University of Anbar

College of Engineering

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Advanced Communications Systems EE4335

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WEEK 1

SATELLITE COMMUNICATIONS

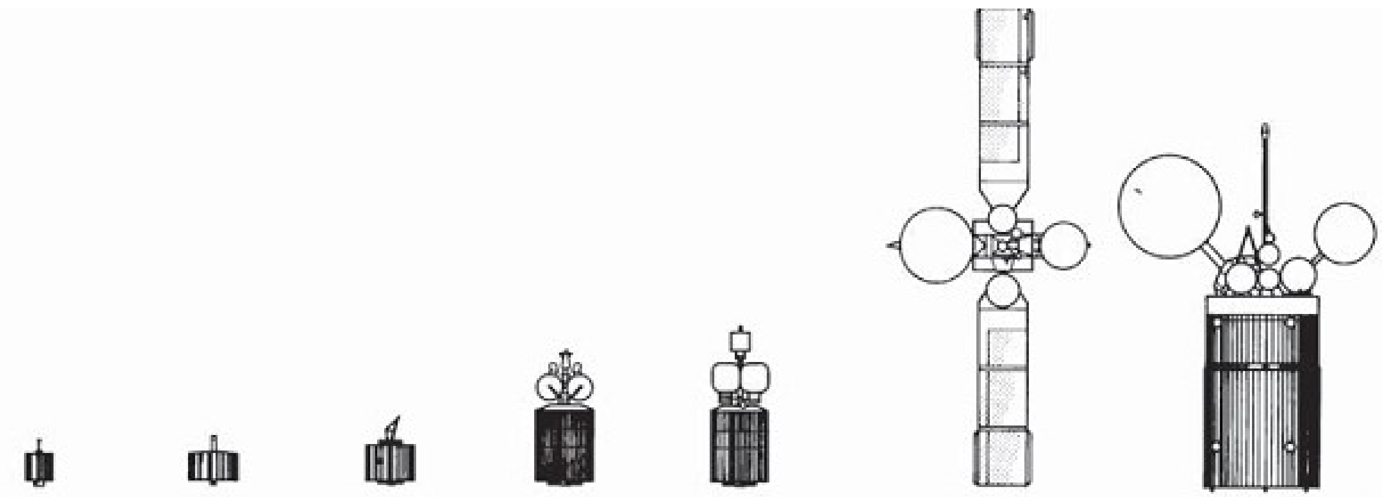
The idea of a communication through a satellite, in particular with a synchronous satellite was conceived by Arthur C. Clarke, a famous British science fiction writer in 1945. Clarke had already pointed out that a satellite in a circular equatorial orbit with a radius of about 42,242 km would have an angular velocity that matched the earth's. Thus, it would always remain above the same spot on the ground and it could receive and relay signals from most of a hemisphere. Three satellite spaced 120 degree apart could cover the whole world with some overlap provided that messages could be relayed between satellites and thus reliable communication between any two points in the world was possible. Clarke had also stated that the electrical power for the satellite would be obtained by conversion of the sun's radiation by means of solar cells. Clarke's paper went almost totally unnoticed until man-made satellites became a reality with Sputnik I (October 4, 1957). However, it may be noted that the synchronous orbit was not achieved until 1963.

Structure of Satellite Communications System

Communications Satellites are usually composed of the following subsystems:

- Communication Payload, normally composed of transponders, antenna, and switching systems.
- Engines used to bring the satellite to its desired orbit
- Station Keeping Tracking and stabilization subsystem used to keep the satellite in the right orbit, with its antennas pointed in the right direction, and its power system pointed towards the sun.
- Power subsystem, used to power the Satellite systems, normally composed of solar cells, and batteries that maintain power during solar eclipse.
- Command and Control subsystem, which maintains communications with ground control stations. The ground control earth stations monitor the satellite performance and control its functionality during various phases of its life-cycle.

The bandwidth available from a satellite depends upon the number of transponders provided by the satellite. Each service (TV, Voice, Internet, radio…etc) requires a different amount of bandwidth for transmission. This is typically known as link budgeting.



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

Figure 1.1 Evolution of INTELSAT satellites. (*From Colino 1985; courtesy of ITU Telecommunications Journal.*)

INTRODUCTION TO ORBITS

Satellites (spacecraft) orbiting the earth follow the same laws that govern the motion of the planets around the sun. From early times much has been learned about planetary motion through careful observations. Johannes Kepler (1571–1630) was able to derive empirically three laws describing planetary motion. Later, in 1665, Sir Isaac Newton (1642–1727) derived Kepler's laws from his own laws of mechanics and developed the theory of gravitation.

Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The more massive of the two bodies is referred to as the primary, the other, the secondary or satellite.

Newton's Law of motion can be written as

$$s = ut + \frac{1}{2}\, at^2$$

$$v = u^2 + 2\, at$$

$$F = ma$$

where: s is the distance travelled from t=0, u is the initial velocity at t=0, v is the final velocity at time=t, a is the acceleration, F is the force acting on the body, and m is the mass of the body.

