Evolution of Front Ends for Satellite Communications in Ka- band

J. Fikart

IEEE ComSoc Presentation 10 Jan 2005

Evolution of Front Ends: Outline

- Part 1: Satellite Communications: Why Ka-band?
- Part 2: "Generic" Satcom Systems with Fixed Terminals
- Part 3: Front End for ASTRA SITs
- Part 4: Ka-band Portable Terminal
- Part 5: Ka-band Challenges and Trends

Part 1:
Satellite Communications: Why Ka- band?

IEEE ComSoc Presentation 10 Jan 2005

Outline

1. Satellite bands for DTH TV, VSATs
2. Ka-Band Pros and Cons
3. Historical Overview
   - The beginnings
   - First Satellites
   - “Newer” Satellites
   - Local contribution
4. New Ka-Band Satellite Systems
   - Recent Ka-Band Satellite Launches
5. Conclusions

Satellite bands for DTH TV, VSATs

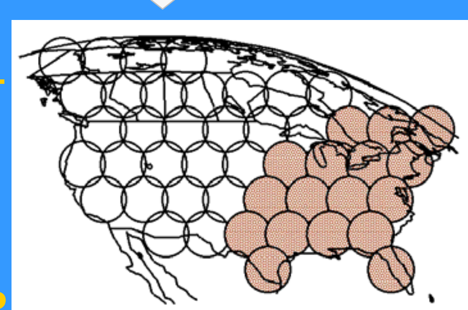
Ka, Ku- and C- bands :

- C: Rx = 3.7 – 4.2 GHz
  Tx = 5.925 – 6.425 GHz
- Ku: Rx = 10.75 – 12.75 GHz with sub-bands
  Tx = 14.0 – 14.5 GHz (extended to 13.75 GHz)
- Ka: Rx = 19.2-20.2 GHz Eu & US
  20.405 –21.105 GHz Asia (Korea)
  Tx = 29-30 GHz Eu & US
  30.135 - 30.835 GHz Asia (Korea)

Most often used Ka Rx/Tx = 19.7-20.2/29.5-30 GHz

Ka-Band Pros and Cons

- **Larger effective bandwidth**
  Higher frequency = smaller wavelength = smaller satellite footprint = many spot beams = frequency re-use
  Example: Typical 500 MHz allocation in a satellite payload is effectively multiplied 4 -10 times through polarization and frequency reuse using spot beam geographical coverage.
- **Higher satellite EIRP for same power, antenna size**
- **Smaller ground terminal VSAT antenna diameters**
- **Reduced interference, fewer regulatory restrictions.**
- **New satellites, some with OBP**



Pros and Cons: narrow beams

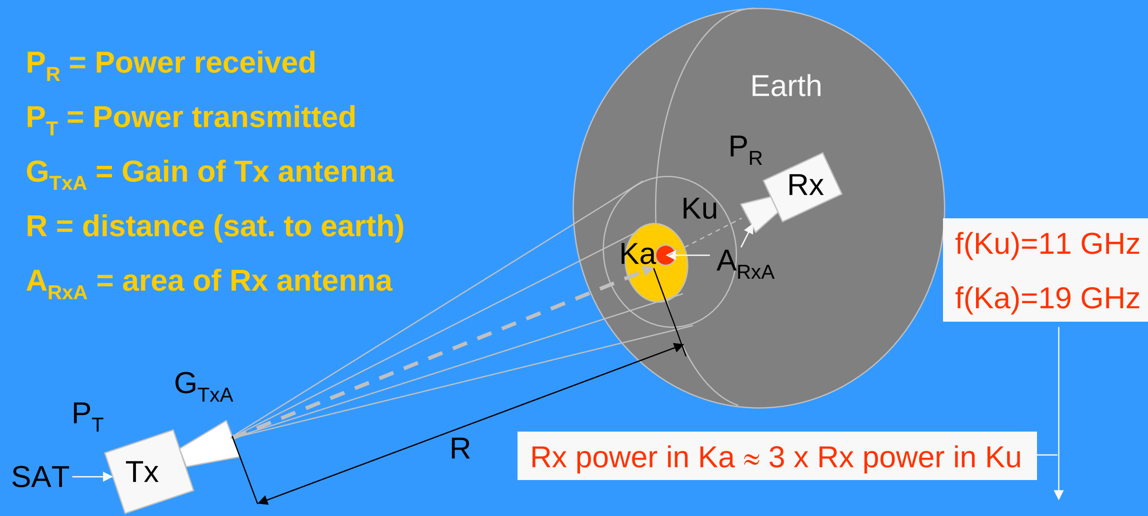
P_R = Power received

P_T = Power transmitted

G_{TxA} = Gain of Tx antenna

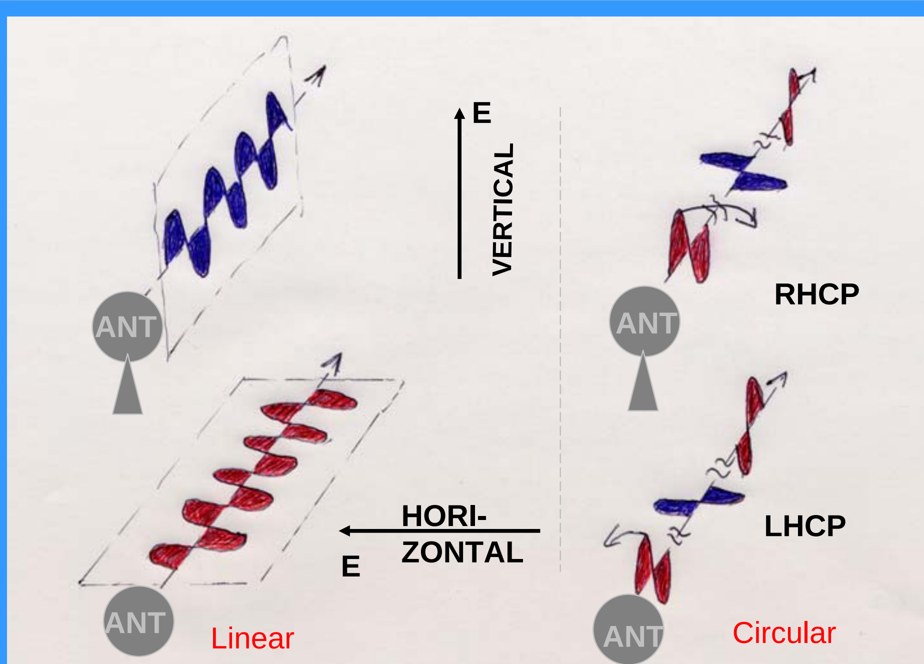
R = distance (sat. to earth)

A_{RxA} = area of Rx antenna

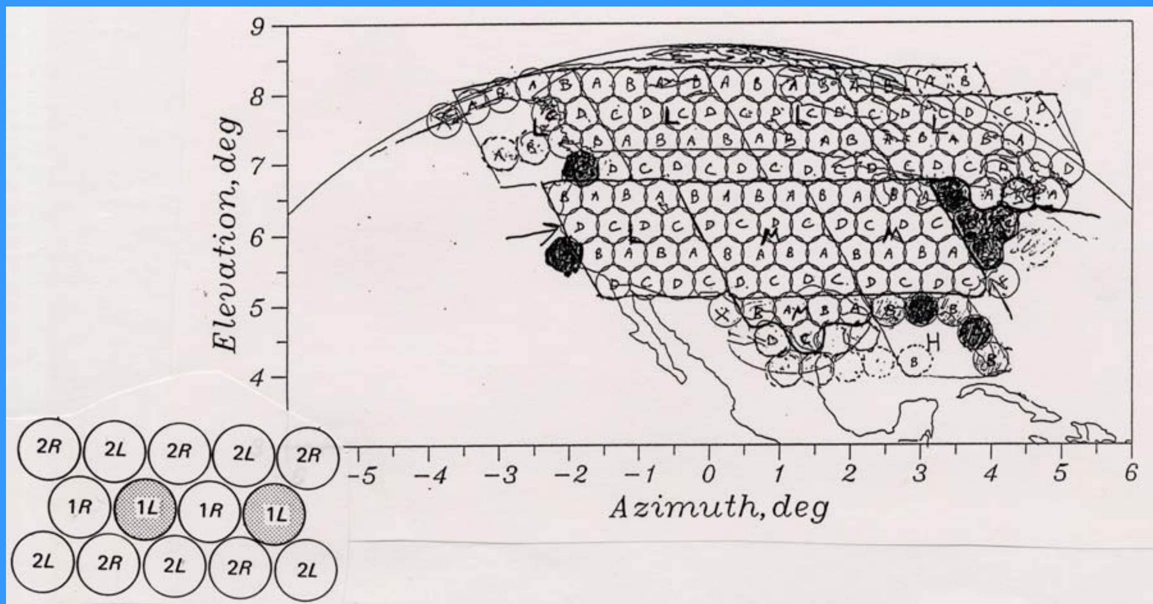


$$P_R = P_T G_{TxA} \frac{1}{4\pi R^2} A_{RxA} \quad \text{and } G_{TxA} = \eta \frac{\pi^2 D_A{}^2}{\lambda^2} = \eta \frac{\pi^2 D_A{}^2 f^2}{c^2}$$

Pros and Cons: Polarization



Pros and Cons: Spot beams (e.g.- US)



Example: 2 frequency bands and 2 polarizations

Pros and Cons: Effects of weather

Main propagation and antenna effects:

- **Path loss due to rain and cloud attenuation** **Depends on location:more loss in heavy rain regions vs. "misty" rain locations. Also, loss increases with frequency (Ka 5 dB > Ku!).**
- **De-polarization due to ice crystals in clouds hence cross-polarization interference.**
- **Antenna wetting, particularly wet feed.** **This must be taken into account in overall system design (larger antennas, Tx power).**

Pros and Cons: Rain fade countermeasures

The following mitigating techniques can be used:

- Site diversity for gateways
- On-board ALC for forward link
- Higher satellite EIRP for forward link
- Uplink Power Control in terminals & gateways
- Larger user antennas for critical applications
- Advanced modems with variable bit rate and code rate (slow down during fade!)
- Antennas less susceptible to wetting loss

This, combined with Ka-band advantages and less stringent availability requirements, enables the use of Ka-band for satellite communications.

