

Higher Surveying
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Module - 05
Lecture - 14
Global Positioning System (GPS)

Hello everyone. Welcome back again in the course of Higher Surveying and today we are in the new module, module 5 Global Positioning System. Today you might be excited also, because we are going to talk about GPS which is a first, relevant at least you are feeling that it is a relevant topic. And before whatever we have covered for example, the module 1, module two which was about reference frame and coordinate system, module 3 about Astronomy and time and module 4 about the adjustments computation and error propagation accuracy error precision and anything like that.

You might be feeling that or might be asking also that why did we cover four modules almost 14 to 15 lectures before we start today's lecture, ok. Let me tell you very clearly and categorically first three modules or four modules are the basic fundamental tools or they are the relevant concepts without which you cannot work or you cannot understand any topic of higher surveying. For example, if I take the module two about reference system and a coordinate system. Reference systems are very useful to understand what is geocentric coordinate system or what is a geodetic coordinate system, what is a local reference frame and so on.

Later we have also talked about astronomy and time that is a part of the higher surveying, although today it is not very much relevant but still it is part of the courses on higher surveying in different universities, colleges, and institutes. There we had we have talked about the time like how to measure the time, what do you mean by time, what is atomic clock, what is atomic time ephemeris time, what is rotational time of earth and so on.

And we also defined something called sidereal time that is related to the orbit as well as a spin time of earth together. Then we talked about astronomy where we find out how to find the coordinates of the star or any celestial body for example, it could be a satellite, artificial satellite. So, we said that let us locate the 2 d position of a star globally, locally.

Locally we have said azimuth and altitude; globally we have said declination and right ascension and so on.

And that is a reason we have set finally, what is the ICRF that is international celestial reference frame and then we have established the relationship between the ITRF and the ICRF. Remember, that ITRF we learned about in the module two in the reference frame and coordinate system. ICRF we learned about in module 3 in time and astronomy. In module 4 we talked about what is accuracy precision; what are the measures of accuracy and precision, and how to do adjustment computations to find out the error and accuracy and how to do error propagation to find out the precision in the propagated variable or the connected variables.

Knowingly that we have some measured precision or estimated precision for some measurements in field, how can we find out the precision if there is a connected variable which is a dependent variable. Now, with this all thing how to use these knowledge or how to use these logic concepts in today's lecture. Let us see and you will appreciate really now from this point onwards that whatever tool we have learnt in last four modulus they are very very useful for development of your concepts about GPS and other technologies like photogrammetry radar, lidar, bathymetry and so on ok.

So, let us dive into today's lecture and it has only one lecture that is Global Positioning System like this and I should have coined this term as GNSS which is global navigation satellite systems, because GPS is the term generally used for Navistar satellite configuration, what is that? Netstar or Lunars or Galileo what is that?

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Module Contents

□ L-1: Global Positioning System (GPS)

We are going to discuss today everything. Moreover, this module or this lecture which is, there is only one lecture in this module it is more about the information that you perhaps need, but you are not aware of that and that is the reason we are taking this GPS. I would like to confirm here one thing if you want a detailed knowledge or the basic fundamental knowledge of the GPS. Please refer NPTEL course on basic surveying that is a surveying course. There they have, authors have or the constructor have elaborately talked about GPS for 5 to 6 lectures and those fundamentals are relevant as well as applicable here also. So, I am assuming that these are the prerequisites for this module or for this lecture.

So, with this idea I am going ahead now. Ok, so these are the books I can say that these three books are fundamental books. And there also this is slightly different book, it has totally different taste or different flavor on the material, but still it is a relevant book, these two books are on the more on technical side. So, if you are electrical engineer interested in the mathematical treatment of the signals, and all this thing you can refer these two books, but first four books are good enough for the any serious learner from the civil engineering perspective; that means, topographic mapping only ok.

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Books

- *Understanding GPS: Principles and Applications*, by E. Kaplan and C. Hegarty, Artech House, USA, 2006.
- *Global Positioning System – Theory and Practise*, by B. Hoffman-Wellenhof, H. Lichtenegger, and J. Collins, Springer Vienna, Austria, 2001.
- *Introduction to GPS: The Global Positioning System*, by A. El-Rabbany, Artech House, USA, 2002.
- *GPS Satellite Surveying*, by A. Leick, L. Rapoport, and D. Tatarnikov, John Wiley & Sons, New Jersey, USA, 2015.
- *Global Positioning System – Signals, Measurements, and Performance*, by P. Misra and P. Enge, Ganga-Jamuna Press, USA, 2012.
- *Fundamentals of Global Positioning System Receivers - A Software Approach*, by J.B. Tsui, John Wiley & Sons, New York, USA, 2000.

Here I would like to say this is the fundamental books are basically Hoffman Wellenhof here and Kaplans book is also good one, Rabbany's book fine. You will get different different ideas, different-different notations, different-different, you know kind of explanations. So, better if you can read this books at least one by one; moreover if you find these book expensive always go to the basic surveying course on NPTEL and the lectures which are about GPS are very very relevant and appropriate fine.

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Satellite Orbits

- ❑ Low Earth Orbit (LEO) satellites
 - ❑ Satellites that can be viewed with naked eyes
 - ❑ Spy satellites, weather satellites
- ❑ Medium Earth Orbit (MEO) satellites ✓
 - ❑ Around 22,000 km above Earth surface
 - ❑ Most of GNSS satellites orbit in MEO
 - ❑ Orbit the Earth in an inclined plane
 - ❑ Orbital period defined in sidereal day(s)
- ❑ Geosynchronous Earth Orbit (GSO) and Geostationary Earth Orbit (GEO)
 - ❑ 35,000-36,000 km above Earth
 - ❑ Geostationary satellites: communication satellites, TV satellites
 - ❑ Some of GNSS satellites are placed
 - ❑ Orbit in equatorial plane (GEO) or inclined plane (GSO) in one sidereal day

Global Navigation Satellite Systems

Let us go ahead, now we have satellite orbits. So, in general satellites are placed in three types of orbits and then we name them accordingly. So, first is Low Earth Orbit or in bracket it is written LEO, right. If you just try to see sometimes in the sky and by accident if you come to know that there is a star which is continuously moving in the sky, perhaps it could be a satellite. If a star which is continuously moving in the sky if you see on one day probably it is a LEO satellite.

Moreover, please differentiate between aeroplane which is quite a big that appears quite big to you compared to the star, star appears like dot in the sky. So, if you are seeing that there is a dot moving in the sky in the night time perhaps you are looking at a LEO satellite you can see with the naked eyes, ok. All the spy satellites for example, Corona satellite program or Lanyard or Argon all this early spy satellite programs they were using LEO orbits and the range of the LEO orbits is less than thousand kilometers above the surface of earth.

So for example, Corona was placed around 150 to 215 or 225-kilometer range orbits, the satellites for orbiting like that, and they were acquiring panoramic images on the surface of earth ok; later on when remote sensing was started. So now, the days remote sensing satellites are placed somewhere around 750 to 900 kilometer range. So, they are also LEO orbits ok. All the weather satellites generally if you look at the weather satellites reporting the weather they are also placed in the LEO orbits ok, next, next is the MEO satellites or the Medium Earth Orbit and the orbit is around 22,000 kilometers above the surface of earth. Well, most of a GNSS; again what is a GNSS, Global Navigation Satellite. I can write here small term Global Navigation Satellite Systems.

GNSS is a generic term that includes all the possible satellite constellations, well GPS is or Navistar is one of the satellite constellation launched by the USA or developed by the USA and now it is in working position well. Apart from that most of the countries developed, and as well as developing like India they are also developed their own satellite constellation. So, as to serve their nation locally, their interest are more on their particular country we will see all this thing.

But I would like to say here most of the GNSS satellites are placed in the MEO orbits ok. These orbits are inclined with respect to the equator of the earth like this or could be like this, could be like this or could be like this and orbital period define sidereal days; that

means, how many sidereal days a satellite is taking to complete the rotation or they complete the orbit around earth not rotation revolution around the earth well.

Then we have third type of orbits called Geosynchronous Earth Orbit, we call it GEO, GSO and Geostationary Earth Orbit called GEO, ok. Let me differentiate between the two GSO and GEO orbits. GEO is Geostationary Earth Orbit they are generally placed on the equator. That means, in the equatorial plane at this height of 35,000 to 36,000 distance from the surface of earth they are revolving or orbiting around the sun.

