1. Introduction to Satellite Communications

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**Extra-terrestrial Relays**—earth's equator, would revolve with the earth and would thus be stationary above the same spot on the planet. It would remain fixed in the sky of a whole hemisphere and unlike all other heavenly bodies would neither rise nor set. A body in a smaller orbit would revolve more quickly than the earth and so would rise in the west, as indeed happens with the inner moon of Mars.

Using material ferried up by rockets, it would be possible to construct a "space-station" in such an orbit. The station could be provided with living quarters, laboratories and everything needed for the comfort of its crew, who would be relieved and provisioned by a regular rocket service. This project might be undertaken for purely scientific reasons as it would contribute enormously to our knowledge of astronomy, physics and meteorology. A good deal of literature has already been written on the subject. Although such an undertaking may seem fantastic, it requires

...meanings would be very small, as direct line of sight transmission would be used. There is the further important point that arrays on the earth, once set up, could remain fixed indefinitely.

Moreover, a transmission received from any point on the hemisphere could be broadcast to the whole of the visible face of the globe, and thus the requirements of all possible services would be met (Fig. 2).

It may be argued that we have as yet no direct evidence of radio waves passing between the surface layer and echoes have been received from meteors in or above the F layer. It seems fairly certain that frequencies from, say, 50 Mc/s to 100,000 Mc/s could be used without undue absorption in the atmosphere or the ionosphere.

A single station could only provide coverage to half the globe, and for a world service three would be required, though more could be readily utilized. Fig. 3 shows the simplest arrangement. The stations would be arranged approximately equidistantly around the earth, and the following longitudes appear to be suitable:

- 30E—Africa and Europe
- 150E—China and Oceana
- 90W—The Americas

The stations in the chain would...
The reality today (2022)

StarLink planned constellation
Contents of the Course

• 1. What is Satellite Communications for?
• 2. Spacecraft and Earth Station/Terminal Architecture
• 3. Basic Technologies, Design Objectives, and Performance Metrics of Satellite Links and Networks
• 4. Examples of Current GSO and NGSO SatCom Constellations and Related Services/Standards
  - by Riccardo De Gaudenzi, Head of Electrical Systems Division, European Space Agency
• 5. Fundamentals of Satellite Positioning and Navigation
• 6. GNSS Receiver Design and Performance Evaluation
1. Introduction to Satellite Communications

**Why do we need satellites?**

- **Communications (TV, Mobile, Trunk, Emergency) 67%**
  - satellites are used for television, radio, and internet broadcasting. This sector increased lately with more and more companies launching satellites to provide internet everywhere on the globe

- **Localization (GNSS, Global Navigation Satellites Systems) 3%**
  - via satellite navigation systems is widely used in almost all industries: transportation, emergency response, farming, banking, military, science. These satellites determine the location, velocity, and current time of small electronic devices (like the ones in our smart phones)

- **Earth Observation (METEOSAT, LandSat) 20%**
  - satellites provide information about earth resources, weather, climate, and environmental monitoring. Imaging satellites produce high-resolution data of almost the entire landmass on earth

- **Space Exploration (APOLLO...) 2 %**
  - satellite telescopes have been critical to understanding phenomena like pulsars and black holes as well as measuring the age of the universe
Communications Satellites: A bit of History

- **First experiment of uplink/downlink transmission:**
  - SCORE (1958, pre-recorded message in FM bands, 22 days of life)

- **First passive reflector:**
  - ECHO 1 (1960, 30-m metallized sphere bouncing radio waves back, years of life)

- **First Wideband Active Satellite:**
  - TELSTAR 1 (1962, 50-MHz bandwidth at C-band, 6.4/4.2 GHz)

- **First GEOsynchronous satellite:**
  - SYNCOM (1963, range/range-rate tracking)

- **First commercial satellite:**
  - EARLY BIRD/INTELSAT I (1965, the actual date of birth of commercial satellite communications, C-band 6.3/4.1 GHz, TWT amplifier, two 25-MHz transponders)

- **Direct TV Broadcasting:**
  - OTS (1982, by ESA with programs by SkyOne, UK)
Early Samples...

Telstar

INTELSAT I
**Example of modern High-Throughput Satellite**

- Launched 2012
- 6000 kg
- 24 C-band transponders, 54 Ku-band transponders, 1 Ka-band transponder
- 18 years expected lifetime

[https://www.satbeams.com/satellites](https://www.satbeams.com/satellites)
Why a dedicated course on SatCom?

• Satellite Communications traditionally require dedicated, expensive terminals and networks

• It is considered as a completely different technology than, say, cellular communications altogether

• Even service providers are not the same...
• Different from Cellular Networks’
Satellite Bands

Satellite navigation signals, Navigation aids (e.g. loran-C), AM maritime radio, Shortwave radio, radiotelephony, VHF TV FM radio, navigation aids, UHF TV cell phones, GPS, Satellite/microwave telecommunications, Radio astronomy, radar landing systems.