Historical Overview: The beginnings

Demand for wide-band services started to be evident in the late 1970's

NASA, NASDA (Japan), ESA and ASI Space Agencies started to pioneer Ka-band

Wide total bandwidth but slow going initially due to:

- large rain attenuation
- Cost of providing high-availability commercial services

Then emphasis changed to Direct-to-User (DTU) services with less stringent availability requirements

➔ Era of broadband satellite communications capable of linking users around the world has opened

Historical Overview: First Ka Satellites

The following were the first satellites, used mostly for experimental purposes (propagation, earth station hardware, various types of traffic etc.)

- ETS-II: Japan, 1977
- Olympus: Europe (ESA), 1989
- Kopernikus: Germany, 1990

The above were "bent-pipe" types. The next two below had OBP (On-Board Processing):

- Italsat: Italy (ASI), 1991
- ACTS: USA (NASA), 1993

Historical Overview: "Newer" Ka Satellites

By 2001, several "commercial" satellites with a Ka-Band payload were (and are still now) in service:

Italsat F2 has been used in trials involving a university network as well as some telephony backhaul services within the European continent.

KoreaSat 3 has been used for a Distance – Education network.

Astra's 1H satellite has been used as part of the AstraNet Return Channel System (ARCS) later re-named BroadBand Initiative (BBI) for Multimedia applications.

Historical Overview: Local Projects (MPR Teltech, IMT ComSys, NORSAT)

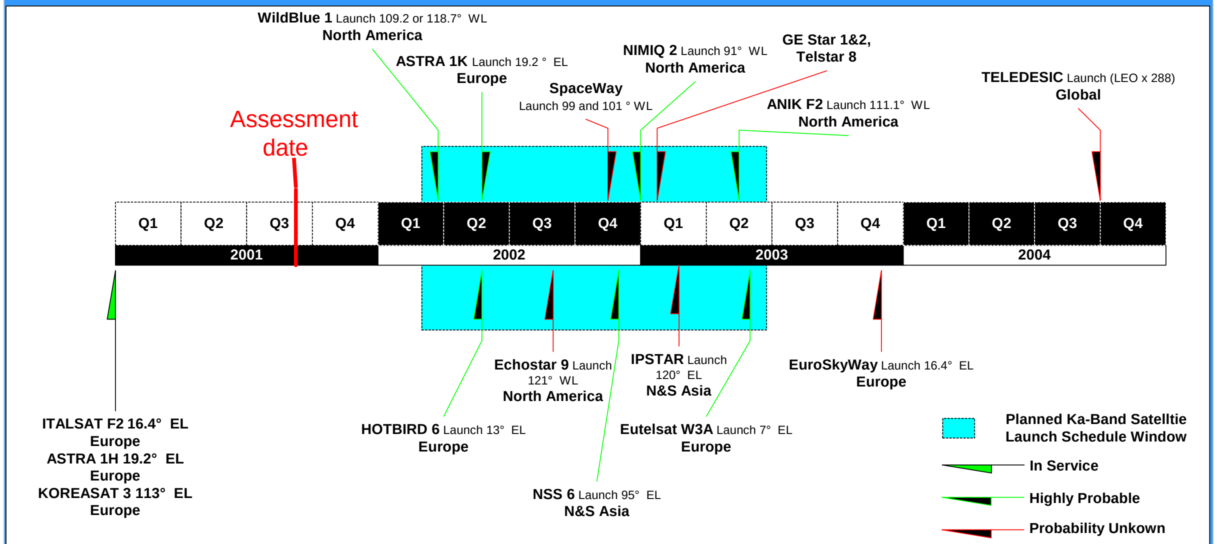
- Picoterminal (MPR, 1993 – 1996, with ESA): First Ka-band (30/20 GHz) briefcase terminal
- VSAT terminal (IMT, 1995-1998, with ESA): 30/20 GHz, up to 2Mb/s, 1.5m antenna
- SIT (Satellite Interactive Terminal) ODUs (NORSAT, 1998- 2002) for ASTRA's BBI for Multimedia: 30/12 GHz, 128-2000 kb/s,75-120 cm
- Trial ODU for the IMMIS system (1998- 2002) NORSAT partnered up with Alenia Spazio.
- ODUs for Korea Telecom Distance education network: 30/20 GHz, up to 2Mb/s,120 cm ant.

New Ka-Band Satellite Systems/Projects

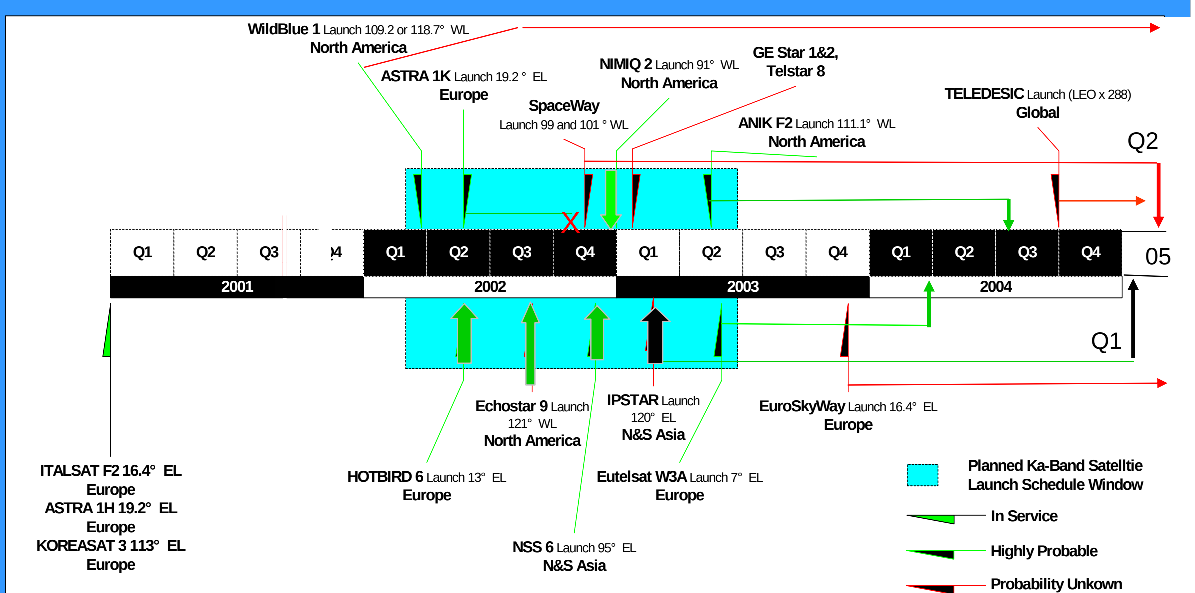
As of 2001, there were many industry announcements for new satellites that would include Ka-Band communications payloads and these were expected to be launched in the period of early 2002 to end of 2004.

- Of these, there were several satellites already under construction that could be considered probable to succeed.

Ka-Band Satellite Launches Plans: 2001



Ka-Band Satellite Launches: 2004



Conclusions

- Ka-band systems could provide up to 10 Gb/s throughput compared to 1Gb/s in Ku-band
- Speeds of 10 Mb/s up, 100 Mb/s down possible
- OBP in satellites will enable mesh connectivity
- Less interference & fewer regulatory problems
- Rain fades require more margin in link budgets
  - ≈ 5 dB more than in Ku-band for 99% availability
  - Mitigation techniques such as higher satellite EIRP, uplink power control and variable bit rate modems in terminals may have to be used
  - Pay attention to antenna wetting (keep feed dry)
- Smaller antennas ➡ smaller portables

Conclusions

In Ka-band, this is possible!

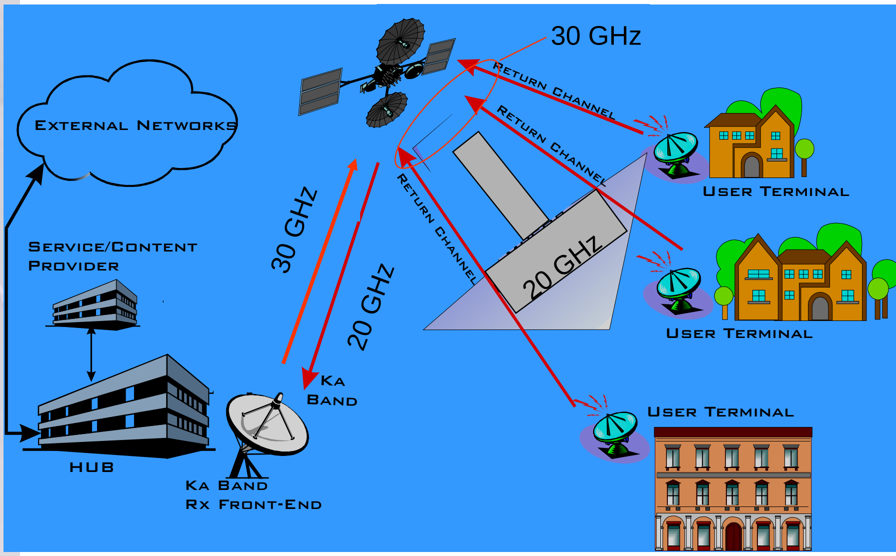
Part 2:

“Generic” Satcom Systems with fixed terminals

Outline

- General overview
  - Network Configuration
  - Earth station subsystems:ODU, IDU, IFL
  - Description of ODU components
    - Complete ODU
    - Antennas, feeds, OMT/diplexers
    - Transceivers
- Specific example
  - Korea Telecom Project (KoreaSat III)

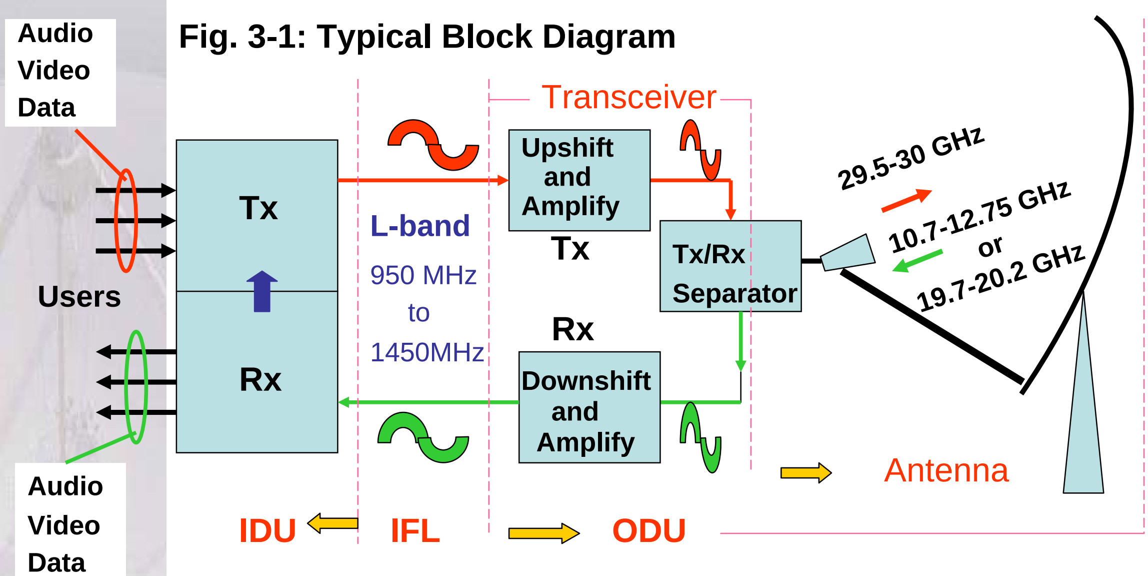
General: Satellite Network Configuration



