Satellite Communications
Space Segment

Prof. Otto Koudelka

Institute of Communication Networks and Satellite Communications,
TU Graz
koudelka@tugraz.at

CONTENTS

ADVANTAGES OF SATCOMS

- Wide coverage
- Broadcast capability
- High bandwidth
- Flexibility in network set-up
- Mobility
- Rapid deployment
- Reliability
- Economic solutions available
- Availability in areas without adequate terrestrial telecom infrastructure

Source: ESA

SATELLITE ORBITS

Distance:
- Low-earth orbit (LEO): 500…1700 km
- Medium-earth orbit (MEO): 10.000…20.000 km
- Geostationary orbit (GEO): 35.786 km

Inclination:
- Equatorial: $i = 0°$
- Polar: $i = 90°$
- Inclined: $0 < i < 90°$

Eccentricity:
- Circular
- Elliptical

KEPLER's LAWS

1) Orbit of each planet (satellite) is an ellipse with the sun (earth) at one focus

2) Line joining the sun (earth) to a planet (satellite) sweeps out equal areas in equal times (1609)

3) Square of the period of revolution is proportional to the cube of the semimajor axis (1619)

GEO ORBIT

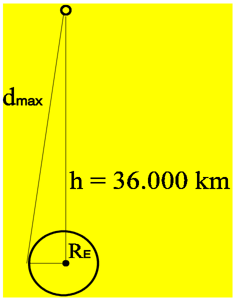
- Period of satellite same as period of earth (~ 24 h)
- No relative movement between satellite and ground station
- No tracking required (with small antennas)
- But:
  - significant propagation delay due to distance (~ 0.25 s)
  - significant free-space loss: 207 dB at 14 GHz

DELAY TIME

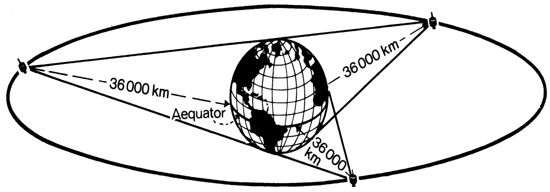
- Distance satellite - ground station essential

$$\tau = \frac{d}{c} = \frac{36.000\text{km}}{300.000\text{km/s}} = 120\text{ms}$$

- Geostationary orbit: 120 ... 140 ms for ground station to satellite, 240…280 ms for one hop



COVERAGE BY GEO SATELLITE



3 satellites cover globe with exception of polar regions

GEO SATELLITES

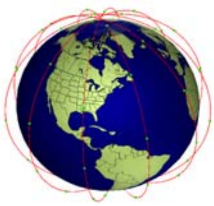
- Most TV distribution satellites
- Also used for data communications services (e.g. VSAT networks)
- Internet access by satellite

LEO ORBIT

- Distance typically 500-1700 km
- Avoid atmospheric drag
- Stay below Van Allen belt to avoid heavy radiation

IRIDUM constellation:
Satellite phone system

66 satellites!



LEO ADVANTAGES

- low propagation delay: 5.3 ms (800 km): advantageous for interactive services
- low distance
- low free-space loss
- less power needed for ground and satellite transmitters
- smaller antennas, omnidirectional antennas for hand-held terminals
- global coverage with many satellites, including polar regions

LEO DISADVANTAGES

- many satellites needed for full coverage
- more launch capacity needed (however, multi-satellite launches are state-of-the art)
- complex hand-over procedures
- can lead to processing delays due to buffering
- larger antennas need tracking (complexity, costs)

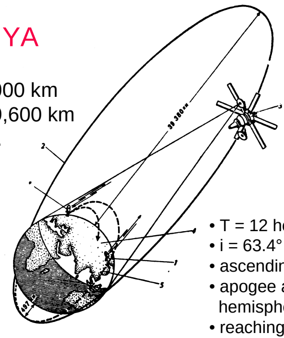
HIGHLY ELLIPTICAL ORBIT (HEO)

According to Kepler's law:
- satellite is slowest at apogee
- satellite is fastest at perigee

ratio of velocity at apogee to velocity at perigee is equal to ratio of orbit radius at perigee to orbit radius at apogee

MOLNIYA

perigee = 1000 km
apogee = 39,600 km
T = 718 min.



