Satellite Communication Systems
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Lecture – 02
Orbit-1

Welcome to this course on Satellite Communication Systems.

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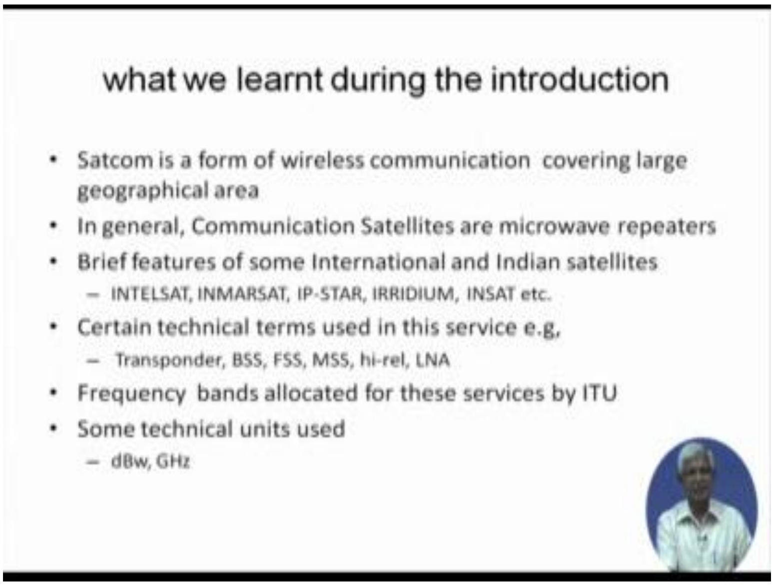

In last lecture we have learnt couple of things in the introduction. One of them is the satellite is a form of wireless communication where it covers a large geographical area that is one of the basic feature of satellite commutation. In general also we have seen that satellite communication or communication satellites are microwave repeaters other frequencies are also available, but generally it is microwave repeaters.

Some of the brief features of international and Indian satellites also we have seen like, INTELSAT, IMMARSAT, IP-STAR, IRIDIUM, INSAT etcetera. Then we have seen we have learnt about certain technical terms which are used in the service. Some of the terms are transponder we will come to know later what is it. Then terms like BSS, FSS, MSS, etcetera like broadcast satellite service, fixed satellite service, mobile satellite service hi-rel that is high reliability LNA low noise amplifier some of them you are familiar for some of them it is new terms. We will frequently use these types of terms.

Also we have seen the frequency bands allocated for these services like fixed satellite or broadcast service services by International Telecommunication Union. That is say international arrangement for sharing this natural resource which is a large wireless frequency band for different types services satellite services followed them. And also we have seen just a few technical units that are used like dBW, Giga hertz etcetera. We will frequently use this terms also we should know the meaning of these most of you know about it.

With this very brief basic knowledge we will start on the satellite communication system. Yesterday we have seen that it consists of three segments; space segment, ground segment and the propagation medium. Very briefly this can be described in three segments. Now, for space segment it consists of a satellite which is in the orbit and the ground station which controls that satellite. Now let us know something about this orbit. Orbital mechanics or orbital dynamics is a very large subject and we are looking at it from the communication angle. So, we will try to see those features of the orbit of this particular satellite orbit that will affect our communication system like, change in frequency, like the communication delay, like the noise, like power these are certain things which will be affecting our communication system which are the effect of orbit; so we will start with orbit.

And in this course I would try to go with some examples in between. So, all of your must have a calculator ready with you in hand so that in between whatever I try to show some formulas or numbers try to calculate and verify and you will get convinced that yes this is correct; that is how we will learn.

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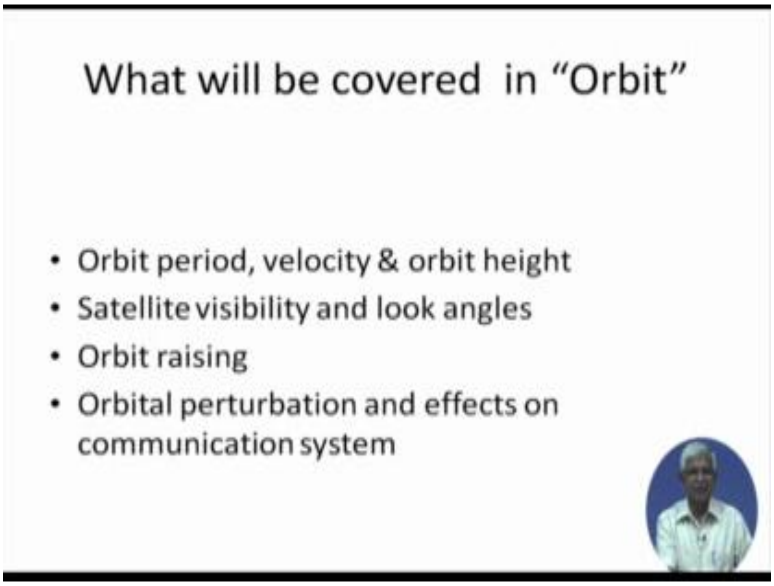

