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1. Introduction
1.1 What do satellites do? (Types of satellites, The satellite market)
1.2 Different orbits for different missions.
1.3 Advantages and disadvantages of satellite communications.
1.4 Frequency Allocations for satellite services Satellite frequencies (L, S, C, X, ku, ka, examples)

2. Orbit control and Launching Methods
2.1 Launch Vehicles and services (How are satellites placed into orbit)
2.2 Keppler law, coverage area, Doppler effect
2.3 Tracking, telemetry and Command
2.4 Attitude control subsystem
2.5 Launching orbits (polar, inclined, equatorial, LEO, MEO, GEO)
2.6 Power, Thermal Control

3. Microwave Link Budget
3.1 Link budget (system noise, uplink, downlink, effects of Rain)
3.2 Cross link
3.3 Interference
Course Contents

4. Space Segment (BUS Configuration and subsystems)
   4.1 Transponder model, Payload, Bus, TT&C
   4.2 Satellite Transponder
   4.3 Station keeping and TT&C subsystem
   4.4 Space segment processing (frequency translation)

5. Earth station Segment
   5.1 Earth station configuration
   5.2 Tracking Telemetry & Command (TT&C) ground facility
   5.3 FECC, Direct broadcasting satellites
   5.4 Home TV systems, LNB

6. Satellite Antennas
   6.1 Corrugated Horn antenna, Double reflector antennas.
   6.2 Multifeed Offset Fed Parabolic Reflector.
   6.3 Shaped reflector for (multibeam radiation).
   6.4 Phased arrays.
   6.5 Earth footprints and power levels (EIRP).
Course Contents

7. Digital communication techniques
7.1 Modulation Techniques.
7.2 FDMA (Power requirement of the transponder)
7.3 TDMA (Network synchronization, closed loop timing)
7.4 CDMA (DS, FH)
7.5 Error Correcting Codes

Course grades

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWs</td>
<td>10%</td>
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<tr>
<td>Lab:</td>
<td>10%</td>
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<tr>
<td>Test1</td>
<td>15%</td>
</tr>
<tr>
<td>Test2</td>
<td>15%</td>
</tr>
<tr>
<td>Term Project</td>
<td>10%</td>
</tr>
<tr>
<td>Final test</td>
<td>40%</td>
</tr>
</tbody>
</table>
Course References

Textbook:

References:
Seminars: communication applications

1. Satellite Internet Based.
2. Direct Broadcasting satellite services
3. Satellite mobile services
4. VSATs (very Small aperture satellites)
5. Remote sensing satellites +SAR
6. ‘GPS’ Global positioning Satellite system
7. GMDSS, search and rescue(SAR), NOAA
8. Small Satellites
9. Digital communications for satellites
10. International Space Station (ISS)

Required:
1. Written report with references.
2. Each subject should consider a specified sat as an example (30%)
3. Power point presentation (30%)
4. Every student will be given a time to present his report to the class in 45 min and 15 mins for discussion.
4. The seminars will start from the 8th week.
Course Description:

This course covers the most relevant aspects of satellite communications, with emphasis on the most recent applications and developments.

The course begins with a review on the background and basic concepts of satellite communications. Next it covers the orbital aspects, with emphasis on the geostationary orbit. Satellite subsystems, launching methods, and on-board processing are also discussed.

The design of a digital satellite link is discussed in detail, including link budgets, modulation, error control coding, baseband signaling theory, and multiple access methods. Frequency assignments and propagation aspects that affect the satellite link are then discussed.

Antennas and earth station technology are presented, including the design of very small aperture terminals (VSATs). The course then covers non-geosynchronous orbits and their applications. Specific applications of satellites are also explored, including the global positioning system (GPS), satellites for mobile communication, and satellites for internet
Topics to be Covered:
• Introduction and Background
• Orbital Aspects and Launching
• Spacecraft Subsystems
• Link Budgets
• Modulation
• Multiple Access & On-Board Processing
• Coding
• Frequency & Propagation Aspects
• Earth Station Technology & VSATs
• Applications (GPS, Mobile, Internet, etc.)
• Non-Geosynchronous Orbits (NGSO)
Introduction

