Satellite Communications

Part I-Introduction ,History and Orbital Mechanics

Lecturer Madeeha Owais

Presentation Credits

- Mr.Aamir Habib,Vienna University
- Dr N.D Gohar,Fall 2007 ACS Lectures
- Books Referenced:
  - Advanced Electronic Communication Systems by Wayne Tomasi
  - Satellite Communications by Timothy Pratt

Learning Objectives

- What is a Satellite?
- What is a Satellite System?
- Why Satellite Communications?
- Historical Perspective & Background
- Radio Spectrum for Satellite Communications
- Orbital Mechanics
- Defining Space
- Newton's Laws of Motion→Forces on a Satellite
- Keplar's three laws on planetary motion

What is a Satellite ?

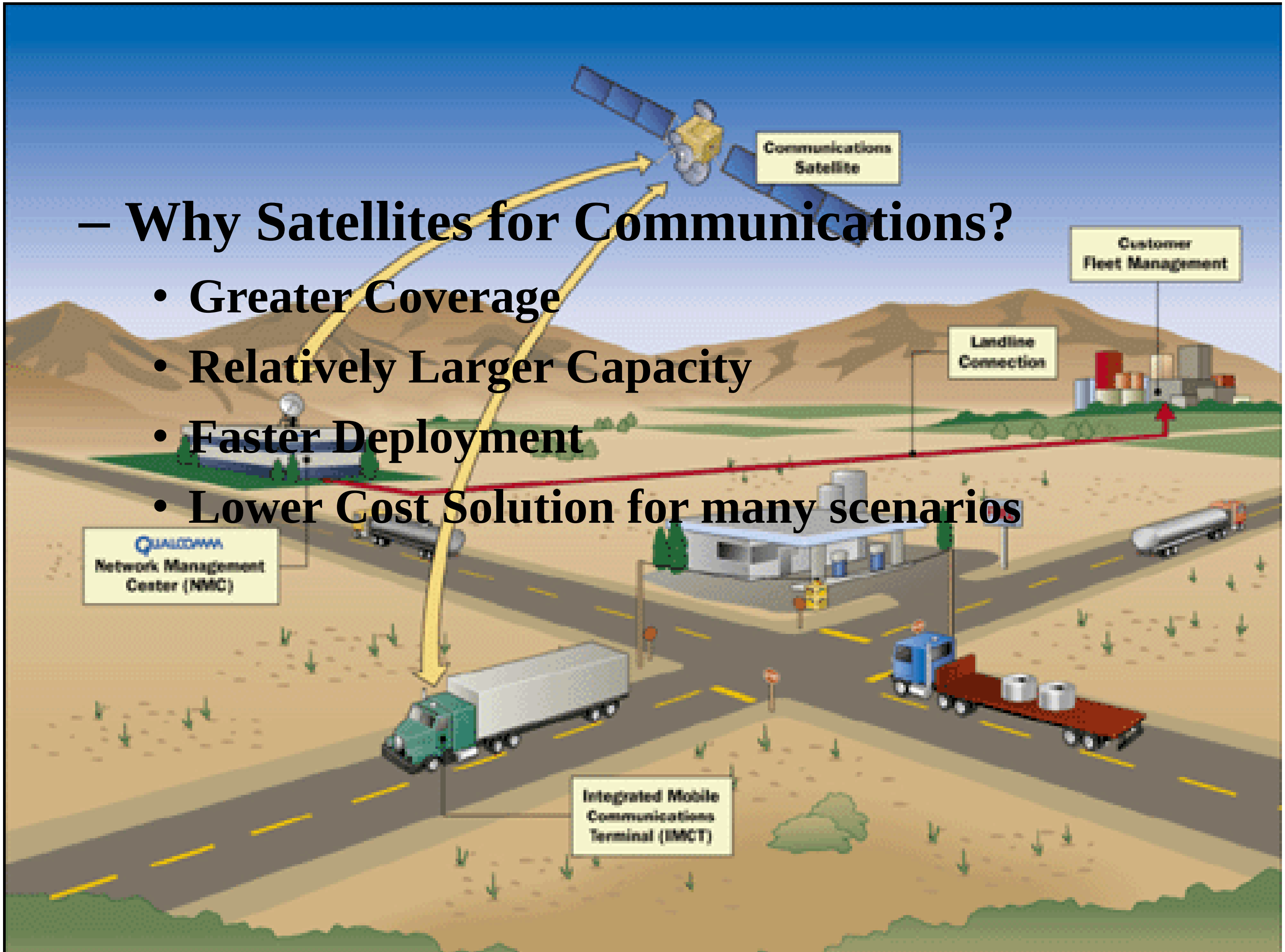
- A celestial body – In astronomical term, e.g. moon
- A space vehicle launched by humans and orbits the earth or another celestial body – In aerospace terms
- Communication Satellite – provides communication and other services to variety of consumers
  - It is a microwave repeater in the sky
  - A satellite radio repeater is called a transponder
  - A satellite may have one to many transponders

What is a Satellite Systems ?