So, let us say, this is my equatorial plane of the earth. So, somewhere it is 35,000 distance and now satellite is orbiting in this plane of equator or equatorial plane or you can say celestial equator plane. So, these are called GEO satellite or called GEO orbit, fine. Generally they rotate or they revolve around the earth in the same direction of the earth rotation that is anticlockwise.

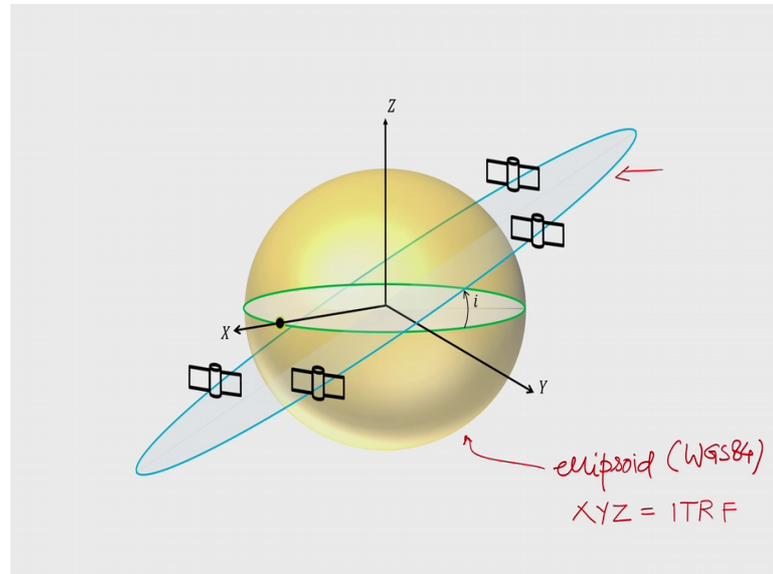
Well then we have geosynchronous earth orbit you will be surprised that if I place the same orbit at 35, thick's 35,000 height above the surface of earth and in this inclined plane like this or it could be like this and let us say this is equatorial plane. So, these orbits are called Geosynchronous Orbits. So, what is the purpose of Geosynchronous or Geostationary Earth Orbit? Well, these satellites which are placed at almost 35,000 kilometer height they remain fixed with the earth.

That means when they are projected or when they are placed at certain point with respect to earth then they will remain over that always; why because, they are rotating with the speed of the earth which means they are completing their 1 revolution or 1 orbit around earth in 1 sidereal day. And that is why they are called synchronizing with the earth geosynchronous satellites or geostationary they remained stationery with respect to the earth, but geostationary are placed in the equatorial plane geosynchronous are placed in the some inclined plane.

So, we have two kind of now satellites Geosynchronous Geostationary remember both revolve around the earth with the same speed of the earth and that is why their name Geostationary or Geosynchronous ok. Well, all the communication satellites like for example, that used for the mobile phones or TV satellites, television they are placed in the Geostationary orbit right and some of the GNSS satellites are placed in the

Geosynchronous orbits also as well as GEO orbits also. Both we will see, let us go ahead, ok.

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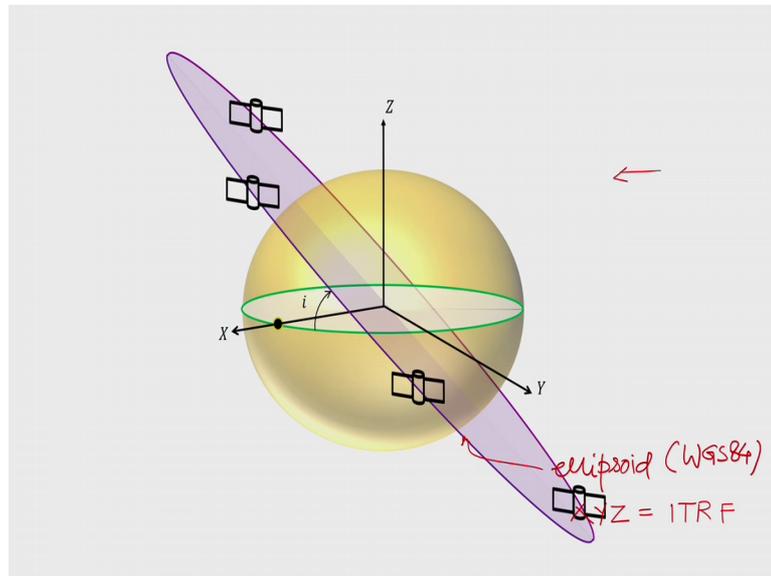


Let us see this is my one orbit here fine and now I can say here this is the inclination of orbit. Now I am trying to define; what do you mean by an orbit or orbital plane of satellite. We can see here the capital X Y Z is a geocentric reference frame, generally this capital X Y Z is ITRF, International Terrestrial Reference Frame. Secondly, we associate with this reference frame a ellipsoid. For example for GPS we associate WGS84 ellipsoid right. So, the moment there is a association of the two; one is reference frame which is geocentric in nature and then we have ellipsoid. So, I got a datum surface with respect to which I can refer the heights, what we call ellipsoidal heights.

So, I will use that ellipsoid for measuring the ellipsoidal height and GPS is going to use that particular ellipsoid in order to report the ellipsoidal heights, right. So, that the purpose here to associate two things. Now this is one of the orbit of the satellite here, shown here fine. So, this is the inclination angle what we have seen here. So, now I can see that all the satellites are moving let us say in this orbit for example, like this there are four satellites are shown that are moving in this orbit and so, they are maintaining some speed and as a result they are not colliding with each other rather they are moving at a constant speed with each other and what is the order of the speed? The order of the speed of satellite is in the kilometers per second right, ok.

Now, with this idea you can now imagine that for these four satellites this is the one orbital plane. And rather these four satellites are assigned to this particular orbit and they are moving always in this orbit, right. Let us go ahead, let us take another orbit.

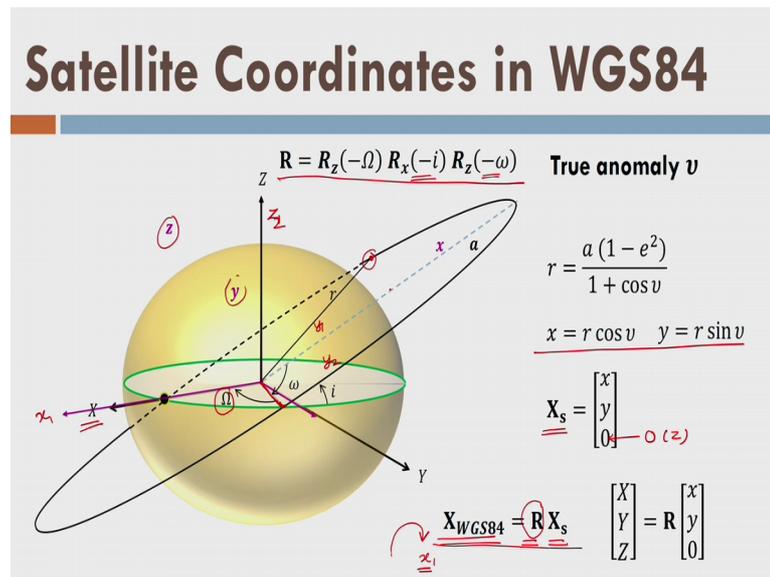
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This is another orbit and what is the inclination of this orbit. So, if I measure the angle of this orbit with the equator that is called inclination. So, let us see this is the angle i for this orbit because it is inclined with respect to the equatorial plane by this angle i . So, that is called inclination. Now, you can imagine there are two orbits like this right it could be another orbit like this, it could be another orbit like this fine. So, you can imagine now that at given inclination i angle; I can have these many orbits which are let us say this is the orbit.

So, this can be this orbit, orbital plane like this, this can be this way also, this can be this also, like this and this can be this also, like this orbital plane. So, basically this orbital plane is making an angle i with respect to the equatorial plane. And that is why all these are different-different orbits although, but they are having the same inclination right. So, now let us place like this there are four satellites placed in the particular orbit having inclination i ok. Let us go ahead.