Now, the basic knowledge about the orbit in that we are going to cover in general, one is at the orbit, what is the velocity of the satellite, what will be the orbital height and the period and their relations. Also the satellite whether it is visible from the location where you are a user, what is the visibility of the satellite and at which direction which angle you can get that satellite.

Then briefly we will learn about how to reach that orbit, how people try and try to reach the orbit. And then this orbital perturbation the changes in the orbit and the effect of the orbital location of the satellite on communication system also we will learn. So, very briefly these are the major sub topics that we will cover.

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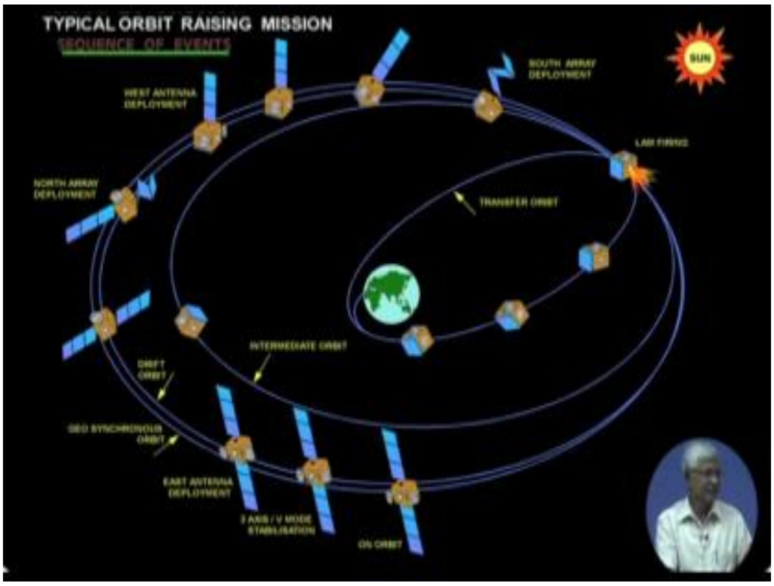

Now let us go back to our school days that is, before that let us look at this; this is a picture taken from the internet and a satellite which is launched from the earth here it looks like a cube packed. And then it goes into a particular orbit which is called transfer orbit and from there some rockets are fired in the satellite and it takes a different orbit and these orbital height is slowly changed and during that process the solar panel etcetera are getting deployed. And then finally, it reaches the intended orbit. This is a pictorial representation from all the internet sites.

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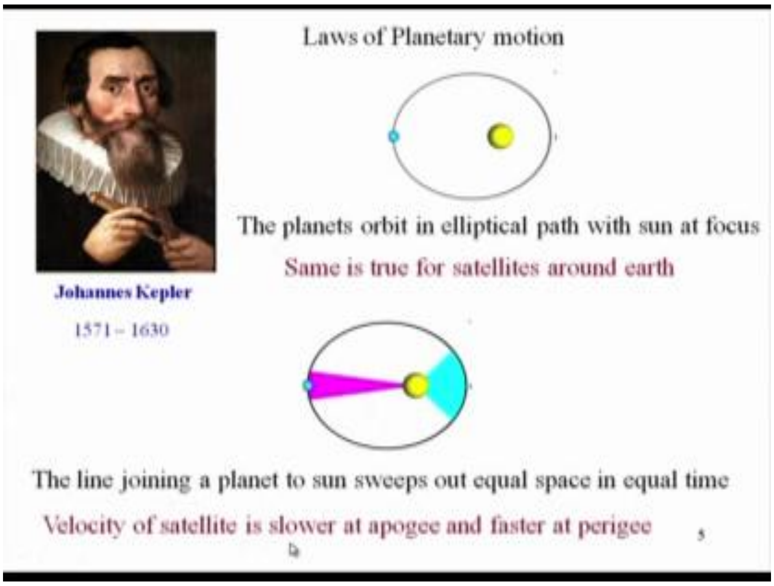

