EEEN 567 – SATELLITE ENGINEERING

INTRODUCTION TO SATELLITE ENGINEERING - STUDY GUIDE

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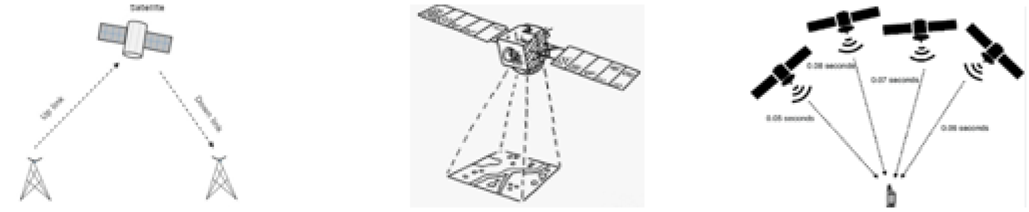
1. INTRODUCTION

1.1. What is a satellite?

A satellite is an object, natural or artificial, that orbits a larger celestial body like a planet or star. From the engineering point of view, a satellite is an artificial object placed into a precise and stable trajectory (orbit) around a celestial body, designed to perform a specific function, such as communication, Earth observation, or navigation.

From an electrical engineering perspective, it is essentially a sophisticated, remote electronic platform comprised of several critical subsystems: a communication payload (transponders, receivers, and high-power amplifiers) to receive, amplify, and retransmit signals; an electrical power system (solar cells and batteries) to generate and store energy; and a command and data handling system that acts as the spacecraft's computer. Its operation is defined by the physics of its orbit, which determines its coverage area and connection time with ground stations, making the design of its electronic systems a complex exercise in reliability, power efficiency, and signal processing within a harsh radiation environment.



(a) Communication satellite (b) Earth observation satellite (c) Navigation satellites

Figure 1. Different functions performed by satellites

2. ORBITAL MECHANICS

2.1. What is Orbital Mechanics?

Orbital mechanics is the application of classical mechanics, primarily Newton's laws of motion and universal gravitation, to predict and explain the motion of satellites in space.

2.2. Why Orbital Mechanics in Important?

Engineers can't design a communication links or a power system without knowing where the satellite is, how fast it is moving relative to the earth, and what it’s view of Earth (communication link) and the Sun (source of solar power) is.

2.3. Kepler's Laws:

Understand the shape (elliptical) of orbits and the relationship between orbital period and semi-major axis.

- Key Equation: $T^2 \propto a^3$ (Orbital Period squared is proportional to the semi-major axis cubed).

2.4. Newton's Law of Universal Gravitation & Centripetal Force:

Derive the orbital velocity ($v = \sqrt{(GM/r)}$) and the concept of geostationary orbit (GEO).

2.5. Orbital Elements (Keplerian Elements):

Explain the six parameters that define a satellite's orbit (e.g., inclination, eccentricity, right ascension of the ascending node). These are crucial for predicting satellite position and planning contacts with ground stations.

- **Types of Orbits:**
    a) **GEO (Geostationary Earth Orbit):** ~36,000 km altitude. Appears stationary. Excellent for weather and comms satellites. **High latency (~250 milliseconds round trip)**.

    b) **LEO (Low Earth Orbit):** ~160 - 2,000 km altitude. Low latency, high orbital velocity. Used for imaging, science, and mega-constellations (Starlink, OneWeb). **Requires many satellites for continuous coverage.**

    c) **MEO (Medium Earth Orbit):** ~2,000 - 36,000 km. The "Goldilocks" zone for navigation systems (GPS, Galileo, Beidu).

3. SATELLITE SUBSYSTEMS

3.1 Introduction:

A satellite is comprised of several specialized subsystems that work in concert to ensure its survival and mission success. The core is typically the **communication subsystem**, which includes transponders, receivers, and high-power amplifiers for handling signals. The **electrical power subsystem** features solar arrays and batteries for generation and storage and regulated by power management electronics. Other systems include the **attitude determination and control system (ADCS)** for precise pointing using sensors and reaction wheels, the command and **data handling (C&DH) subsystem** which acts as the onboard computer, and a **propulsion subsystem** for orbital adjustments.