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Now, have you ever thought of a problem that how a coordinate of satellites are available to us, because if you can recall the fundamental concepts of the GPS from the basic surveying course. Then you will realize one thing that we need to first have the coordinate X Y Z of satellite using that coordinate X Y Z we try to find out the receivers coordinate net X Y Z and what do we do, basically we have this X Y Z available to us.

Then we measure the distance by the time difference or maybe phase difference logic between the receiver and the satellite and then we using this two information which as known for example, distance and the coordinate of the satellites. We try to find out the location of the receiver by some logic called space resection. Well, that was the idea we have already discussed or you have already learnt in the basic surveying, right.

So, we assume that satellite coordinates X Y Z are available in some Geocentric Coordinate System. So, let us say that my Geocentric Coordinate System is X Y Z, it could be ITRF or it could be any other does not matter, but for the purpose of concept let us assume it is ITRF or it can be other right. Then we have a orbit shown here and what are the characteristics of the orbit that remains same for all the satellites moving in that same orbit that we try to learn now.

So, let us see this is a satellite here and this point if I connect the center of the earth to this point where it is intersecting the orbit intersecting with equatorial plane, we call it Node right. Now if you say this is the angle inclination as explained in the previous slide

ok. Then this is my inclination of orbit i that is already marked in the slide what next; next thing is that this blue line here indicating this blue line is the semi major axis small a right. So, this is my semi major axis, fine ok.

Since this Node point is fixed for a given satellite orbit and equatorial plane right. We can define this angle ω that is the angle between this line which is connecting the center of the earth to the Node and the line called semi major axis. So, this angle ω is defined in the orbital plane. So, this angle ω is defined in the orbital plane of satellite fine. So, now, you can understand this. This is called argument of perigee. Remember what is a meaning of perigee? Perigee is the point on the orbit which is nearest to the earth right because this is the satellite of the earth. So, we are defining like that.

Remember that earth itself is a satellite or the planet of the sun. So, we defined perigee and apogee for the earth when we talked about the rotation of the earth and the orbit of the earth around sun. So, when we talked about the orbit of the earth around sun, we defined apogee and perigee points for the earth. Similarly, we are defining here perigee point for the satellite which is revolving around the earth. So, this is my orbital plane where it is supposed to revolve, where it is supposed to revolve around the earth.

Now this angle that is called the right ascension of ascending Node; so this node is ascending node because satellites will be ascending from this node and up it will come in the northern hemisphere right. So, now you can see here this is called right ascension of ascending node remember we have also defined ascending node for the sun in their apparent path of sun and that we call vernal equinox ok. And, through the vernal equinox we are saying that Greenwich meridian was passing to define the terrestrial meridian and terrestrial longitude and latitude and so on.

So, now we are saying here X axis remember, we define the Greenwich meridian X axis, and everything we are saying it is not relevant that it passes through Greenwich meridian or vernal equinox rather it is passing through these 0 degree longitude which we have decided based on the average rotation axis. And all the average values or basically it is ITRF system. So, ITRF is giving me the 0 degree longitude by X axis that is why we are measuring the right ascension of the node like this.

Let us go ahead. Now this is a satellite and this is now the coordinate system small x y z like this and this small x y z is an orbital plane. That means, x and y are the aligned with orbital plane or they are in the orbital plane. And as a result now you can see the z axis which is small z shown in purple color here. It is perpendicular to the orbital plane and that is the reason somehow, we have some facility here what let us look into that let us look into the motion of the satellite which is moving in the orbital plane.

So, now you can see that since satellite is moving in the orbital plane it is changing its coordinate in the orbital plan, but the z coordinate is 0, because my small x y coordinate system is defined in the orbital plane. Now you can easily imagine that if I measure the time. So, with respect to time satellite is changing its position only in the orbital plane right. So, I can always define the position in the 2 dimension, I need not to define in 3 dimension, because the small z the z dimension of the satellite in orbital plane or with respect to orbital plane or with respect to small x y z coordinate system is 0, third dimension is 0.

Let us take the advantage of that and let us say this is the radius r or the radial location of the satellite. So now, this is the point of satellite which we are indicating that this is cg of the satellite. So, let us remove the satellite and talk about the point. So, this is the point indicating the satellite here red dot. Now this is the radius ok. So, a satellite is moving this r variable will keep on changing here I need to define the position of satellite by one more coordinate so that I can fix its location anywhere in the orbit. So, this angle what we call here it is called true anomaly μ and that is the location fixing the 2 d portion of satellite.

So, this is the variable that is fixing the 2 d location of the satellite in the orbital plane. Now I can define any position using these two variables r and μ in a satellite orbit or in this orbital plane ok. So, this is my y here. So, I can write r here like this well. So, this is my eccentricity of the elliptical orbit which is close to the circular orbit let us say or does not matter it is in elliptical orbit e.

So, I am saying that this is the r given by. So now, it is representing a position of the satellite ok, what about x which is r here from this point center of earth to this point here. So, this is my $r \cos \mu$ you can see Cartesian coordinate system and this is y which is the

perpendicular distance from x in the small y direction. So, these two are already given here.

Now, I can express the position of the satellite like this three coordinates. Remember third coordinate is zero small z axis, well done. We have defined the position of a satellite in the orbital plane. Now we know that there are two coordinate system, one is small $x y z$ and another is capital $X Y Z$ and capital $X Y Z$ is the WGS84. For example: so, I want to bring the coordinates or I want to measure the coordinates of the satellite using the available information here on the screen into the capital $X Y Z$; That means, I have expressed the position of satellite in orbital plane and now I want to calculate the position of satellite in the capital $X Y Z$ system or reference frame.

So, let us see we need to do some rotations only why because both systems are geocentric and as a result I need not to do any translation there. Their origins are basically coinciding with each other. There are only difference of orientations are there. So, let us try to understand what kind of rotation you need. So, I can write like this where my R is rotation matrix or the $X Y Z$ of the satellite is equal to R times $X Y 0$. Well, first of all now I will look rotate my small $x y z$ system around z axis such that this x axis will be aligned, with this line what we call as, with the here blue line or right now I mark it again this line right.

So, let us see what kind of rotation we do, this rotation now it is aligned ok, now what will I do, I have aligned and I have rotated this system about z axis. So, there is no change in the z value of the satellite coordinates ok. So now, just think that if you rotate about this new axis say- x_1 right and it is your new axis called y_1 and z is still z . So, about x_1 if you give another rotation by angle i remember this ω direction it is in the clockwise direction. So, we have written minus ω now you are rotating your new coordinate system $x_1 y_1 z$ about x_1 axis. So, that z and y_1 will rotate and they will come into the plane of equator by i angle rotation.

Let us see. So, this is explained like this like, this kind of rotation we are doing, done. Remember that, we have not changed the orbital plane of the satellite just for the purpose of explanation. We are showing it by animation. So, now you have rotated by minus i also about the x axis which was this, like this kind of rotation you have given right and as a result z has aligned with the capital Z . Now still these small are marked here. They are

of no use there are this is my new z_1 axis small z_1 and this is my y_2 axis or I can I can call it z_2 also does not matter z_2 y_2 and x_1 is still.

Now what else I have already bring my coordinate system small x y z into the equatorial plane only I need to give one more rotation. So, that this axis that is x_1 will be aligned with the capital X and this rotation is required here which is equal to this rotation and again in the negative direction because we are going to rotate now about the Z axis in the clock wise direction, see how do we do it like this. So, now my x_1 axis which is here earlier is now aligned with the capital X here after rotation by this angle.

So, my small x y z system is now completely aligned with the capital X Y Z . So, whatever coordinates I have transformed. Now I will can measure the in this position in the capital X Y Z . Again we have used the logic of coordinate transformation only here and that is the reason whatever we have talked in module 2 was relevant ok. So, this is my total rotation matrix here and now we got if we place this rotation matrix here and I place this values here I will get the coordinates of satellite in WGS 84 or any geocentric coordinate system or geocentric reference frame.