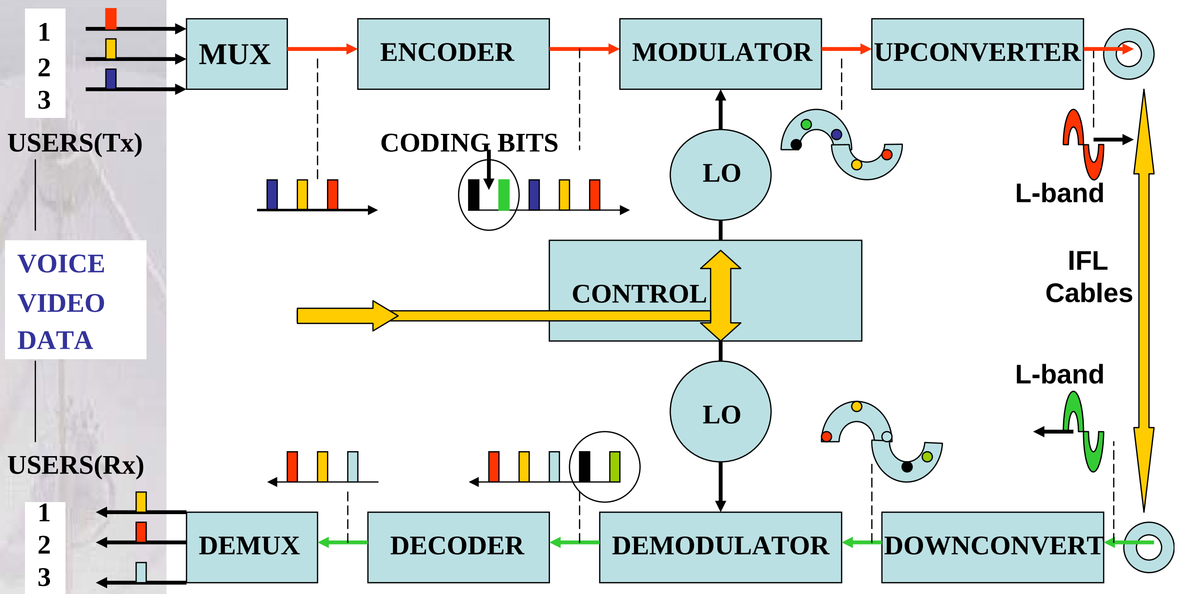
Star Network Example

General: Earth Station & its Subsystems

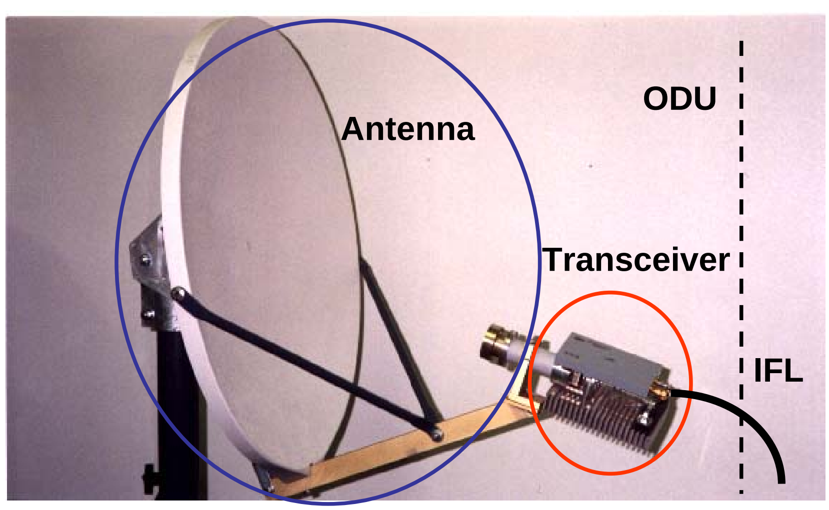
Fig. 3-1: Typical Block Diagram



General: ES Indoor Unit (IDU)



General: Typical ES OutDoor Unit (ODU)

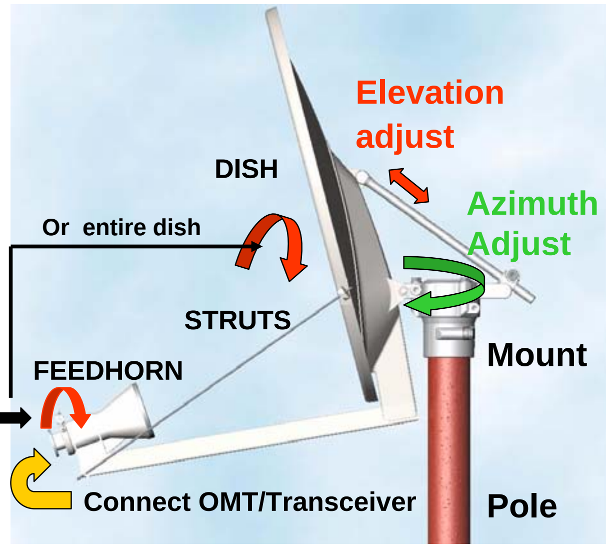


General: ODU Components

Antenna: (dish / feed)

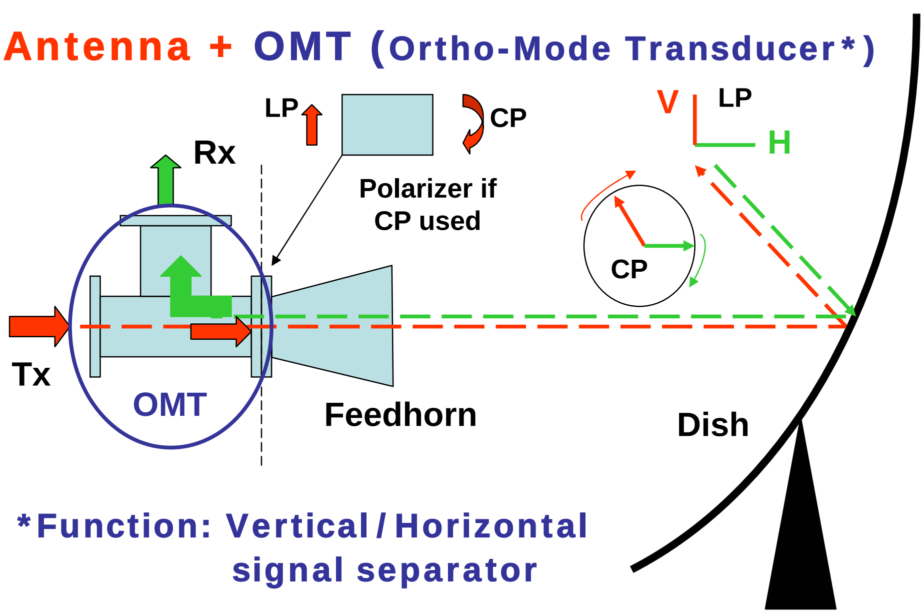
- In most cases single-offset parabolic antenna is used

Polarization adjust for Linear polarization.



General: ODU Components continued

Antenna + OMT (Ortho-Mode Transducer*)



***Function: Vertical / Horizontal signal separator**

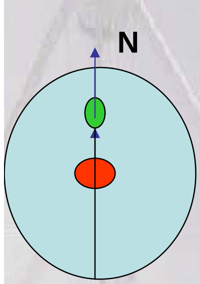
General: Polarization- VP as seen by the ES

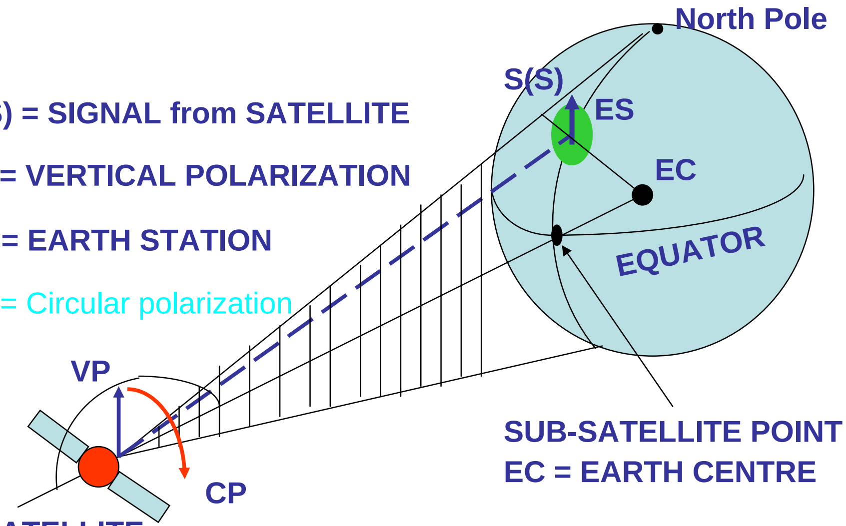
S(S) = SIGNAL from SATELLITE

VP = VERTICAL POLARIZATION

ES = EARTH STATION

CP = Circular polarization





ES on meridian passing through the sub-satellite point

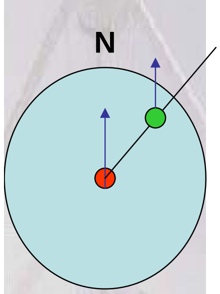
General: Polarization-VP as seen by the ES