Types of satellite services

1. Fixed satellite service (FSS)
   - Links for existing telephone networks
   - Transmitting TV signals to cable companies.
2. Broadcasting Satellite Service (BSS)
   - Direct to home (DTH) = Direct broadcasting satellites (DBS)
3. Mobile satellite service (MSS)
   - Land mobile, maritime mobile and aeronautical mobile
4. Navigation satellite service (GPS)
   - Global positioning system (S&R)
5. Meteorological satellite service (Weather Forecast)
6. Deep Space Satellites
(FSS) Radio Relay station in space

Deep Space Satellites in space
Figure 1.5 Components of a direct broadcasting satellite system. (From Government of Canada, 1983, with permission.)
Advantages of satellite communications

1. Mobile/Wireless Communication, independent of location
2. Wide area coverage: country, continent, or globe
3. Wide bandwidth available throughout
4. Independence from terrestrial infrastructure
5. Rapid installation of ground network
6. Low cost per added site
7. Uniform service characteristics
8. Total service from a single provider
9. Small Fading margin (3dB)

Disadvantages of satellite communications

1. High cost for satellite
2. Short life time maximum of 15 years
3. Redundancy in component!
The shaded part represents the Tropical Zones as defined in Nos S5.16 to S5.20 and S5.21.
<table>
<thead>
<tr>
<th>Frequency range, GHz</th>
<th>Band designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1–0.3</td>
<td>VHF</td>
</tr>
<tr>
<td>0.3–1.0</td>
<td>UHF</td>
</tr>
<tr>
<td>1.0–2.0</td>
<td>L</td>
</tr>
<tr>
<td>2.0–4.0</td>
<td>S</td>
</tr>
<tr>
<td>4.0–8.0</td>
<td>C</td>
</tr>
<tr>
<td>8.0–12.0</td>
<td>X</td>
</tr>
<tr>
<td>12.0–18.0</td>
<td>Ku</td>
</tr>
<tr>
<td>18.0–27.0</td>
<td>K</td>
</tr>
<tr>
<td>27.0–40.0</td>
<td>Ka</td>
</tr>
<tr>
<td>40.0–75</td>
<td>V</td>
</tr>
<tr>
<td>75–110</td>
<td>W</td>
</tr>
<tr>
<td>110–300</td>
<td>mm</td>
</tr>
<tr>
<td>300–3000</td>
<td>μm</td>
</tr>
</tbody>
</table>
K band: DBS and FSS
Ku band: DBS and FSS
C band: FSS (no DBS are allowed)
VHF band: certain MSS and data transfer from weather satellites.
L band: MSS and navigation sat. systems.
Uplink freq. > downlink freq. (Ex. FSS:C=6/4 GHz) (DBS:ku14/12GHz)
Spectrum Allocation
Frequency Spectrum concepts:

• Frequency: Rate at which an electromagnetic wave reverts its polarity (oscillates) in cycles per second or Hertz (Hz).

• Wavelength: distance between wavefronts in space. Given in meters as: \[ \lambda = \frac{c}{f} \]
  
  Where: \( c \) = speed of light (3x10^8 m/s in vacuum)
  
  \( f \) = frequency in Hertz

• Frequency band: range of frequencies.

• Bandwidth: Size or “width” (in Hertz) or a frequency band.

• Electromagnetic Spectrum: full extent of all frequencies from zero to infinity.
Radio Frequencies (RF)

- RF Frequencies: Part of the electromagnetic spectrum ranging between 300 MHz and 300 GHz. Interesting properties:
  - Efficient generation of signal power
  - Radiates into free space
  - Efficient reception at a different point.

Differences depending on the RF frequency used:
- Signal Bandwidth
- Propagation effects (diffraction, noise, fading)
- Antenna Sizes
Microwave Frequencies

- Sub-range of the RF frequencies approximately from 1GHz to 30GHz. Main properties:
  - Line of sight propagation (space and atmosphere).
  - Blockage by dense media (hills, buildings, rain)
  - Wide bandwidths compared to lower frequency bands.
  - Compact antennas, directionality possible.
  - Reduced efficiency of power amplification as frequency grows:

<table>
<thead>
<tr>
<th>Radio Frequency Power OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Current Power IN</td>
</tr>
</tbody>
</table>
Spectrum Regulation

International Telecommunication Union (ITU): Members from practically all countries around the world.

