Satellite Communication Systems
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Lecture - 40
Satellite Navigation – II

Welcome back. So, we are talking of the satellite navigation and how to estimate the position velocity and time and we started with position estimation in that we have seen that it is coming as a quadratic equation. So, those ambiguities can be removed by a simple technique of linearization. Where you have to have an approximate guess of your position and then iterate and try to find out your position.

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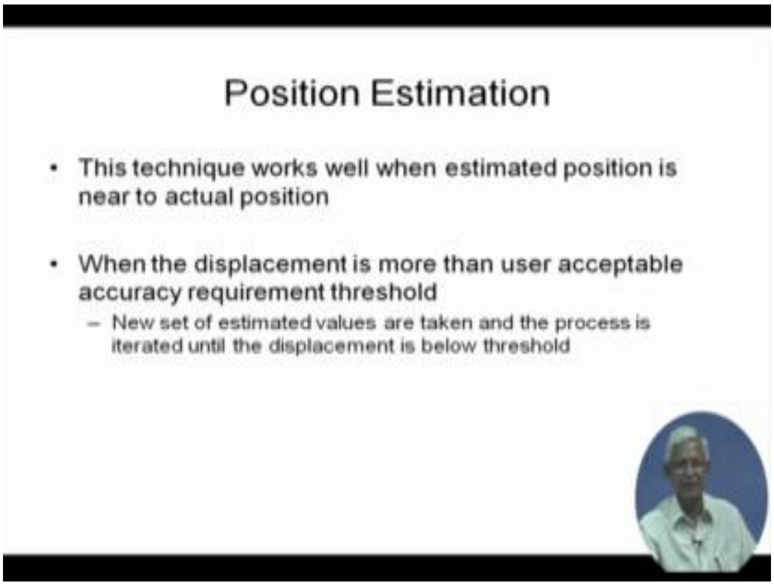

Now, like that you find out the position and with the iteration value and it can be seen that it has been seen already, even if your initial guess is slightly away within 2, 3 iteration you will reach to the to your required position with sufficient accuracy required accuracy.

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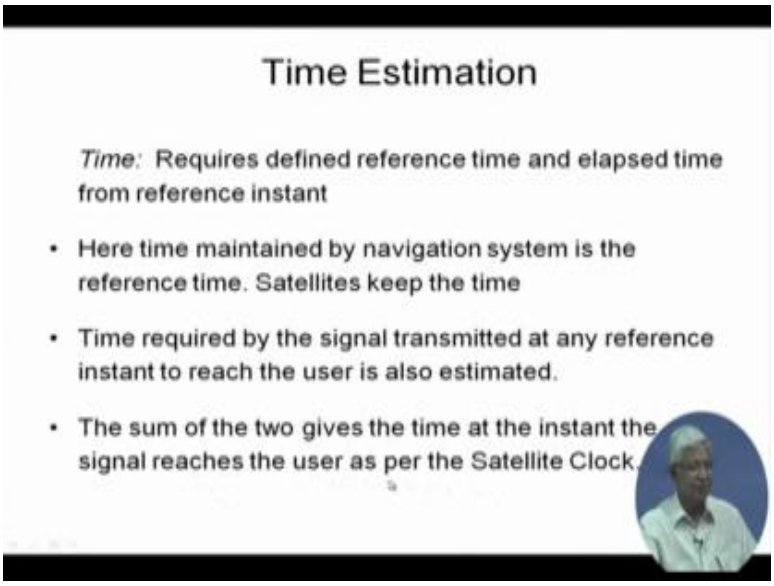

Now, time estimation time requires a defined reference time and the elapsed time from the reference instant. Now the time is maintained by navigation system is that reference time satellite keeps the time the time required for the signal transmitted at any reference instant to reach the user is also estimated that, propagation part once these two are added then you give get the time instant when the signal reaches at the user as per the satellite clock.