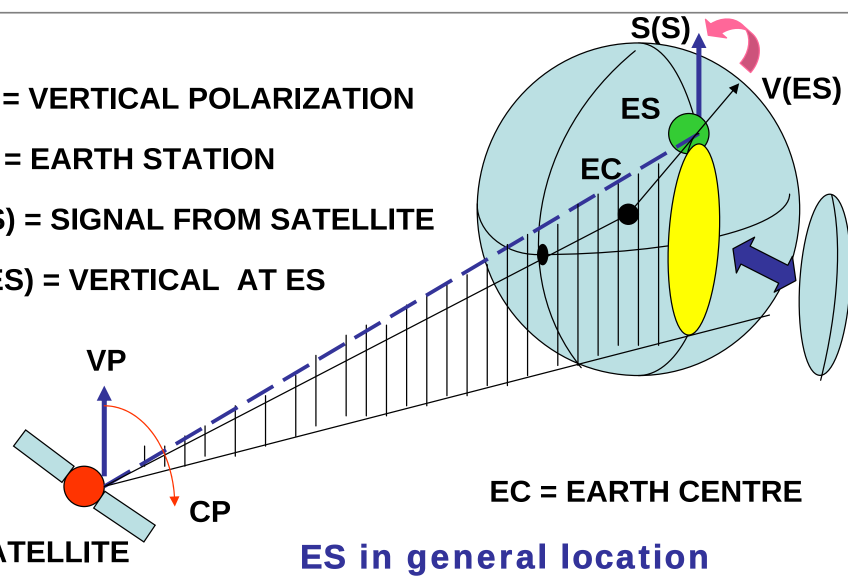
VP = VERTICAL POLARIZATION

ES = EARTH STATION

S(S) = SIGNAL FROM SATELLITE

V(ES) = VERTICAL AT ES



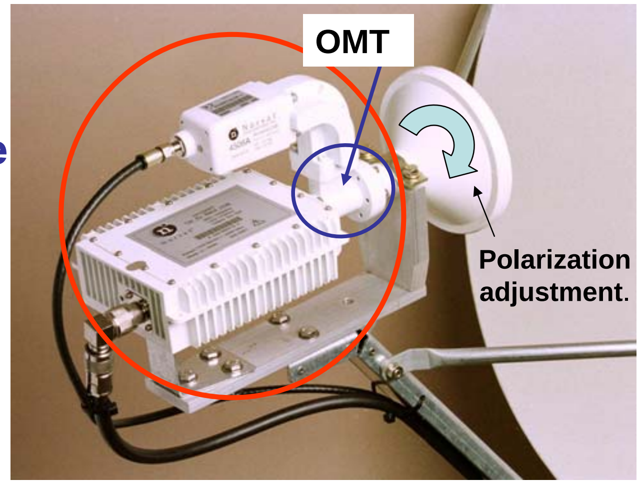


ES in general location

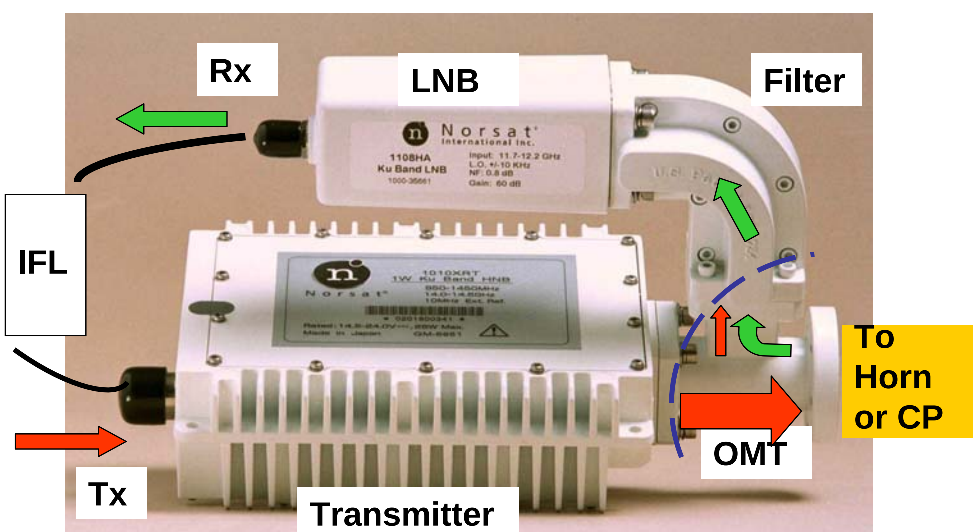
General: ODU Components continued

Transceiver (mounted on OMT/Feed)

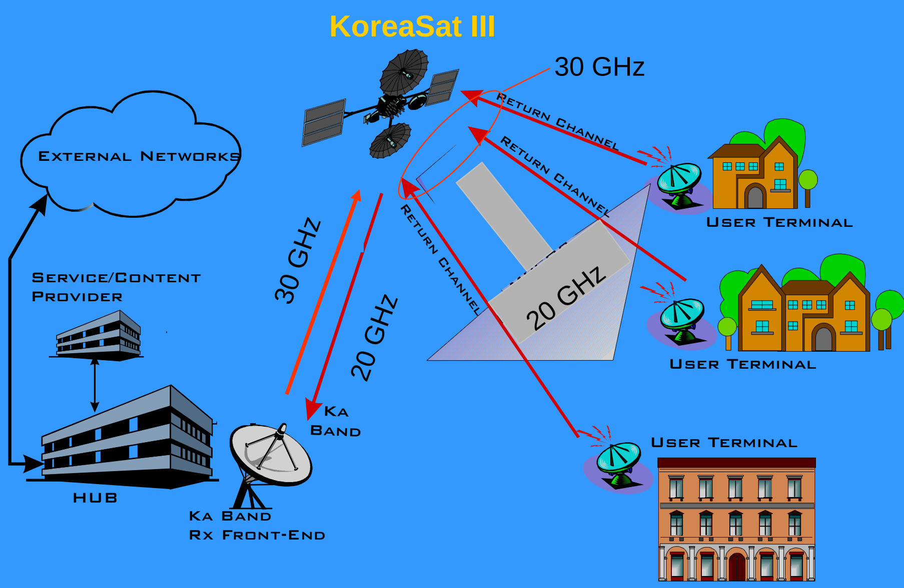
OMT = Ortho-Mode Transducer



ODU Components/Transceiver detail



Part 2 continued: Korea Telecom Project

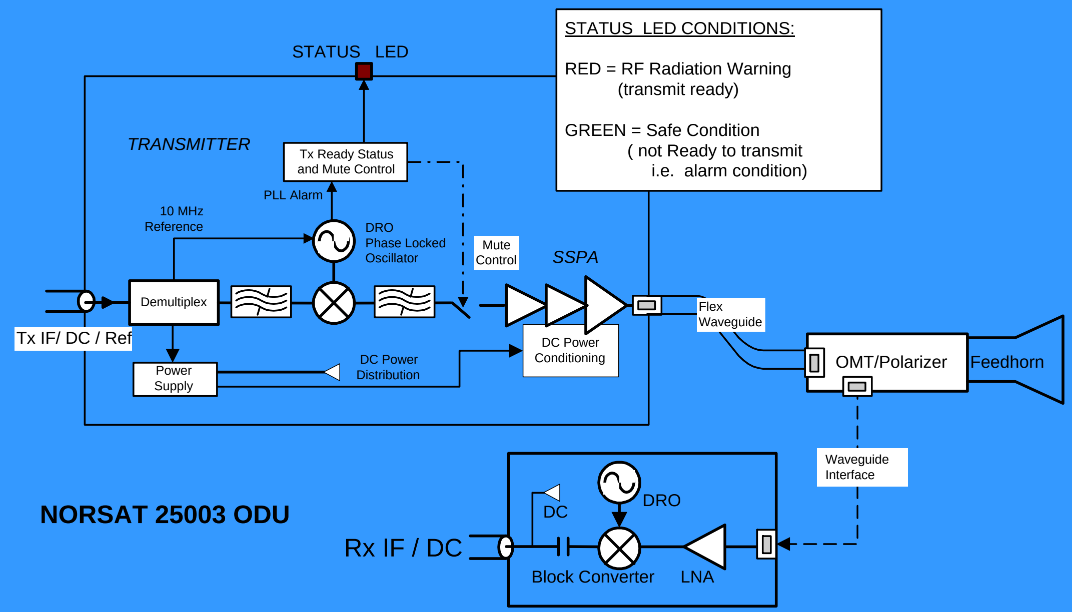


KT Distance Education Network

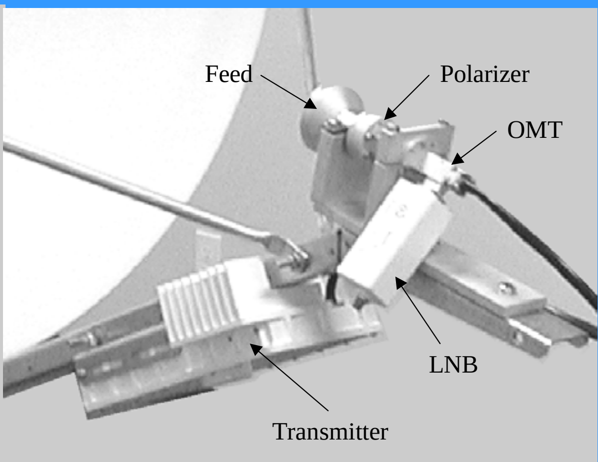
KT Ka project: ODU requirements

- **30.135 - 30.585 GHz Tx1, 30.385 – 30.835 GHz Tx2**
- **20.405 - 21.105 GHz Rx**
- **Support up to 2 Mb/s Tx data rates**
- **Single-offset antennas 92/122/180 cm**
- **Circular polarization (Tx = RHCP, Rx = LHCP)**
- **2W of Tx power at 1 dB CP**
- Standard **L-band Tx and extended L-band Rx IF**
- **Two-cable IFL with Tx IF, 10 MHz, and DC on Tx cable, and Rx IF and DC on Rx cable**

