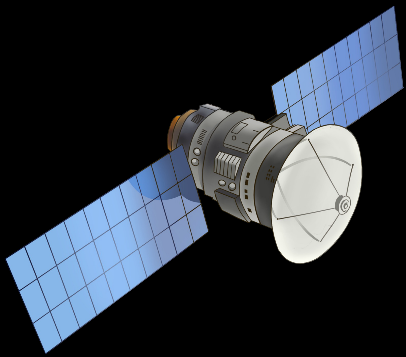


Satellite Communications

History of Satellites – Early Experiments

October 4, 1957 – The first artificial Earth satellite *Sputnik 1* was launched.

- It operated on two frequencies – **20.005 MHz** and **40.002 MHz**.
- The radio transmitter was designed to study radio wave propagation in the ionosphere.

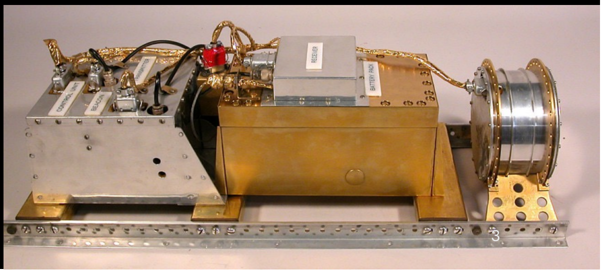
This event marked the **beginning of the space age**.

History of Satellites – Early Experiments

December 18, 1958 – The first satellite specifically designed for active communication relay, **SCORE**, was launched.

- It was used to broadcast a Christmas message from **U.S. President Dwight D. Eisenhower**.

In historical listings of communication satellites, SCORE is often recognized as the first.

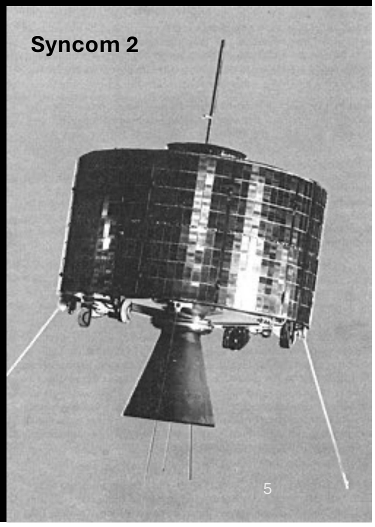


History of Satellites – Early Experiments

- 1960 – The Echo 1 was the first passive balloon reflector for radio signals.
- The Courier 1B (1960) became the first active communication relay satellite.
- 1962 – Telstar 1, funded by AT&T, became the first commercial satellite to transmit a live TV and telephone signals across the Atlantic.

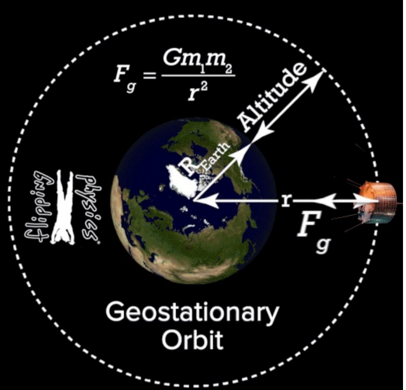
History of Satellites – Geostationary Satellites

- **1963 – Syncom 2** became the first **geosynchronous satellite**.
- **1965 – Intelsat I (Early Bird)** was the first **commercial geostationary communications satellite**, enabling direct phone calls between the **U.S. and Europe**.
- **1969 – Intelsat III series** provided **global coverage** for the first time.



Geostationary Orbit – GEO

- **Altitude:** Approximately **35,786 km** above the equator.
- The **orbital period** is **23 hours 56 minutes 4 seconds**, matching Earth's sidereal day
- **Feature:** The satellite moves **synchronously with Earth's rotation**, appearing **stationary in the sky** over a fixed point.
- **Coverage:** One GEO satellite can cover roughly **one-third of Earth's surface**.



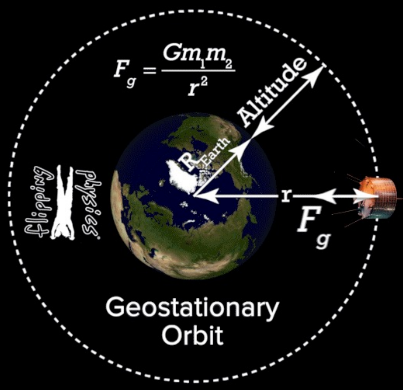
Geostationary Orbit – GEO

Advantages:

- Continuous coverage over one location.
- Fewer satellites required for global connectivity.