- T = 12 hours
- i = 63.4°
- ascending node stays stable
- apogee always in Northern hemisphere (~10 hours)
- reaching high latitudes

MEO ORBITS

- Used for navigation satellites:
  - GPS
  - GLONASS
  - GALILEO
- orbit 10,000 ... 20,000 km
- lower number of satellites (GPS: 24, GALILEO: 30)
- longer distance
- higher free-space loss
- longer propagation delay

Source: ESA

SPACECRAFT

"Bus" provides
- mechanical structure
- stabilization
- power supply
- thermal subsystem
- attitude control
- propulsion system
- tracking, telemetry & control (TT&C)

Payload: satellite transponder (in case of satcom system)

SPIN-STABILIZED SATELLITE

- earliest version
- whole body is momentum wheel
- for stability the momentum around desired axis must be greater than around any other axis
- despun antenna platform for higher gain antennas
- easy thermal balance
- only ~ 1/3 of solar panel area useable

Source: BOEING

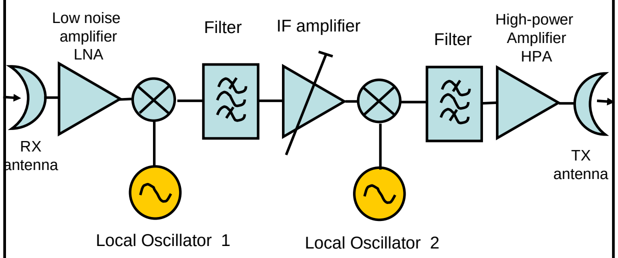
THREE-AXIS STABILIZED SATELLITE

- Momentum wheels in each axis: roll, pitch, yaw for stabilization
- No despun platform needed for antennas
- large solar panels possible (power generation)
- optimum orientation towards the sun
- high efficiency
- more complex design
- more complicated thermal control

Source: ESA

TRANSPARENT (BENT-PIPE) TRANSPONDER

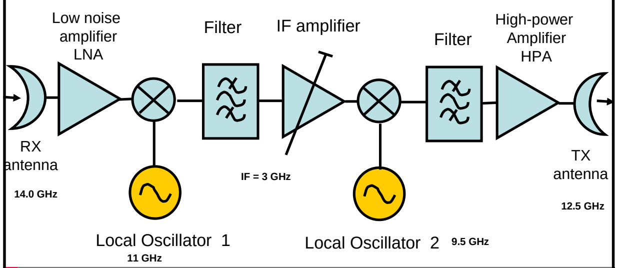
- Communications payload



Institute of Communication Networks and Satellite Communications

TRANSPARENT (BENT-PIPE) TRANSPONDER

- Communications payload



Institute of Communication Networks and Satellite Communications

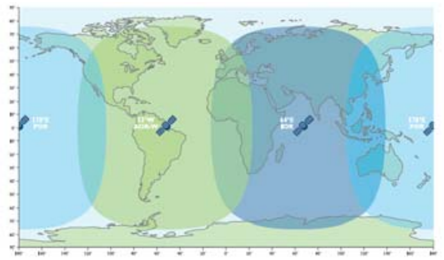
TRANSPARENT TRANSPONDER

- Receives and amplifies signal
- Converts frequency (uplink higher than downlink)
- Carries out high-power amplification

- Relatively simple
- Independent of uplink signal format (modulation, coding, multiple access scheme)
- Flexible, e.g. transition from analog modulation (FM) to digital modulation (DVB-S) straight forward
- Disadvantage: noise & interference also retransmitted