KT ODU: Block Diagram



KT ODU: Implementation & Technology

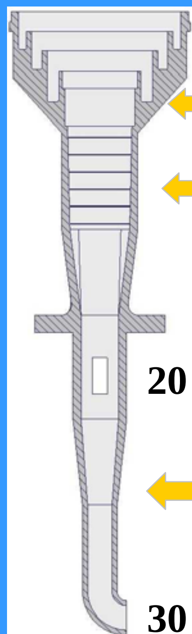


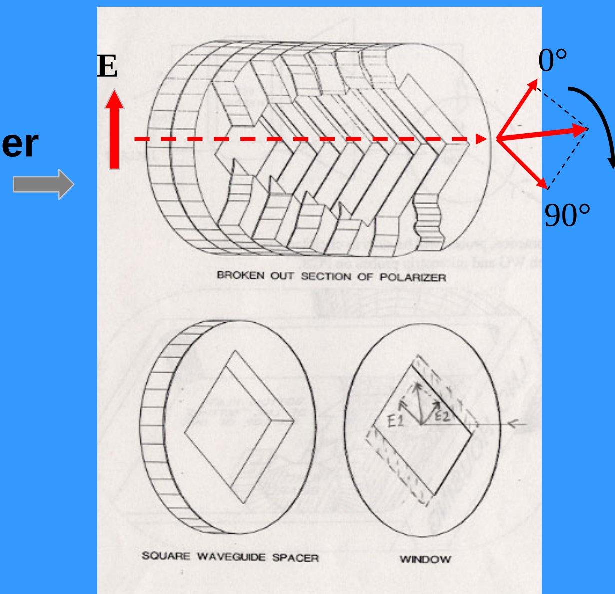
ODU (1.2m, F/D = 0.6)

Feed/Polarizer/OMT + LNB & Tx

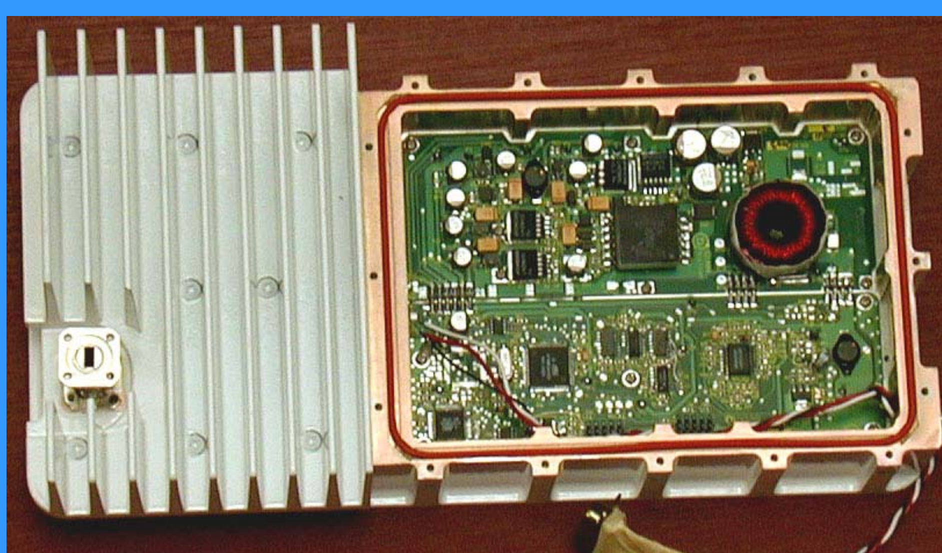
Implementation & Technology continued

30/20 GHz OMT & Dual-band polarizer:



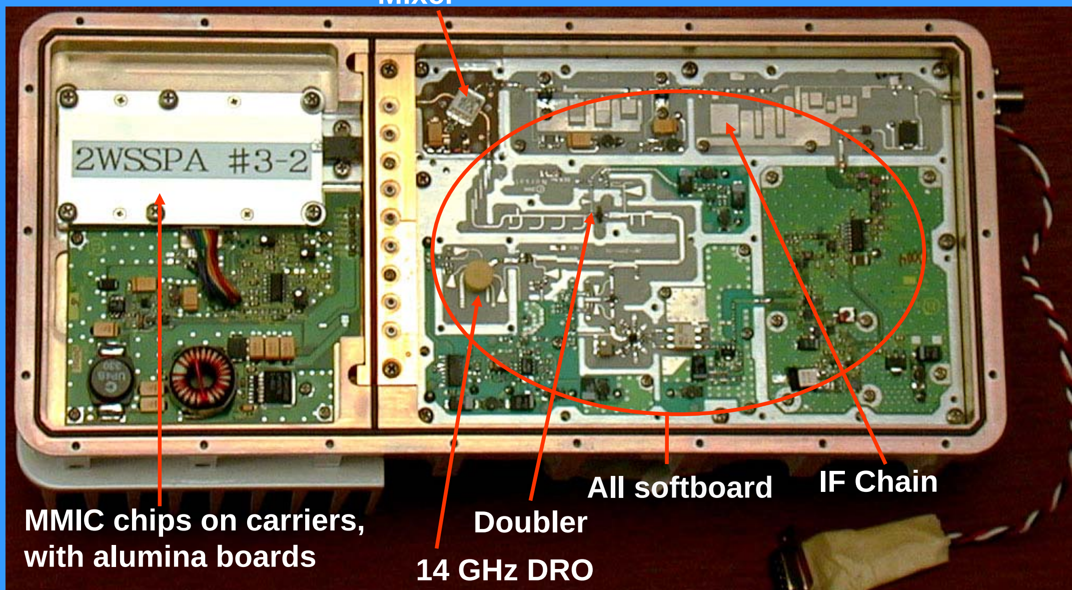


Implementation & Technology continued



Transmitter - DC side

Implementation & Technology continued



Transmitter - RF Side

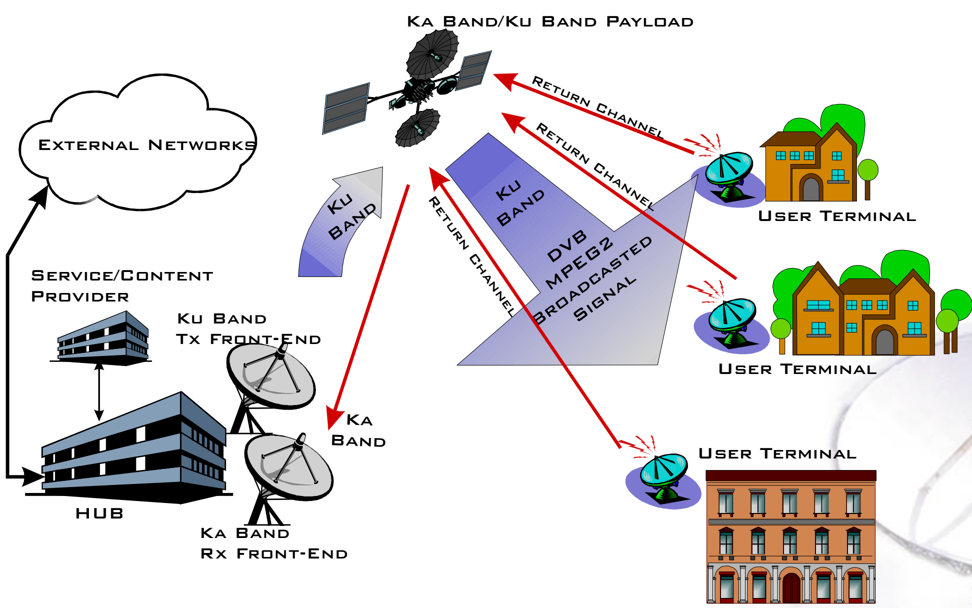
Korea Telecom Project Summary

- ODUs for 20/30 GHz Satellite User Terminals
- System using KoreaSat III
- Application: Distance Education Network
- ODUs delivered by NORSAT
- IDUs delivered by other contractor to KT
- About 10 units delivered in two phases
- Units working OK but some rain fade issues

Part 3: Front End for ASTRA SITs for multimedia applications (1999-2002)

IEEE ComSoc Presentation 10 Jan 2005

Astra RCS (BBI) Network Configuration

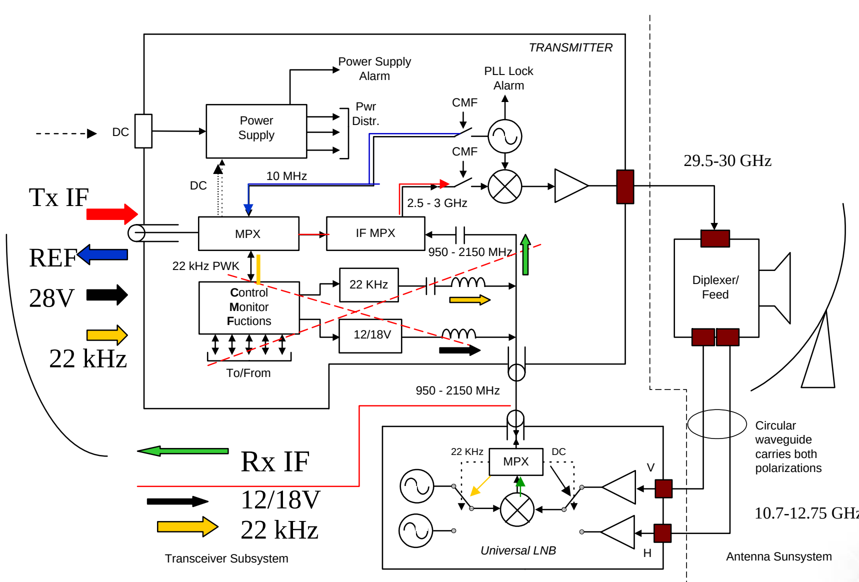


IEEE ComSoc Presentation 10 Jan 2005

Main Requirements

- 29.5 -30 GHx Tx, 10.7 – 12.75 GHz Rx
- 3 terminal sizes (antennas): 76/92/122 cm
- **S**upport 128kb/s, /512 kb/s and 2 Mb/s Tx data rates, 40 Mb/s Rx rates
- Linear polarization (Tx = V or H by installation), In Rx use universal LNB, remotely selectable V/H
- 0.5W/1W**/**2W of Tx power at 1 dB CP, 1 dB Rx NF
- S-band Tx IF (2.5 – 3 GHz) & L-band Rx IF (0.95-2.15 GHz) for optional multiplexing on one IFL cable
- Two-cable IFL with Tx IF, Ref and DC on Tx cable, and Rx IF, 12V/18V DC and 22 kHz on Rx cable
- Optionally single cable IFL