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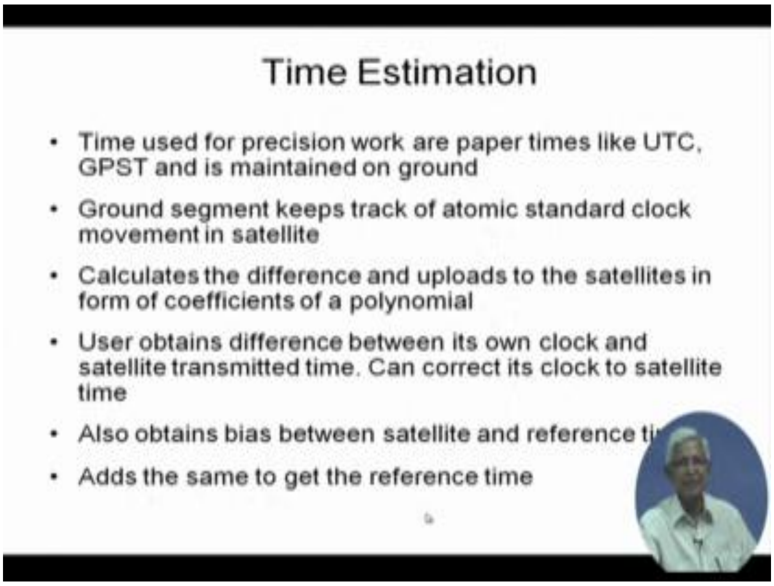

So, the reference time is the quadratic time that is UTC, GPST, GPS time is also maintained that is maintained on the ground and ground segment keeps the track of the atomic clock standard and that atomic clock movement that small del t. So, that error and it calculated the difference in upload the satellite in the form of coefficients of a polynomial. So, that instead of correcting the clock on the satellite using additional circuitry it simply sends a polynomial or the correction parameter. So, which will be broadcasted to the user obtains a difference between it is own clock and the satellite transmitted time and can correct the clock to the satellite time and also it ups obtains the bias between satellite and the reference time which was modeled and uploaded and adds the same to get the reference time.

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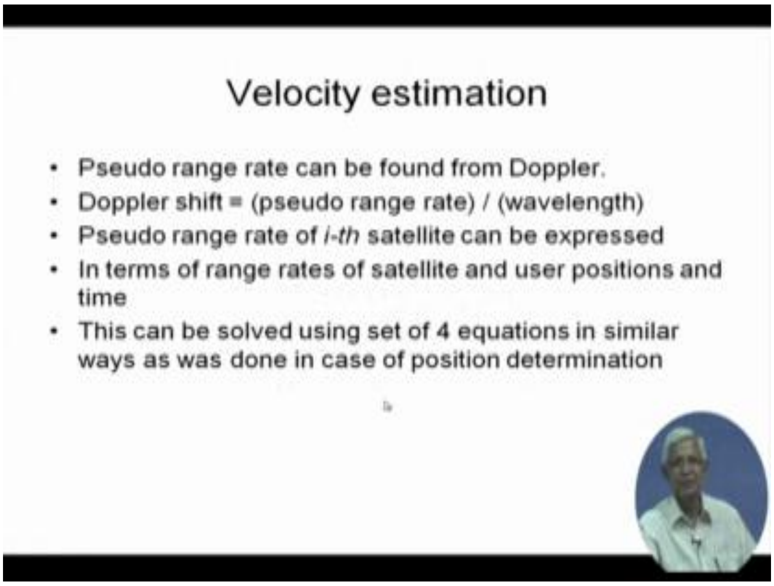

That is how user gets the time velocity estimation is much simpler that is the pseudo range rate can be found out from the Doppler. And the Doppler shift is pseudo range divide by the wavelength and the pseudo range rate of the ith satellite can be expressed can be found out in that form and that derivative form of our earlier quadratic equation.

So, in terms of range rates of satellite and user positions and time it can be found out this can be solved using a set of four equations, similar way at the position determination are maintained.

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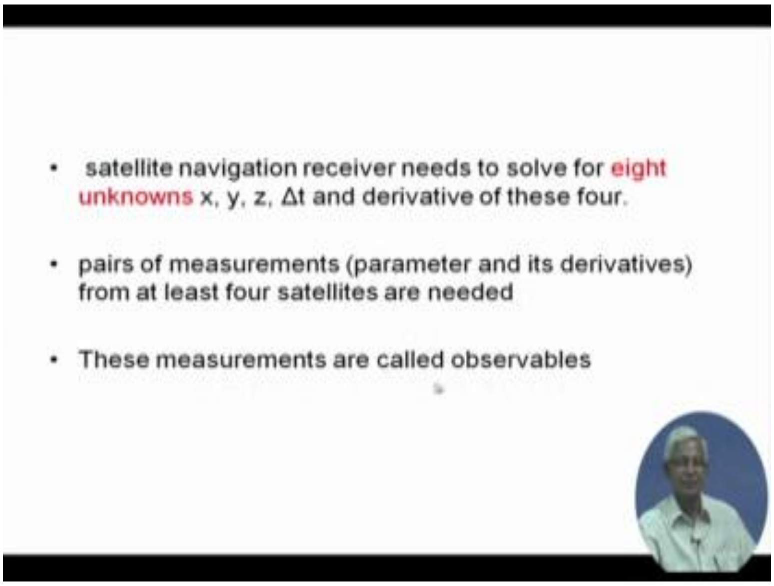