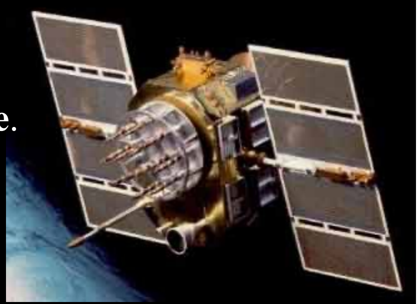
Disadvantages:

- **High latency (~250–300 ms)** due to distance.
- Less optimal for **latency-sensitive applications** such as interactive internet or VoIP



History of Satellites – Medium Earth Orbit Satellites

- **February 22, 1978** – Launch of the first **GPS satellite (Navstar 1, Block I)**.
- **September 16, 1983** – Announcement that **GPS** would become available for **civilian use**.
- **October 10, 1985** – Launch of the last **Block I satellite** (the tenth in the series).
- From **1989**, **Block II satellites** were launched — the **operational version** used for both **military and civilian applications**.
- The **GPS system** became fully operational in **1995**.



Medium Earth Orbit – MEO

- **Altitude:** Approximately **2,000–20,000 km.**
- MEO satellites typically have **orbital periods of 4–12 hours.**
- **Orbit Type:** Usually circular but may also be inclined.

Applications:

- **Navigation systems** – e.g., GPS (USA), Galileo (EU), BeiDou (China), GLONASS (Russia).
- Some **telecommunication** and **internet systems**.

Medium Earth Orbit – MEO

Advantages:

- Better coverage than LEO.
- Lower latency compared to GEO.

Disadvantages:

- Requires a **network of satellites** to maintain continuous coverage.
- **Tracking and control** are more complex than for GEO satellites.

History of Satellites – Low Earth Orbit Satellites

- **1960–1980:** LEO satellites were mainly used for **experiments** and **Earth observation**.
  Example: **Landsat** (first launched in 1972) — for monitoring Earth's surface.
  Communication during this period was dominated by GEO satellites due to LEO's technical challenges.
- **Mid-1990s:** The **commercial LEO communication boom** began.
  The first **global constellations** were launched —
  Iridium (1997) and **Globalstar (1998)**.

History of Satellites – Low Earth Orbit Satellites

- **2019–present:** The **massive LEO era** started.
- **SpaceX's Starlink (~550 km)** began deploying hundreds and now thousands of LEO satellites.
  - The first launch occurred in **May 2019, and over 6,000 satellites launched by 2025**

Low Earth Orbit – LEO

- **Altitude:** Approximately **160–2,000 km**.
- **Orbital Period:** About **90–120 minutes** per revolution around Earth.

Applications:

- **Starlink, Iridium,** and other internet or mobile communication constellations.
- **Earth observation –** for climate, agriculture, and reconnaissance.
- **Space exploration** and **the International Space Station (ISS)**.

Low Earth Orbit – LEO

Advantages:

- Very **low latency (~20–50 ms)** – ideal for internet and interactive services.
- **High data transfer rate** due to proximity to Earth.

Disadvantages:

- Covers a **small area** – requires large **satellite constellations**.
- **Inter-satellite communication** and **handover** are technically complex.

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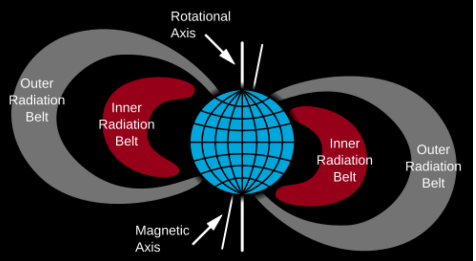
Van Allen Radiation Belts

- The **Van Allen belts** are **radiation zones** that can **damage electronics, sensors,** and **reduce satellite lifespan**.
- They significantly influence the **selection of orbital altitudes**, especially for **military, communication, and navigation satellites**.
- **Inner Belt:** ~1,000–6,000 km – composed mainly of **protons**.
  Outer Belt: ~13,000–60,000 km – dominated by **electrons**.



