Satellite Communication Systems
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Lecture – 03
Orbit-2

Welcome again. Let us try to recollect where we last time stopped, that was we were talking about Geostationary Orbit of a Satellite.

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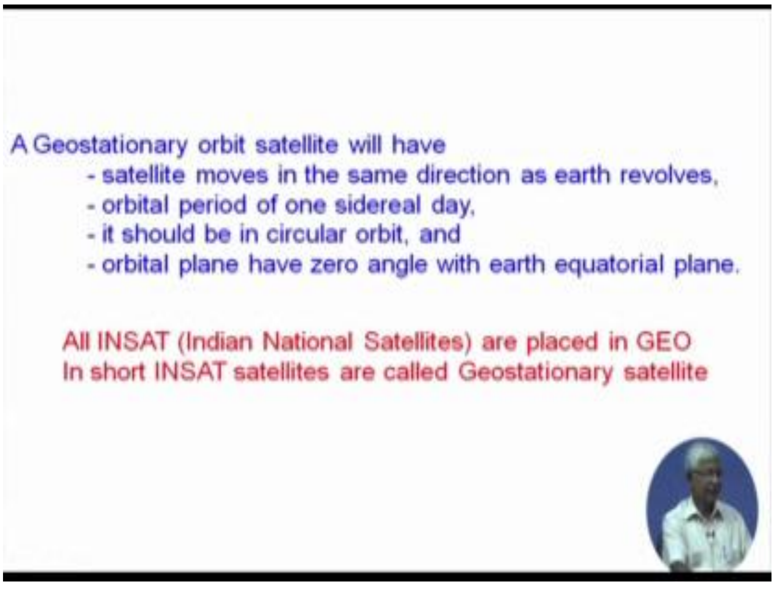

So, by definition a geostationary orbit of a satellite will have satellite moving in the same direction as the earth revolves, the orbital period of one sidereal day, it should be in a circular orbit and orbital plane have a zero inclination angle with the earth equatorial plane. Now as we said that our Indian National Satellites INSATs are all placed in geostationary orbit or it is called GEO.

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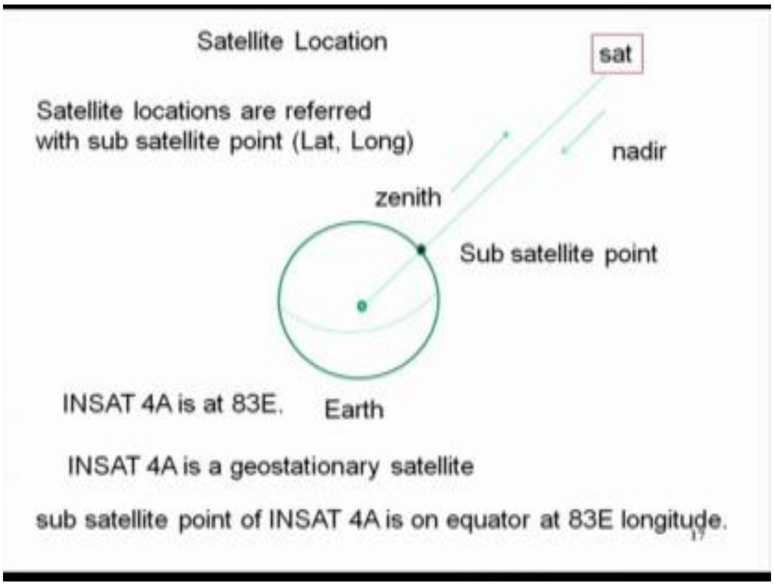

Let us see some more definitions of that. Let us assume this sphere earth sphere and this center of the earth and this is the equator and a satellite is there. Now this satellite where it is, how do you define, there are many ways you can have different coordinate systems and define where the satellite is. But, very common used terminology is at this satellite to the center of the earth if we draw a line at some point it cuts the earth surface so that is called sub satellite point as if somebody is looking from the satellite directly to the center of the earth, then on the earth surface the line crossing there its called sub satellite point. And towards the some satellite point it from the satellite if we look it is called nadir; n a d i r. And from the sub satellite point if we look at the satellite it is called zenith. This term will come when we talk about the antenna.

Now, the location of the satellite is defined in terms of sub satellite point; latitude, longitude a funny way. But this is very commonly used that is satellite locations are referred with sub satellite point latitude longitude. Let us see for INSAT how it will look like. They say INSAT 4A is one of the fourth generation satellite is at 83 degree east stop there. So, it talks about the longitude it does not say there is a latitude means it is a geostationary orbit satellite where latitude is zero and its sub satellite point is at 83 degree east on equator.

So, INSAT 4A is a geostationary satellite and sub satellite point of INSAT 4A is on equator at 83 degree east longitude, it is on equator here; here it is not shown that way this satellite is not geostationary satellite just for your understanding I have drawn it like that. But, if it is INSAT 4A at 83 degree east then 4A is a geostationary satellite and sub satellite point of INSAT 4A is on equator at 83 degree east longitude.

Now, I am going to ask you a question, think carefully.