Institute of Communication Networks and Satellite Communications

COVERAGE

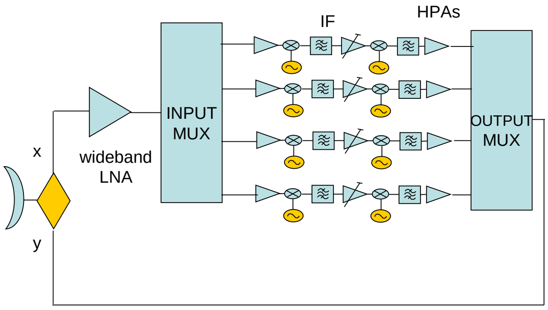


Source: INMARSAT

Simple antenna with coverage of ~ 1/3 of earth surface
Relatively small power flux density
Example: INMARSAT

Institute of Communication Networks and Satellite Communications

MULTI-TRANSPONDER SYSTEM

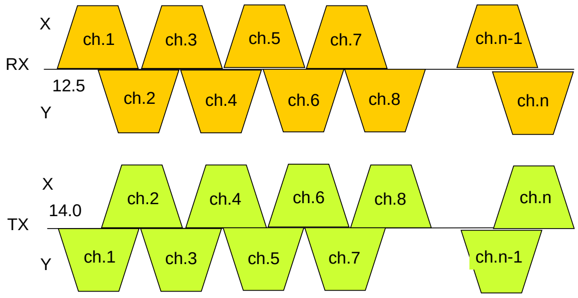


Institute of Communication Networks and Satellite Communications

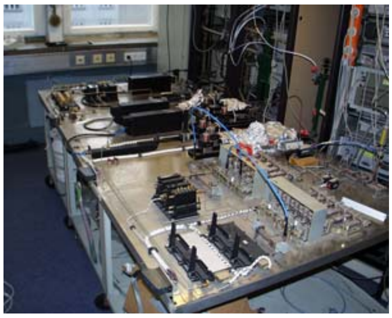
DUAL POLARISATION

- Linear, circular
- Orthogonal prolarisations do not interfer with each other
- Frequency re-use
- Duplication of available spectrum

FREQUENCY PLAN



TRANSPONDER



ON-BOARD PROCESSING (OBP) PAYLOADS

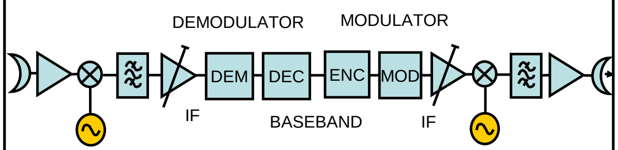
Intelligent, regenerative transponders advantageous:

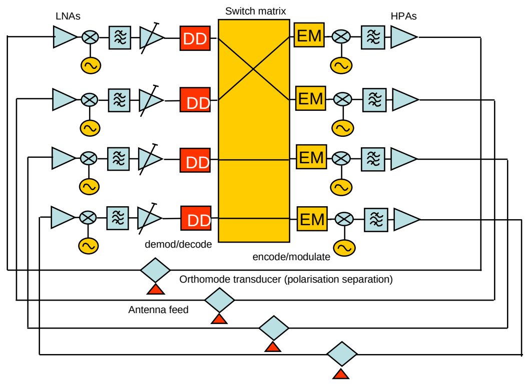
- signal regeneration
- separation of up- and downlink
- change of transmission format on board
  - FDMA uplink
  - TDM downlink
  - Different data rates in up- and downlink
- on-board switching and in future on-board routing: lower complexity and cost of ground stations