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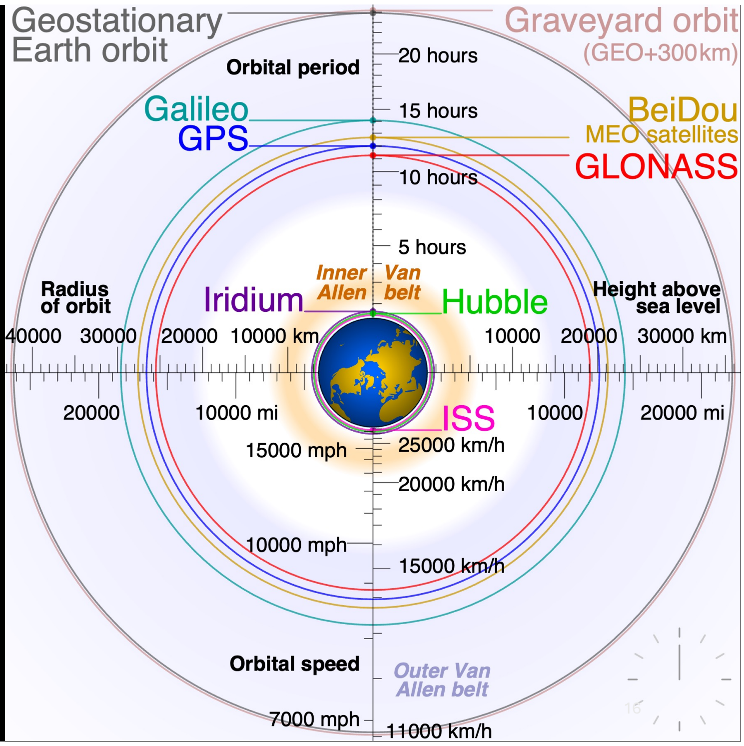
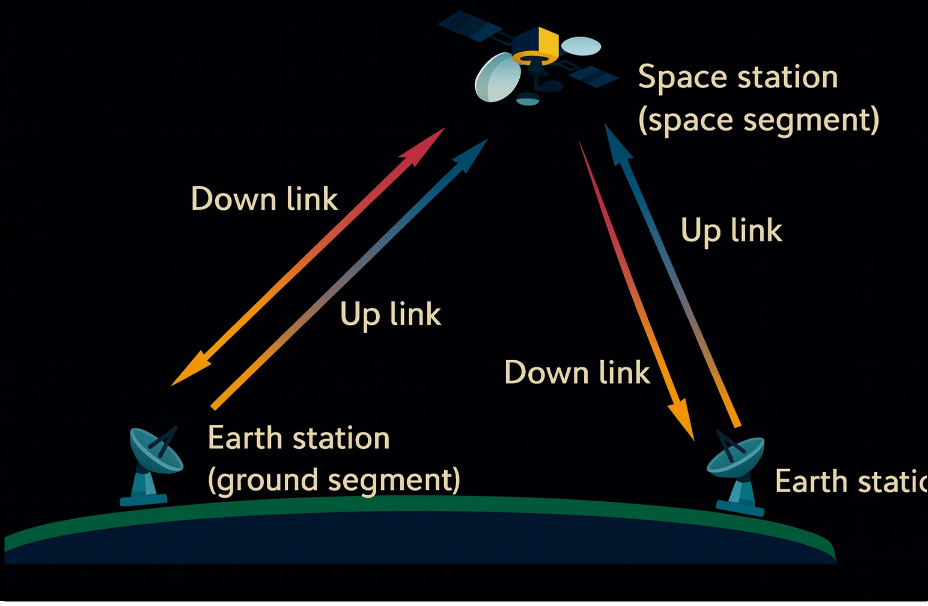
Why is the radiation so intense near Earth?