- Allocates frequency bands for different purposes and distribute them around the planet.
- Creates rules to limit RF Interference (RFI) between countries that reuse same RF bands.
- Mediates disputes and creates rules to deal with harmful interference when it occurs.
- Meets bi-annually with its members, to review rules and allocations: World Radio Communication Conference (WRC).
- There are also the Regional Radio Communication Conferences (RCC), which happen less often.
Radio Frequency Spectrum
Commonly Used Bands

Terrestrial Bands

Space Bands

Shared (Terrestrial and Space)
Space-Earth Frequency Usability

Resonance frequencies below 100GHz:
- 22.2GHz ($\text{H}_2\text{O}$)
- 53.5-65.2 GHz (Oxygen)

Atmospheric attenuation effects for Space-to-Earth as a function of frequency (clear air conditions).
(a) Oxygen; (b) Water vapor. [Source: ITU © 1988]
Insights on Frequency Selection:
(Part 1: Lower frequencies, stronger links)

- LEO satellites need lower RF frequencies:
  - Omni-directional antennas on handsets have low gain - typically
    \[ G = 0 \text{ db} = 1 \]
  - Flux density \( F \) in \( \text{W/m}^2 \) at the earth’s surface in any beam is
    independent of frequency
  - Received power is \( F \times A \) watts, where \( A \) is effective area of
    antenna in square meters
  - For an omni-directional antenna \( A = G \frac{\lambda^2}{4 \pi} = \frac{\lambda^2}{4 \pi} \)
  - At 450 MHz, \( A = 353 \text{ cm}^2 \), at 20 GHz, \( A = 0.18 \text{ cm}^2 \)
  - Difference is 33 dB - so don’t use 20 GHz with an omni!
Insights on Frequency Selection:
(Part 2: Higher frequencies, higher capacity)

- GEO satellites need more RF frequencies
  - High speed data links on GEO satellites need about 0.8 Hz of RF bandwidth per bit/sec.
  - A 155 Mbps data link requires 125 MHz bandwidth
  - Available RF bandwidth:
    - C band 500 MHz (All GEO slots occupied)
    - Ku band 750 MHz (Most GEO slots occupied)
    - Ka band 2000 MHz (proliferating) Q/V band?
Satellite Systems Applications
Classical satellite systems

- Mobile User Link (MUL)
- Inter Satellite Link (ISL)
- Gateway Link (GWL)
- Small cells (spotbeams)
- Gateway footprint
- Base station or gateway
- ISDN
- PSTN
- GSM

PSTN: Public Switched Telephone Network
## Initial application of GEO Satellites: Telephony

<table>
<thead>
<tr>
<th>Year</th>
<th>Satellite</th>
<th>Weight (kg)</th>
<th>Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>Early Bird</td>
<td>34</td>
<td>240</td>
</tr>
<tr>
<td>1968</td>
<td>Intelsat III</td>
<td>152</td>
<td>1500</td>
</tr>
<tr>
<td>1986</td>
<td>Intelsat VI</td>
<td>1,800</td>
<td>33,000</td>
</tr>
<tr>
<td>2000</td>
<td>Large GEO</td>
<td>3000</td>
<td>8 - 15 kW</td>
</tr>
</tbody>
</table>

- Large GEO: 1,200 kg payload
Current GEO Satellite Applications:

- **Broadcasting** - mainly TV at present
  - DirecTV, PrimeStar, etc.

- **Point to Multi-point** communications
  - **VSAT**, Video distribution for Cable TV

- **Mobile Services**
  - Motient (former American Mobile Satellite), INMARSAT, etc.
Satellite Navigation: GPS and GLONASS

GPS is a medium earth orbit (MEO) satellite system

- GPS satellites broadcast pulse trains with very accurate time signals
- A receiver able to “see” four GPS satellites can calculate its position within 30 m anywhere in world
- 24 satellites in clusters of four, 12 hour orbital period

“You never need be lost again”

- Every automobile and cellular phone will eventually have a GPS location read-out
LEO Satellites in year 2000

- Several new systems are just starting service
  - Circular or inclined orbit with < 1400 km altitude
  - Satellite travels across sky from horizon to horizon in 5 - 15 minutes
  - Earth stations must track satellite or have omni-directional antennas
  - Constellation of satellites is needed for continuous communication.
  - Handoff needed.
System Elements
Satellite System Elements