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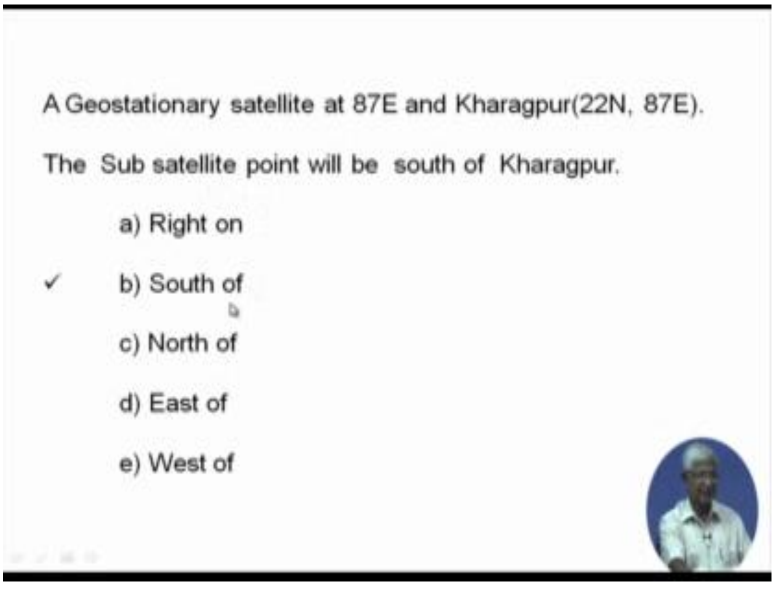

A geostationary satellite at 87 degree east and Kharagpur is 22 degree north and 87 degree east. The sub satellite point will be; right on Kharagpur, south of Kharagpur, north of Kharagpur, east of Kharagpur, west of Kharagpur where think and then you should answer, just do not look at the next part of the video and try to find the answer. Think see Kharagpur is north of equator it is not at equator. And for a geostationary satellite sub satellite point is on equator. So therefore, the answer will be from Kharagpur sub satellite point will be south of Kharagpur.

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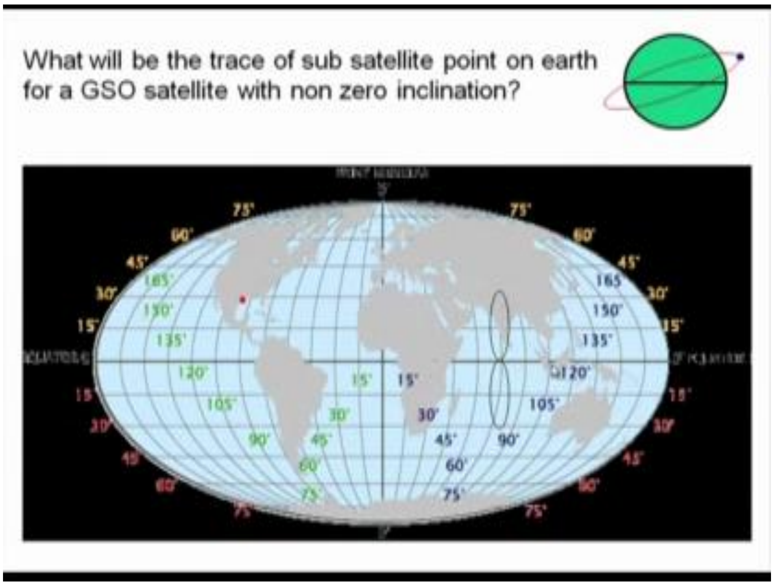

Now, what will be the trace of sub satellite point on earth for a GSO, now it is not GEO geosynchronous orbit satellite with non zero inclination? We have seen that sidereal time and the earth satellite orbital period is same then it becomes geosynchronous, but if I say inclination it is not geostationary. So, its sub satellite point will be moving, it is like this earth and this is the equatorial plane and orbital plane is making some inclination not zero inclination. Then the sub satellite point earth is revolving.

How the sub satellite point will revolve? Take atlas and then try to see where the sub satellite point of this is India and let us see INSAT is somewhere here and one of the INSAT is not geostationary, we have slightly changed it make it made it geosynchronous. So, what will be the sub satellite point trace? You have to think and find out. Here I am going to show you it is like a figure of 8. And for some other purpose not a communication satellite, navigation satellite, Indian regional navigational satellites some of them are placed in geosynchronous orbit. So, that it moves top and bottom that is from equator plane north and south and exactly in sidereal d it completes this figure of 8.

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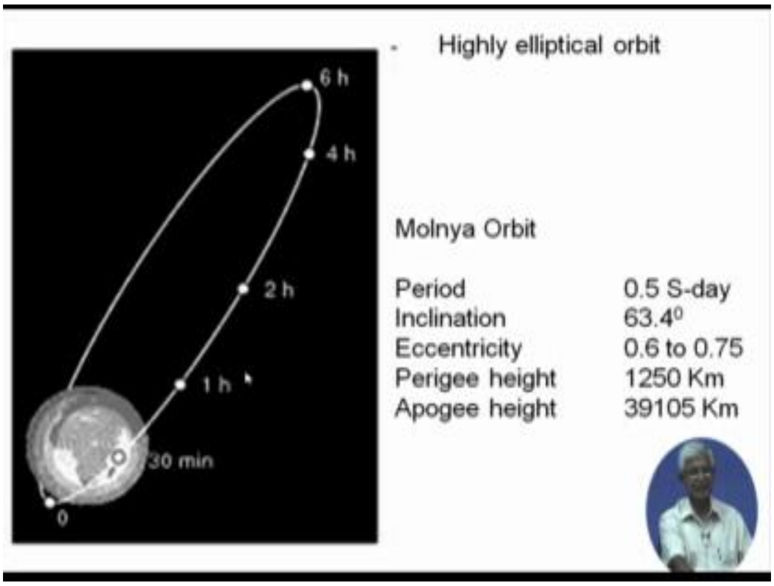