- A Satellite System may consist of :
  - one or more satellite space vehicles,
  - a ground based control earth station,
  - and a network of user earth stations that provides the interface facilities for the transmission and reception of terrestrial communications traffic through the satellite systems.
- Transmissions to and from the satellites are categorized as either bus or payload.
- The payload is the actual user information conveyed through the system.
- The bus includes control mechanisms that support the payload operation

– Why Satellites for Communications?

- Greater Coverage
- Relatively Larger Capacity
- Faster Deployment
- Lower Cost Solution for many scenarios



Passive and Active Satellites

- Passive Satellite
  - Simplest type of satellite is a *passive reflector*
  - It simply “bounces” signals from one place to another.
  - It reflects signals back to earth as there are no gain devices on board to amplify or modify the signals
  - Moon became the first passive satellite in 1954 when the U.S Navy successfully transmitted the first message over an Earth-to-moon-to-Earth communication system.
  - But moon proved to be unreliable communication satellite as it is above the horizon only half of the time and its position relative to earth is constantly changing.

Passive and Active Satellites

- Advantage of Passive Satellite
  - No sophisticated electronic equipment on board.
  - Radio beacon transmitters are required for tracking and ranging purposes.
  - A beacon is a continuously transmitted un-modulated carrier that an earth station can lock on to and use to determine the exact location of a satellite so the earth station can align its antennas.
- Disadvantage of Passive Satellite
  - Inefficient use of transmitted power
  - As little as 1 part in every 10^{18} of an earth station's transmitted power is actually returned to earth station receiving antennas

Passive and Active Satellites

- Active Satellite
  - It is capable of receiving,amplifying,reshaping,regenerating and retransmitting the information
  - Has sophisticated electronic equipment on-board.

History & Background of Satellites-I

- 1957 –*Sputnik I* (USSR),First active satellite, Transmitted telemetry info for 21 days
- In same year, *Explorer I* (US),transmitted telemetry info for 5 months
- 1958,NASA's *Score*,first artificial satellite used for relaying terrestrial communications.
- 1960, *Echo-1* (US), a Passive Satellite
- 1962, AT&T *Telstar 1*, LEO satellite, First active satellite to simultaneously transmit and receive radio signals, damaged by radiation
- 1963, *Telstar 2*,electronically similar to *Telstar 1* except more radiation resistant,accomplished first successful video transmission

