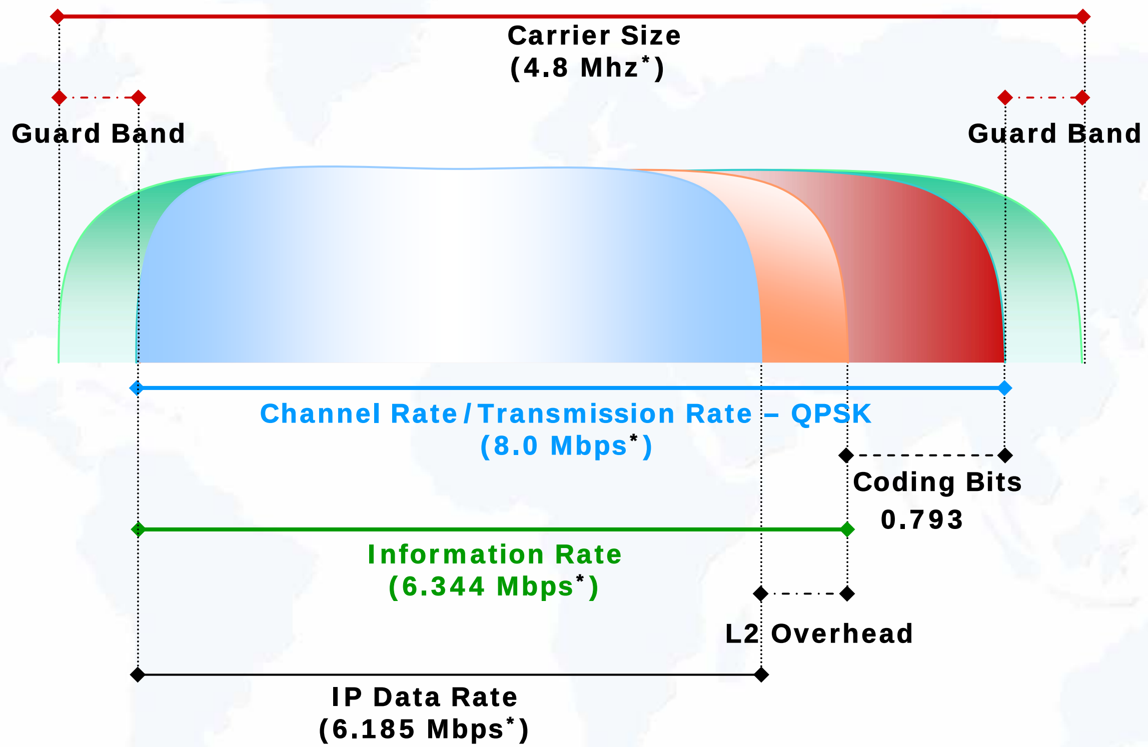
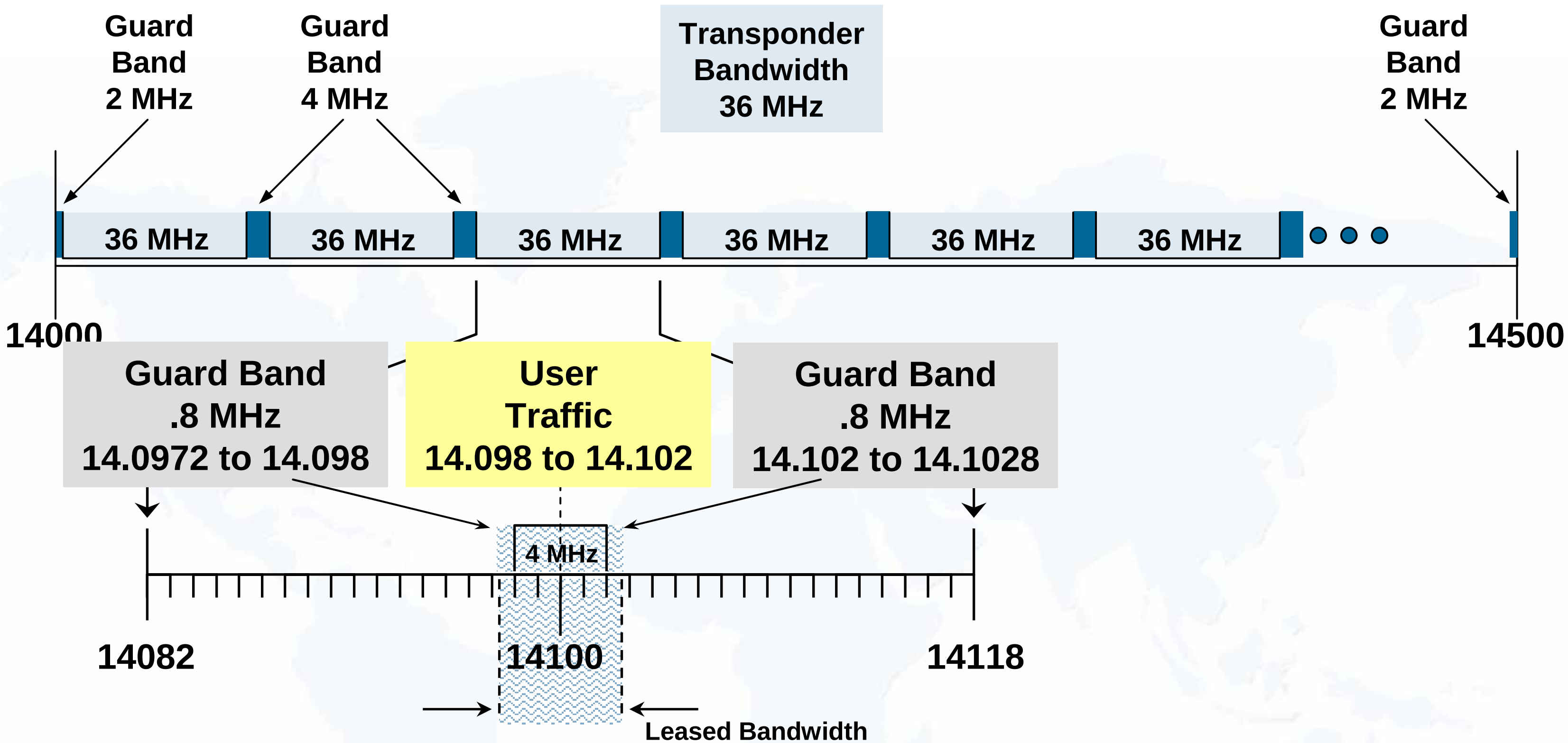
Anatomy of A Satellite Space Segment