Now, at each of these positions satellite attains certain velocities certain height and takes some time to orbit. Let us recollect from our school days the Laws of Planetary motion, It was initially stated by John Kepler and all of you are familiar with that, so we need not go into the detail just to recollect the things. Is a natural law what John Kepler stated is the planets orbit in elliptical path with the sun at one of the focus. This is a sketch of that, is a natural force. So, these can be utilized between two bodies having mass. And therefore, it can be used that a satellite can move around the earth instead of sun let us call it earth now and the satellite can move around the earth and natural law is it can move in elliptical orbit. A special case could be a circular orbit, this is natural law. And that natural law gets affected by the velocity and the time period and the orbital height etcetera, we will try to calculate those numbers

There is second law which states that the line joining the planet to the sun sweeps out equal space in equal time. That means, this area to travel the planet over this much arc will create this much are which is swiped. The time taken to travel from this arc will be same as time taken to travel this earth which has the similar area. This has very good implication. That is you can see always that here the time taken and here the time taken are same. Therefore, relatively the time taken here is slower compared to the time taken here is faster between them. And if it is ellipse there is a perigee and apogee the way we define, so, at perigee the velocity will be larger faster compared to at apogee. So, this is a very important law we will try to utilize this. So, velocity of satellite is slower at apogee and faster at perigee this is the second law.

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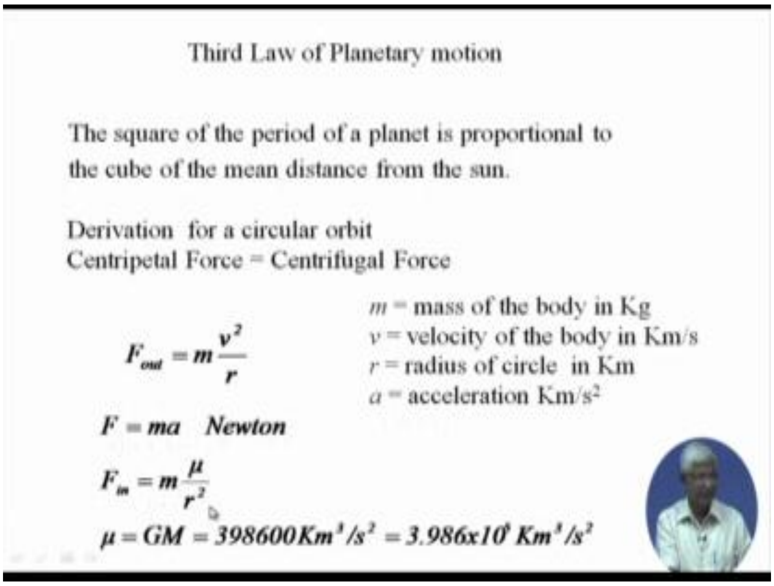

And the third law of planetary motion states the square of the period of the planet to the orbit is proportional to the cube of mean distance from the sun. These things can be derived let us say for a circular orbit you have learnt this things in school days that centripetal force is equal to centrifugal force then it will move in a circular orbit.

And if we take m as mass v as velocity r as radius of circle and a is acceleration the outward force is m v square by r, and that inward force is m mu by r square or mu is a constant whose value is 3.98 into 10 to the power of 5 kilometers cube per meter square. Remember that this is in kilometer, so if we have to calculate some time in meter we have to look at these numbers and change some of the numbers here. So, this mu will come very frequently in our calculation.

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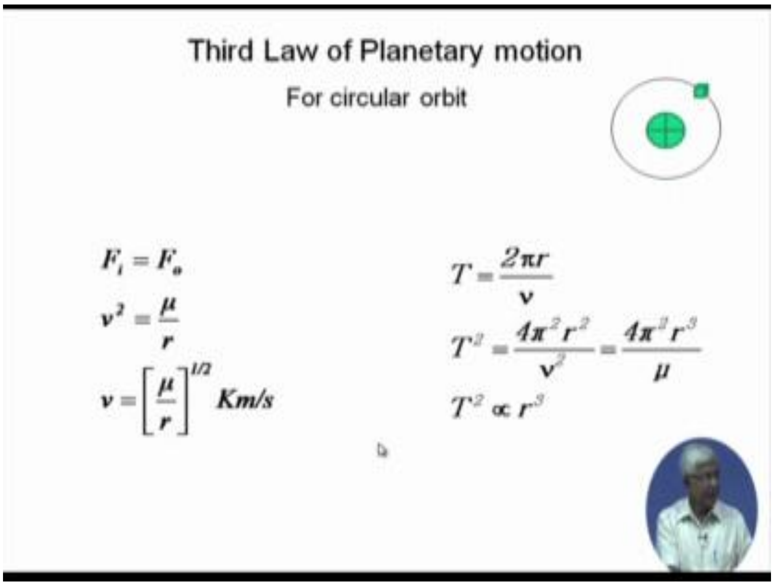

When f in and f out are equal in a circular orbit we get velocity square is equal to mu by r or velocity is mu by r root over, it is in kilometer per second. From this we can find out the time period to the orbit. That is time is 2 pi r that is the circumference by velocity and replacing the velocity T square is equal to 4 pi square r square by v square by squaring this term and put the value of v square that is mu by r so it becomes 4 pi square r cube by nu or T square is proportional to r cube. That is what is stated by Kepler.