Now, there is another possibility that is a highly elliptical orbit. That is the inclination was non zero and there could be eccentricity non-zero then it is a highly elliptical orbit. There are some satellites which are highly elliptical orbit is called molniya orbit which are mainly used by Russia and some of them are in this case the period is not full one sidereal d its half of sidereal d inclination is 63 degree, eccentricity is given, perigee and apogee heights are given. These are numbers taken from one year.

So, there are some satellites which are used for highly elliptical orbits purpose is different. We will concentrate our Indian purpose.

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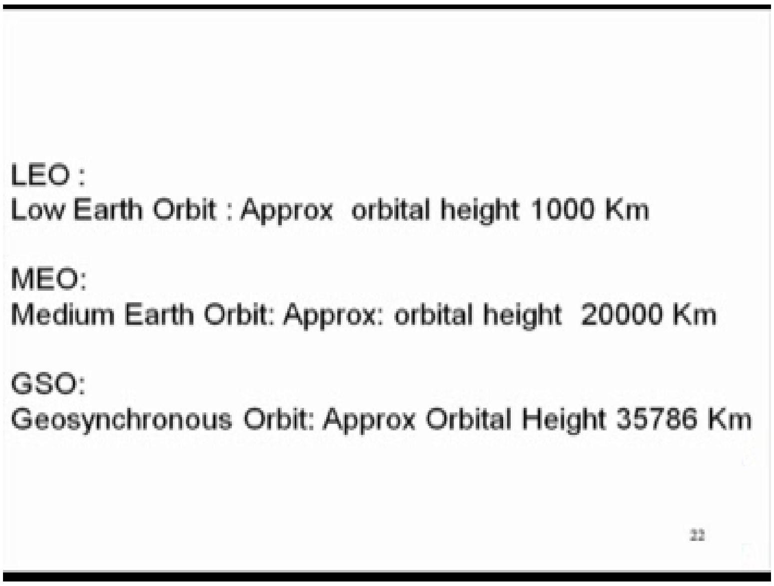

Now, there are other orbits also. Approximately it is defined that is low earth orbit its approximate height is 1000 kilometer. There is no boundary that is it has to be so and so orbit. Of this order 1000 kilometer is low earth orbit, medium earth orbit is approximately 20000 kilometer around that, and geosynchronous orbit is approximately 36000 kilometer we have seen. So, these are very brief definitions of; we will use this term LEO, MEO and GSO and GEO that is why I have shown this.

Now, this is what we have seen about orbit briefly, but where is the satellite. It can be defined in terms of sub satellite point, but wherever you are on the earth surface you have to put your antenna looking at the satellite then only you will get the signal. So, you must know which direction is the satellite and how to look at it. Let us do some look angle understanding and calculation.

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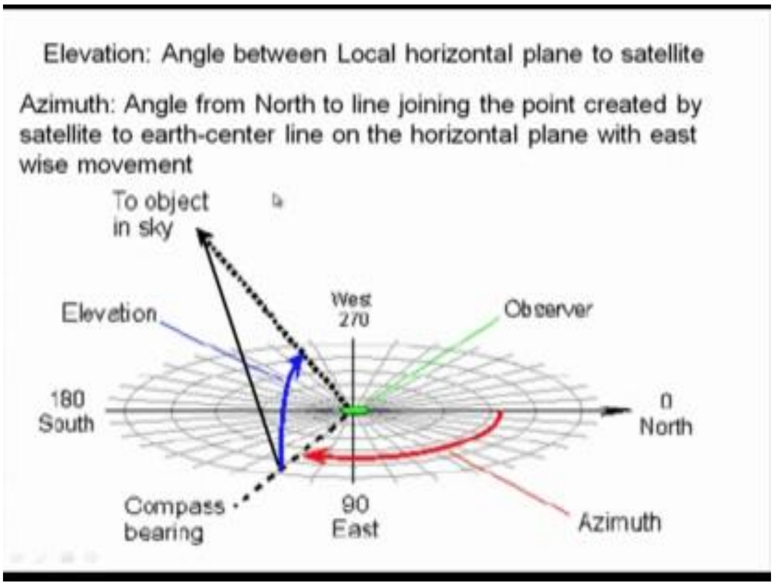

So, here also certain common terminologies are used which is called azimuth and elevation. This diagram is taken from internet from somewhere, let us try to understand this diagram I could not draw it properly so just I will try to explain it here. Below this elliptical circle what I have drawn here assume that this is a plane and observer is standing here so below that there is earth which is not drawn here, so this plane which is called horizontal plane if you stand on surface of the earth how many foot you just put a plane around the earth that is tangent to the earth it is horizontal plane; it is called horizontal, this is drawn as a horizontal plane.