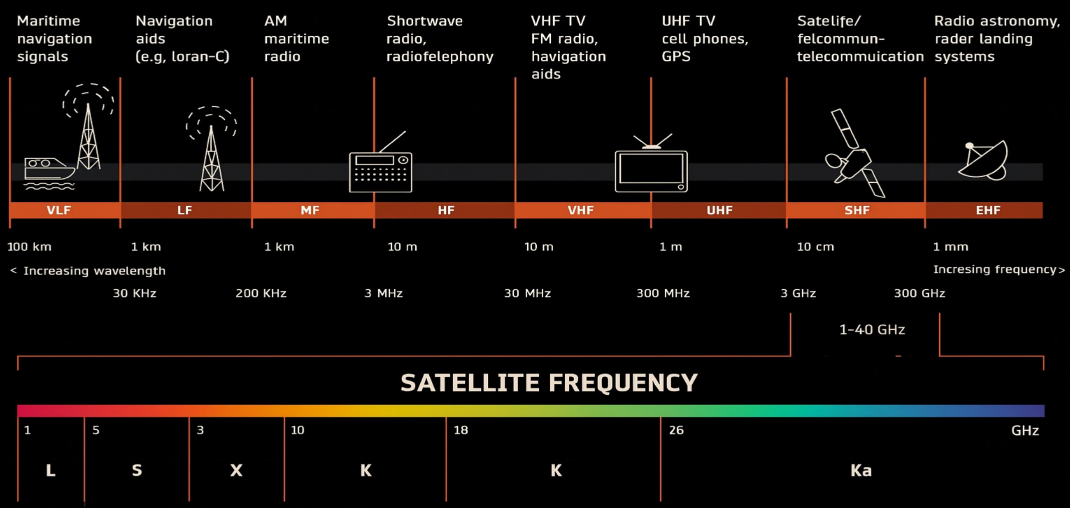
Satellite Communication System Diagram



Frequency Bands Used in Satellite Communications

- **L Band (1–2 GHz):** GPS, mobile satellite phones.
- **S Band (2–4 GHz):** Meteorological radars, ship radars, and some NASA satellites for communication with the ISS.
- **C Band (4–8 GHz):** Widely used for satellite communications, television networks, and raw satellite feeds; less sensitive to rain than Ku Band.
- **X Band (8–12 GHz):** Used in weather monitoring, air traffic control, maritime control, defense tracking, and radar speed measurement.
- **Ku Band (12–18 GHz):** Television broadcasting.
- **K Band (18-26.5):** Inter-satellite links (ISL).
- **Ka Band (26.5–40 GHz):** Used in broadband satellite internet and high-resolution radar systems.

Frequency Bands Used in Satellite Communications



Signal Power

The **power of a satellite signal** depends on:

- The **distance from Earth** (LEO, MEO, GEO)
- The **available energy source** (usually solar panels)
- The **sensitivity** of the ground receiver
- The **type of application** (TV, data transmission, GPS, telephony)

Why signal power is important?

- Shannon Information Capacity (or Shannon–Hartley Theorem) is one of the foundational results in communication theory.
- It defines the maximum data rate (capacity) that can be transmitted over a channel with a given bandwidth and signal-to-noise ratio (SNR), without error, assuming ideal coding.

$$C \text{ [bits/s]} = BW \text{ [Hz]} \log_2(1 + SNR \text{ [W]})$$

LEO Satellites – Signal Power (160–2 000 km)

UPLINK (Earth → Satellite)

- Transmitter power: ~1–20 W (user equipment)
- EIRP: ~20–45 dBW

  Example: A Starlink terminal transmits at ~3–6 W, with the antenna increasing EIRP through gain.

DOWNLINK (Satellite → Earth)

- Transmitter power: ~5–20 W
- EIRP: ~30–50 dBW (high antenna gain)

* ERIP defines the Effective Isotropic Radiated Power — the effective power "leaving" the antenna when its gain is considered.

$EIRP(dBW)=10 \cdot \log_{10}(P_{tx}(W)) + G_{ant}(dBi)$

MEO Satellites – Signal Power (~2000–20,000 km)

UPLINK (Earth → Satellite):

- Transmitter power: ~50–250 W (ground stations)
- EIRP: ~60–80 dBW
- Typically used for **navigation** and **regional internet** services.

DOWNLINK (Satellite → Earth):

- Transmitter power: ~5–50 W
- EIRP: ~27–45 dBW
  (Example: A GPS satellite transmits at about 25 W.)

GEO Satellites – Signal Power (~35,786 km)

UPLINK (Earth → Satellite):

- Transmitter power: ~100–500+ W (large ground stations)
- EIRP: ~70–85 dBW
  (Example: TV broadcasting stations transmit with high-power signals.)

DOWNLINK (Satellite → Earth):

- Transmitter power: ~20–200 W
- EIRP: ~40–60 dBW (due to large antenna gain)
  (Example: Satellite TV → small home dish receivers.)