Space Segment

- Satellite
- TT&C Ground Station
- SCC

Ground Segment

- Earth Stations
- Coverage Region
Space Segment

- Satellite Launching Phase
- Transfer Orbit Phase
- Deployment
- Operation
  - TT&C - Tracking Telemetry and Command Station: Establishes a control and monitoring link with satellite. Tracks orbit distortions and allows correction planning. Distortions caused by irregular gravitational forces from non-spherical Earth and due to the influence of Sun and Moon forces.
  - SSC - Satellite Control Center, a.k.a.:
    - OCC - Operations Control Center
    - SCF - Satellite Control Facility
    Provides link signal monitoring for Link Maintenance and Interference monitoring.
- Retirement Phase
Types of Satellite Stabilization

• Spin Stabilization
  – Satellite is spun about the axis on which the moment of inertia is maximum (ex., HS 376, most purchased commercial communications satellite; first satellite placed in orbit by the Space Shuttle.)

• Three-Axis Stabilization
  – Bias momentum type (ex., INTELSAT V)
  – Zero momentum type (ex., Yuri)
Satellite Subsystems

- Communications
  - Antennas
  - Transponders
- Common Subsystem (Bus Subsystem)
  - Telemetry/Command (TT&C)
  - Satellite Control (antenna pointing, attitude)
  - Propulsion
  - Electrical Power
  - Structure
  - Thermal Control
Ground Segment
Collection of facilities, users and applications.

Earth Station = Satellite Communication Station (air, ground or sea, fixed or mobile).
System Design Considerations
Basic Principles
Signals

Signals:

- Carried by wires as voltage or current
- Transmitted through space as electromagnetic waves.
- Analog:
  - Voltage or Current proportional to signal; e.g., Telephone.
- Digital: Generated by computers.
  
  Ex. Binary = 1 or 0 corresponding to +1V or −1V.
Separating Signals

Up and Down:

- **FDD**: Frequency Division Duplexing.
  - \( f_1 = \text{Uplink} \)
  - \( f_2 = \text{Downlink} \)

- **TDD**: Time Division Duplexing.
  - \( t_1=\text{Up}, t_2=\text{Down}, t_3=\text{Up}, t_4=\text{Down}, \ldots \)

- **Polarization**
  - V \& H linear polarization
  - RH \& LH circular polarizations
Separating Signals
(so that many transmitters can use the same transponder simultaneously)

Between Users or “Channels” (Multiple Access):
- **FDMA**: Frequency Division Multiple Access; assigns each transmitter its own carrier frequency
  $$f_1 = \text{User 1}; f_2 = \text{User 2}; f_3 = \text{User 3}, \ldots$$
- **TDMA**: Time Division Multiple Access; each transmitter is given its own time slot
  $$t_1 = \text{User 1}, t_2 = \text{User 2}, t_3 = \text{User 3}, t_4 = \text{User 1}, \ldots$$
- **CDMA**: Code Division Multiple Access; each transmitter transmits simultaneously and at the same frequency and each transmission is modulated by its own pseudo randomly coded bit stream
  Code 1 = User 1; Code 2 = User 2; Code 3 = User 3
Digital Communication System
Current Developments and Future Trends
Current Trends in Satellite Communications

- Bigger, heavier, GEO satellites with multiple roles
- More direct broadcast TV and Radio satellites
- Expansion into Ka, Q, V bands (20/30, 40/50 GHz)
- Massive growth in data services fueled by Internet
- Mobile services:
  - May be broadcast services rather than point to point
  - Make mobile services a successful business?
The Future for Satellite Communications – 1

- **Growth requires new frequency bands**

- Propagation through rain and clouds becomes a problem as RF frequency is increased

  - C-band (6/4 GHz)  
    - Rain has little impact
    - 99.99% availability is possible

  - Ku-band (10-12 GHz)  
    - Link margin of ≥ 3 dB needed for 99.8% availability

  - Ka-band (20 - 30 GHz)  
    - Link margin of ≥ 6 dB needed for 99.6% availability
The Future for Satellite Communications - 2

- **Low cost phased array antennas** for mobiles are needed

  - Mobile systems are limited by use of omni-directional antennas

  - A self-phasing, self-steering phased array antenna with 6 dB gain can quadruple the capacity of a system

  - Directional antennas allow frequency re-use
Satellite-Related Terms

- Earth Stations – antenna systems on or near earth
- Uplink – transmission from an earth station to a satellite
- Downlink – transmission from a satellite to an earth station
- Transponder – electronics in the satellite that convert uplink signals to downlink signals
Ways to Categorize Communications Satellites