Assume that this side is north and this is horizontal plane and there is object in the sky which is in this case satellite. So, this satellite to the center of the earth it will draw a line and drop a line to the center of the earth, it will cut this horizontal plane at some point; it is not sub satellite point, sub satellite point is different that is on the earth surface, it is on the horizontal plane you cut. If you draw a line from observer to this point then the angle from the north towards the east is azimuth and the angle from horizontal plane to the line joining observer to the satellite is elevation.

The line joining the point which is cut which is going towards the sub satellite point, so this line to the line joining from the observer to the satellite this angle is elevation; that means, you are looking from the horizontal plane you are going up and looking towards the satellite and also this angle has to be rotated from the north eastward, so you orient your antenna eastward and you will again come to that line and you will get the azimuth. So, this is azimuth and elevation. In the text book different diagrams are there you can look at those and try to understand. But main thing is understanding what is elevation and what is azimuth.

So, the antenna has been pointed skyward in angle of elevation and from the north eastward on the horizontal plane in the angle of azimuth. So, let us try to do some calculation for that you may have to recollect the geometry and the derivations and other things we need not go into that much detail. Our interest is to know that from my location that is user location on the earth surface how much distance away is the satellite, which direction I should look to the satellite, whether satellite is visible to me or not. Those types of questions will be we will try to answer. So therefore, some derivations we are not doing, but certain definitions we have to understand clearly. You do those calculations.

So, let us do the spherical geometry calculation. Here again azimuth is the angle from the north to the line joining the point created by the satellite to the earth center line on the horizontal plane with east wise movement, I am explain this one.

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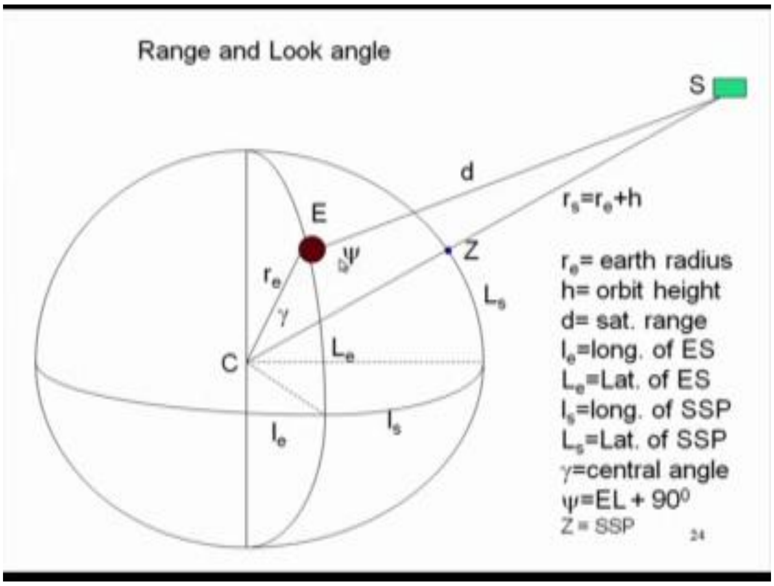

So, let us go to the next line. Here, I have drawn in another way this is the center of the earth and this is the equator on the surface of the earth, from the center of the earth. The earth station E, center of the earth we call C and the satellite I call S, so S to C if I draw a line Z is the point which cuts the surface of the earth so Z is the sub satellite point. Again on the surface of the earth there is a station called earth station I call it E, so from E to the satellite that is this length E S is the distance from the observer that is the earth station to the satellite. This is important for us because we will try to find out what is the delay for the signal to reach the satellite or from satellite to the earth station.

And also these are the radius of the earth. Assuming earth as a sphere C to E is the radius of the earth. Similarly there are latitude longitudes that will be coming. So, this is the longitude of the earth station called E and this will be the latitude both are L. So, let us define small l for a longitude and capital L for latitude. So, I will try to define r e as a earth radius, h as a orbital height that is Z to S, d as a satellite range that is E to S, small l e is the longitude of the earth station that is small l e this is the radius of the earth C E. Then the distance from satellite to the center of the earth C or C S is we call r s which is C Z that is r e plus the orbital height that is Z s; so r s is equal to r e plus h.

Then E to S is the distance from the earth observation that is earth station to satellite.

Longitude of the station small l e is this particular angle, assuming it is the meridian. Latitude of the station is this angle and sub satellite point longitude is small l s is this angle and latitude of the sub satellite point is capital L s is this angle.

Now, in this process we have created a triangle that is C E and S form where we can find out what is the distance d, that is our target for calculation. So, this C E and S we must have some angles which are defined inside, one of the angle is gamma let us define which is called central angle which is E C to S that is at the centre of the earth the angle created by this triangle. Then we have angle psi which is C to E that radius to E to S this line. This psi if you think carefully you will find that this psi is 90 degree plus that is from the earth station if we put a horizontal plane it will be 90 degree with the centre of the earth to a station and plus some angle, so psi will be 90 degree plus that angle which is nothing but elevation.