So, therefore, the satellite navigation receiver needs to solve 8 unknowns xyz del t for the position and derivatives of these 4 for velocity. So, pairs of measurement parameters measurements parameters and it is derivatives from at least four satellites are needed these measurements are called observables.

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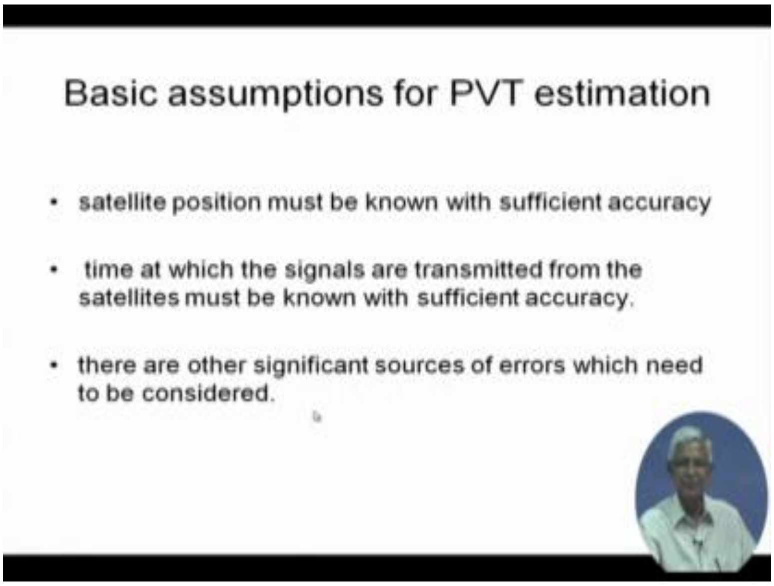

So, basic assumptions of this PVT estimation let us recollect that is satellite position must be known with sufficient accuracy. If that is an error your position is error because you start with reference the reference is the satellite at the time at which the signal are transmitted from the satellite must be known with sufficient accuracy. If that is an error you are also in error because you are finding the range with respect to the time and the propagation a time and there are other significant sources which need to be considered we will see what are those different errors.

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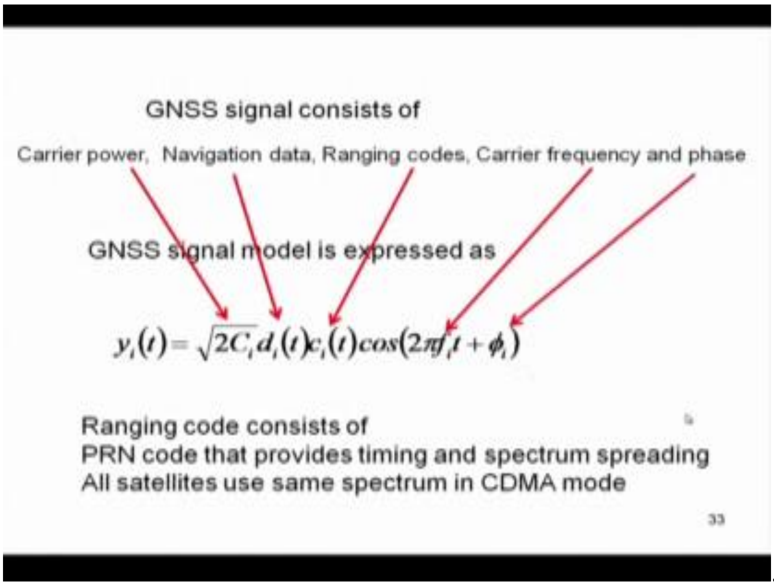