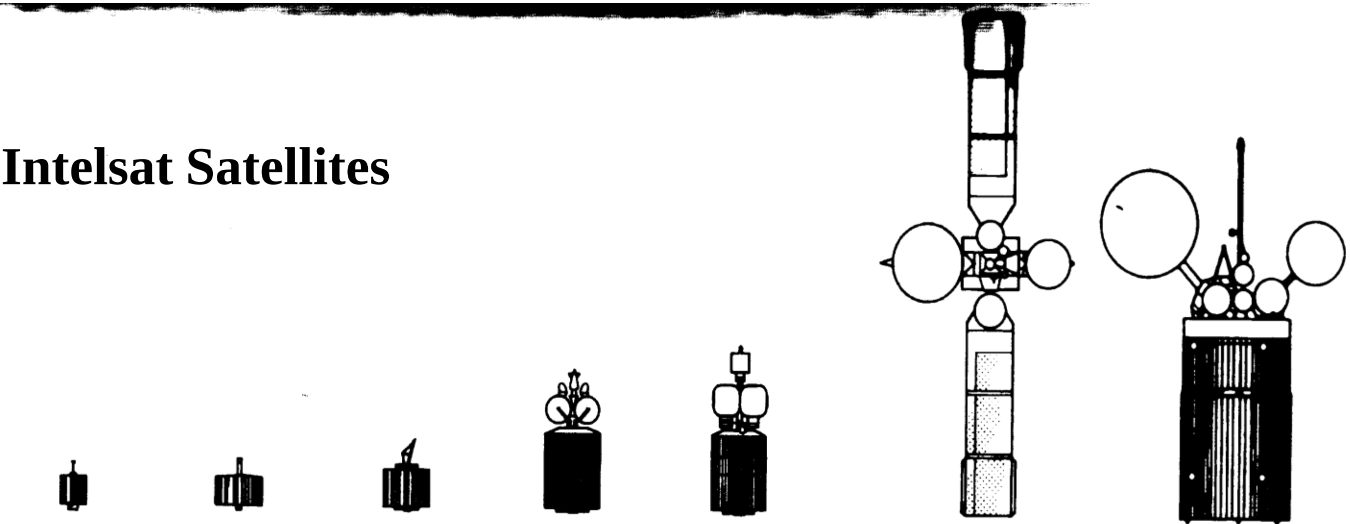
History & Background of Satellites-II

- 1963,*Syncom I*-First attempt to place a geosynchronous satellite into orbit, lost during orbit injection
- 1963,1964-Successful launches of *Syncom II*, *Syncom III* (linked Japan and USA),*Syncom III* was used to broadcast 1964 Olympic Games from Tokyo
- Meanwhile in 1961,US President defined U.S policy in regard to satellite communications and showed interest to develop a single worldwide system.
- ITU was asked to examine aspects of space communication for which international co-operation is required.
- As a result commercial investment started in an international satellite organization called Intelsat(International Satellite Organization) by 12 interested countries. By 2000, Intelsat had 143 member countries

History & Background of Satellites-II

- *Intelsat I*(called *Early Bird*) was the first commercial telecommunications satellite in geo-synchronous orbit in 1965.
- Between 1966 and 1987,Intelsat launched series of satellites designated as *Intelsat II, III,IV,V,VI.*
- Within 10 years,Intelsat was self-supporting and since it was not allowed to make profit, it began returning substantial revenues to its members.
- Four basic service categories of Intelsat are:
  - International public switched telephony
  - Broadcasting
  - Private line/business networks
  - Domestic/regional communications

History of Intelsat Satellites



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

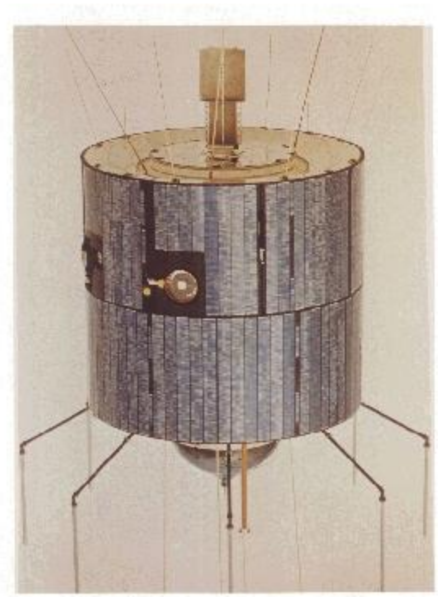
History & Background of Satellites-III

- USSR launched first regional satellite system,*Molniya*,of highly elliptic orbit(HEO) in 1965
- Canada was the first country to build a national telecommunication system using GEO satellites called *Anik* in 1974.
- 1970’s and 1980’s saw rapid deployment of GEO satellites for international,regional and domestic telephone traffic and video distribution.
- Inmarsat(International Maritime Satellite Organization) has provided services to ships and aircrafts for decades.
- Implementation of LEO and MEO satellite system for mobile communication has proven to be costly and has smaller system capacity
- Satellite navigation systems, notably GPS,have revolutionized navigation and surveying

History & Background of Satellites-IV

- Satellite Communication Organizations
  - International Organizations such as Intelsat, Inmarsat, Intersputnik,Eutelsat,RASCOM
  - Many regional organizations in Africa,Asia,Europe and North-America
  - Experimental Organizations such as ATS
- You can read more at Wikipedia about the various satellite organizations.