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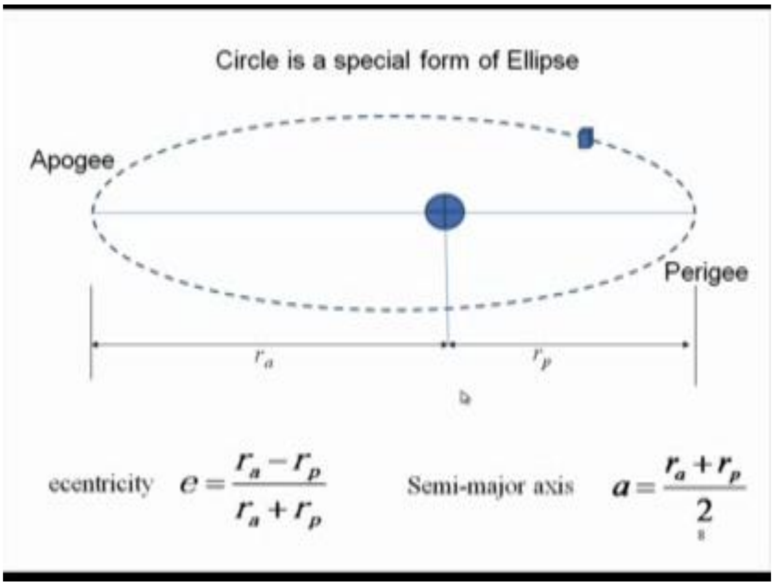

Now, you know circle is a special form of ellipse. So therefore let us look at ellipse, ellipse if you remember that is from the focus through the perigee we can call r p, focus to the apogee the distance is r a and there is a semi major axis and eccentricity which are expressed in terms of r a and r p are like this. These are school days expression.

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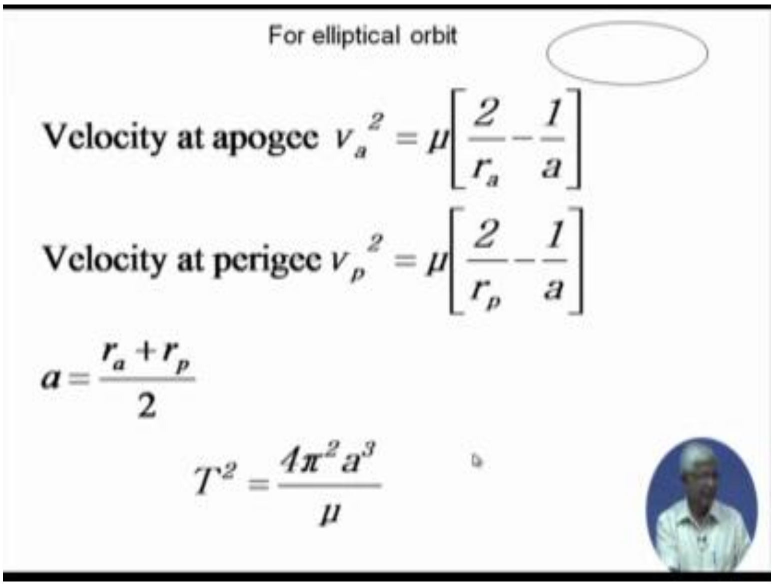

So, if we put the planet in or planet or satellite in the elliptical orbit at r a, the velocity will be v a square is equal to nu by 2 by r a minus 1 by a; a is same major axis and velocity of at perigee is r p you will be coming. Therefore, you can see depending on the r a and r p the velocity at apogee and perigee is different. And T square is represented by 4 pi square a cube by nu, just like inserting it is 4 pi square r cube by mu. These are the formulas which we know.