* - Example Case Study using 1.2 Channel Spacing



<u>User bandwidth required 4 MHz</u>

Network Operator assigns a transmit frequency of 14.1 GHz

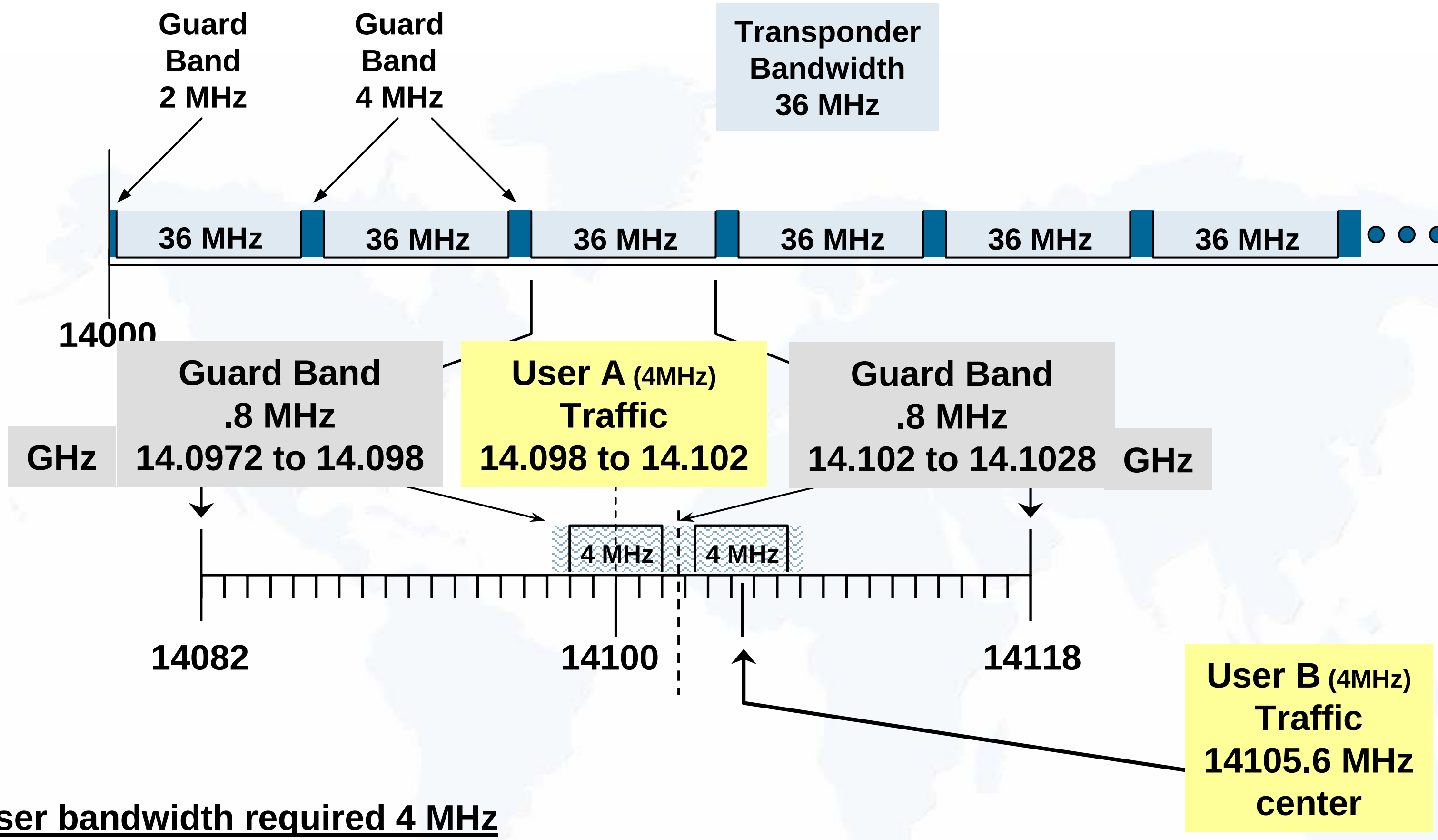
Assigned frequency is the center of the user bandwidth required