3.1. Communication Subsystem

- **Transponder:** The core hardware. Includes receivers, frequency converters (e.g., down-converting from C-band to L-band), and high-power amplifiers (TWTA - Traveling Wave Tube Amplifiers or SSPA - Solid-State Power Amplifiers).
- **Antennas:** Trade-offs between gain, directivity, and beamwidth. Parabolic dishes vs. phased arrays. **Gain is everything in space comms.**
- **Modulation/Demodulation:** QPSK, 8PSK, QAM are common for high spectral efficiency.
- **Multiple Access Schemes:** How multiple users share the satellite.
    - **FDMA (Frequency Division):** Different users on different frequencies.
    - **TDMA (Time Division):** Different users at different times.
    - **CDMA (Code Division):** Different users with different codes.

3.2. Electrical Power System (EPS)

a) **Power Generation:** Photovoltaic (Solar) Cells. Understand I-V curves, efficiency, and the impact of the space environment (radiation degradation, temperature swings).

b) **Energy Storage:** Rechargeable Batteries (Nickel-Cadmium, Nickel-Hydrogen, Lithium-Ion). Key metrics: Energy Density, Charge/Discharge Cycles, Depth of Discharge (DOD).

c) **Power Management & Distribution (PMAD):** Regulates voltage, manages battery charging via solar array switching, and provides conditioned power to all subsystems. Involves DC-DC converters, maximum power point trackers (MPPT), and protection circuits.

3.3. Attitude Determination and Control System

Satellite attitude refers to the precise three-dimensional orientation of a spacecraft in space, which is critical for pointing its solar panels toward the Sun for power generation, directing its communication antennas toward Earth for reliable data links, and aligning its payload (e.g., cameras, sensors) toward its intended target. This orientation is actively measured by sensors like sun sensors, star trackers, and gyroscopes and is maintained or changed by control systems such as reaction wheels, magnetorquers, or thrusters. Accurate attitude control is fundamental to mission success, as even minor misalignments can lead to communication blackouts, power shortages, or the collection of useless data.

Key attitude components are:

a) **Sensors:** How the satellite knows where it's pointing (Sun sensors, star trackers, Earth sensors, gyroscopes, magnetometers).

b) **Actuators:** How the satellite moves itself (Reaction Wheels, Magnetorquers, Thrusters). Understand the principles of torque and angular momentum.

c) **Role of electrical Engineer:** Designing sensor interfaces, control loops, and motor drivers for the actuators.

4: THE RADIO LINK & LINK BUDGET

4.1 What is Link Budget?

A link budget is a fundamental accounting exercise in communication engineering that quantifies the entire signal path from a transmitter to a receiver, calculating the received signal power and comparing it to the noise floor to determine if the link is viable. It sums all gains (primarily from transmitter and receiver antenna directivity) and subtracts all losses, including the dominant free-space path loss—which increases with distance and frequency—as well as atmospheric attenuation and hardware inefficiencies.