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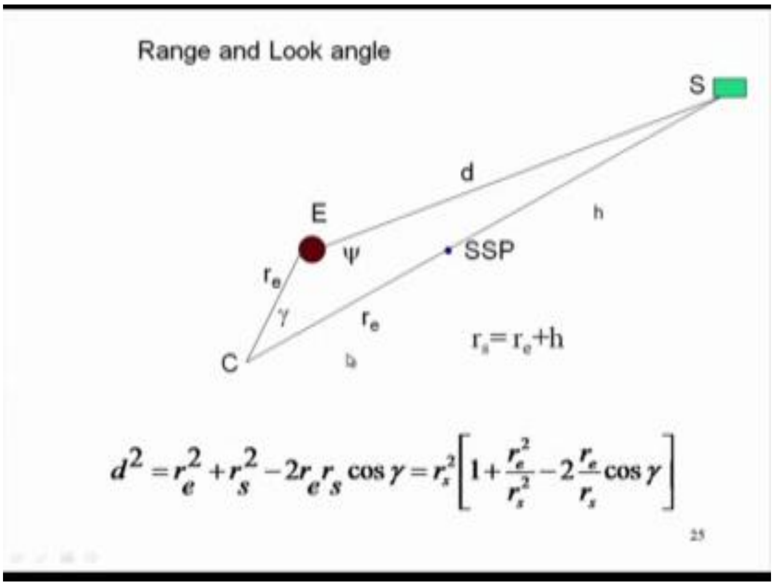

So, let us put this diagram in a different way remove the earth and we are interested in this triangle, where the C E and S is there and r s is equal to r e plus h which consist of the sub satellite point r e is C E, E S is d, gamma is the central angle and psi is 90 degree plus elevation. So, in a triangle we know to find out a one side of the triangle we can use the other two sides and the angle made by them and those standard formulas are d square is r e square and r s square minus 2 r e r s and cos gamma of this.

Now, if we take the r s square outside then this same expression can be given as 1 plus r e square by r s square minus 2 into r e by r s cos gamma just r s square is taken out we will see the implications of this. So, try to remember this particular triangle this gives us lots of information, one of the information right now we are deriving is the distance from the earth station to the satellite d and for which we must know what is the radius of the earth assuming the whole earth as a sphere and what is the orbital height which is h from there we can find out the distance from the centre of the earth to the satellite that is r s. So, to find out d I need r e and r s, and also we need to know the angle gamma.

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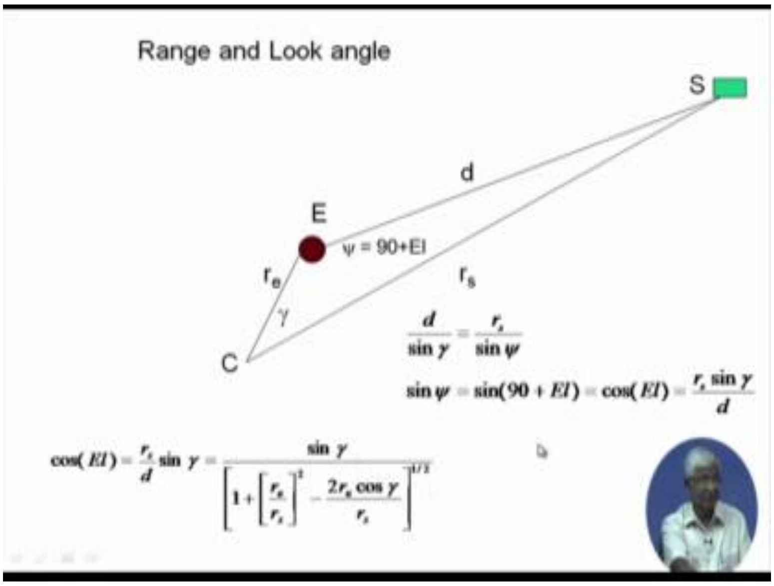

Lets look at it how do we find out the elevation. One uncertainty still remains how to find the gamma we will see that. First let us see that in this triangle again which is C E and S and which forms a central angle gamma at C and sides are d r e and r s. Using sin law we can state that d by sin gamma opposite side angle is r s by sin of opposite angle which is sin psi, which is nothing but 90 plus elevation. So, sin psi is sin 90 plus elevation which is nothing but cos elevation and by side changing you can find out the cos elevation is r s sin gamma by d simple triangle.

Now here we can replace d by r e and r s and gamma. So, cos elevation is r s by d sin gamma and if you remember in the last expression we have taken out r s outside so that r s and the numerator r s gets cancelled. So therefore, the expression becomes sin gamma by 1 plus r e by r s square minus 2 r e cos gamma by r s. In this case for elevation what is required? We need to know r e radius of the earth which is set in assumption as assuming earth as the sphere, and r s where we should know the orbital height in case of geostationary satellite it is known. And a cos gamma and sin gamma, so the gamma has to be known.