So, here I said that it is ITRF it could be any. So, you got how to calculate the position of the satellite in a geocentric coordinate system when it measures something else like r and μ in the orbital plane ok

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Brief Overview of GNSS

- Global Navigation Satellite System (GNSS)
- Satellite constellations
 - **NAVSTAR** (GPS) – **NAV**igation **SaT**ellite **And** **R**anging (USA)
 - **GLONASS** – **GLO**bal **NA**avigation **Sa**tellite **S**ystem (Russia)
 - **Galileo** (European Union)
 - **IRNSS** – Indian **R**egional **NA**avigation **Sa**tellite **S**ystem (India)
 - **QZSS** – **Q**uasi **Z**enith **Sa**tellite **S**ystem (Japan)
 - **BeiDou** or **Compass** (China)

Let us go ahead. So, let us have the brief overview of the GNSS. Now what is GNSS, global navigation satellite system or systems. So, satellite constellations are these are the various constellations available and their countrywide. For example Navistar what we call GPS is navigation satellite and ranging and developed by the USA department of defense initially for the purpose of military use; however, it is now more popular for the civilians. Right you might be using it at least in a mobile phone.

I am very sure because if you have a smart phone like this right you are definitely having a GPS inbuilt into that right. And now you are using for your mobile locations or for your restaurant location or all merrymaking or all your entertainment and so on or at least for the purpose of navigation in your city keep on using it, it is a good facility.

Second is the GLONASS that stands for Global Navigation Satellite System and it is developed by the Russia ok, third is the Galileo that is developed by the European union and that satellite constellation is given the name called Galileo because famous scientist Galileo was from Europe perhaps that could be a reason but yes his name is Galileo. Thirdly, we have for India that Indian regional navigation satellite system IRNSS, for Japan they have Quassi Zenith Satellite System and for China we have BeiDou or compass. Well these countries have developed their own systems. Now, earlier we have only GPS developed by the USA ok.

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NAVSTAR (GPS)

- ❑ Minimum 24 satellites
- ❑ Generally available: 30 satellites these days
- ❑ Orbits: 6 orbits, each at height 20,200 km and inclined at 55°
- ❑ Number of satellites in a orbit: 5
- ❑ Orbital period: half sidereal day
- ❑ Foot print of satellite: vertical S shape
- ❑ Frequencies: L1 (1575.42 MHz), L2 (1227.6 MHz), L5 (1176.45 MHz)
- ❑ Code: C/A code, P code
- ❑ Combinations of code and frequencies: L1-C/A, L2-C/A, L2-P, L5-N

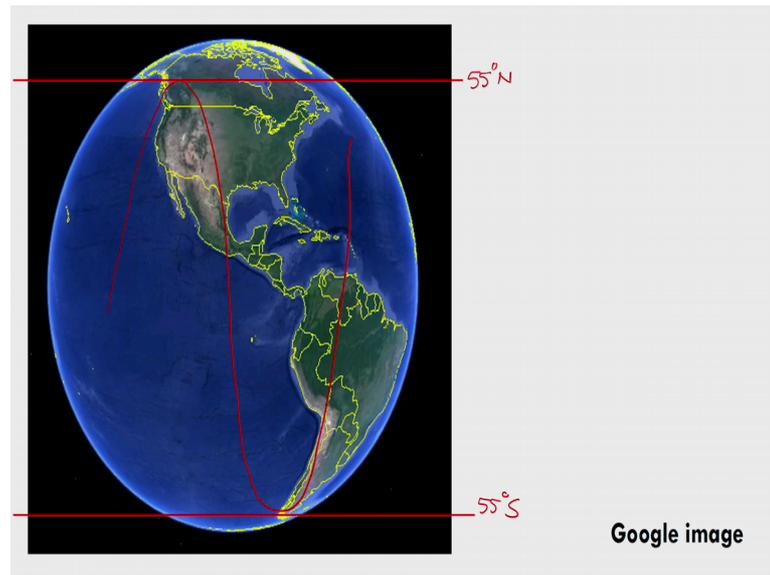
So now, let us look into the next, what is NAVSTAR? Ok there are minimum 24 satellites you might be reading this thing again and again. So, now the days we have 30 satellites in the NAVSTAR or GPS right. I am trying to update you. You can also read on internet. All this informations are available on internet also.

Well so, these 30 satellites are placed in the 6 MEO orbits at the height of approximately this 20,200 and these each orbit is inclined at 55 degrees. So, remember I had said that inclination i 55, 55 like this. So that, 6 orbits inclined to the equatorial plane at 55 degrees well and they have different-different longitudes for this to defining the semi major axis.

So, now you can place all this orbits with respect to each other like this but they are basically inclined towards with respect to the equator of the earth by 55 degrees. Ok what about the orbital period. That means each satellite is completing 1 orbit in half sidereal day. That means, they are each satellite is making two orbits in a one sidereal day around the earth right. That means, when it, it starts from one position in half a day it completes one orbit in remaining half day it completes one more orbit.

So, again the point which is here of earth that comes one sidereal day it comes back by the time satellites make two revolutions around the earth that is the meaning here, ok. What about the foot print of satellite, it creates vertical S shape that we will talk in next slide and that is related with somehow this 55 degrees then we have this frequency L 1, L 2. Well, these two are already discussed in basic surveying course then we have L 5 one more frequency now for the civil in use they have this codes C A code, P code. And then we have different combinations of the code and the frequencies which are available for the use or for the receiver to receive it.

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So, let us go ahead and see what is a vertical S shape. Let us see this is the shape of the earth shown here and somehow if I try to make the 55 degree line, this is two lines that is 55 degree North approximately and this is 55 degree South latitude ok. So, since your satellite is moving in elliptical orbit or in the inclined orbit. So, when satellite goes up above equator it is going to rise on the surface of earth. That means, its foot print or its track on the earth is going to increase it will go maximum to 55 degrees that is inclination of the orbit and then it will start moving down.

So, that kind of pattern we should expect on the surface of the earth or rather if I draw on the plane this pattern will be somehow like this, a kind of S pattern this way and this way and so on. It will keep on repeating. So, such tracks are two tracks in a day we will have right that sidereal. So, that is the meaning of.

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Galileo

- ❑ Total 30 satellites
- ❑ Orbits: 3 orbits, each at height 23,200 km, and inclined at 56°
- ❑ Number of satellites in a orbit: 10
- ❑ Orbital period: (10/1) sidereal day = 10 orbits in 1 sidereal day
- ❑ Foot print of satellite: vertical S shape
- ❑ Frequencies: 3; E1 (L1), E5a (L5), E6 (1278 MHz)
- ❑ Signals do not interfere with GPS signals

Next is the Galileo which is very similar to the GPS and it has total 30 satellites and they are placed in 3 orbits of this height which is slightly above the GPS satellites and again the inclinations more or less same. So, it is going to create the same more or less same track on the surface of the earth. That means that track of the satellite will be more or less same as that of the GPS satellites.

In each orbit we have 10 satellites and what is the orbital period is written 10 by 1 here which means they complete 10 orbits in one sidereal day. GPS satellites complete two orbits in one sidereal day, but they complete 10 orbits in one sidereal day ok.

So, again vertical S shape will be created and then they have three signals called E1 which is same as L1. Again, they have E5 which is same as L5 then they have E 6 which is different here, right. So, they have three frequencies; hence this signals although they are on L1, L5 but they do not interfere with the GPS signals ok. So, I am not drawing the path vertical S path which is similar to the GPS.

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GLONASS

- ❑ Total 24 satellites
- ❑ Orbits: 3 orbits, each at 19,100 km height and inclined at 66°
- ❑ Number of satellites in a orbit: 8
- ❑ Orbital period: (8/17) sidereal day = 17 orbits in 8 sidereal days
 $17/8 = >2$
- ❑ Frequencies: 14 different frequencies for 24 satellites
- ❑ Opposite satellites across Earth use same frequency ||
- ❑ Code: only one PRN code

So, let us talk about GLONASS for Russia. In this constellation we have total 24 satellites. They are placed in the 3 orbits almost at this height 19,100 kilometers which is different from GPS as well as Galileo. Galileo was slightly higher or Galileo is slightly higher than the GPS, and GLONASS is slightly lower than the GPS, but all are MEO orbits and they are inclined at 66 degree. So, you will be surprised why 66 degree where as GPS and Galileo they are around 55 degrees or 56 degrees. We will see the reason if you just check the latitude of the Russia which is around 66 degree or the since Russia is very big part but around we can see they are major part of their country its around 66 degree.