Network Operator provides a Guard Band around user bandwidth

Guard band typically is 40% of allocated bandwidth (called 1.4 Channel spacing)

4 MHz x .4 = 1.6 MHz > .8 MHz on low end and .8 MHz on high end

Network Operator will not assign these guard band frequencies to other users

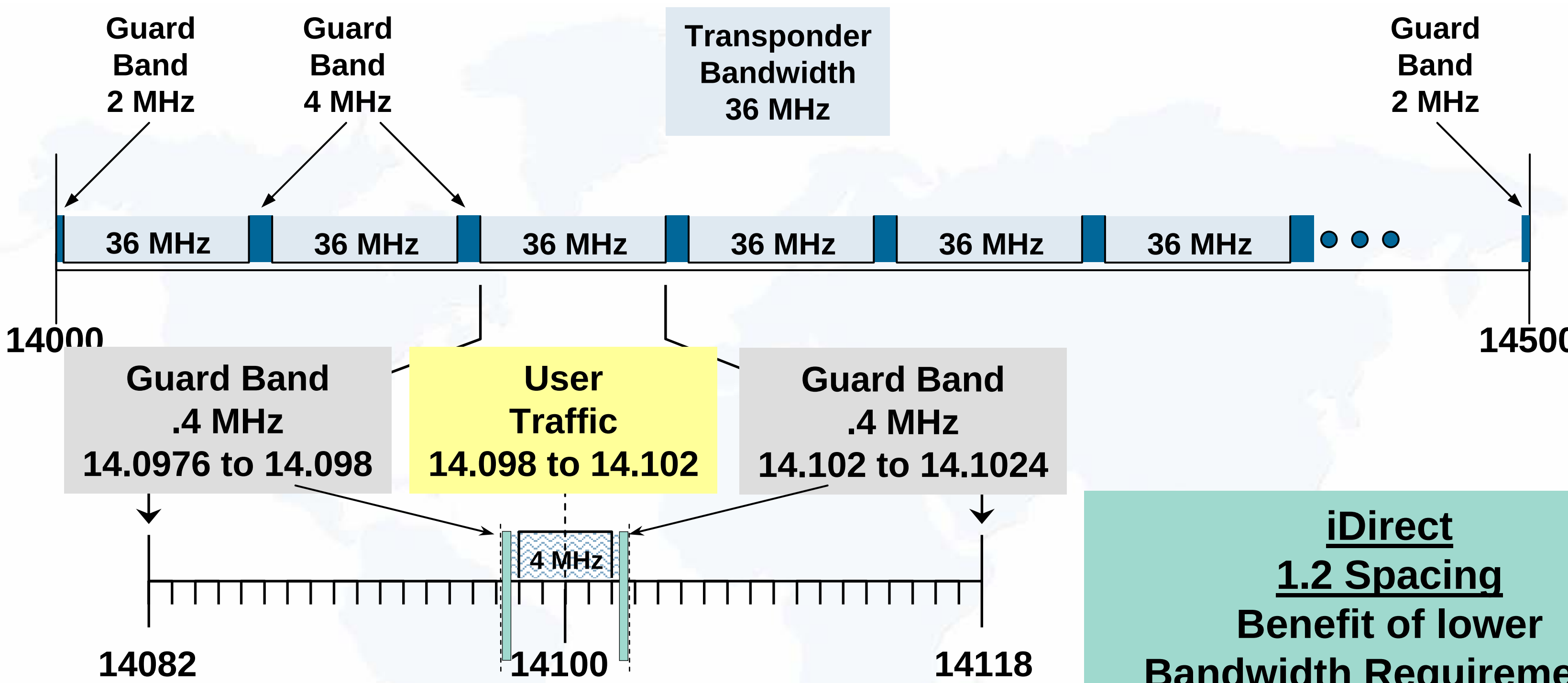


<u>User bandwidth required 4 MHz</u>

Network Operator assigns User A bandwidth of 4 MHz
User A uses a transmit frequency of 14.1 GHz center (14097.2 MHz to 14102.8 MHz)

Network Operator assigns User B bandwidth of 4 MHz
User B uses a transmit frequency of 14105.6 MHz center (user 14103.6 to 14107.6)
Guard Band includes frequencies 14102.8 to 14108.4

1.2 v 1.4 Spacing



<u>iDirect</u>
<u>1.2 Spacing</u>
Benefit of lower Bandwidth Requirements On Satellite (14.3% savings v 1.4 spacing)