ODU Block Diagram

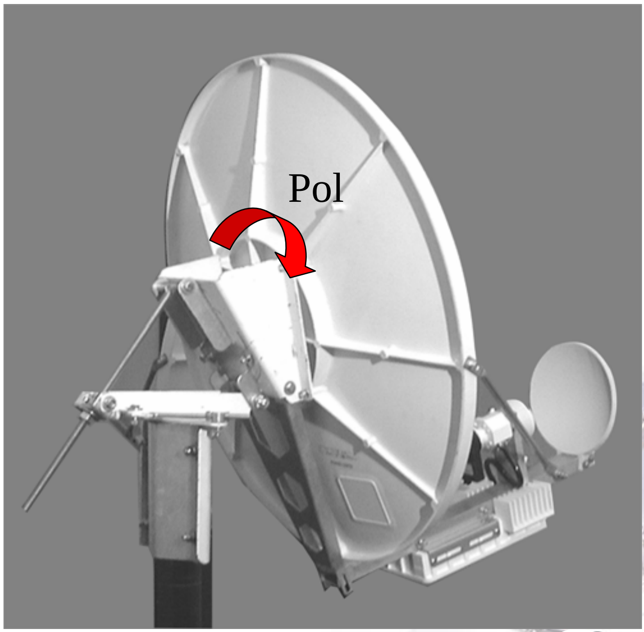


Implementation & Technology

Physical realisation:

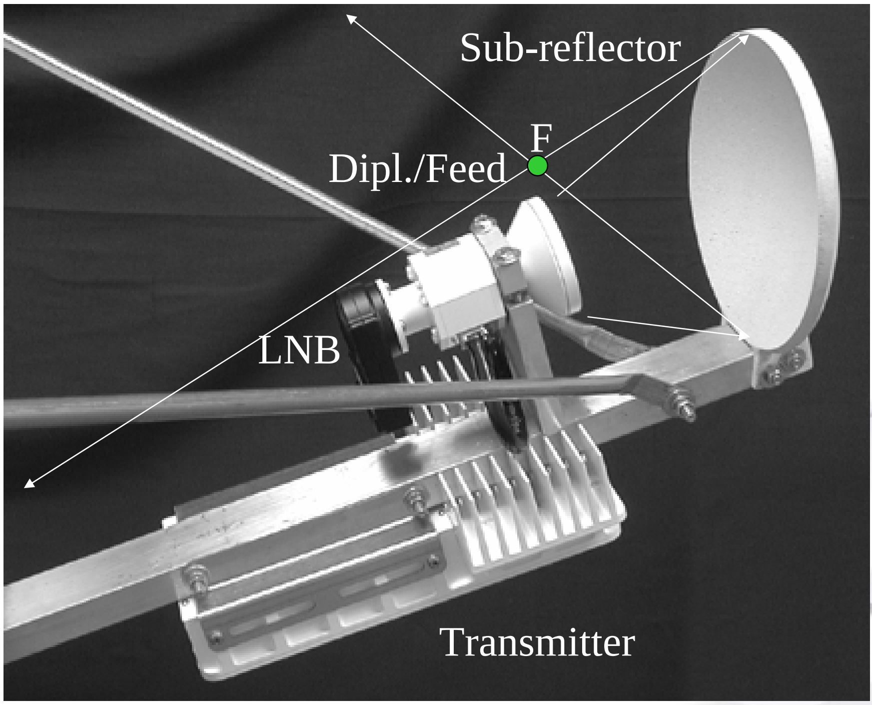
Dual - offset Gregorian Antenna

Transceiver mounted close to feed

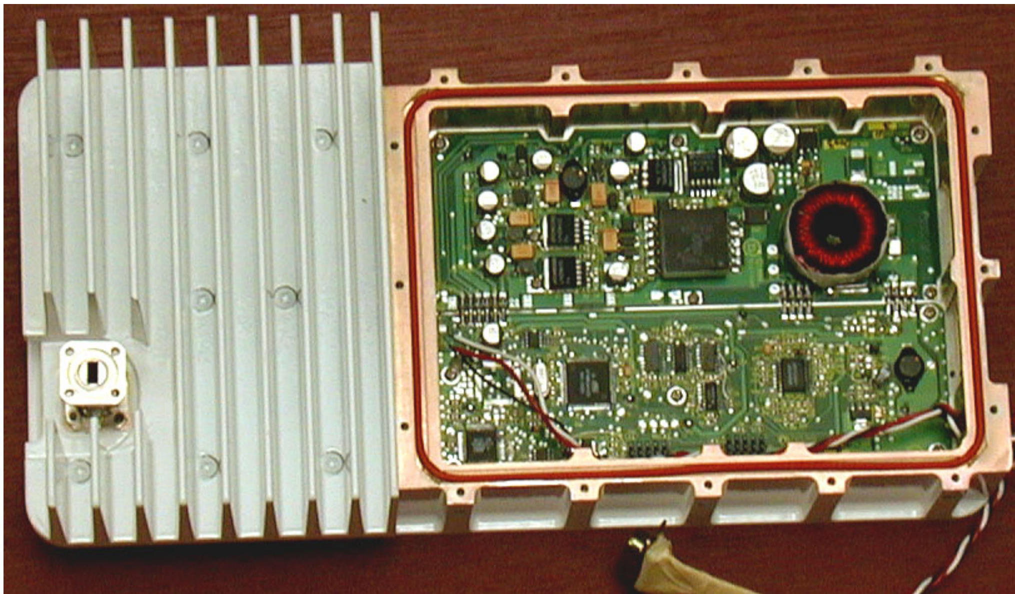


ODU Assembly with a 76 cm, 0.6 F/D reflector

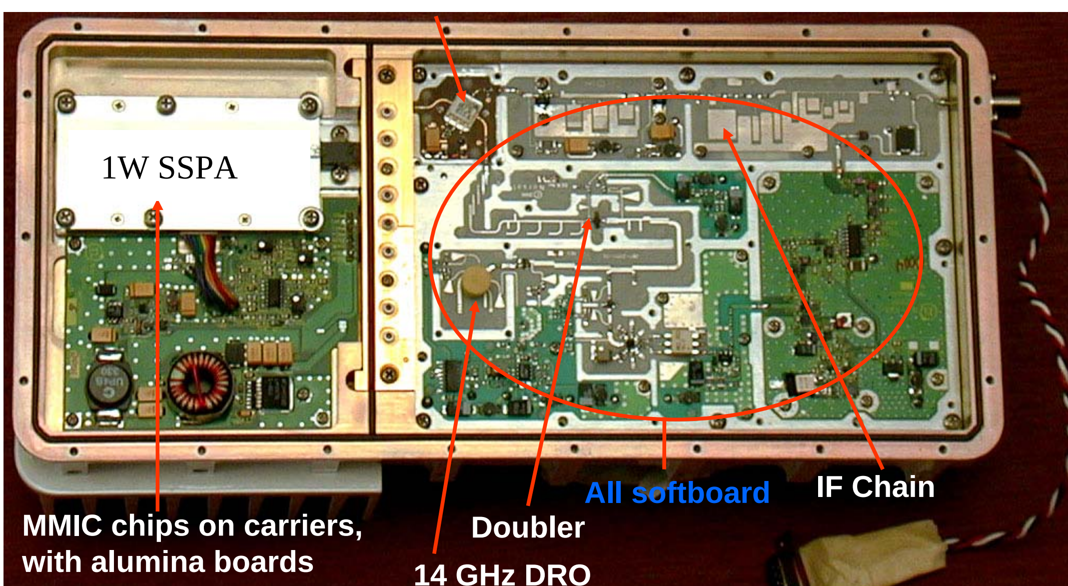
I&T: Detail of Feed/Dipl., Flanged LNB & Transmitter



I&T: Transmitter Layout: DC

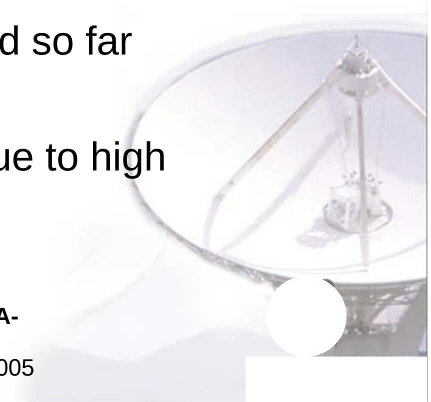


I&T: Transmitter Layout: RF/Ka



Summary

- 12/30 GHz ODU for SITs
- Designed to support 128 kb/s to 2 Mb/s Tx data rates, 40 Mb/s Rx rates (e.g. digital TV)
- Relatively small terminals (76/92/122 cm antennas)
- Single-cable IFL option for easier installation
- Specifications met, **1000 units delivered to ASTRA**
- About half of these have been installed so far for trial purposes
- Larger volumes still far in the future due to high cost of Ka-Band hardware.



-Research work supported by ESA and CSA-

Part 4: Ka -band Portable Terminal (PT) for Voice/Data Communications over Satellite

IEEE ComSoc Presentation 10 Jan 2005

Introduction & Requirements

Picoterminal (Ka-band Portable Terminal):

Developed for ESA (1993-1998) in cooperation with Joanneum Research in Graz, Austria

- Two-way briefcase terminal for voice and low-speed (4.8 kb/s) data, spread into 128 kcps
- Operation over Italsat & Kopernikus satellites
  (29.5-30 GHz up and 19.7-20.2 GHz down)
- Had to comply with IATA regulations for on-board luggage (50 x 35 x 25 cm)
- Weight 18 kg max
- capable of short time operation (1 hour) on enclosed batteries

Overall Description: choices

Physical configuration chosen:

- 34 x 35 cm offset fed parabola with detachable boom, folding into case

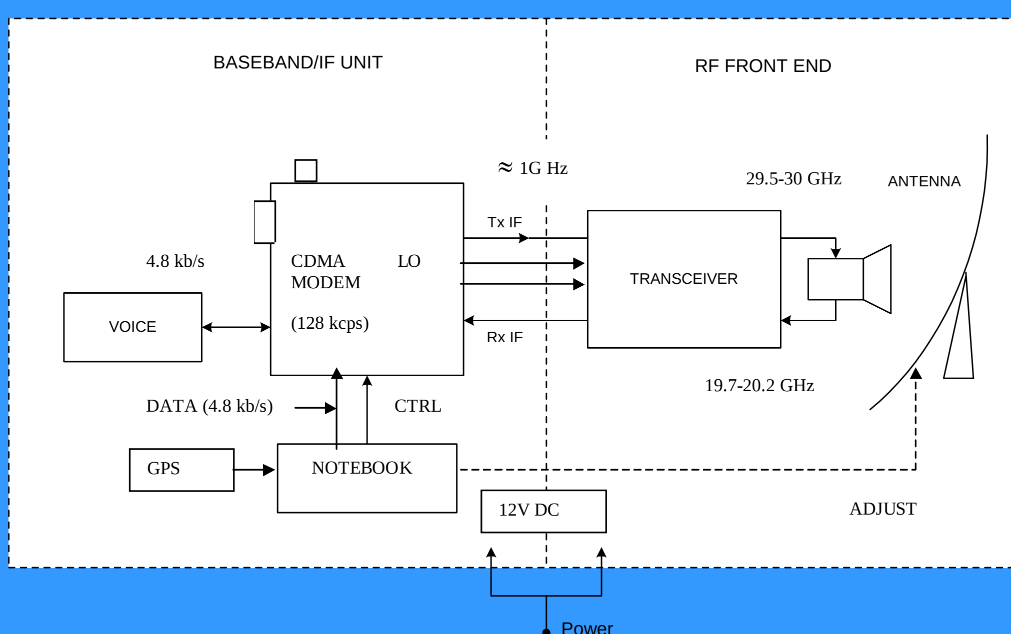
The above results in:

- Antenna Tx/Rx gain = 38.6/35.2 dB

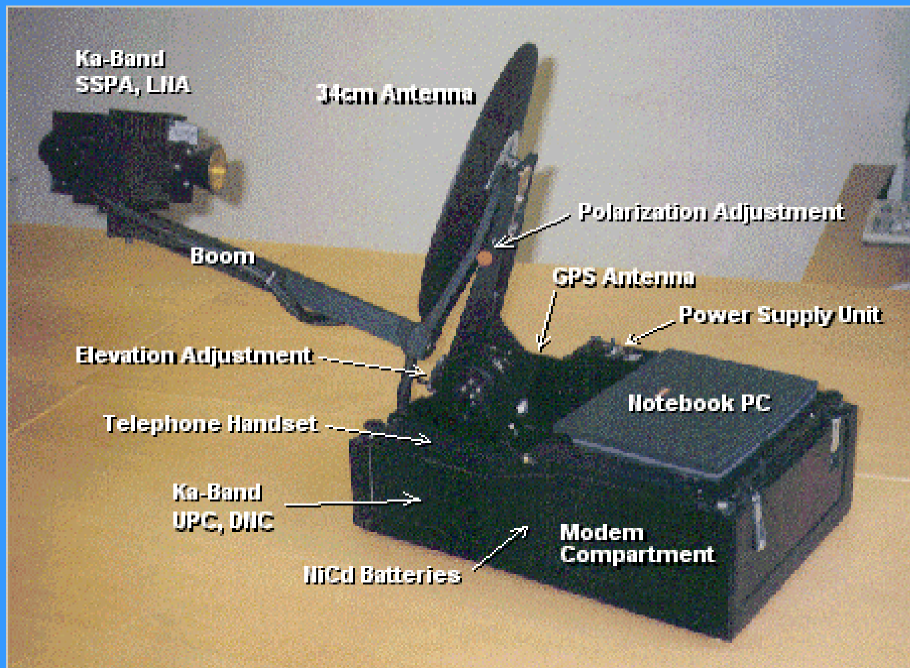
To close the link budget (EIRP = 35 dBW, G/T = 10 dB/K) with the above antenna required:

- Tx power = 27 dBm (0.5 W)
- LNA noise figure < 2.9 dB

Overall Description: Block Diagram



Implementation and Technology

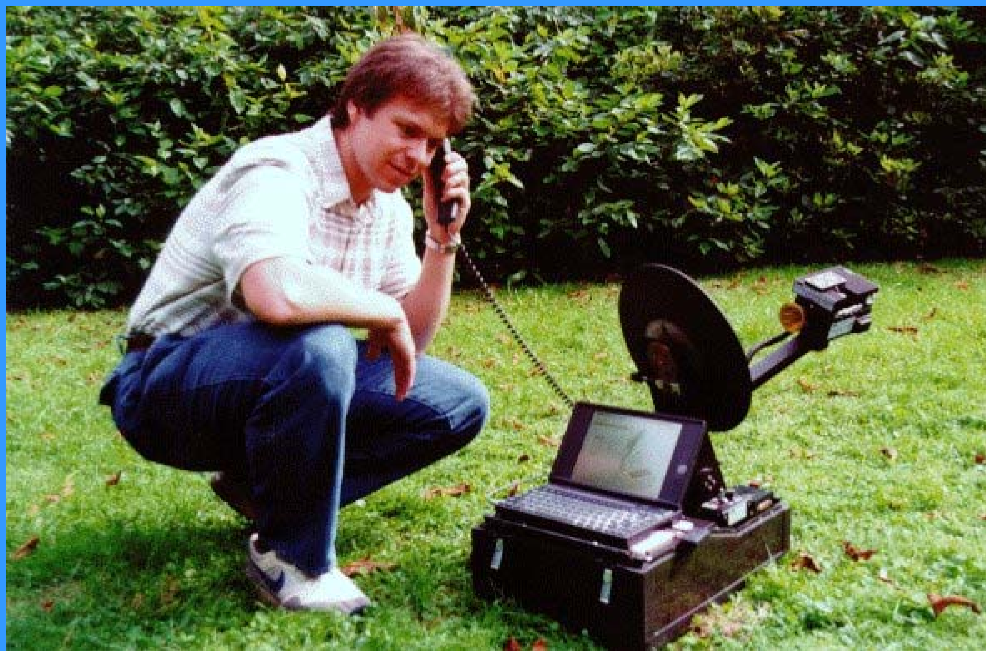


I and T continued

Antenna alignment:

- GPS Receiver used to determine location
- Location data transferred to laptop
- Laptop calculates antenna azimuth, elevation and polarization angles for a given satellite
- Antenna coarse-aligned, then fine-tuned by detecting beacon level, displayed on PC as bar of variable length

In operation



Summary

Ka-band portable terminal for voice and data (4.8 kb/s) using CDMA has been designed, prototyped and successfully tested over the Kopernikus and Italsat satellites in Europe

- Terminals in use by ESA for trials
- Traffic tests confirmed performance expectations

The technical success of this effort gave rise to new PT terminal developments for video transmission at NORSAT(currently at Ku-band)

Part 5: Ka-band Challenges & Trends

IEEE ComSoc Presentation 10 Jan 2005

Limitations and Problems

Challenges for Ka-band

- Smaller but more expensive Front End components
- Higher losses in general
- Propagation and wet antenna effects.

Areas of greatest concern

- Link budget on the uplink from subscriber terminal
  This relates to two areas specifically:
  1) Tx Power ⇨ cost of transmitter
  2) Effect of Rain on FE parameters
- Low cost, high performance antenna/feed

Tx Power: MMIC Technology

$$$$ Cost $$$$

- Ten years ago:
  - $800 US for one
- Five years ago:
  - $400 US for one
- Today
  - $80 US @ for Qty:1000
- Future target
  - $20???
    ($ 2/mm^2)

Power (1 dB CP)

- Ten years ago:
  - 0.5 W
- Five years ago:
  - 1 W
- Today
  - 2 W
- Future
  - 4 W, 5 W
    (4W on 10 mm^2)

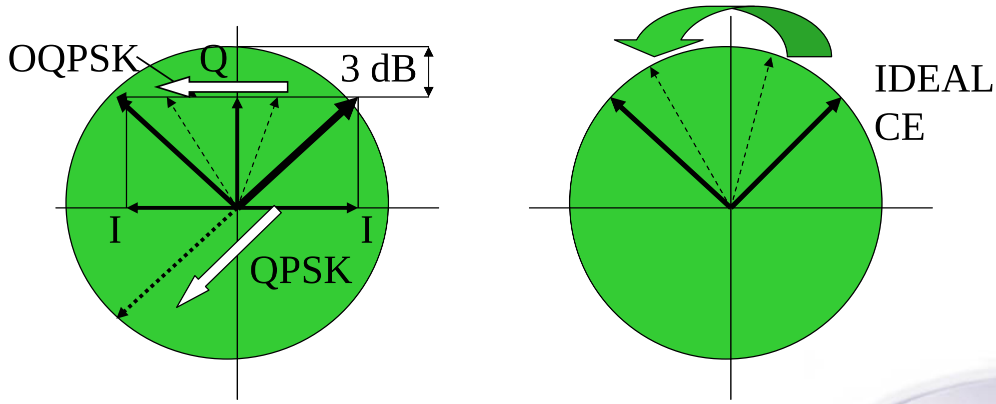
➢ Power efficiency 10-20% typical today
(requires efficient heat removal)

Ka-band Tx Power Issues

➢ Most current systems use QPSK modulation:
Linear power amplification required to prevent signal Distortion. About 2W linear needed in small FEs.
- Power is at a premium (backoff from saturation)
- Power combining techniques have been explored.
- Active antenna arrays have been considered
  - Amplitude and phase tracking over time and temperature

➢ System Solution:
Constant Envelope (CE) modulation makes nonlinear amplification possible without signal distortion
- more power available
- However, more bandwidth is required

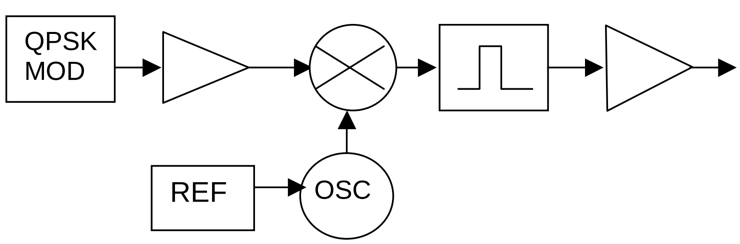
Modulation: *QPSK, OQPSK and MSK*



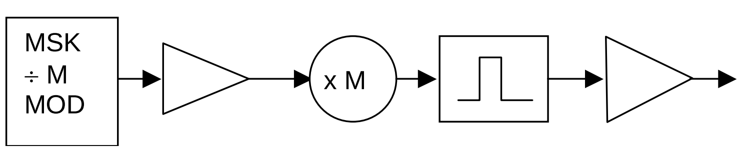
- In QPSK, the RF vector can go through zero
- In “regular” OQPSK, there is still a 3 dB AM
- If the OQPSK I and Q vectors are sinusoidal rather than rectangular pulses, the combined RF vector has constant amplitude $\Rightarrow$ **MSK**