- Experimental Organization-Application Technology Satellite (ATS): Launched on Nov 05, 1967, for TV and Data Transfer Experiments, NASA Approved Users, Provide emergency communications during natural disasters



Frequency Bands used in Satellite Communications

Frequency bands used in satellite communications

Frequency range	Frequency	Band designation	Application
100 – 300 MHz	225 – 390 MHz	P	
300 – 1.0 GHz	350 – 530 MHz	J	
	1530 – 2700 MHz	L	Mobile satellite services, navigation systems
1.0 – 2.0 GHz	1575.42 MHz	L1	GPS: Coarse acquisition code
	1227.6 MHz	L2	GPS: Precision code
2.0 – 4.0 GHz	**3400 – 6425 MHz**	**C**	Fixed satellite services
4.0 – 8.0 GHz	7250 – 8400 MHz	X	Military use
12.0 – 18.0 GHz	**10.95 – 14.5 GHz**	**Ku**	Direct broadcast satellites
18.0 – 27.0 GHz	27.5 – 31GHz	K	
27.0 – 40.0 GHz		Ka	
40.0 – 75.0 GHz	46 – 56 GHz	V	
75.0 – 110 GHz	56 – 100 GHz	W	

Orbital Mechanics

Defining Space

- US Astronauts get their wings if they fly at an altitude of 50 miles (80 km)
- International Treaty boundary can be at an altitude of 100 miles (160 km)
- Atmospheric drag starts at 400,000 ft on re-entry (76 miles, 122 km)

- Most satellites for any mission of more than a few months are places into orbits of atleast 250 miles(approx 400km) above the earth
- Even at this height, atmospheric drag is significant…!!

Is 250 miles(400km) enough?

- ISS injected into orbit at 397 km on 9 June 1999
- It was down to 360 km by the end of 1999
- Need to raise the orbit or it will decay into the atmosphere
- Most satellites with lifetimes >5 years are at 500+ miles (800+ km)

Newton's Laws of Motion

s = Distance traveled in time, *t*

u = Initial Velocity at *t* = 0

v = Final Velocity at time = *t*

a = Acceleration

F = Force acting on the object

This is the Key equation

- $s = ut + (1/2)at^2$
- $v^2 = u^2 + 2at$
- $v = u + at$
- $F = ma$

Concept of Force

- Force (F) = Mass(m) × Acceleration(a)
  - ***m*** is the mass of the satellite
  - Unit of Force is a ***Newton***
  - A ***Newton*** is the force required to accelerate 1 kg by 1 m/s^2
  - Underlying units of a ***Newton*** are therefore (kg) × (m/s^2)
  - In Imperial Units 1 ***Newton*** = 0.2248 ft lb.

Acceleration Inwards

a_{IN} = acceleration due to gravity = μ / r^2

- r = radius from center of earth to satellite
- $\mu = G^* M_E$, is the Kepler's Constant

  $\mu = 3.9861352 \times 10^5$ km³/s²

- G = Universal Gravitational Constant

  $G = 6.672 \times 10^{-11}$ Nm²/kg²

  $= 6.672 \times 10^{-20}$ km³/(kg s²) (other units)

- M_E = Mass of the earth

  $M_E = 5.9733 \times 10^{24}$ kg

Note: An object near the earth's surface accelerates at a rate of 9.811 m/s²

Acceleration Outwards

a_{OUT} = *centrifugal acceleration* = v^2 / r

Where:

- r = radius from center of Earth to satellite
- v = speed component on a direction perpendicular to rotation.

Forces on a Satellite

- Force **inwards** due to gravity (i.e.centripetal force) is:

$$F_{IN} = m \times (\mu / r^2) = m \times (GM_E / r^2)$$

- Force **outwards** (i.e. *centrifugal force):*

$$F_{OUT} = m \times (v^2 / r)$$

Balancing the Forces

-

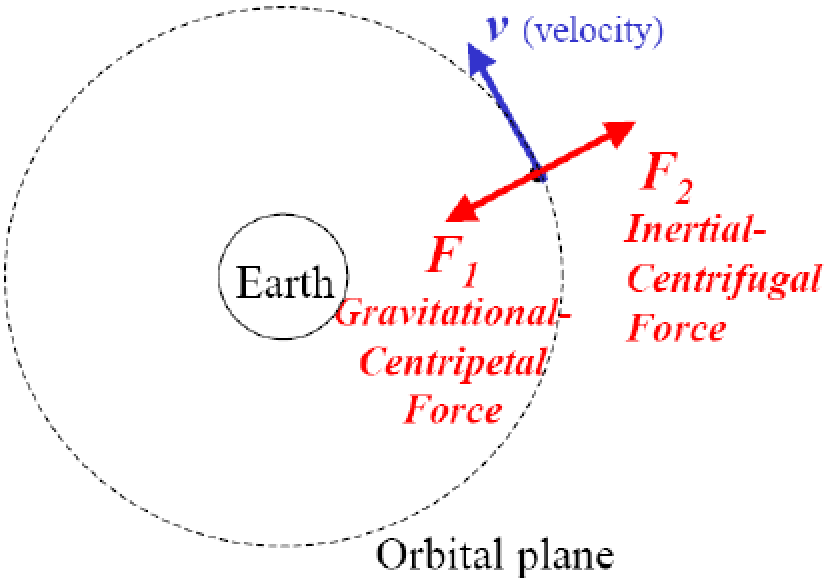
- For the satellite to stay in orbit, the forces must balance; set $F_{IN} = F_{OUT}$, solve for the required speed v