So, is it a kind of GPS or its kind of global system or it is a local system we call it as the regional system they are basically targeted or tailored or basically they are tuned to serve the particular territory on the earth. So, each of these system what we are talking about now are basically the regional systems or we can say regional GPS in loose language. Well, go ahead ok.

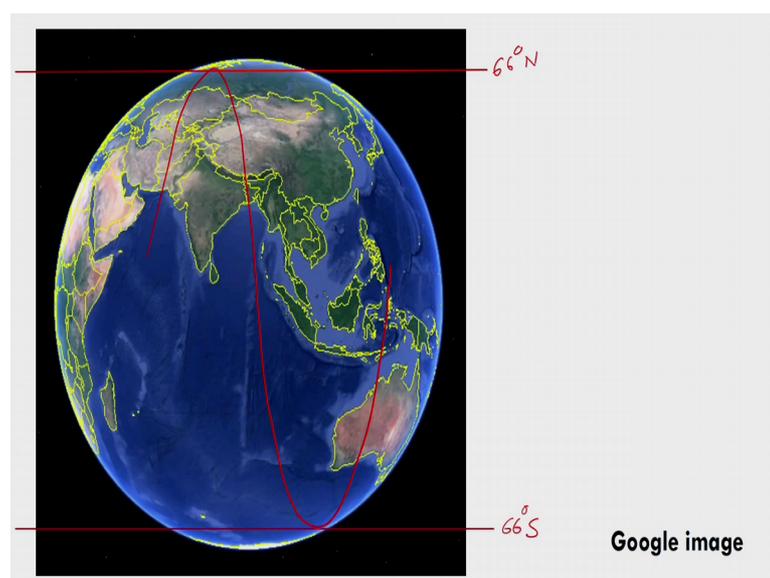
I would like to interrupt you here these are the regional systems, but does it mean that others cannot use or the people of one region can only use, No, it is not like that. If you are having a receiver which can acquire the data of particular satellite constellation for example, GLONASS or Galileo you can also use it no problem and we will talk about

this thing the specifications of the your receiver also which are very - very relevant to learn in this lecture only.

The next is the orbital period which is 8 by 17 what does it mean they finish the 17 orbits and 8 sidereal days. Ok what is the meaning here which is I can say almost since 8 by 17 is I can say less than half or I can say it is if I take the ratio like this 17 by 8. So, orbital period will be something more than 2 right so; that means, they are completing more than 2 orbits in one sidereal day and that is a reason in order to give the integer number we have expressed like this; that means, they are covering 17 orbits in 8 sidereal days. So, after 8 sidereal days satellite have completed its 17 orbits around the earth and again the point where it started above the earth and the point where it started both are coinciding after 17 orbits or after 8 sidereal days, that is the meaning here.

What are the frequencies it uses 14 different frequencies remember GPS is using L1, L5 and L2 three frequencies, but they use different-different frequency on the other hand they use only one PRN code. GPS is using 2 or 3 codes. C A code P code may be 5 code also which is not available for the civilians it is for military only, but still it using 3 codes. However, the GLONASS is using only 1 PRN code but different frequencies for 24 satellites and then we have opposite satellites across earth uses the same frequency the that is the idea here this is specification of this system, ok.

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Now if I try to draw the shape you will be surprised here. So let us draw the 6 this is the Russia here somewhere this is Russian part here territory right ok. So, I am removing this right here. So now, let us define the 66 degree line. So, this is my approximately 66 degree North and this is 66 degree South and Russia is somewhere here as we have shown in the last slide somewhere here. So, let us remove this one ok. So, now if I try to predict or if I try to draw the track of the satellite on earth it will be something like this and so on. It will complete 17 such tracks complete cycles in 8 days 17 orbits in 8 days well that is the idea here.

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Quasi Zenith Satellite System

- ❑ Total 7 satellites
- ❑ 4 geosynchronous satellites and 3 geostationary satellites over Japan
- ❑ 4 satellite are placed in one geosynchronous orbit (eccentricity ≈ 0.075)
- ❑ Asymmetric elliptical orbit creates asymmetric figure of 8 as foot print of satellite on Earth (especially on Japan)
- ❑ Orbits: 1 orbit, each at height 35,800 km, and inclined at 41°
- ❑ Number of satellites in geosynchronous orbit: 4 \rightarrow (41° inclination)
- ❑ Number of satellite in geostationary orbit: 3 (equatorial plane)
- ❑ Orbital period: (1/1) sidereal day = 1 orbit in 1 sidereal day
- ❑ Foot print of satellite: figure of 8 (small lobe over Japan)
- ❑ Signals: L1C, L1 C/A, L2C, L5, L6 or LEX (L1 experimental)
- ❑ Signals do not interfere with GPS signals

Now we have the Quasi Zenith Satellite System which is used for the Japan developed by the Japan. So, it has total 7 satellites not surprising well it is. So, we have 4 geosynchronous satellite and 3 geostationary satellites here over Japan and four satellites are placed in one geosynchronous orbit which are of this eccentricity, yes.

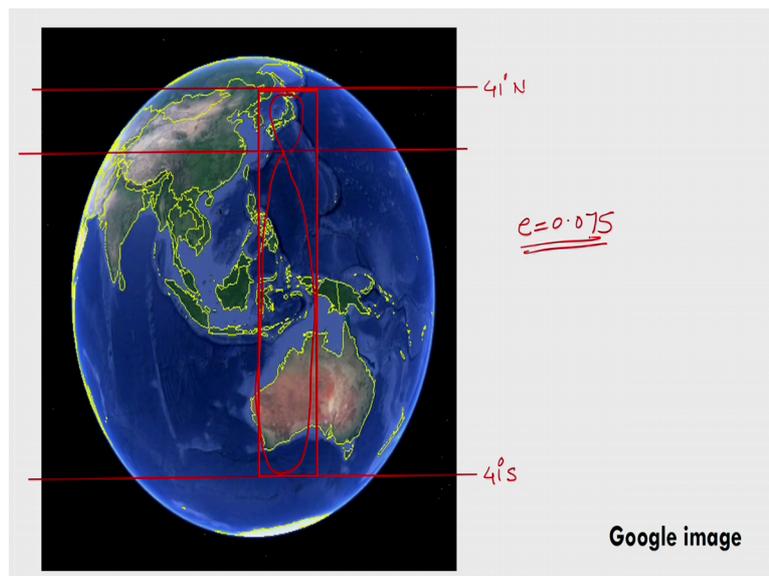
Eccentricity is very important, because most of the satellites are using almost close to circular orbit or we can say eccentricity is in that order of 10 to the power of minus 3 0.004 0.001 something like that. But it has very high eccentricity and that has very special use here about especially the drawing the track we will see it.

The idea is that Japan is very small country and they want to use this QZSS very precisely all around their country specifically not around the they are not restricting anyone to use it, but still they would like to use it more specifically over their territory

and that is why they have designed their system like that. So, it has 1 orbit of this height which is a since we said it is a geosynchronous or geostationary. Geoheight and these satellites are inclined at 41 or these orbits are inclined at this degree 41 degree because that is the latitude of the Japan somewhere fine.

Number of satellites in geosynchronous orbit is 4 and number of satellites in geostationary orbit is 3 that is in the equator plane that is 0 degree inclination and they are 41 degree inclination of this orbits, ok. What is orbital period they orbit 1 in 1 sidereal day 1 orbit in 1 sidereal day, what is a foot print. Yes, we will talk about it creates kind of small lobe over Japan and then they have these signals L1C, L1C A, L2C, L5, L6 or LEX. It is called also called LEX that is L1 experimental they have some different signals which is slightly different from the GPS, but L1, L2 and L5 are same right again signals do not interfere.

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Go ahead ok. So, let us draw the 41 degree line like this. Yes, I have change the looks also because and this is 41 degree approximately or they could be 44 degree I do not remember exactly now or let us say it is around 41 degree North or it they are around 44 degree also could be possible let say ok; so now if I define a box because it is creating. Let us define a box because the lobe of 8 or 8 figure of 8 is very - very restricted here and yes this axis is also important here I will show you why ok.