Linear vs. nonlinear Tx

Conventional Linear Tx Chain

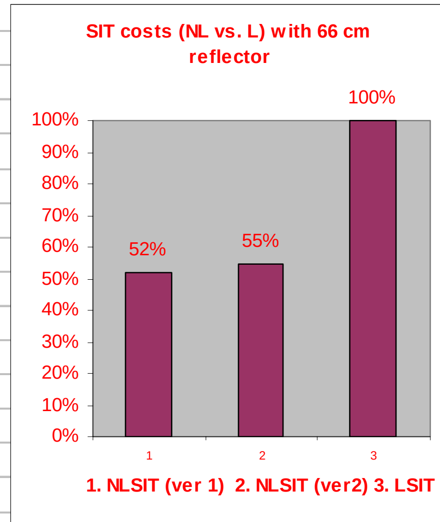


Multiplier-type saturated Tx chain



Cost: *LSIT vs. NLSIT Cost Comparison*

SIT cost comparison (qty = 100k, 66 cm single offset antenna)			
	1	**2**	**3**
Item	NLSIT	NLSIT	LSIT
	(ver.1)	(ver.2)	
transmitter	**17%**	**20%**	**65%**
IDU	18%	18%	18%
LNB	1%	1%	1%
diplexer/feed	1%	1%	1%
antenna	6%	6%	6%
off-axis LNB	1%	1%	1%
IFL: Three cables	2%	2%	2%
shroud	1%	1%	1%
ODU assy & test	3%	3%	3%
Packaging	1%	1%	1%
Total SIT cost:	**52%**	**55%**	**100%**

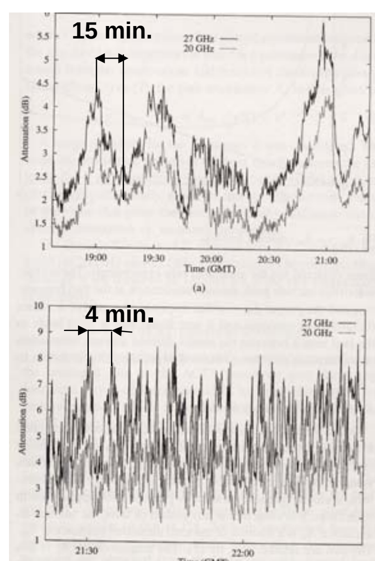


Rain fade/antenna wetting

1) Increased Path Loss, up to 5 dB over Ku-band

2) Antenna wetting *

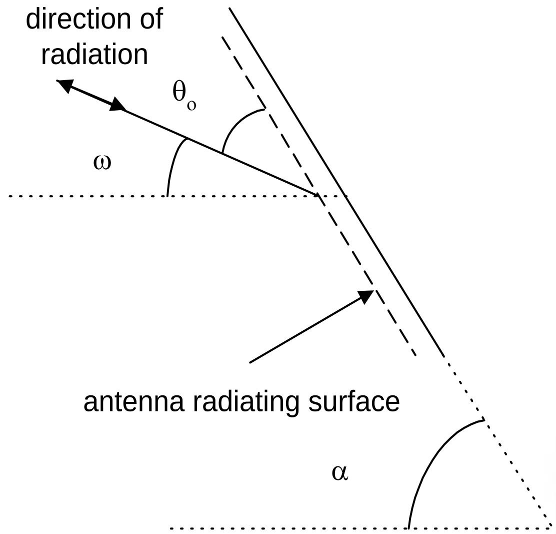
- **Time-varying loss {wet rough reflector surface (2 dB) but mostly, wet feed radome (6 dB)}**
- **up to 8 dB peak loss**
- **Average loss approx. 3 - 4 dB**
- **In heavy rain, fast variation (2 minutes from max to min loss)**
- **Slower in "mist" like precipitation, approx. 15 min from max to min.**
- **This is due to "build-up and slide"**



*UBC (Prof. Kharadly) contributed , among others

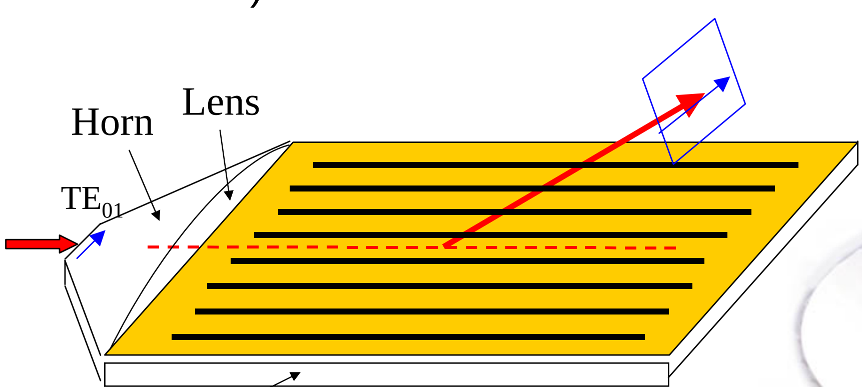
Concept for "rainproof" Antenna

- An antenna whose radiating surfaces face downward while its main beam points upwards



Experimental Version*

- Longitudinal-slot array (H-polarization)
- Horn-lens feed (for simplicity and broad bandwidth)

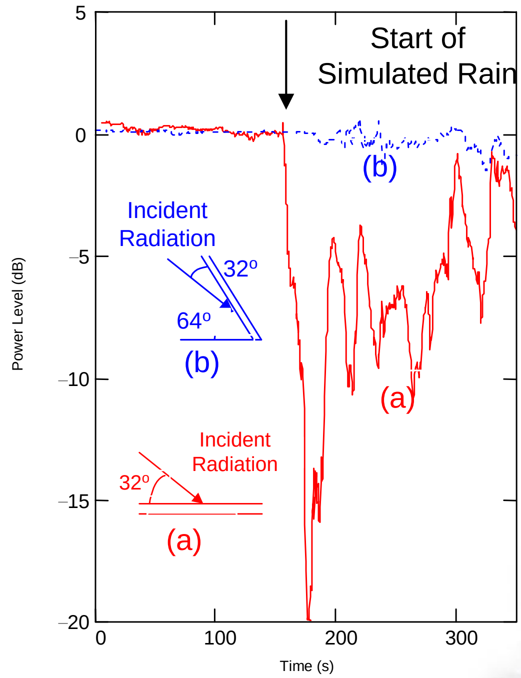


* A. Chan, PhD thesis (with Prof. Kharadly at UBC)

Sample of observations in experiments

$\theta_o = 32^o$

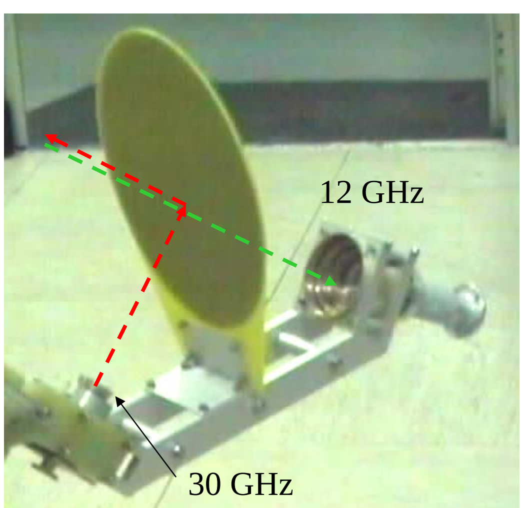
f = 39.5 GHz

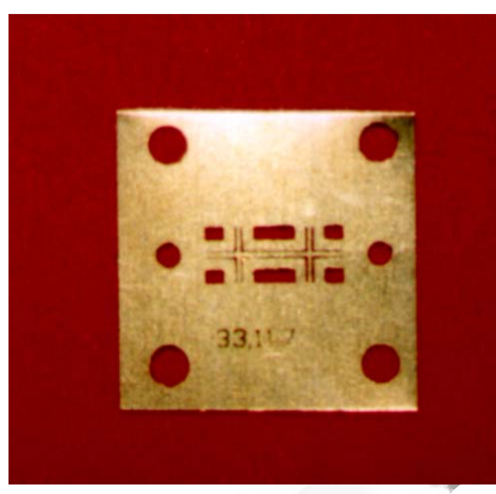


Special Components

FSS (Frequency Selective Surface) Applications

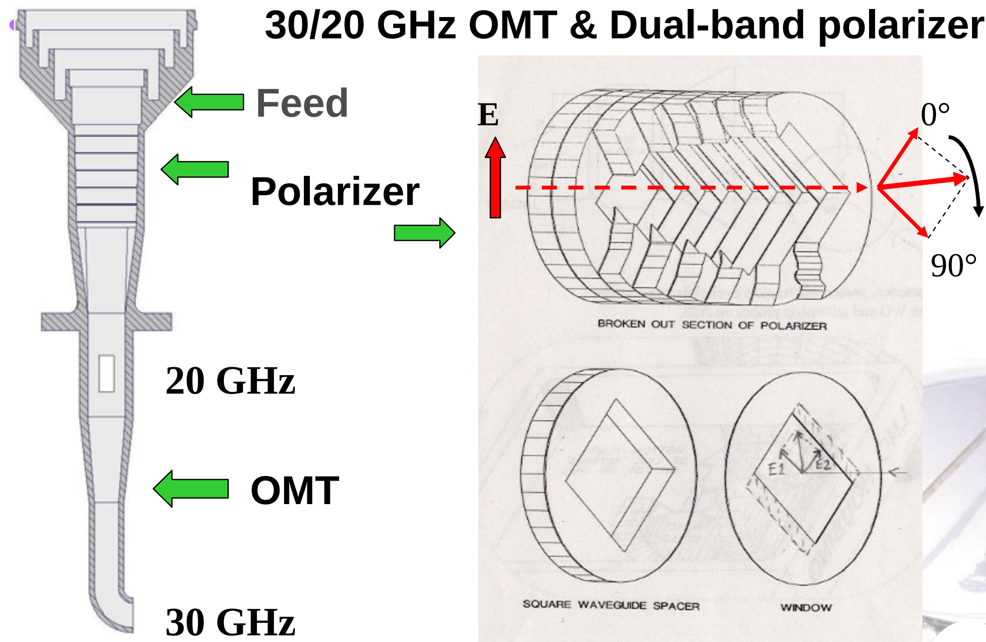
- Dichroic antenna feeds
- Flat waveguide filters





Special Components

30/20 GHz OMT & Dual-band polarizer:



Future work

- Higher, inexpensive power: 2 W, 4 W, 8W
- More efficient power combining techniques
- Possibility of CE modulation systems with nonlinear Tx chains in Front Ends
- Variable bit rate modems for rain fades
- Indoor Unit possibly integrated into ODU
- Improved feed/diplexers & polarizers for Parabolic antennas, waveguide filters
- Array antennas (very challenging):
  - Good gain and sidelobes
  - tracking capability
  - Robust to precipitation
  - Electronically configurable to various polarizations combinations