$$v = (\mu / r)^{1/2}$$

- If circular orbit:

$$T = 2\pi r / v$$

$$T = 2\pi r^{3/2} / \mu^{1/2}$$



Orbit Limits

- There must be a balance between inward gravitational (centripetal) forces and outward centrifugal forces
- Must not be too close to the earth as it will be slowed down by the atmosphere
- Velocity must be in the **right direction** (parallel to earth surface).

Kepler’s Three Law of Planetary Motion

- Background
  - Kepler, a German Scientist, discovered the laws governing the planetary motion, describing the shape of the orbit, planet velocity, and its distance w.r.t the Sun. He derived these laws empirically by observation only of the behavior of planets in solar system over many years .
  - Isaac Newton, a British scientist, mathematically calculated these laws 50 years later by making use of differential calculus.
  - These can be applied to any two body system interacting through gravitation such as the Earth and its Satellite.
  - The large of the two bodies is called the Primary and smaller is called Secondary body.

Kepler's Three Law

- First Law: The orbit of any smaller body about a larger body is always an ellipse,with the center of mass of the larger body as one of the two foci or

  Satellite will orbit the Earth following an elliptical path, with barycenter (center of the mass of two body system) lying at one of its two foci, that is geocenter (center of the Earth)

- Second Law (also known as law of areas): For equal intervals of time, a satellite /planet will sweep equal areas in the orbital plane.

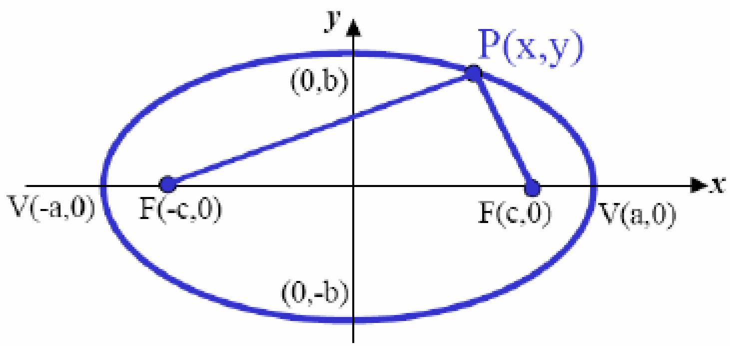
  – Third Law (also known as harmonic law): the square of the orbital period of any satellite/planet is proportional to the cube of the average distance(semi-major axis of its elliptical orbit)from the satellite/planet to the earth/sun. or

    The square of the time revolution of a planet /satellite divided by the cube of its mean distance from the sun /earth gives a number that is same for all planets/satellites.

Kepler's Three Law

- **First Law:** Orbit is an *ellipse* with the larger body (earth) at one focus
- **Second Law:** The satellite sweeps out *equal arcs* in *equal time* (*NOTE*: for an ellipse, this means that the orbital speed varies around the orbit)
- **Third Law:** The square of the period of revolution equals a *constant* × the *third power* of the *semi-major axis* of the ellipse

Review of Ellipse Geometry



- Points (-c,0) and (c,0) are the **foci**.
- Points (-a,0) and (a,0) are the **vertices**.
- Line between vertices is the **major axis**.
- ***a*** is the length of the ***semi-major axis.***
- Line between (0,b) and (0,-b) is the **minor axis**.
- ***b*** is the length of the ***semi-minor axis.***