- **Why do uplink and downlink powers differ?**

Why do uplink and downlink powers differ?

	Uplink	Downlink
Who transmits?	From Earth	Sattelite
Energy source	Has a lot more energy than satellite	Usually, solar pnnels
Permited max value	More powerfull tramsmission stations	Small transmiters
Distance	From Earth to satellite	From satellite to Earth

Orbit	Direction	Tx (W)	EIRP (dBW)	Examples
LEO	Uplink	1–20	20–45	Starlink terminal
LEO	Downlink	5–20	30–50	Starlink satellite
MEO	Uplink	50–250	60–80	GPS control station
MEO	Downlink	5–50	27–45	GPS satellite
GEO	Uplink	100–500+	70–85	TV uplink station
GEO	Downlink	20–200	40–60	SAT TV, Internet

Free Space Path Loss (FSL)

Definition:

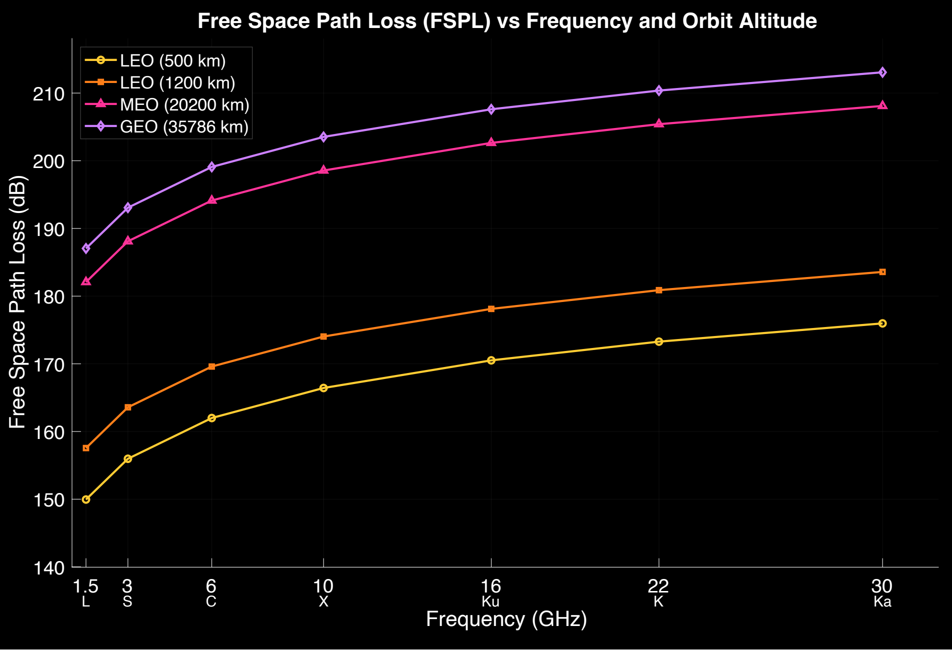
Free Space Path Loss (FSL) represents the **attenuation of a radio signal** as it propagates through free space.
Even in the absence of obstacles (clouds, trees, or buildings), the signal weakens naturally with distance as the radio waves spread out.

- **Formula (logarithmic form):**

$$FSL\ [\mathrm{dB}] = 20 \cdot \log_{10}(d\ [\mathrm{km}]) + 20 \cdot \log_{10}(f\ [\mathrm{MHz}]) + 32.45$$

Interpretation:

- Higher **frequency** or **distance** results in greater loss.
- Critical for designing **uplink/downlink power budgets**.



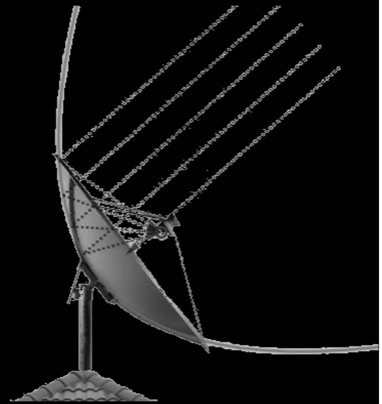
Problem

The signal is transmitted from Earth to a geostationary satellite. The initial signal power is 3.2 kW. As the signal propagates through space, it is attenuated by 194 dB. Calculate the signal power received by the satellite.