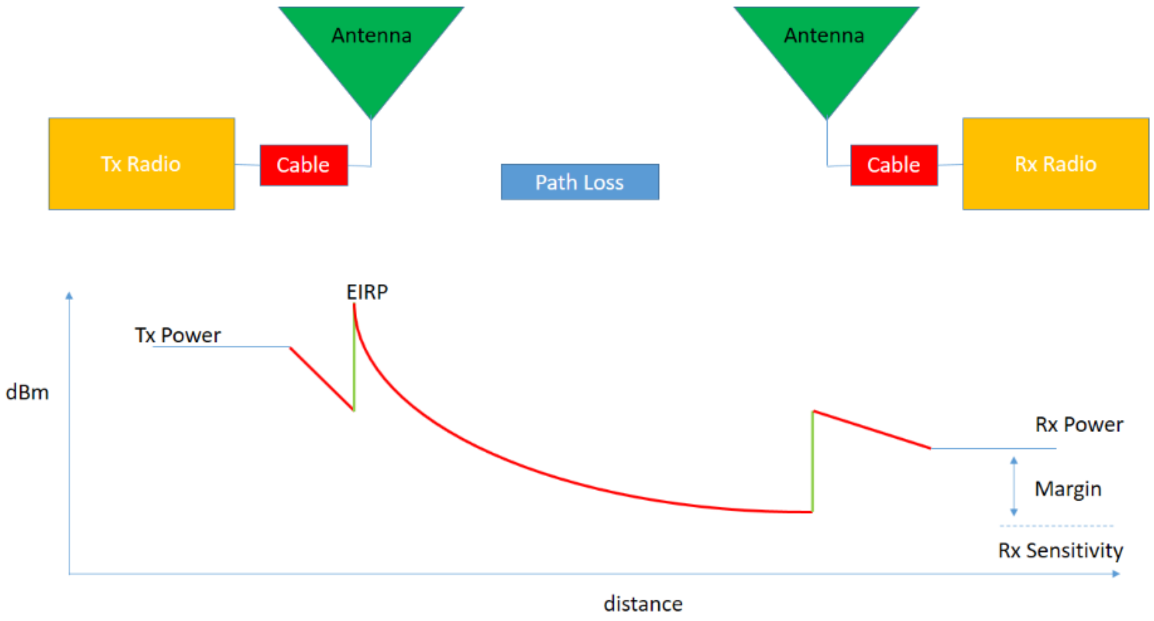


Figure 2. Link budget is a communication system

4.2 The Decibel (dB)

The language of link budgets. Be fluent in dB, dBm, dBW, dBi.

4.3 Link Budget Equation:

Received Power (dBW) = Transmitted Power (dBW) + Transmitter Antenna Gain (dBi) - Path Loss (dB) + Receiver Antenna Gain (dBi) – Receiver Cable Losses (dB)

4.5 Key Components of Link Budget

a) EIRP (Equivalent Isotropically Radiated Power)

$P_{tx} + G_{tx}$. A measure of the "effective" power radiated by the antenna.

b) Path Loss (Free Space Path Loss - FSPL)

FSPL = $(4\pi d / \lambda)^2$ or in dB: $20*\log10(d) + 20*\log10(f) + 92.45$ (where d is in km, f is in GHz). This is the biggest loss in the system.

c) Noise Calculation

Noise Power = k * T * B (k=Boltzmann's constant, T=system noise temperature, B=bandwidth).

d) Figure of Merit (G/T):

Receiver antenna gain divided by system noise temperature. A key measure of a receiver's sensitivity.

4.6 Final Metric:

a) C/N_0 (Carrier-to-Noise Density Ratio)

b) E_b/N_0 (Energy-per-bit to Noise-density Ratio) = C/N_0 - 10*log10(data rate)

c) Compare calculated E_b/N_0 to the required E_b/N_0 for your modulation and coding scheme to find the link margin.

5: GROUND SEGMENT & EARTH STATIONS

5.1 Components

Parabolic antennas (e.g., 13m dishes), high-power amplifiers (HPAs), low-noise amplifiers (LNAs), up/downconverters, modems.

5.2 Key Electrical Engineering Concepts

Noise Figure of the LNA is critical for the entire system's G/T. Beam steering and tracking for non-GEO satellites.

6. SAMPLE EXAM QUESTIONS

6.1. Conceptual

A communications satellite moves from a Low Earth Orbit (LEO) to a Geostationary Orbit (GEO). How does this change affect (a) the free space path loss, (b) the orbital period, (c) the latency for a phone call, and (d) the required number of satellites for continuous global coverage?

6.2. Calculation

A LEO satellite transmits at 8 GHz with an EIRP of 30 dBW. The ground station antenna has a gain of 45 dBi and a system noise temperature of 150 K. The distance is 2000 km. Calculate the received carrier-to-noise ratio (C/N) if the signal bandwidth is 50 MHz. (Assume no other losses).

6.3. Design

Describe the key components of a satellite's Electrical Power System (EPS). What are the trade-offs between using Lithium-Ion batteries vs. Nickel-Hydrogen? Why are solar cells typically made from Gallium Arsenide (GaAs) instead of Silicon for space applications?

6.4. Analysis

Explain the purpose of a link budget. What does a negative link margin indicate, and what are two ways an engineer could improve it?