Important Relationships:

$$a^2 = b^2 + c^2$$

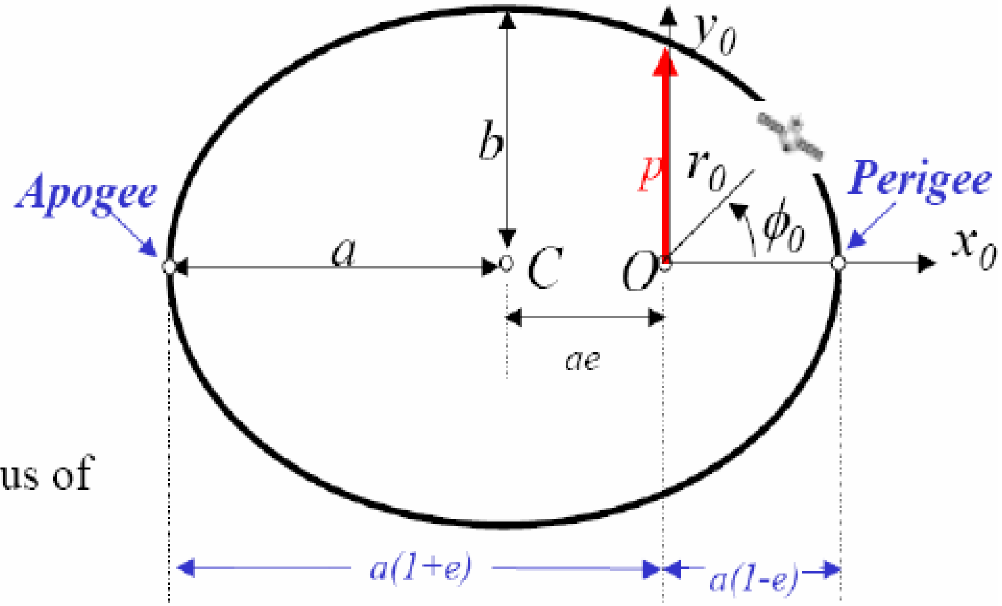
Standard Equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

Area of ellipse:

$$A = \pi ab$$

Kepler's First Law-Elliptical Orbits



Important Definitions:

- e = ellipse's eccentricity
  $0 < e < 1 \Rightarrow$ ellipse
  $e = 0 \Rightarrow$ circle
- O = center of earth (one focus of ellipse)
- C = center of ellipse
- Perigee = Point closest to earth
- Apogee = Point furthest from earth
- a = length of semi-major axis
  = (perigee + apogee)/2
- b = length of semi-minor axis

- p = width of ellipse at focus = $a(1-e^2)$
- r_0 = distance earth's center to satellite
- φ_0 = angle between r_0 and the perigee (the true anomaly)

Orbit Characteristics

- **Semi-axis lengths of the orbit**

$$a = \frac{p}{1 - e^2} \quad \text{and} \quad b = a\left(1 - e^2\right)^{1/2}$$

where $p = \frac{h^2}{\mu}$ and h is the magnitude of the angular momentum

- Eccentricity,e,is measure of elongation and is given by

  $e=[(a^2-b^2)/a^2]^{1/2}$

NOTE: For a circular orbit, $a = b$ and $e = 0$

- # SATELLITE ORBITAL TERMS
  - Basic Definitions to remember!!
    - Apogee
    - Perigee
    - Major Axis
    - Minor Axis