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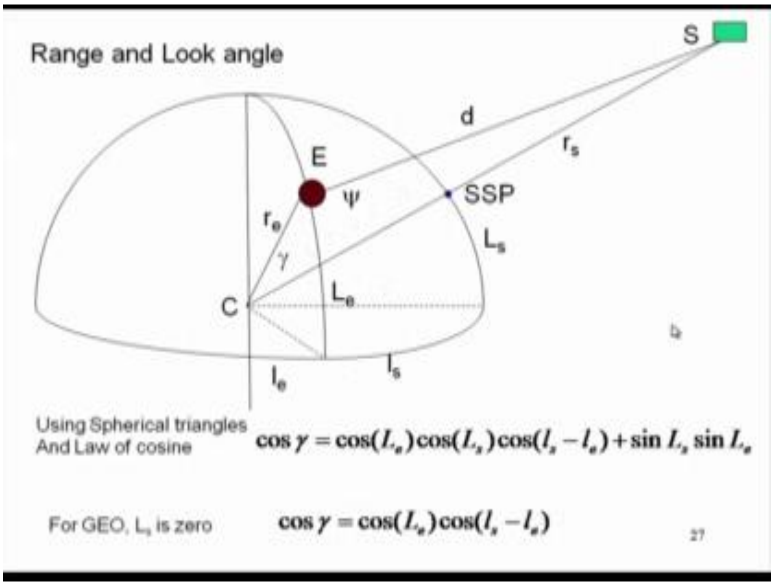

Now again in terms of latitude longitude and the same triangle using some spherical triangle and law of cosine, straightaway I am giving the expression the derivations are available in the books; it will take time if you go on explaining the derivation. You can remember that cos of gamma in terms of latitude and longitude of earth station and satellite the subscripts indicate whether if it is e it is a station, if it is s it is for satellite, capital L for latitude, small l for longitude.

So, cos gamma is expressed as cos of latitude of a station multiplied by cos of latitude of a satellite sub satellite point multiplied by cos of difference between longitude of a station and sub satellite point plus sin of latitude of satellite sub satellite point and sin of latitude of a station, this is a cos gamma so you can find out gamma and you can go back to the previous expression. Sin gamma and cos gamma values you can put and you will find what the elevation is.

One interesting thing that this is a generalized expression, so for geostationary orbit we have said that sub satellite point is having no latitude that is it is on the equator. So therefore, L s is 0 putting L s is equal to 0 here you get cos gamma is equal to cos L e cos of difference of longitude of a station and sub satellite.

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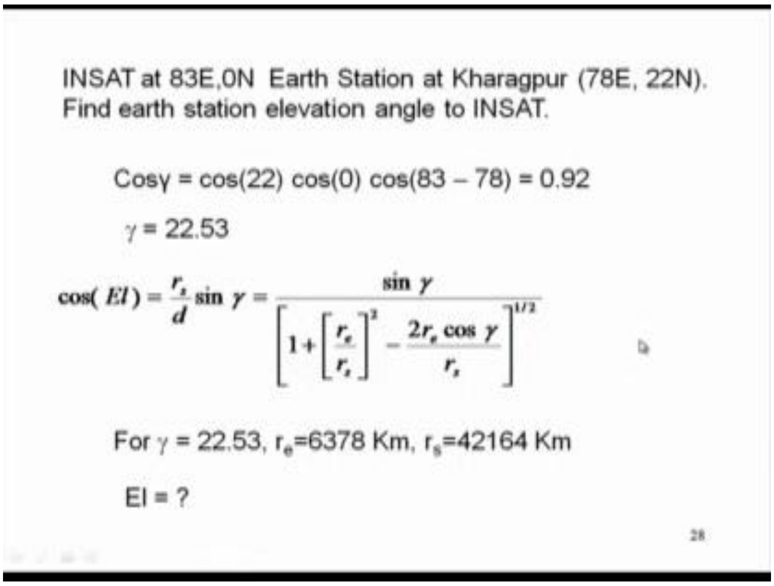

Now this is to find the distance and the elevation for azimuth, before going to azimuth let us do some quick calculation that is INSAT at 83 degree east and I have said here 0 degree north, but people do not say that 83 degree east it is geostationary satellite earth station at Kharagpur 78 degree east and 22 degree north. Find the earth station elevation angle to INSAT. Since, it is a geostationary satellite you can put those numbers and find out the cos gamma as 0.92. And therefore, gamma is 22.53 and I put cos elevation it is the same expression and find out what is the number.

So, for gamma you put this value 22.53 and for r e 6378 kilometer approximately and r s we calculated 42164 kilometer. Find out what is the elevation. I am not giving the number here we use that simple calculation, but very interesting thing you should look at it either. I have given example with Kharagpur and as you look at the map of India Trivandrum or Southern part of India is very near to the equator, what should be the elevation angle. Compare to say let us say Delhi or Northern part of India which is away from equator; what should the elevation, which elevation angle will be lower. You can verify by putting some numbers here and doing calculation, but intuitively you can also say which elevation angle whether it is a north of India is elevation angle will be lower than the south of India or vice versa for geostationary satellite for INSAT satellites.

You should do this your exercise and try to understand, understanding is more important than just putting some numbers into formulas and getting some results understand this.