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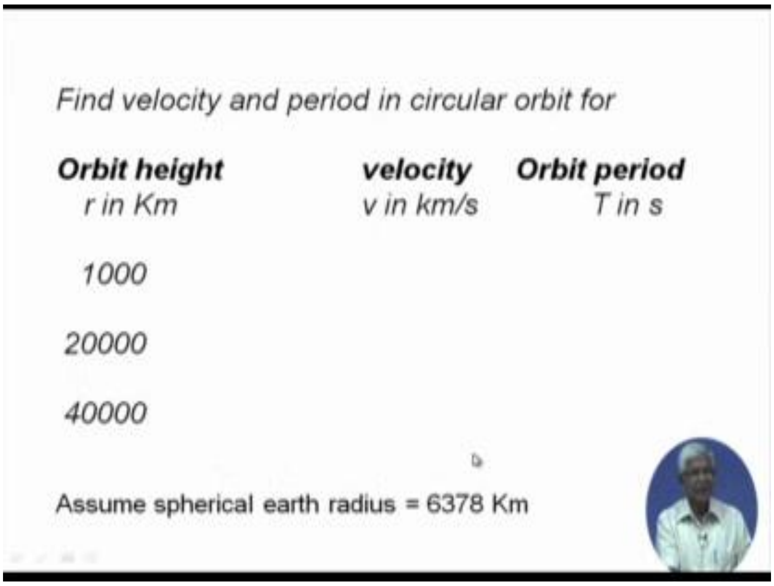

Now let us use these formula, this is where your calculator will come into picture. Let us use the formula and try to understand the implications. Let us try to make a table where orbital height we increase in numbers like 1000 kilometer, 20000 kilometer, 40000 kilometer like that and correspondingly for each of these orbital heights we calculate the velocity and orbital period. Try to remember try to see that I am using a term orbit height, orbit height I am calling height normally where we stand from there how high it is. So therefore, I am assuming that this is orbit height is from the surface of the earth, but the calculations were based on the center point of the circle. Therefore, the radius of the earth has been added to this to get from the centre what is the radius of the earth orbit.

So, to find out the radius of the orbit for 1000 kilometer orbital height it will be 1000 kilometer plus 6378 this is just assumption, because earth is not exactly sphere we assume here that earth is a sphere with this type of number as a radius of a sphere. So, this radius of the earth plus this orbit height to be added and then you do the calculation of velocity and orbital period. You must try it, just do not look at the number what I am going to show you these numbers have to be verified by you. Anyway I will show you the numbers.

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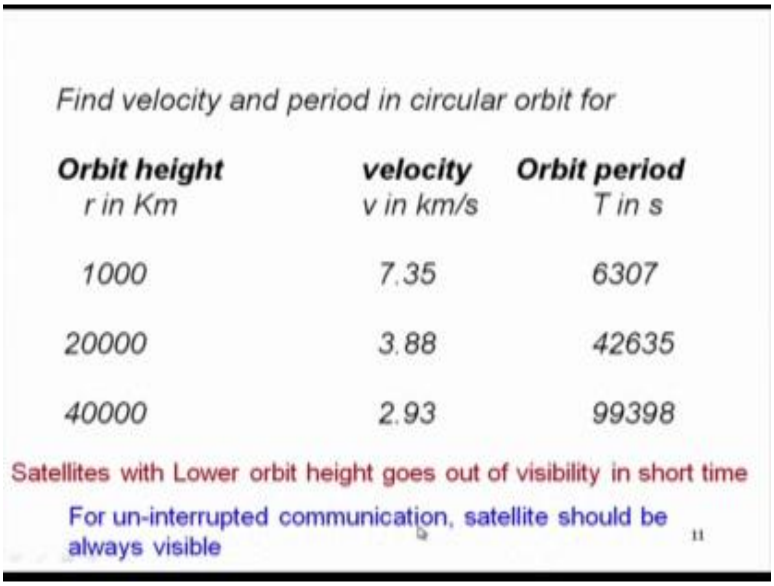

Let us say for 1000 kilometer orbital height you get the velocity 7.35, this decimal number do not get much worried if there is some slightly different number appears just calculate the errors that is all. But is more than 7 kilometer per second at 1000 kilometer orbital height. Based on the center of the orbit is 6378 plus 1000 kilometer from the center of the orbit, if we assume earth is sphere.

And corresponding orbit period is slightly more than 100 minutes which is in second 6307 that is what this calculation shows you get the similar number. So, we sped fast at 1000 kilometer orbit 7 kilometer per second. And it revolves around the earth in 100 minutes that is for a short time it will be visible to you on the earth because you are on sitting standing on a earth surface at just road goes out of view it will appear after about 100 minutes period.