1. Formula: $Attenuation = 10\log_{10}(\frac{P_{received}}{P_{transmitted}})$
2. Substitute: $-194 = 10\log_{10}\left(\frac{P_{received}}{3.2 * 10^3}\right)$
3. Divide both sides by10: $-19.4 = \log_{10}(\frac{P_{received}}{3200})$
4. Get rid of log: $10^{-19.4} = \frac{P_{received}}{3200}$
5. Finally: $\underline{P = 3200 \times 10^{-19.4} = 1{,}274 \times 10^{-16}\ W}$ = –129 dBm

Most RF and communication system powers naturally fall between −130 dBm and +60 dBm, except GPS that uses very week signals −130 to −155 dBm.

Satellite Antennas – Parabolic Dish Antennas



Description:

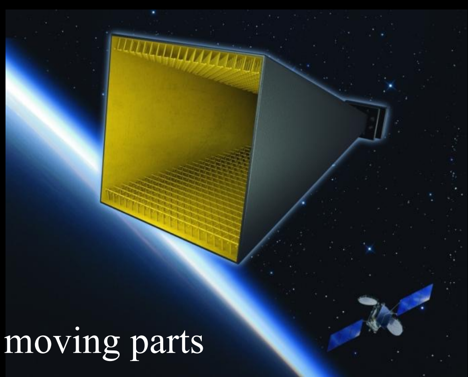
Parabolic dish antennas employ a **paraboloid-shaped reflector** that focuses radio waves onto a single point, enabling efficient long-distance signal transmission.

Characteristics:

- High gain (often exceeding **30 dB**), gain is proportional to $(D/\lambda)^2$, where D = dish diameter.
- Narrow beamwidth for precise directional transmission
- Commonly used on **geostationary satellites**

Example: Large satellite TV dishes used for broadcast and reception.

Satellite Antennas – Horn Antennas



Description:

Horn antennas feature an **expanded waveguide structure**, allowing radio waves to be transmitted and received efficiently with minimal reflection losses.

Characteristics:

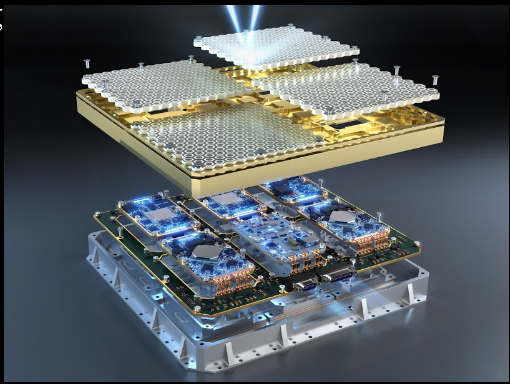
- Broad frequency range
- Robust, mechanically simple design with no moving parts
- Suitable for both transmission and reception
- **Example:** Used in **NASA space missions** for spacecraft communication.

Satellite Antennas – Phased Array Antennas

Description:
Composed of multiple small antenna elements whose **phases are electronically controlled**, enabling rapid beam steering (microseconds) **without mechanical movement**.

Characteristics:

- Fast electronic beam steering
- Ideal for **mobile** and **high-velocity** platforms
- Commonly applied in **LEO satellite constellations**, e.g., **Starlink**

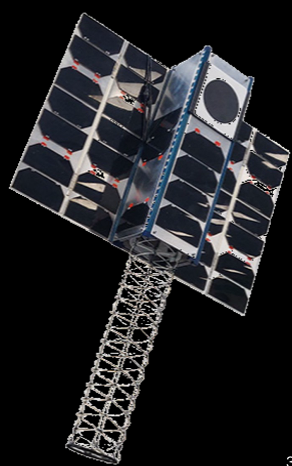


Satellite Antennas – Helical Antennas

Description:
Helical antennas use a **spiral-shaped conductor** to produce **circularly polarized radio waves**, enabling stable communication with rotating or moving satellites.

Characteristics:

- Capable of generating **circular polarization**
- Suitable for communication with **rotating satellites**
- Frequently used in **small satellite systems**



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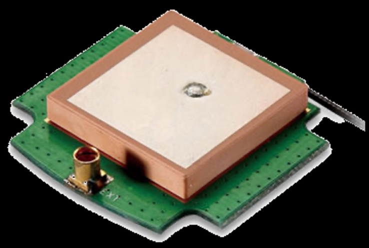
Satellite Antennas – Patch Antennas

Description:
Compact, flat antennas that can be **integrated into devices** due to their low profile and lightweight design.