- **VLF**: 100 km
- **LF**: 10 km
- **MF**: 1 km
- **HF**: 100 m
- **VHF**: 10 m
- **UHF**: 1 m
- **SHF**: 10 cm
- **EHF**: 1 cm
- **1-40 GHz**: 1 mm
- **3 KHz**: Increasing wavelength
- **30 KHz**: 3 MHz
- **300 KHz**: 30 MHz
- **3 MHz**: 300 MHz
- **3 GHz**: Increasing frequency
- **30 GHz**: 300 GHz

**Satellite Frequency**

- L
- S
- C
- X
- Ku
- K
- Ka

1. Introduction to Satellite Communications
How does it work?

**SPACE SEGMENT**
- Intersatellite Link
- Uplink
- Downlink
- EIRP
- G/T

**GROUND SEGMENT**
- Interface station
- User station
- Service station
- Gateway
- VSAT
- Handset
- Hub/feeder station

**CONTROL SEGMENT**
- TTC station
- Network management station

**TERRESTRIAL NETWORK**
- User terminal
- User terminal
- From/to service provider

"1. Introduction to Satellite Communications"
1. Introduction to Satellite Communications

GEO, LEO, MEO, HEO Satellites

- **Geosynchronous Orbit (GSO or GEO)**
  - Orbit: 23,000 n. mi. (36,000 km)
  - Plane: Circular orbit, inequatorial plane
  - Delay: ~260 ms

- **Low Earth Orbit (LEO)**
  - Orbit: 100 – 400 n. mi.
  - Plane: Circular orbits
  - Delay: ~10 ms

- **Medium Earth Orbit (MEO)**
  - Orbit: 1,000 – 3,000 + n. mi.
  - Plane: Circular orbits
  - Delay: ~100 ms

- **High Earth Orbit (HEO)**
  - Orbit: ~23,000 n. mi.
  - Delay: ~10 to 260 ms

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How do they launch it?
1. Introduction to Satellite Communications

Satellite Anatomy

- Deployable Antennas
- Top-Floor Antennas
- Repeater equipment
- Payload Walls
- Propulsion Tanks
- Solar Array
- Batteries
- Liquid-Apogee Engine
- Avionics
Satellite Anatomy

ESA’s AlphSat
1. Introduction to Satellite Communications
• **Broadcasting**
  – By far, the most money-making. Being supplanted by streaming.

• **Backbone (Trunk)**
  – Was, together with broadcasting, the killer application until the ’90s. Being supplanted by fiber cables.

• **Internet Connection to fixed points**
  – Intended to break the Digital Divide into remote areas. Revived by StarLink.

• **Mass-Market Mobile Communications/IoT**
  – Was the future of SatCom in the 90’s (IRIDIUM, GLOBALSTAR), before the advent of digital cellular. Now relegated to governmental usage.
• **Remote-Areas Mobile Communications**
  - At sea, in the desert, a niche but safe market (INMARSAT, THURAYA).

• **Emergency**
  - When the terrestrial network is disrupted (flooding, earthquake, terrorism) satellite is the only means

• **Military**
  - A resilient (see above), private and secure network under the control of Defense Departments

• **Interplanetary**
  - Imagine Man really goes to Mars...
1. Introduction to Satellite Communications
Space Agencies/Entities

- NASA National Aeronautics and Space Administration (USA)
- ESA European Space Agency
- EUSPA European Union Agency for the Space Program
- ASI Agenzia Spaziale Italiana
- CNES Centre National d’Etudes Spatiales (FR)
- DLR Deutsches Zentrum für Luft- und Raumfahrt (D)
- CNSA China National Space Administration
- ROSCOSMOS федеральное космическое агентство (Russia)
- JAXA Japan Aerospace Exploration Agency

- SPACEX Space Exploration Technologies Corporation, Elon Musk, 2002
## SatCom Companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Revenue (USD millions)</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singtel Satellite</td>
<td>12,041</td>
<td>Singapore</td>
</tr>
<tr>
<td>SES</td>
<td>2,328</td>
<td>Luxembourg</td>
</tr>
<tr>
<td>Intelsat</td>
<td>2,061</td>
<td>Luxembourg</td>
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<tr>
<td>Eutelsat</td>
<td>1,499</td>
<td>France</td>
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<tr>
<td>Arqiva</td>
<td>1,290</td>
<td>UK</td>
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<tr>
<td>Telesat</td>
<td>684</td>
<td>Canada</td>
</tr>
<tr>
<td>Hispasat</td>
<td>239</td>
<td>Spain</td>
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<tr>
<td>Globecast</td>
<td>188</td>
<td>France</td>
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<tr>
<td>Thaicom</td>
<td>150</td>
<td>Thailand</td>
</tr>
<tr>
<td>EchoStar Satellite Services</td>
<td>1.886</td>
<td>USA</td>
</tr>
</tbody>
</table>
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- Map of Satellites

- List of Satellites
  - [https://www.satbeams.com/satellites](https://www.satbeams.com/satellites)

- Statistics
  - [https://geoxc-apps.bd.esri.com/space/satellite-explorer/](https://geoxc-apps.bd.esri.com/space/satellite-explorer/)

- Naïve Orbit Calculator
  - [https://www.omnicalculator.com/physics/earth-orbit](https://www.omnicalculator.com/physics/earth-orbit)

Internet Resources