• Coverage area
  – Global, regional, national

• Service type
  – Fixed service satellite (FSS)
  – Broadcast service satellite (BSS)
  – Mobile service satellite (MSS)

• General usage
  – Commercial, military, amateur, experimental
Classification of Satellite Orbits

• Circular or elliptical orbit
  – Circular with center at earth’s center
  – Elliptical with one foci at earth’s center

• Orbit around earth in different planes
  – Equatorial orbit above earth’s equator
  – Polar orbit passes over both poles
  – Other orbits referred to as inclined orbits

• Altitude of satellites
  – Geostationary orbit (GEO)
  – Medium earth orbit (MEO)
  – Low earth orbit (LEO)
Geometry Terms

• Elevation angle - the angle from the horizontal to the point on the center of the main beam of the antenna when the antenna is pointed directly at the satellite
• Minimum elevation angle
• Coverage angle - the measure of the portion of the earth's surface visible to the satellite
Minimum Elevation Angle

• Reasons affecting minimum elevation angle of earth station’s antenna (>0°)
  – Buildings, trees, and other terrestrial objects block the line of sight
  – Atmospheric attenuation is greater at low elevation angles
  – Electrical noise generated by the earth's heat near its surface adversely affects reception
GEO Orbit

• Advantages of the GEO orbit
  – No problem with frequency changes
  – Tracking of the satellite is simplified
  – High coverage area

• Disadvantages of the GEO orbit
  – Weak signal after traveling over 35,000 km
  – Polar regions are poorly served
  – Signal sending delay is substantial
LEO Satellite Characteristics

- Circular/slightly elliptical orbit under 2000 km
- Orbit period ranges from 1.5 to 2 hours
- Diameter of coverage is about 8000 km
- Round-trip signal propagation delay less than 20 ms
- Maximum satellite visible time up to 20 min
- System must cope with large Doppler shifts
- Atmospheric drag results in orbital deterioration
LEO Categories

• Little LEOs
  – Frequencies below 1 GHz
  – 5MHz of bandwidth
  – Data rates up to 10 kbps
  – Aimed at paging, tracking, and low-rate messaging

• Big LEOs
  – Frequencies above 1 GHz
  – Support data rates up to a few megabits per sec
  – Offer same services as little LEOs in addition to voice and positioning services
MEO Satellite Characteristics

• Circular orbit at an altitude in the range of 5000 to 12,000 km
• Orbit period of 6 hours
• Diameter of coverage is 10,000 to 15,000 km
• Round trip signal propagation delay less than 50 ms
• Maximum satellite visible time is a few hours
## Frequency Bands Available for Satellite Communications

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency Range</th>
<th>Total Bandwidth</th>
<th>General Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1 to 2 GHz</td>
<td>1 GHz</td>
<td>Mobile satellite service (MSS)</td>
</tr>
<tr>
<td>S</td>
<td>2 to 4 GHz</td>
<td>2 GHz</td>
<td>MSS, NASA, deep space research</td>
</tr>
<tr>
<td>C</td>
<td>4 to 8 GHz</td>
<td>4 GHz</td>
<td>Fixed satellite service (FSS)</td>
</tr>
<tr>
<td>X</td>
<td>8 to 12.5 GHz</td>
<td>4.5 GHz</td>
<td>FSS military, terrestrial earth exploration, and meteorological satellites</td>
</tr>
<tr>
<td>Ku</td>
<td>12.5 to 18 GHz</td>
<td>5.5 GHz</td>
<td>FSS, broadcast satellite service (BSS)</td>
</tr>
<tr>
<td>K</td>
<td>18 to 26.5 GHz</td>
<td>8.5 GHz</td>
<td>BSS, FSS</td>
</tr>
<tr>
<td>Ka</td>
<td>26.5 to 40 GHz</td>
<td>13.5 GHz</td>
<td>FSS</td>
</tr>
</tbody>
</table>
Satellite Link Performance Factors

• Distance between earth station antenna and satellite antenna

• For downlink, terrestrial distance between earth station antenna and “aim point” of satellite
  – Displayed as a satellite footprint

• Atmospheric attenuation
  – Affected by oxygen, water, angle of elevation, and higher frequencies