Characteristics:

- Small size and mass
- Easy integration into electronic systems
- Ideal for **low-power communication systems (**GNSS receivers and IoT devices**)**



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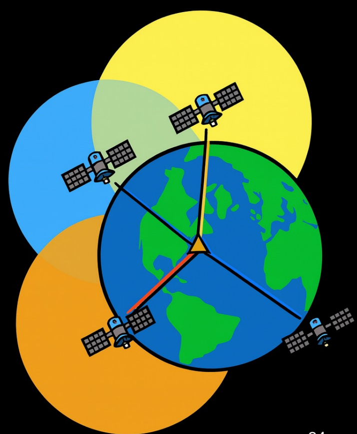
Global Positioning Systems (GNSS) – How GNSS Works

Satellite Transmission:
Each GNSS satellite continuously transmits a signal that contains:

- The **exact date and time** (from an onboard atomic clock)
- The **satellite's position** in its orbit

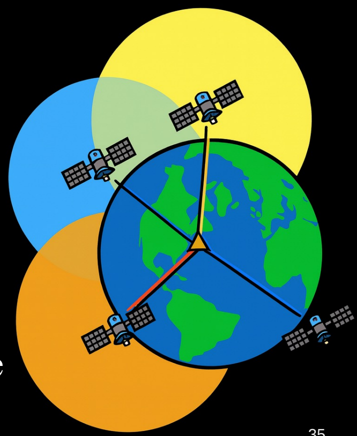


Global Positioning Systems (GNSS) – How GNSS Works

Receiver Operation:

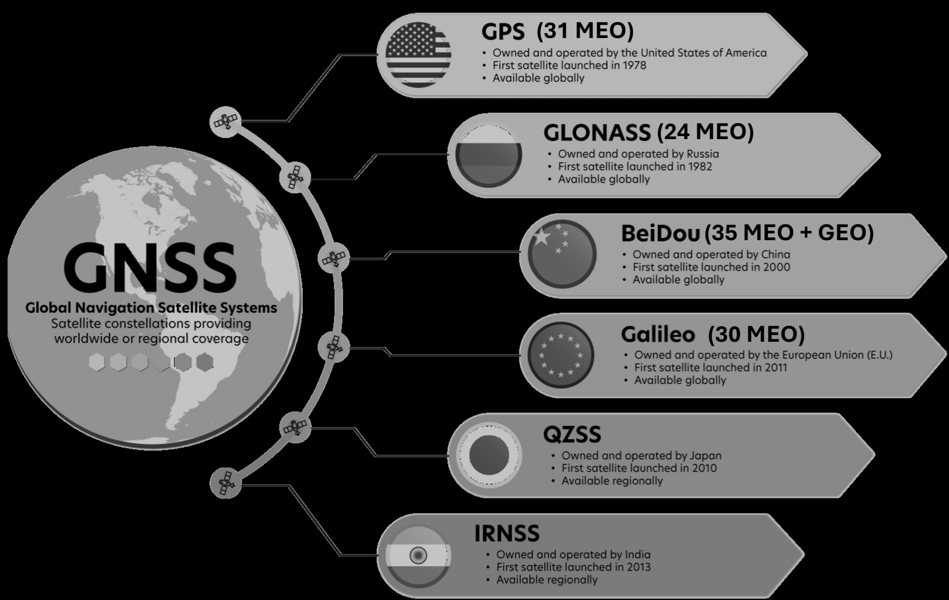
A receiver (e.g., in a smartphone or GPS device):

- Captures signals from at least **four satellites**
- Calculates the **distance** to each satellite based on **signal delay**
- Determines its position (**longitude, latitude, altitude**) using **trilateration**



Outcome:

The receiver computes an accurate **three-dimensional position** and time reference anywhere on Earth.



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Starlink

Description:

- Number of Satellites: Over 5,000 satellites are currently active, with a planned network of up to 12,000–42,000 satellites.
- Orbit Altitude: Satellites orbit in low Earth orbit (LEO) at about 550 km.
- Orbital Speed: Each satellite travels at roughly 27,000 km/h, completing an orbit in ~90 minutes.
- Satellites include laser links, enabling data routing between satellites without relying on ground stations, improving global coverage and reducing latency.