Now, let us go to the signal what is transmitted from the satellite that is GNSS that is global navigation satellite system signal that consists of carrier power the navigational data the ranging code the carrier frequency and phase and the it can be mathematically expressed as let say y it i-th satellite i-th satellite signal is root 2 ci that is the amplitude the d i t i stands for the i-th satellite d t ct and cos 2 pi f t plus phi where that root 2 ci is the power component, the navigation data component is d i t navigation data which is being broadcast which contains a satellite (Refer Time: 04:47) and other models and other polynomials etcetera. The code is the ranging code c i t and that ranging code consists of a PRN code unique for a satellite. So, satellites are identified by the PRN code, instead of satellite number that provides the timing and the spreading, spectrum spreading. So, all satellite use the CDMA mode of communication mostly that is (Refer Time: 05:13) had FTMA, but they are changing over CDMA most of the all most all the satellite navigation system are using CDMA modes mode of communication.

So, this is that ranging code which uses with the purpose of overlapping over the same band width as well as unique identification of the particular satellite as well as time mark and then the carrier frequency is fi and the phase is phi i.

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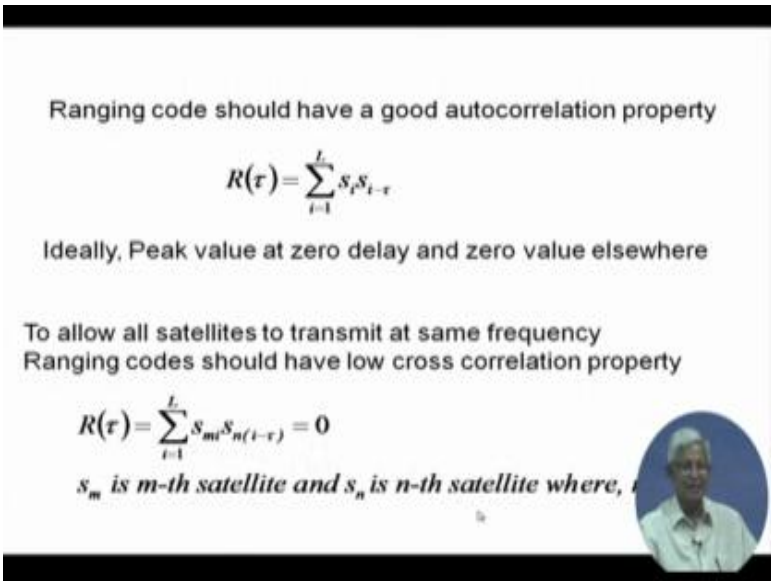

Now, ranging code should have a good auto correlation property; obviously, we know and auto correlation property r t, r tau is expressed s i and s i minus tau is expressed like this and ideally auto correlation peak is known to you peak should be peak value should be at 0 delay and 0 value at elsewhere, and it should have a low cross correlation property because all other satellites are transmitting at a different PRN codes. So, is to allow all satellites to transmit at the same frequency band the ranging codes should have low cross correlation property that is s mi s n i minus tau. If you sum then it should be 0 ideally. So, s m is the mth satellite s n is the nth satellite where m is not equal to is not the same satellite that is it.

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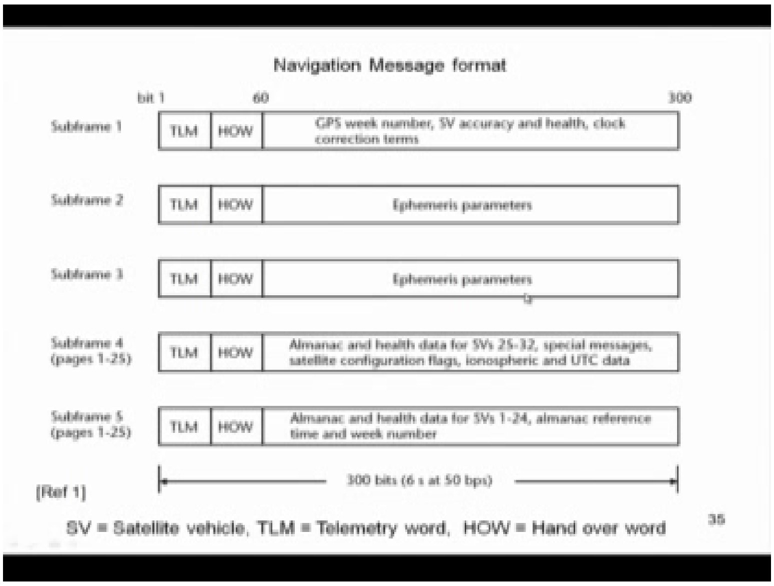