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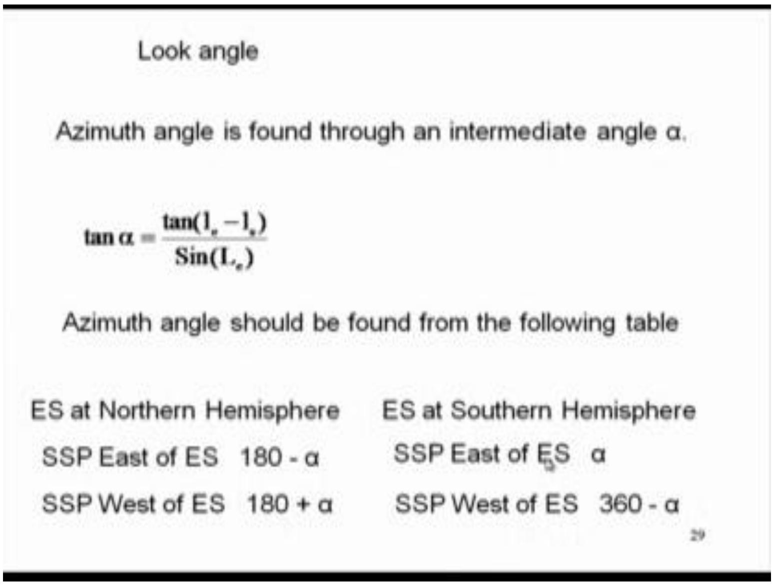

Now azimuth angle is a much more complex calculation so we will show you the results. There is a intermediate angle called alpha or a is found out first which is in terms of latitude longitude is a tan alpha is tan difference of earth station and sub satellite point longitude divided by sin of latitude of earth station. Some books give different expressions for this and derivations are there all results are correct I have taken this expression.

So, now this intermediate angle alpha azimuth as you find out with respect to alpha as where is a station. So, if the earth station is in the Northern Hemisphere that is above the equator and the sub satellite point is east of the earth station it is 180 minus alpha. If the sub satellite point is west of a station is 180 plus alpha. If it is Southern Hemisphere it if the sub satellite point is east of a station it is alpha and if the sub satellite point is west of a station its 360 minus alpha. This table has to be remembered because geometrically it can be explained I will try to do it briefly, but you can see.

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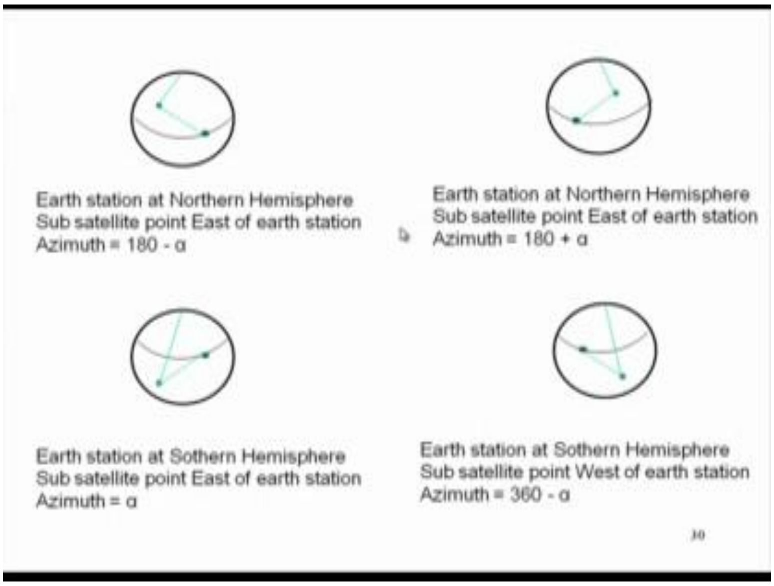

So, let us say this side is north and this is the equator this is the Northern Hemisphere and your sub satellite point is here earth station which is here. So, the azimuth will be from north to this angle. Whatever alpha you find out you do 180 minus alpha that means, actually a alpha is this side angle which I have not drawn here. Similarly, if the sub satellite point is west of the earth station in Northern Hemisphere it will be 180 plus alpha you can see from the north you come this way 180 plus alpha. So, the alpha is a angle like this.

If it is Southern Hemisphere same its azimuth is equal to alpha and if it is a sub satellite point is west of earth station 360 minus alpha. Yes, I tried to put it in books you can search and find out the way of expression, but as a communication engineer let us not worry much we can use this standard formula for.

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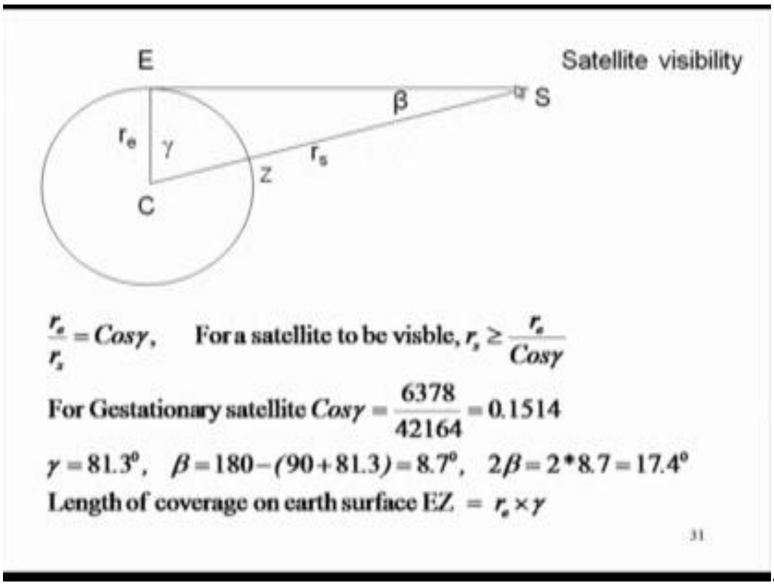