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Starlink

- Due to this high velocity, a ground antenna must **switch communication** between satellites approximately **every four minutes** to maintain a stable connection.
- Handover Time: Typically occurs in under 20 milliseconds, imperceptible to users.
- Latency (Delay): Generally 20–40 milliseconds, suitable for real-time applications like video calls and gaming.
- Download Speeds: Often range from 50 Mbps to over 200 Mbps, depending on network load and location.

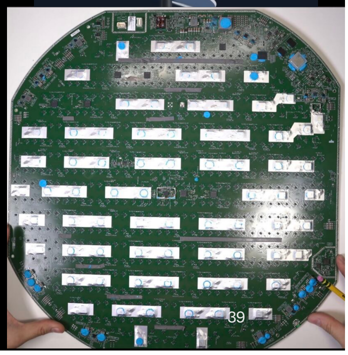
Starlink Antenna Technology – "Dishy McFlatface"

Technology:

The antenna employs **phased array technology** consisting of about **1,280 small antenna elements**, which enable **electronic beam steering** without mechanical motion.

Each element emits an **electromagnetic wave** whose **phase** is precisely controlled so that all waves combine to form a strong beam directed toward the satellite.

- This process, known as **beamforming**, allows multiple simultaneous beams for different users.

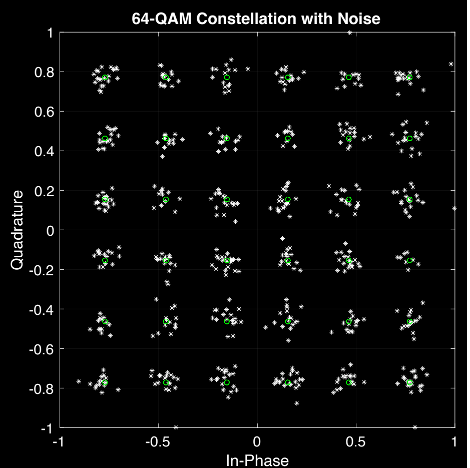


Starlink – Data Transmission Rate and Modulation

Despite the long transmission distance, data is exchanged between the antenna and the satellite at **hundreds of megabits per second**, ensuring **high-speed internet connectivity**.

The system uses **64QAM,** allowing **8 bits of information per symbol** to be transmitted.

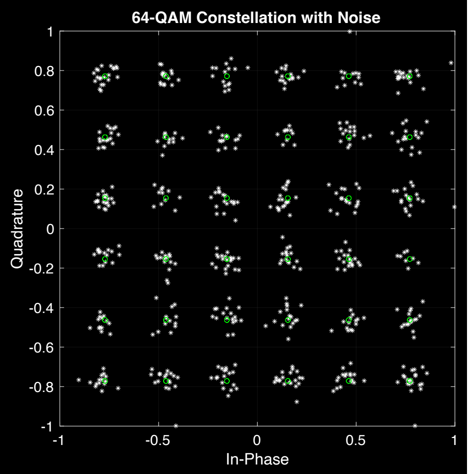
It requires high signal-to-noise ratio (SNR > 25 dB) for reliable performance.



Starlink – Data Transmission Rate and Modulation

Since the antenna cannot **transmit and receive simultaneously**, each second is divided into:

- Approximately **74 milliseconds** for **uplink** (Earth → Satellite), and
- The remaining time for **downlink** (Satellite → Earth).
- This ensures **efficient time-division duplexing (TDD)** for two-way communication.



Starlink – Applications

Use Cases:

- **Mobile and Transportation Sectors:** Connectivity for moving vehicles and logistics.
- **Aviation:** Enhanced inflight internet "Starlink Aviation".
- **Maritime connectivity:** "Starlink Maritime" is an operational product.
- **Defense and Security:** Tactical communication and surveillance.
- **Disaster Response:** Emergency connectivity during natural disasters.
- **Private Users:** Broadband access in remote or underserved areas.

Thank You for Your Attention

Useful Video References:

- https://www.youtube.com/watch?v=nlQamhsCGeU
- https://www.youtube.com/watch?v=DFIXfcL43_4
- https://www.youtube.com/watch?v=nlQamhsCGeU
- https://www.youtube.com/watch?v=ror4P1UAv_g
- https://www.youtube.com/watch?v=qs2QcycggWU&t=7s