Let us see what happens at 20000 kilometer, at 20000 kilometer the velocity again you have to calculate 20000 kilometer is orbital height and you have to add that surface the radius of the earth as 6378 in this case and you will get a velocity number slightly more than almost 4 kilometer per second, slightly less than 4 kilometer per second. And orbital period is 42600 second, velocity has reduced.

Now, you try for 40000 kilometer, and then you get a number like this almost 3 kilometer per second orbital period and orbital sorry, orbital velocity 3 kilometer per second orbital period is 99300 or 400 seconds. So, looking at the tables these numbers gives us some indication that is as we increase the orbital height, based on natural law we see that at those orbital height when we increase the velocity of the satellite or that particular space craft is reducing and it is talking more time to complete the orbit, it is a circular orbit.

One of the observations from this table is satellites with lower orbit heights goes out visibility in a short time, now you are communication engineer. Look at it from the communication point of view if you want uninterrupted communication then only for few minutes you will be able to use that satellite as a repeater and quite a long time you have to wait almost for 1000 kilometer more than an hour more than an hour or hour and half you have to wait for that repeated to appear again. So, you start communicating with one and half hour, again start communicating it is irritating. For real time communication it is irritating. There are some forms of communication where it is to and forward you can use it. But then it is this one of the important observation. So, for uninterrupted communication satellite should be always visible.

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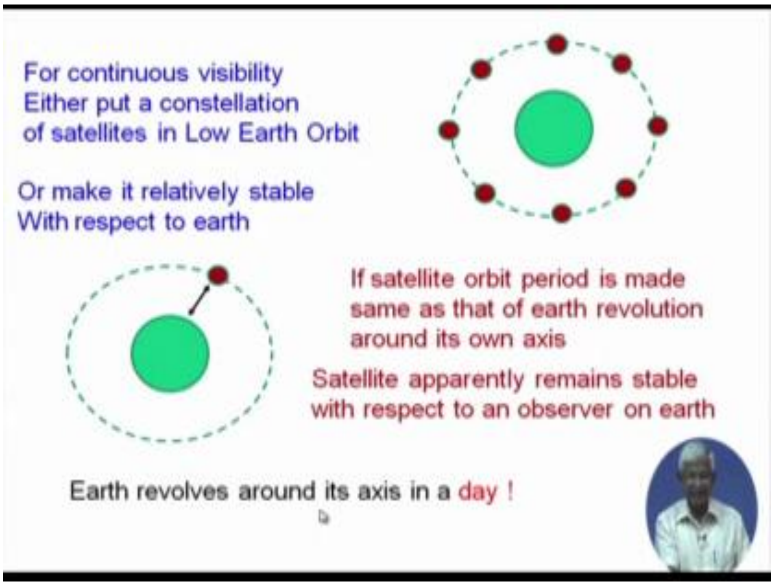

So, how we can do it? There are possibilities simple possibilities shown here we are talking let us put a constellation of satellites, large number of satellites at lower earth orbit. So, that one satellite it you are here, one satellite goes out of visibility the second satellite will come if that goes out of visibility the third satellite is coming. But then there is that handover takeover mechanism and lot of other complications are there, but still some repeaters in the sky are available for you to support your communication. This is one way.

There is another way. The other way is make this satellite relatively stable with respect to the movement of the earth. Now how that can be done, that can be done only if the satellite period is made same as that of revolution of the earth on its own axis because earth is moving. If the earth is moving that revolution what is the time it takes to revolve once the orbit and period is same as that then it is relatively stable. So, this is one important observation we have seen. And how much earth rotates in its own axis complete one axis we have seen, that it is called earth revolves around its axis in a day.

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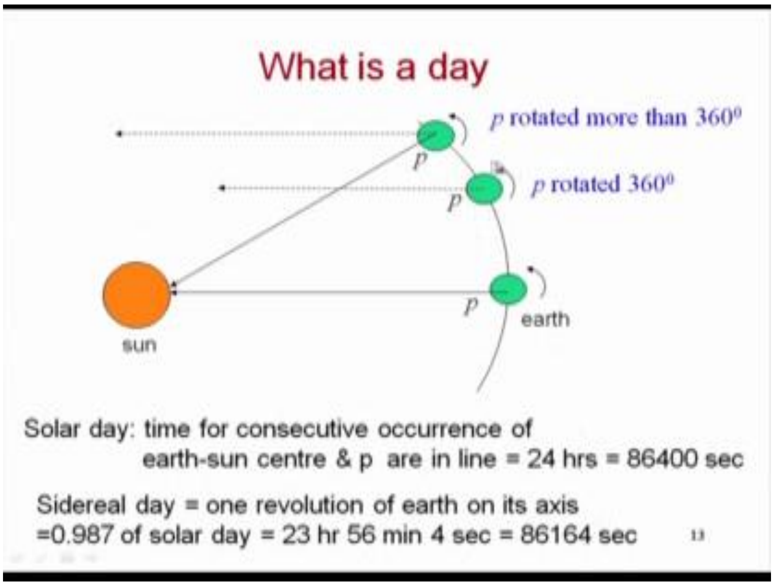