Now, let us see satellite how it is visible whether it is visible to us or not. Now this same triangle 0 degree inclination let us say, and that is earth station is at 0 degree inclination to the satellite then this r e by r s is equal to cos gamma this is a right angled triangle r e by r s is equal to cos gamma. So to make the satellite visible this r s should be greater than r e by cos gamma it should be larger for a, in case of geostationary satellite cos gamma is equal to r e by r s. Now we put the numbers you will get 0.1514 and from that you can find out gamma is equal to 81.3.

And this angle form the satellite visible is 180 minus 90 this is 90 degree so 90 plus 81.3 which is 8.7 degree double of that is 17.4 degree. That means, satellite with 17.4 degree angle it can see the earth into end into end. So, the length of the coverage for the satellite visibility is this r that is E Z that is r e into gamma r e into gamma is this r or anywhere in the satellite.

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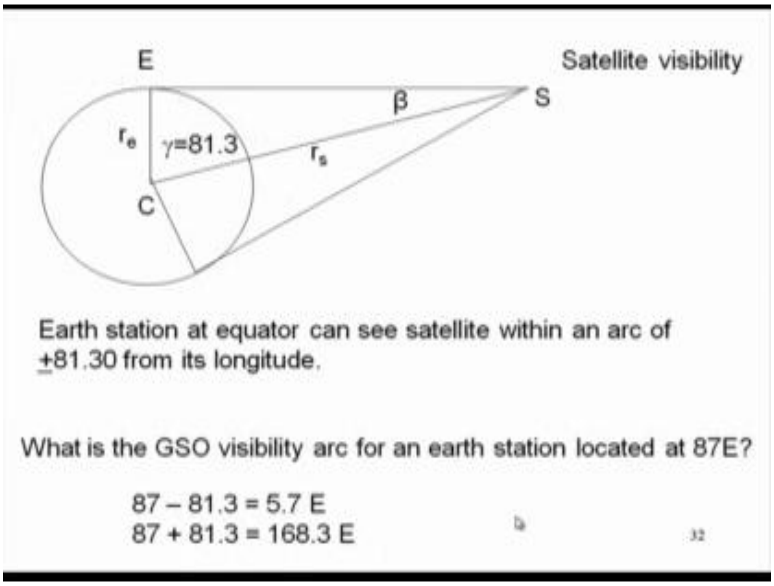

So, visibility is earth station at equator, if the station is at equator it can see satellite. Let us say earth station is at equator it can see satellite in this direction in the other direction. It is plus minus 81.3 degree from its own longitude. So, you can find out the earth station at 87 degree east. What is the GEO visibility? GSO visibility or GEO visibility 87 minus 81.3 that is 5.7 degree east to 87 plus 81.3 163 degree east. So that much distance it can see.

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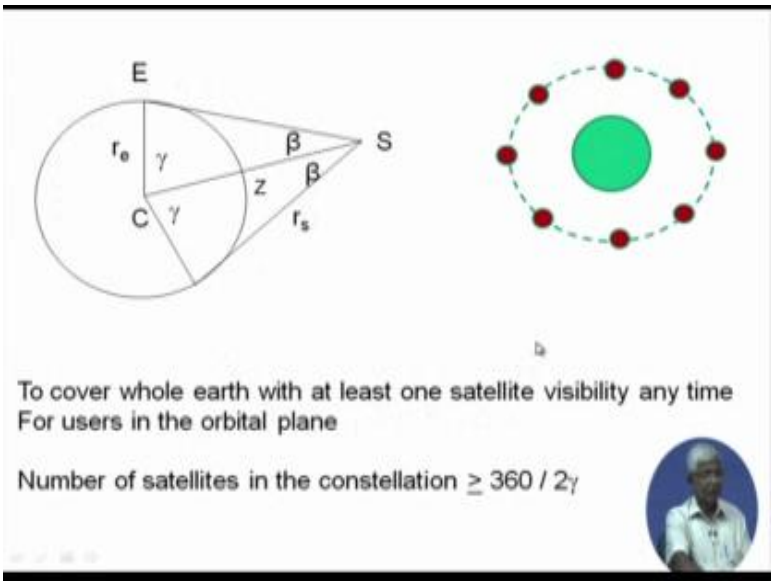

And if it is a low earth orbit, the number of satellite that is required is 360 divided by 2 gammas. How many satellites are required so that you can have a continuous visibility around the plane?

So, for the time being time is giving up so we stop here and we will continue the discussion in the next session.

Thank you very much.