So, here if I draw some figure so that will be like this kind of 8 over the Japan here and then it will be big lobe over covering the Australia part of the Australia and like this, this kind of 8 shape is satellite is going to create the track of the satellite and that is the reason that eccentricity of 0.075 is developed or its created or it is designed that way. Let us go ahead.

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IRNSS

- ❑ Indian Regional Navigational Satellite System
- ❑ Total 8 satellites: 5 geosynchronous satellites and 3 geostationary satellites over India
- ❑ 5 satellites are placed in 2 geosynchronous orbits
- ❑ Symmetric circular orbit creates two symmetric figures of 8 as foot print of satellite on Earth (especially around India)
- ❑ Orbits: 2 orbits, at height 35,800 km, and inclined at 29°
- ❑ Number of satellites in geosynchronous orbit: 5 (IRNSS 1A, 1B, 1D, 1E, 1I)
- ❑ Number of satellites in geostationary orbit: 3 (IRNSS 1C, 1F, 1H, 1G)
- ❑ Orbital period: (1/1) sidereal day = 1 orbit in 1 sidereal day
- ❑ Signals: S (2492 MHz), L5

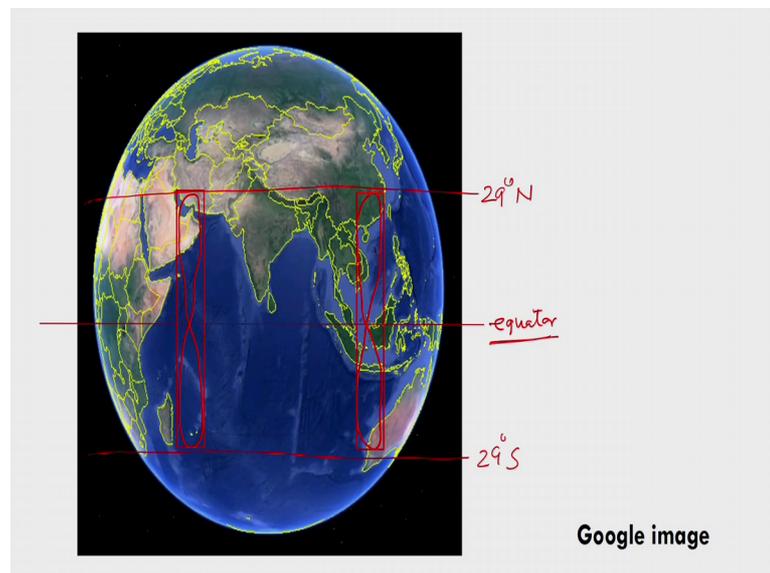
Now, coming to the Indian Regional Navigation Satellite System it has total 8 satellites right. I have taken the recent update from the website of ISRO and there they have placed 5 geosynchronous satellites and 3 geostationary satellites over India. It has certain longitude where these orbits are there. So, these satellites are moving exactly over the particular point on the Indian Territory somewhere. So, 5 satellites are placed in the 2 geosynchronous orbits well these all 5 satellites these are 5 satellites.

Since it creates symmetric circular orbit and two symmetric figures of 8 as foot print of satellite on earth especially around India not exactly over the India ok. So, there are 2 orbits as we showed here these 2 orbits here and these 2 orbits are at height of this much and inclined at 29 degree. Again this is the kind of latitude India has or most of the part of the India is around this latitude that is a reason. So, all the systems are now regional GPS or the regional GNSS, but still they are global because anyone can use across the world.

So let us see these are the 5 satellites right and these names are IRNSS 1A, 1B, 1D, 1E and 1I. In this geostationary orbits we have 31C, 1F, 1G, 1H is somehow could not be placed rather it is kind of lost or well it is a failed mission. So, we have total 3. What about the orbital period we have one sidereal day? So, one orbit in one sidereal day remember it is a geostationary. So, it is going to create one orbit in that height of 35000 kilometers well.

So, we have signals on the S band which is called 2492 megahertz and we have also L 5. See it is quite different from the other satellite constellations.

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Now, if you see what about the shape of 8. So, let us see this is the two shape of eights, why, because these are the lines of equator. I can say here approximately ok. So, these lines which we generally place here it is 29 degrees North similarly this line is around 29 degree South well.

Now what about the shape of 8, the shape of 8 is created some here by the satellite tracks? In this way one like this and another is like this. So, these are the shape of 8 and this is kind of equator position approximately equator positioning ok. So, that is the reason here. So, we are having two shape of eights that is satellite tracks around India.

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BeiDou (Compass)

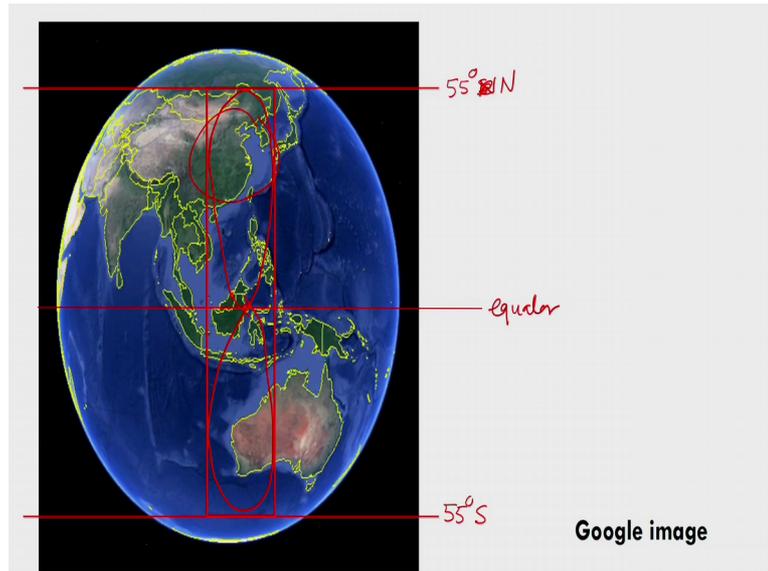
- ❑ **BeiDou Navigation Satellite System (BDS)**
- ❑ Total 35 satellites: 3 geosynchronous satellites (GSO), 5 geostationary satellites (GEO) over China, 27 MEO satellites
- ❑ 5 satellites are placed in 2 geosynchronous orbits
- ❑ Symmetric circular orbit creates one symmetric figure of 8 as foot print of satellite on Earth (over China)
- ❑ Orbits of GEO satellites: 1 orbit, at height 35,786 km, and inclined at 0° , longitude range 58.75° E to 160° E
- ❑ Orbits of GSO satellites: 3 orbits, height 35,786 km, and inclined at 55°
- ❑ Orbits of MEO satellites: 3 orbits, height 21,528 km, and inclined at 55°
- ❑ Orbital period: 12 hours 53 min of sidereal day
- ❑ Signals: B1, B2, B3

Last is the BeiDou or compass it is developed by the China. So, it has 35 total satellites and we can say here 3 geosynchronous satellites; GSO 5 geostationary and 27 MEO satellites ok. So, 5 satellites, these 5 satellites here are placed in 2 orbits then it has symmetric circular orbit because its eccentricity is 0.004 which is very close to the circle or circle has eccentricity of 0 well.

So, it creates a symmetric figure of 8 as foot print over China region and then it has GEO satellites: 1 orbit at a height of this and inclined at 0 degree well that is a geostationary. So and this is the longitude range; that means, over these longitudes this orbits are placed in a geostationary form. So, satellites are basically moving at some longitude permanently, it will appear like that.

So, then orbit of GSO satellites are 3 orbits at this height and inclined at 55 degrees fine. Now it has MEO satellites also, 3 orbits and the 21,528 which is slightly lower than the GPS and they are inclined at 55 degrees. Well, what about the orbital period more than a half hour sidereal period, more than that. So, 12 hour 53 minute almost. We can say 13 hours of sidereal day right and then it has three signal frequency B1, B2, B3, ok.

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So, that is the kind of total introduction about all this thing. These two lines which is say 55 degrees North and 55 degrees South, well what about the shape.

It will again, let us create the space here. This is the box here and this bounding box if I create the shape of 8 it will be like this. It will be shape will be somehow like this I am trying to draw a appropriate shape well. So, that is the idea here. So, this is Chinese region here. So, it is going to serve the Chinese region.