This is say a format in which the navigation message is transmitted it comes very slowly you just see the 300 bit is of information at 50 bit is per second it takes 6 second to come the complete message of 300 bit is and it is divided into many sub frames. So, each of the sub frame TLM is telemetry how is hand over word then GPS week number when first GPS was transmitted launched and service started from that weeks are counted. So, how many weeks have elapsed then, satellite vehicle accuracy it is health clock correction terms then, the sub frame 2 and 3 contains the ephemeris parameters of the satellite and then, sub frame four contains the health data of satellite extra satellites vehicles which are aw this is GPS actually. So, they have 24 satellites 25 to 30-32 satellites what are their health position special any other message ionospheric and UTC data certain models also sent.

So, like that many other addition information are broadcast, but most important thing are these 2 sub frame 2 and sub frame 2. Where the ephemeris are transmitted, as we are seen that it is to be extracted separately and used.

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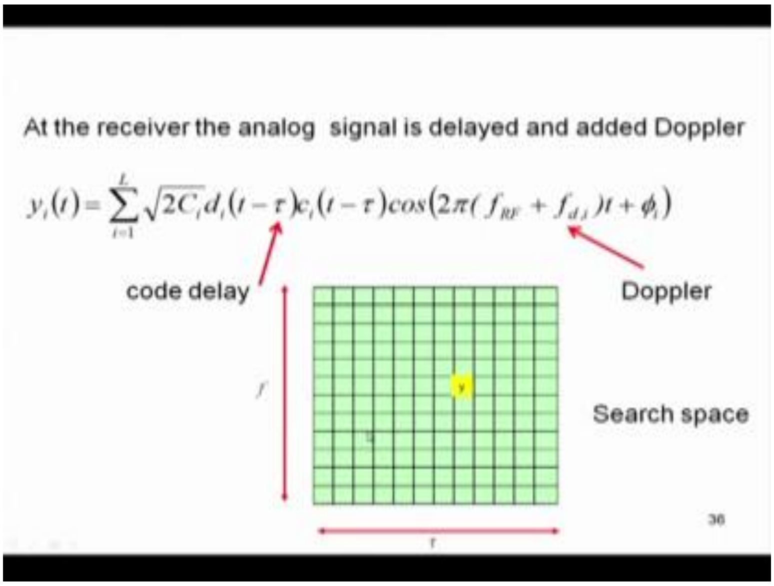

Now, at the receiver the analog signal is delayed and Doppler is added satellites moving where the user is also might be moving. So, Doppler is added to it. So, it is the same equation from the all the satellites i equal to 1 to l let root over two ci it is di t minus tau ci t minus tau. So, this tau is the delay whereas, reference f RF the frequency with on which it transmit it is do Doppler delay by f d that ith 1 and then phi i.

So, that is the tau could delay and this is the Doppler. So, the receiver has to search not only for the code to identify which, a satellite it is it has to also search for the Doppler. So, it has a search space in that search space it is frequency beams as well as it has time beams. So, digitized information which is available where the energy is maximum let us say here this is the y it goes on searching goes on searching in frequency domain and time domain and find out this.

So, it is a acquisition process is involved and once it is acquired it take some time to acquire time to first acquire and after that it has to track that it because of Doppler it might be moving the position, might be moving code delays are also changing. So, therefore, it is acquisition and tracking both the functions are required in this process needs a signal processing.

