Evolution of Front Ends for Satellite Communications in Ka-band

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Evolution of Front Ends: Outline

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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?

Outline

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3. Historical Overview
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   - 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: \(Rx = 3.7 - 4.2 \text{ GHz}\)
  \(Tx = 5.925 - 6.425 \text{ GHz}\)

- Ku: \(Rx = 10.75 - 12.75 \text{ GHz with sub-bands}\)
  \(Tx = 14.0 - 14.5 \text{ GHz (extended to 13.75 GHz)}\)

- Ka: \(Rx = 19.2 - 20.2 \text{ GHz Eu & US}\)
  \(20.405 - 21.105 \text{ GHz Asia (Korea)}\)
  \(Tx = 29 - 30 \text{ GHz Eu & US}\)
  \(30.135 - 30.835 \text{ GHz Asia (Korea)}\)

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

Rx power in Ka ≈ 3 x Rx power in Ku

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

Pros and Cons: Polarization

- RHCP
- LHCP
- Linear
- Circular

SAT \rightarrow Tx \rightarrow R \rightarrow Rx
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.
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

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.

Antenna + OMT (Ortho-Mode Transducer*)

*Function: Vertical/Horizontal signal separator
General: Polarization—VP as seen by the ES

S(S) = SIGNAL from SATCHELLITE
VP = VERTICAL POLARIZATION
ES = EARTH STATION
CP = Circular polarization

ES on meridian passing through the sub-satellite point
General: ODU Components continued

Transceiver (mounted on OMT/Feed)

OMT = Ortho-Mode Transducer

ODU Components/Transceiver detail

OMT = Ortho-Mode Transducer

Polarization adjustment.

Rx

LNB

Filter

IFL

Tx

Transmitter

To Horn or CP
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

STATUS LED CONDITIONS:
RED = RF Radiation Warning (transmit ready)
GREEN = Safe Condition (not Ready to transmit i.e. alarm condition)

TRANSMITTER

Demultiplex

Tx IF/DC/Ref

Power Supply

10 MHz Reference

DRO Phase Locked Oscillator

STATUS LED

Mute Control

Tx Ready Status

SSPA

DC Power Conditioning

OMT/Polarizer Feedhorn

Rx IF/DC

Block Converter

LNA

DC Power Distribution

NORSAT 25003 ODU

PT OK

IEEE ComSoc Presentation 10 Jan 2005

KT ODU: Implementation & Technology

ODU (1.2m, F/D = 0.6) Feed/Polarizer/OMT + LNB & Tx

IEEE ComSoc Presentation 10 Jan 2005
Implementation & Technology continued

30/20 GHz OMT & Dual-band polarizer:

Feed

Polarizer

OMT

20 GHz

30 GHz

Transmitter - DC side
Implementation & Technology continued

Transmitter - RF Side

*MMIC chips on carriers, with alumina boards
*Doubler
*14 GHz DRO
*Mixer

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
Main Requirements

- 29.5 -30 GHz Tx, 10.7 – 12.75 GHz Rx
- 3 terminal sizes (antennas): 76/92/122 cm
- Support 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

- Power Supply
- Alarm
- MPX
- 22 KHz
- 12/18V
- CMF
- CMF
- PLL Lock
- Alarm
- 10 MHz
- 2.5 - 3 GHz
- 950 - 2150 MHz
- Tx/Rx
- DC
- 22 kHz PWK
- Power Supply
- 950 - 2150 MHz
- Circular waveguide carries both polarizations
- Antenna Subsystem
- 29.5-30 GHz
- 10.7-12.75 GHz
- REF
- 28V
- 22 kHz
- 12/18V
- 22 kHz
- Transceiver Subsystem
- Universal LNB
- Circular waveguide carries both polarizations
- Antenna Subsystem
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**

- All softboard
- MMIC chips on carriers, with alumina boards
- 1W SSPA
- 14 GHz DRO
- Doubler
- IF Chain

**I&T: Transmitter Layout: RF/Ka**

- All softboard
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

**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 onboard 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
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 a 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

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/mm²)

*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 mm²)

- 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 ⇒ MSK

Linear vs. nonlinear Tx

Conventional Linear Tx Chain

Multiplier-type saturated Tx chain

MSK ÷ M MOD → x M →
**LSIT vs. NLSIT Cost Comparison**

SIT cost comparison (qty = 100k, 66 cm single offset antenna)

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>transmitter</td>
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<td>IDU</td>
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<td>1%</td>
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<tr>
<td>diplexer/feed</td>
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<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>antenna</td>
<td>6%</td>
<td>6%</td>
<td>6%</td>
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<tr>
<td>off-axis LNB</td>
<td>1%</td>
<td>1%</td>
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<tr>
<td>IFL: Three cables</td>
<td>2%</td>
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<tr>
<td>shroud</td>
<td>1%</td>
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<tr>
<td>ODU assy &amp; test</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Packaging</td>
<td>1%</td>
<td>1%</td>
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<tr>
<td><strong>Total SIT cost:</strong></td>
<td>52%</td>
<td>55%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**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

![Diagram of antenna radiating surface and direction of radiation]

**Experimental Version**

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

![Diagram of horn-lens feed and TE₀₁ mode propagation]

* A. Chan, PhD thesis (with Prof. Kharadly at UBC)
Sample of observations in experiments

$\theta_o = 32^\circ$

f = 39.5 GHz

- Incident Radiation
- Start of Simulated Rain

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