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Specifications of GPS Receivers

- Number of channels ✓
- Position accuracy ✓
- Data logging rate and data output rate ✓
- Data storage (internal memory and SD card) ✓
- Data delivery format ✓
- Post processing ✓
- Special features ✓

So, all these are regional GPS systems or we can see all are global in nature; however, they are tuned for regional requirements; now so, if they are somewhere at this equator.

Now we have learned about all the GNSS constellations. So, let us try to look into these specifications of GPS receivers that you may buy or you are planning to buy ok. So, if I have already viewed couple of specifications of GNSS systems and I have also reviewed, I have already reviewed.

So, couple of satellite, couple of GPS manufacturers specifications; and I found that these are very common things number of channels position accuracy, data logging rate and data output rate, data storage data delivery format, data post processing or the preprocessing whatever and special features. Now, the days they have some special features also they are provided by the manufacturers in their GPS machines or a receiver machines basically.

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Number of Channels

☐ Number of channels

- 120 channels
- 220-230 channels
- 440 channels
- 530-560 channels

GNSS Name	No of Satellites	Signals	Channels
GPS	<u>30</u>	<u>L1 C/A, L1C, L2C, L2P, L5</u>	<u>150</u>
GLONASS	<u>24</u>	<u>L1 C/A, L2C, L2P, L3, L5</u>	<u>120</u>
Galileo	<u>30</u>	<u>E1, E5, AltBOC, E5a, E5b, E6</u>	<u>180</u>
QZSS	<u>7</u>	<u>L1 C/A, L1C, L2C, L5, L6</u>	<u>35</u>
BeiDou	<u>28</u>	<u>B1, B2, B3</u>	<u>84</u>
<u>IRNSS</u>	8	Not mentioned	<u>570</u>

So, start with number of channels ok, what do you mean by number of channels? If I take the number of satellites say 30 for GPS and all these are signals L1 C A, L1C, L2C, L2P, L3 and L5 right. They are available for the civilians and now if I say this 1 2 3 4 5 signals and 30 satellites. So, if I multiplied by 2 because each satellite is transmitting the signals on these 5 frequencies and code. So, they have 30 satellites we have 5 such signals.

So, 30 into 5, 150. In the same fashion if I take these as a number of satellites which are working or which are in the operation. And if I multiply with number of signals each satellite is transmitting, let us say 5 here again then we will get 120 here. Similarly for

Galileo 30 and 1 2 3 4 5 6; so got something this figure this could be wrong slightly right.

But there is a purpose to tell all this things QZSS 7 then we have something this kind of number. So, I got 35 here 28 satellites for BeiDou then 3 frequencies or 3 signals. So, we have total 84 here and for IRNSS. So, far I could not find or basically IRNSS perhaps not allowed manufacturers to do develop the receivers appropriate for the receiving the signals or they might be having some different plan; but so as on date this IRNSS are not mentioned in these specifications of the GPS machines or GPS.

So, if we make the total of this thing it will come close to 570, close to 570. Just try to calculate it. Now, we have the different, different combination some specification say 120 channel some say 220 channels some say 420 channels and the maximum is this channels.

So, perhaps I have shown the calculation for the maximum number of channel maybe I could have missed some satellite number or I could have placed little more satellites and maybe a little more signals whatever. But yes, while you purchase something at least a GPS receiver of high quality of geodetic quality or mapping quality where you expect millimeter level accuracy. You should first ask your vendor what is the meaning of channels. If he is aware of that he will definitely explain you this calculation, but be sure what you are purchasing, right.

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Position Accuracy

- DGPS accuracy: $0.25 \text{ m} + 2 \text{ ppm}$ (format: $a + b \text{ ppm}$)
- RTK performance (accuracy) ← $8 \text{ mm} \pm$
- Static performance (accuracy) $3 \text{ mm} - 5 \text{ mm} \pm$
- RMSE accuracy
 - Vertical accuracy (VA) ✓
 - Horizontal accuracy (HA) ✓
 - Accuracy in Geocentric Coordinate System
 - Confidence level 99.9%
 - Thumb rule: $VA = \text{two times of HA}$

$VA = 15 \text{ mm}$

Let us go next, DGPS accuracy, what is that if we use the code based and still we use the DGPS, that is differential global positioning system; that means, I have a rover and I have a base. So, with respect to base I am processing the data of the rover and processing the data of the two but I am calculating the position of the rover, this is my rover say this pen with respect to a base which is fixed in location and rover is moving all around in within some range called 30 kilometers or whatever is specified by the manufacturer of the GPS receiver well.

So, this accuracy in the code based in the DGPS mode is around 0.25 meter. It is not frequency received, it is just the accuracy of the code. So, that is the meaning here, ok. What about the accuracy? These accuracies are the local system or are in the geocentric system. All these accuracies of the DGPS or GPS are specified in the geocentric system not on the local reference frame on the surface of earth be careful on this part.

So, how can you verify it, we will see some method today, ok. What about the RTK performance real time kinematic. That means you have a radio modem on the rover. And there is a transmitter radio transmitter on the base and transmitter is sending or the base is sending their corrections in the real time to the rover and rover is finding out its position well.

In this thing we have some accuracy is specified further in the static performance; that means, I am collecting the data at rover as well as base and later on I am processing the data in the laboratory after the mission is over that is data collection is over then I am bringing the data of the base as well as rover and I am processing in the software and that is called a post processing after the mission. I am processing the data and with then these that is called static performance or the accuracy for the static they have different-different static is no doubt higher RTK is also considerably good because RTK accuracies are in general in the range of 8 mm plus minus some ppm right. Similarly static is around now 3 mm to 5 mm. Somewhere, I can say mm plus minus some ppn.

So, now, there is specified also all this accuracies in vertical accuracy form horizontal accuracy, accuracy are as I told they are in the geocentric coordinate system not in the local reference frame. So, do not get confused or the accuracies are not in the map projection system no they are in the geocentric coordinate system capital X Y Z ITRF.

Well they sometimes they specify confidence level also and some of these specifications are saying.

Now, 99.9 percent this kind of confidence level which means if I draw let us say this is a true position I do not know now if I take the position of using GPS machine I may get this kind of position. If I take multiple measurements then if I see that suppose if I take 100 such data which means that in this given accuracy of 8 mm or 3 mm or whatever if I draw a circle here like this 99.9 percent data or 99.9 percent of let us say 100 samples here or 100 position will be within this 8 mm.

Say if I am referring this kind of accuracy or within this 3 mm whatever. So, that I s the meaning here remember these accuracies are specified again in geocentric coordinate system not in the local reference frame. So, with respect to the equator in the equatorial plane I should measure my planimetric accuracy and perpendicular to equatorial plane. I should measure my vertical accuracy slightly difficult or slightly imagination is required lets go ahead and try to see what is the meaning there we will see in this lecture only.

But finally I can say one thing if we can observe that there is thumb rule that vertical accuracy is almost two times of the Horizontal Accuracy. And there is a reason, reason is that since satellite is moving above the equator below the equator like this and here it is moving all around all the satellites. So, I have my horizontal positions calculated from all around this position like this satellite positions.

However vertical position is always calculated if satellite is above the horizon or above the equator in my hemisphere or I can say with respect to my horizon if satellite is above then it can be useful for my position calculation; however, a satellite which is below my horizon will not be used. I can say the half of the satellites are not available to me at a time, but for horizontal positioning all the satellites are available to me or I can that is the reason people give that vertical accuracy is inferior to the horizontal accuracy and the ratio is two times.

So, if you have 8 mm you will observe somehow vertical accuracy will be 15 mm or 16 mm some like something like this.

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Data Acquisition and Processing

- ❑ Data logging rate and data output rate
 - Data logging rate: 1 Hz, 2 Hz, 5 Hz, ... 20 Hz
 - Data output rate ✓
- ❑ Data storage
 - Internal memory ✓
 - SD card ✓
- ❑ Data delivery format ←
 - Propriety format ✓
 - Universal format (RINEX format)
- ❑ Data processing
 - Data is processed through software ✓
 - Data is processed in GPS hardware

Well, let us go ahead now data logging rate these are the rates available now the days in the specifications. That means, they are recording 20 data per second that is 20 hertz 5 data per second and you can do this setting while controlling the receiver data output rate they have some different. That means, once you take the data from the receiver at what rate it will be transferred now, that is not very important because anyhow you will transfer the data whether it will take 1 minute or you will take half a second you will transfer it anyhow.