Now, what is a day? You know the sun is there the earth is there and if we join center point of the sun and the center point of the earth a point P crosses the surface of the earth. So, for the point P observer sitting or standing at the point P, a day is a time for consecutive occurrence of earth sun center and the P in one line. That means at this instance P is here and earth is moving like this around sun, so at some other P next consecutive instance center of the earth P and sun all comes in a line we call it a day. At 12 o clock at noon you stand you have a let us assume that sun is the overhead to you and next day at 12 o clock in the noon sun will come again overhead. These difference of the time is called a solar day.

Let us rotate the earth; earth is rotating so P is also rotated accordingly. So, if you move 360 degrees from here P is here it is not in the straight line at center of the earth P is not reaching the center of this earth. Then we move earth a little more and after some more revolution of the earth we get center of the earth P and sun same line. From here to here that is a solar day, but earth has revolved more than 360 degree on solar day. So that we can define that this is also a day which we call sidereal day and the term. That is one revolution of earth in its axis. So, is one revolution of the earth in its axis is less than a solar day, because solar day took more time that to reach the P center of the earth and center of the sun in same line.

It can calculated, that it is 0.987 of a solar day it is 23 hours 56 minutes 4 seconds roughly which in terms of second comes out to be 86164. Whereas, if full solar day 24 hours is 86400 second. Now, in this process what we have learnt that if we use this time period which is one revolution of the earth 360 degrees is this time and use this time period we can get the orbital height.

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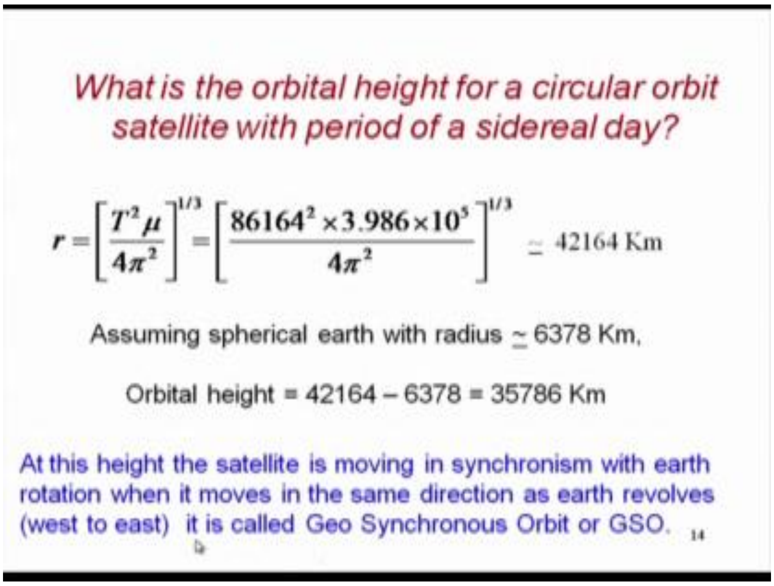

So, what is the orbital height of a circular orbit satellite with a period of one sidereal day that is one revolution of earth? Let us recollect that formula for the time period of the orbit that is T square is equal to 4 pi square by mu and r cube and from that r can be calculated r as T square nu by 4 pi square one third root of that.

Let us put the number sidereal day T square 86164 square nu if you recollect it was 3.986 into 10 to the power of 5 kilometer cube per second square and of course by 4 pi square and one third root of that. So, that you get a number roughly about 42164 kilometer from the center of the earth assuming earth as a sphere.

So, from center of the earth if it is 42164 kilometer at that orbital height if it rotates in the same direction of the earth then the satellite will be relatively stable to a observer on the earth.

So, assuming spherical earth with radius of 6378 the orbital height again from the surface of the earth is 35786 kilometer these are all rough numbers. Roughly sometimes people call 36000 kilometer. If you recollect yesterday in the last lecture we have said that at 36000 kilometer height it will be relatively stable, so this is the calculation which says that orbital height of this that is 36000 or 35700 kilometer assuming this is the radius of the earth it will be relatively stable.

Now, there is certain definition at these height a satellite is moving in synchronism with earth rotation when it moves in the same direction as the earth revolves that is west to east it is called Geo Synchronous Orbit or in short GSO.