Kepler's First Law

Kepler's first law states that **the path followed by a satellite around the primary will be an ellipse**. An ellipse has two focal points shown as F1 and F2 in Fig.1. The center of mass of the two body system, termed the barycenter, is always centered on one of the foci. In our specific case, because of the enormous difference between the masses of the earth and the satellite, the center of mass coincides with the center of the earth, which is therefore always at one of the foci.

The semi-major axis of the ellipse is denoted by a, and the semi-minor axis, by b. The eccentricity e is given by:

$$e = 2\frac{a-b}{a+b}$$

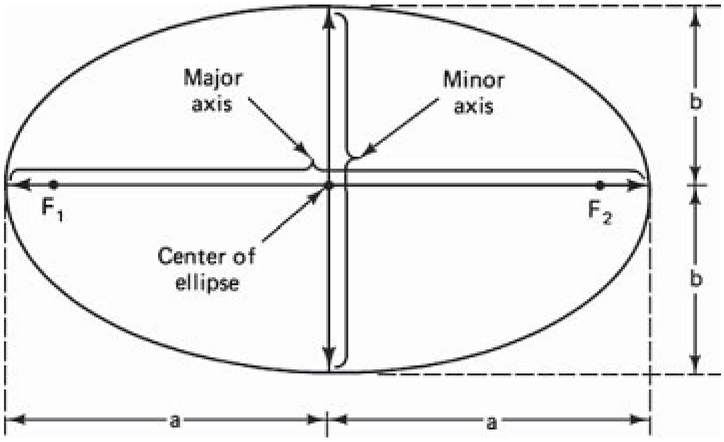


Fig1. The foci F1 and F2 , the semi-major axis a, and the semi-minor axis b of an ellipse.

Note that: e=0 for circular orbits, i.e., a=b

The eccentricity and the semimajor axis are two of the orbital parameters specified for satellites (spacecraft) orbiting the earth. For an elliptical orbit, $0 < e < 1$. When e =0, the orbit becomes circular.

Kepler's Second Law

Kepler's second law states that, **for equal time intervals, a satellite will sweep out equal areas in its orbital plane, focused at the barycenter.**

Referring to fig. 2, assuming the satellite travels distances S1and S2 meters in 1 s, then the areas A1 and A2 will be equal. The average velocity in each case is S1 and S2 m/s, and because of the equal area law, it follows that the velocity at S2 is less than that at S1. An important consequence of this is that the satellite takes longer to travel a given distance when it is farther away from earth. Use is made of this property to increase the length of time a satellite can be seen from particular geographic regions of the earth.

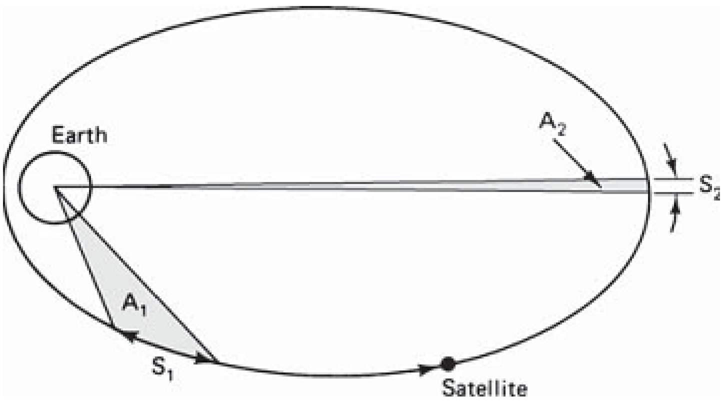


Fig.2 Kepler's second law. The areas A1 and A2 swept out are equal in time.

Kepler's Third Law

Kepler's third law states that **the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies.** The mean distance is equal to the semimajor axis a. For the artificial satellites orbiting the earth, Kepler's third law can be written in the form:

$$a^3 = \frac{\mu}{\eta^2}$$

where η is the mean angular velocity of the satellite in radians per second and μ is the earth's geocentric gravitational constant. Its value is:

$$\mu = 3.986005 * 10^{14} \ m^3/s^2$$

The orbital period in seconds is given by:

$$T = \frac{2\pi}{\eta}$$

The importance of Kepler's third law is that it shows there is a fixed relationship between period and semimajor axis. One very important orbit in particular, known as the geostationary orbit, is determined by the rotational period of the earth. In anticipation of this, the approximate radius of the geostationary orbit is determined in the following example.

Example: Calculate the radius of a circular orbit for which the period is 1 day.

Solution: There are 86,400 seconds in 1 day, and therefore the angular velocity/mean motion is:

$$\eta = \frac{2\pi}{86400} = 7.272 * 10^{-5} \ rad/s$$

From Kepler's third law:

$$a = \sqrt[3]{\left[\frac{3.986005 * 10^{14}}{(7.272 * 10^{-5})^2}\right]}$$

$$a = 42.241 \ km$$

Since the orbit is circular, the semi major axis is the same as the radius.