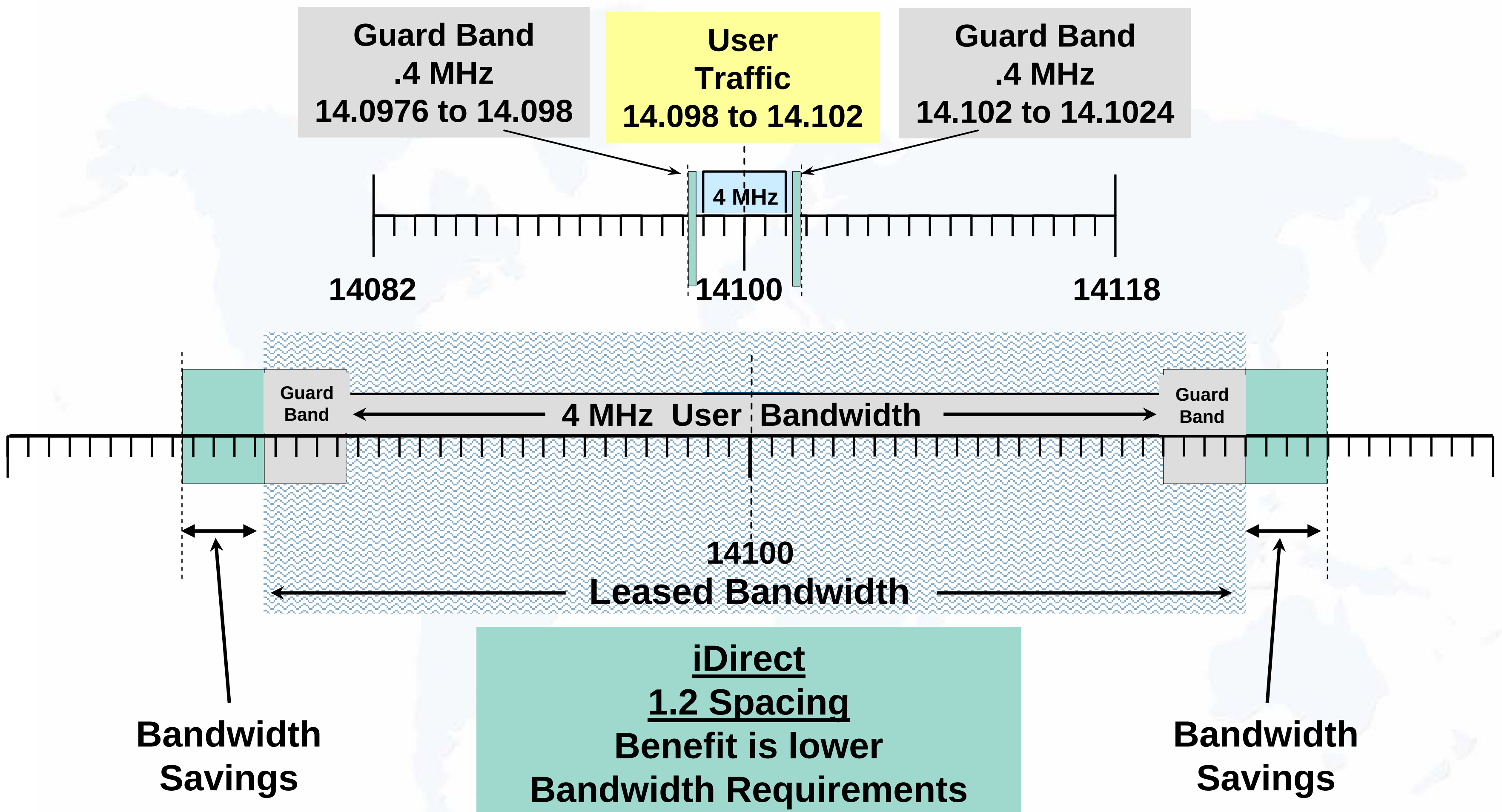
<u>User bandwidth required 4 MHz</u>

Network Operator assigns a transmit frequency of 14.1 GHz
- **Assigned frequency is the center of the user bandwidth required**

Network Operator provides a Guard Band around user bandwidth
- **Guard band typically is 40% of allocated bandwidth (called 1.2 Channel spacing)**
- **4 MHz x .2 = .8 MHz > .4 MHz on low end and .4 MHz on high end**

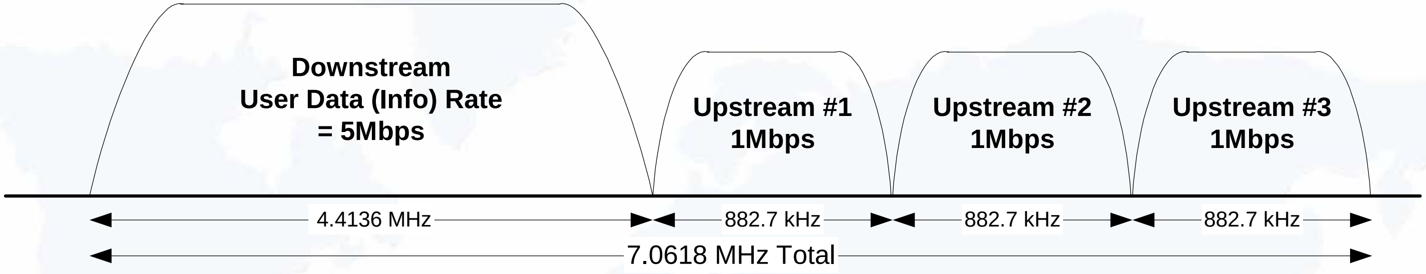
Network Operator will not assign these guard band frequencies to other users

1.2 v 1.4 Spacing

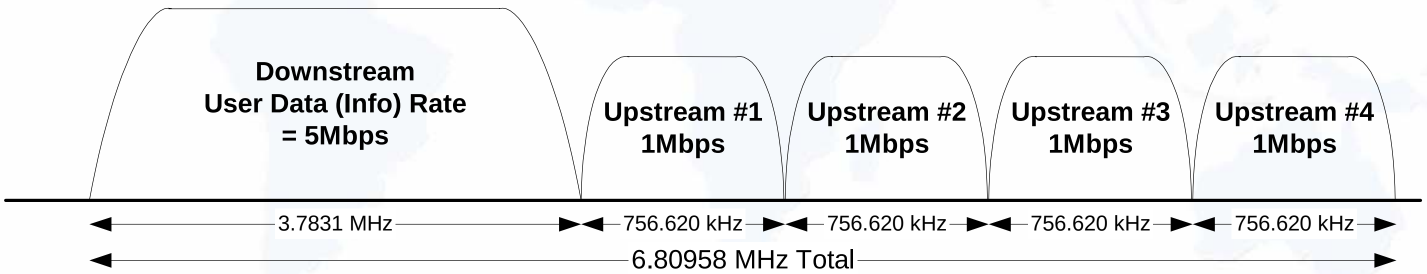


<u>iDirect</u>
<u>1.2 Spacing</u>
Benefit is lower Bandwidth Requirements On Satellite (14.3% savings v 1.4 spacing)

iDirect Network Prior to Carrier Bandwidth Optimization (40% Guardband)



iDirect Network After Carrier Bandwidth Optimization (20% Guardband)
Allows a **fourth upstream** to be added with room to spare!



In this case study, an additional 1Mbps upstream channel is added to an existing network by exploiting the reduced guardband between channels!

- Energy per Bit to Noise Ratio – E_b/N_o
  - Signal to noise ratio

    The ratio given by E_b/N_0, where E_b is the signal energy per bit and N_o is the noise energy per hertz of noise bandwidth iDIRECT

Satellite Communication Concepts

*** Thank You ***