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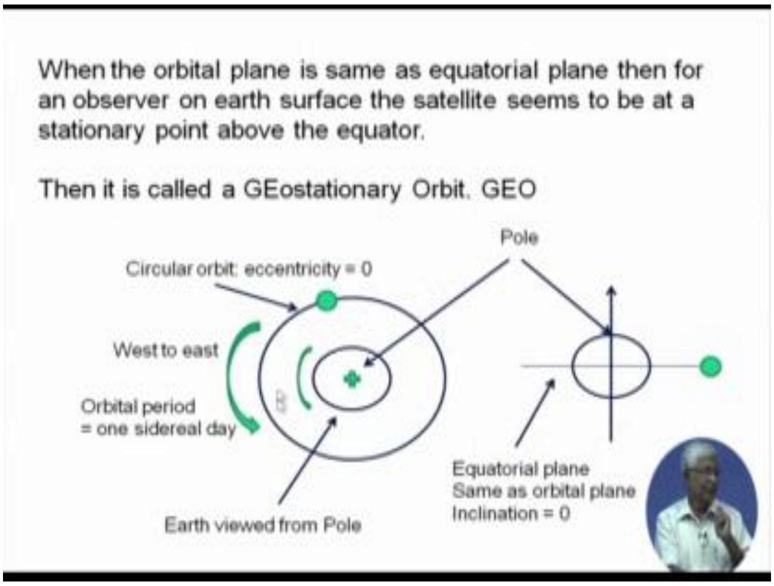

But still there are some more information in it let us see that. When this orbital plane is same as equatorial plane then for observer on earth surface the satellite seems to be at a stationery point above the equator. Just imagine earth as a sphere and the equator is extended, but the earth in between the equator is extended as a plane and on that a satellite is orbiting on the equatorial plane so orbital plane is same as that of equatorial plane. Just here I am trying to show you a view that is as if this is the north side of the pole and this is the earth and this is the equatorial plane at the center of the earth I have cut and satellite is put here which is orbiting on this plane.

That means, satellite orbital plane is about orbital plane has not inclination with a equatorial plane, it is just 0 degree integration. We can view it from the top of the pole that is the north pole from the top, earth viewed from the pole and then you can see that equator earth bulge is the equator let us say this is the equatorial plane and on that the satellite is orbiting and it is in circular orbit, so eccentricity is 0. And it is moving as earth rotates west to east, this is west to east and orbital period is one sidereal day. So, then it is called Geo Stationary Orbit; GEO other one was geo synchronous orbit, so this is geostationary orbit.

I have put lot of conditions, there is no inclination eccentricity is 0 and the same direction and one sidereal day.

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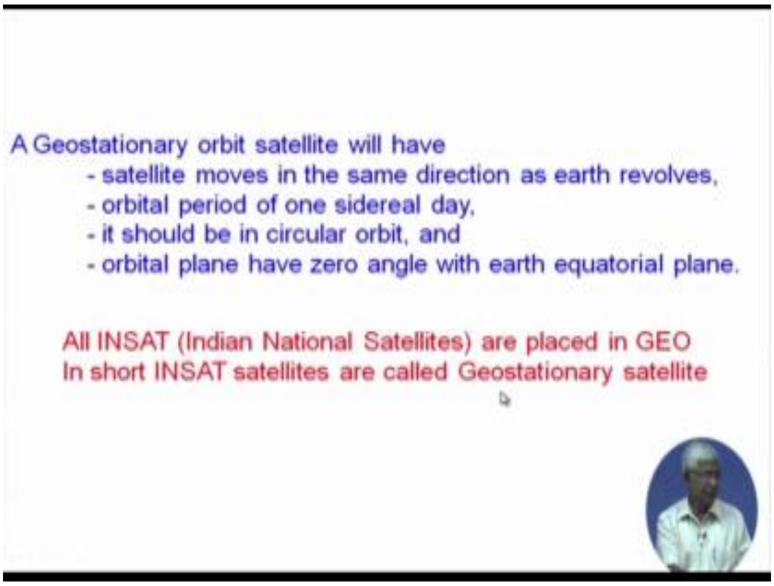

So, geostationary orbit satellite will have satellite moving in the same direction as the earth revolves. Orbital period is one sidereal day it should be in circular orbit and orbital plane have 0 angles with equatorial plane. All Indian national satellites which are INSAT are placed in GEO; in short INSAT satellites are called geostationary satellite.

So, we stop here for this period and we will continue this discussion on orbit in the next period.

Thank you very much.