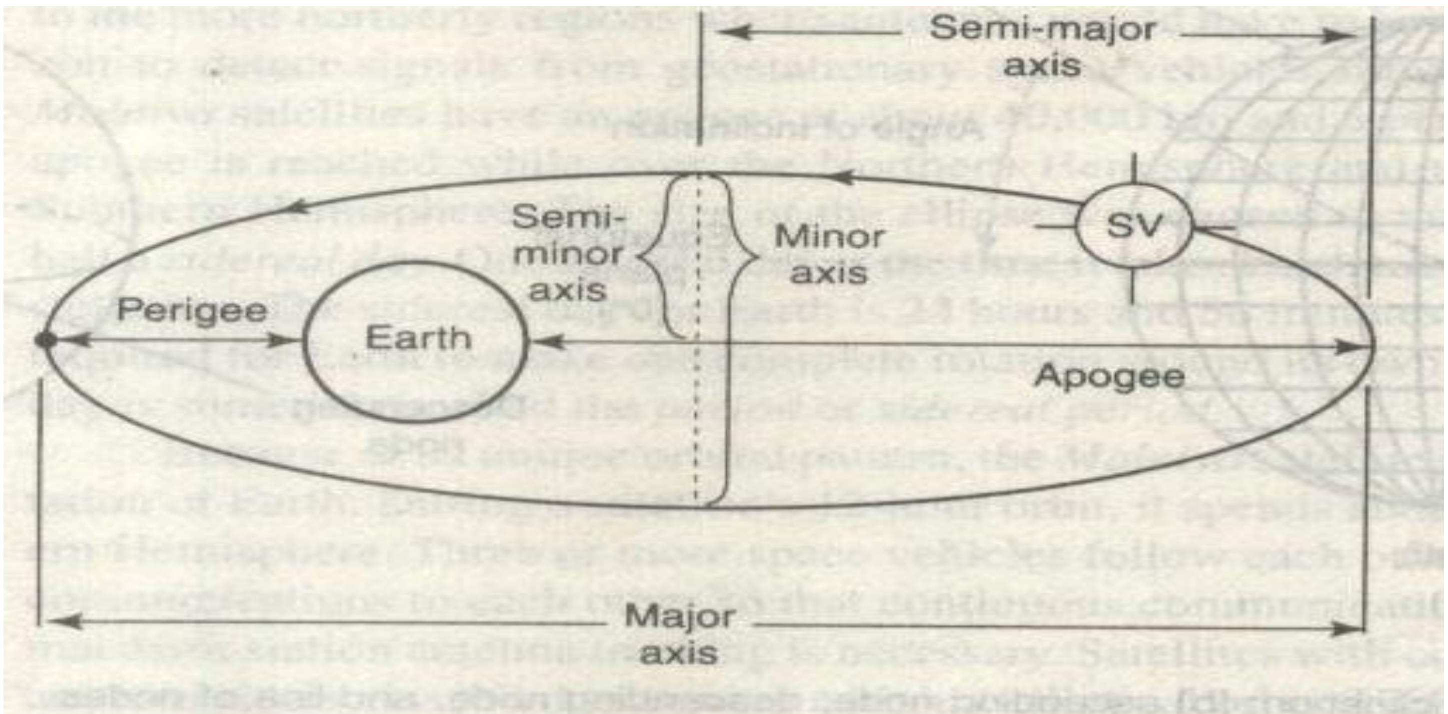
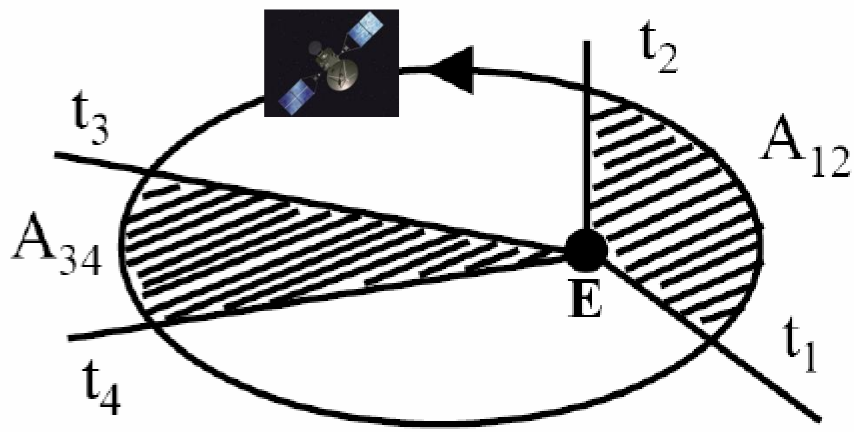


FIGURE 14-3 Satellite orbital terms

Kepler's Second Law:Equal Arc Areas

For equal intervals of time, a satellite /planet will sweep equal areas in the orbital plane.

- **If $t_2 - t_1 = t_4 - t_3$, then $A_{12} = A_{34}$**
- **Velocity of satellite is *slowest at apogee and fastest at perigee***



Kepler's Third Law:Orbital Period

- the square of the orbital period (T) of any satellite/planet is proportional to the cube of the average distance(semi-major axis of its elliptical orbit)from the satellite/planet to the earth/sun. OR
- The square of the time revolution of a planet /satellite divided by the cube of its mean distance from the sun /earth gives a number that is same for all planets/satellites.

• Orbital period and the Ellipse are related by:

$$T^2 = (4\,\pi^2 a^3) / \mu$$

μ = Kepler's Constant = GM_E

- Next Lecture to be Continued from the topic

Solar Day vs Sidereal Day!