More complexity on board

- high reliability required
- potential single-point of failure in the sky

REGENERATIVE TRANSPONDER

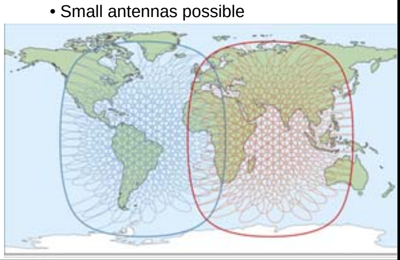




SPOT BEAMS

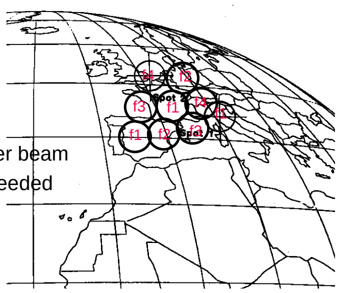
Source: INMARSAT

- The larger the antenna diameter, the smaller the footprint
- High power flux desitity in beam
- Small antennas possible

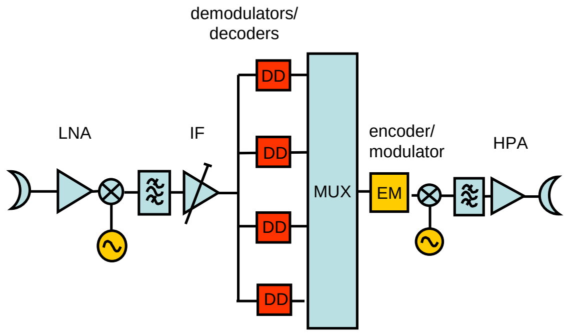


MULTIBEAM COVERAGE

- Frequencies can be re-used, if beams are widely enough separated
- Increase of capacity
- Reduced coverage per beam
- Switching on board needed



EXAMPLE: SKYPLEX TRANSPONDER



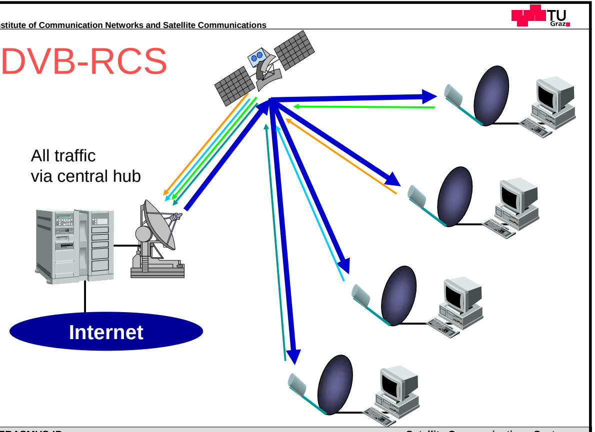
SKYPLEX

- Uplink: several DVB-S compatible narrow-band carriers
- Downlink: one DVB-S compatible multiplex of several channels (TDM)
- Advantage: small ground stations with low EIRP (lower data rate) can be used

AMHERIS PAYLOAD

- Input of transponder: carriers of small DVB-RCS terminals
- Signals are demodulated, decoded (baseband)
- Connections are set up on-board (in contrast to hub station on ground)
- Advantage: single hop (only 250 ms delay) instead of 500 ms (hub-based system)

DVB-RCS



CONTROL SEGMENT

- Large ground stations used to monitor and control the spacecraft (telemetry, tracking & control TT&C)
- Receive telemetry (monitor health status of spacecraft)
- Send commands (e.g. configure payloads)
- Determine position by triangulation

GROUND SEGMENT

- Earth stations:
  - Very Small Aperure Terminal Systems (VSATs) for data communications
  - Uplink stations for TV
  - Satellite News Gathering
  - TV Receive-only Terminals
  - Internet access terminals



TRENDS IN SATCOMS

- Larger spacecraft (> 10 ton class, e.g. ALPHASAT)
- Increasing number of transponders
- Regenerative, OBP payloads (e.g. SKYPLEX, AMHERIS)
- Advanced modulation and coding (better spectrum utilsation)
- Adaptive modulation and coding (e.g. DVB-S2)
- Fade mitigation techniques
- Reconfigurable, multibeam antennas, digital beam forming
- Adaptive bandwidth allocation
- Higher frequency bands (20/30 GHz, 40/50 GHz and above)
- Smaller, low-cost user terminals