Data storage they have the internal memory to store the data. That means, the moment data is collected, it will be immediately it is stored in the internal memory in the receive itself other arrangement is SD card you can apply the card well SD card could be of very high capacity, but internal memory is variable; why because it takes less time to store the data it is kind of ram internal memory is ram and SD card is kind of hard disc that you apply from outside. So, transferring the data from the machine to internal memory is much faster than to transfer to SD card.

Further, sometimes data delivery format once the data is recorded most of the manufacturers prefer to record in a proprietary format; why because then they will use their software to transfer the data into the universal format called RINEX. So, it is kind of developing a proprietariness on their data or they are saying that we have our proprietary you know and you have to purchase the software, but some of the

manufacturers are now providing the facility where they are straight away providing the RINEX data in RINEX format. That means, you are free to use any free software for data processing well.

Data processing that data can be processed through software; that means, in the post processing manner or it can be processed in the hardware. Also these facilities are also available. That means, whatever data you collecting it is directly processed immediately there itself in the hardware of GPS receiver itself. And once you take the data out it is delivered you in the director answer form.

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Special Features

- ❑ Battery
 - Hot swappable]
- ❑ Wire less data transfer
 - Blue tooth ||
 - GSM modem ||
- ❑ Radio modem for RTK survey
 - Internal radio modem (internal UHF)
 - External radio modem ←
- ❑ Tilt sensor ←
- ❑ Operating temperature
 - Temperature range: minimum to maximum (-20 - +55C)

So, there are some special features first is the battery, battery is now the days, they have hot swappable batteries which means there are two batteries in place, but one battery at a time can be charged and one battery will be in service. So now, we realize let say you place two batteries both are working.

So, one battery is being used by the GPS receiver and one is the spare in the box itself in the receiver itself. Now the movement that particular battery which is being used at the starts it will give an indication. So, what will you do now you will remove this battery and automatically receiver starts using another battery, what is advantage now you can charge this battery which you removed. And then once after 2 hours it is charged again you replace this battery and you can check the status of the another battery which is being used. So, this feature is called hot swappable batteries.

What about data transfer data transfer can be done by blue tooth or even with your helping GSM. GSM modem is you can put a sim there inside a GPS receiver and using that sim it can communicate to your mobile or it can you can transfer by email also right. So, that somehow an advantage now what about the radio modem they have internal radio modem as well as external radio modem for external radio modem you need to pay little extra. Nowadays internal modems are also coming for RTK facility, but remember in India transmitting the frequencies or especially radio frequencies are denied.

Then we have facility called tilt sensor this tilt sensor means suppose you are using the GPS or the DGPS on your boat and boat is moving on a water surface definitely it is move like that. So, it is kind of tilt is there. So, these tilt sensor make the measurement of tilt and it will provide you the tilt correction. So, if you read this tilt sensor understand that is the purpose then we have operating temperature.

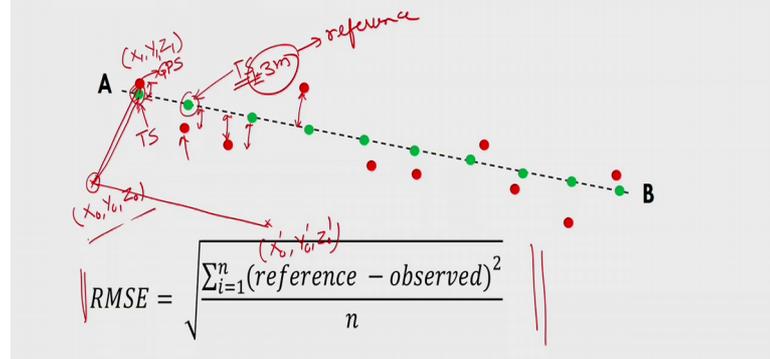
Generally they specify minimum to maximum well these days range is somehow around minus 20 degree or may be minus 30 degree to plus 55 degrees centigrade? That means, you can go in desert where temperature could be rise around 50 degrees and you can work with your DGPS machine or you can go to the glaciers where temperature is sub 0 even up to minus 10 degree centigrade or minus 20 degree centigrade where GPS machine will work there ok.

So, what about the accuracy suppose you have ordered one DGPS and you want to verify your accuracy? So, what will you do now idea is very very simple? So, we have devised a simple way rather we are suggesting.

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Validation of GPS Specifications

Observing a straight line



So, let us say there is a line A B. Nnd now you will collect the position using your DGPS or GPS over these points. Let us say 10 points you have placed like this ok. If you calculate the position which is given by the DGPS; that means, you have placed your DGPS machine here, here and so on then you calculate the position.

Let us say these positions are like this like this right. So, what will you do now you will first take an arbitrary position say this by your DGPS say this is your reference point bring your coordinate system from geocentric coordinate system to the local terrestrial frame. That means, you put let u s say this is your x 0, y 0, z 0 coordinate with the help of DGPS then what do you do you, just assume that this location which you do not know truly but you say that this is an arbitrary position and I am making my arbitrary reference frame.

Now let us say this is my x 1 y 1 z 1 position fine ok. So, you can find out difference; that means, what is the length of this vector like this ok. Similarly you can find out from this position where you can put total station here. Now what is this location of green dot and try to find out the accuracy between the two red dot and green dot right. So, that is they calculated by GPS or DGPS and that is position is calculated by your total station in the same reference frame.

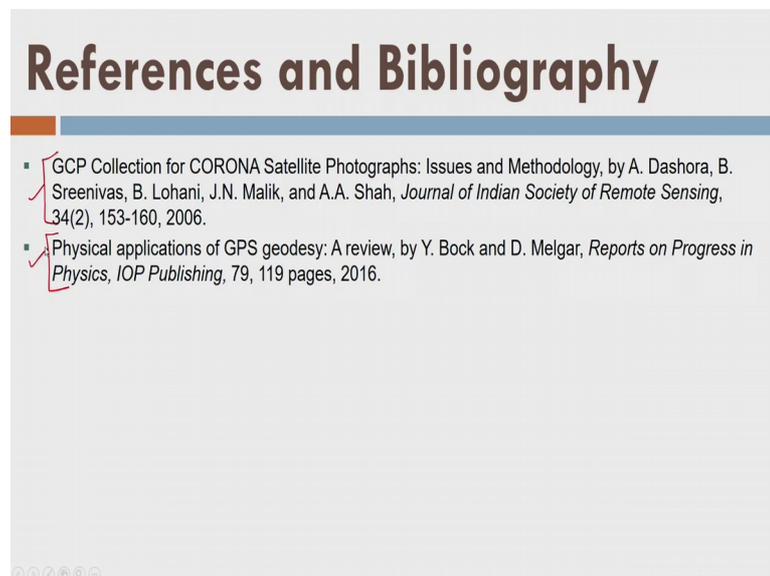
Remember, you will orient your total station in the local terrestrial frame and local terrestrial frame is designed with the help of this point you can also do one thing you can take another point here. And then you can find out the bearing of this line, and by

measuring the bearing of this line let us say x_0 y_0 z_0 , you will use this line for the referencing of your total station.

Again what about the quality use error propagation use adjustment computation to find out the quality? And this is very easy logic here you find out all these accuracies like this or maybe this accuracy. And then you will can find out whatever specifications are there or whatever requirements you have about accuracy whether these accuracy figures are fulfilling those requirements or not. Well, that is the idea here now you can use the RMSE calculation also that is one is reference one is observed. So, this is your observed and position of this by total station which is let us say 3 mm accurate it is your becomes reference.

So, now you do reference minus observed. And if there are number of points then you use this formula to find out the RMSC and check whether whatever claim has been made by the manufacturer are true or not.

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I hope that this lecture was very -very informative for you. And there I would like to recommend if you want to read more on the applications of the GPS then you can go. So, these two papers and report they are available free on internet and you will be enormously benefited if you go through this two.

So, we will meet in the next model on photogrammetry in next lecture.

Thank you. Thank you very much.