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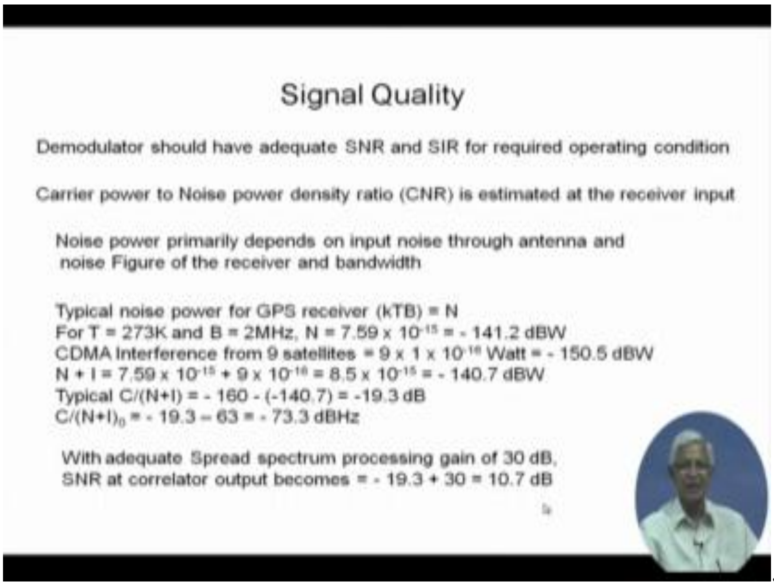

So, signal quality the demodulator should have adequate SNR and sir will do a quick calculation try to see what the quality of the signal is for required this calculation is; obviously, known to you the methods are known. Let us see CNR is estimated at the receiver input and noise power primary depends on the input noise through the antenna as well as the that is the noise figure of the receiver and the band width which is our ktb that is noise power and let see t is 273 degree k 2 mega hertz which is a band width. So, k is known. So, noise power is minus 141.2 dbw or 7.5 910 to the power minus 15 what and the each signal is of the order 10 to the power minus 16 watt which is received at the receiver from the satellite.

So, then 9 of the satellites assuming all of them are interfering with the same power. So, 9 times of this this is minus 150.5 dbw. So, noise plus interference CDMA is acting as a interference noise plus interference in the numerical terms it those these values can be added and you can get 8.5 into 10 to the power minus 15 watt which is minus 140.7 dbw and your signal is minus 160 dbw that is 10 to the power minus 16. So, c by ni is minus 160 minus 140.7 is minus 19.3 db which is very low c by ni is lower CDMA has received. So, which is of course, now the band width is 2 mega hertz is 63 db hertz here and subtracted. So, c by n c by n plus i naught is minus 73.3 db hertz. So, CDMA gain processing gain has to be 30 db with the processing gain of 30 db you get a minus 19.3 plus 30 is 10.7 db SNR at the correlator output you can you receive work up to that. So, that is the CDMA advantage for your extracting output with a two mega bit is spreading you gets 30 db correct just quick calculations.

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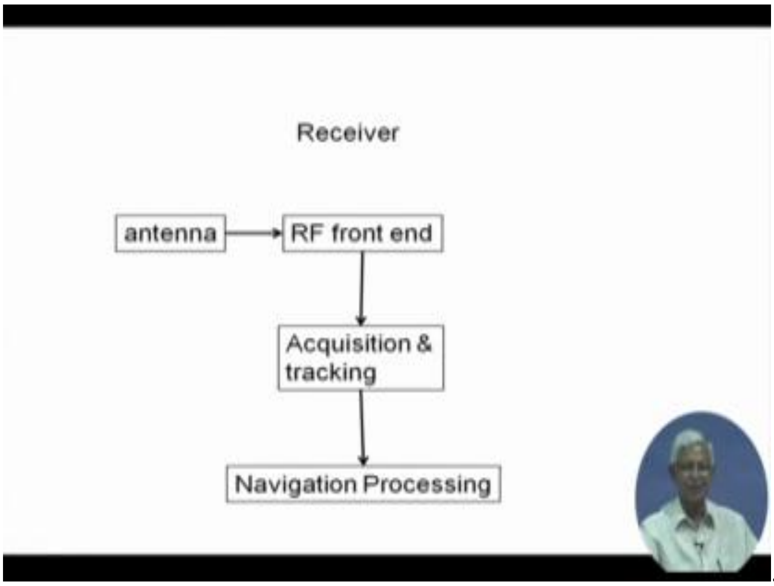

Let us go back to our receiver block diagram is it has a antenna mostly Omni not need not be fully Omni direction, but at least you should look at the sky. So, it is antenna and the RF front end which has the RF amplifiers etcetera and then the after digitization it does acquisition tracking which told you in search space and then once it is a data is found out it goes into navigation processing it extracts the data tries to do that linearization, find out it is position velocity and time.

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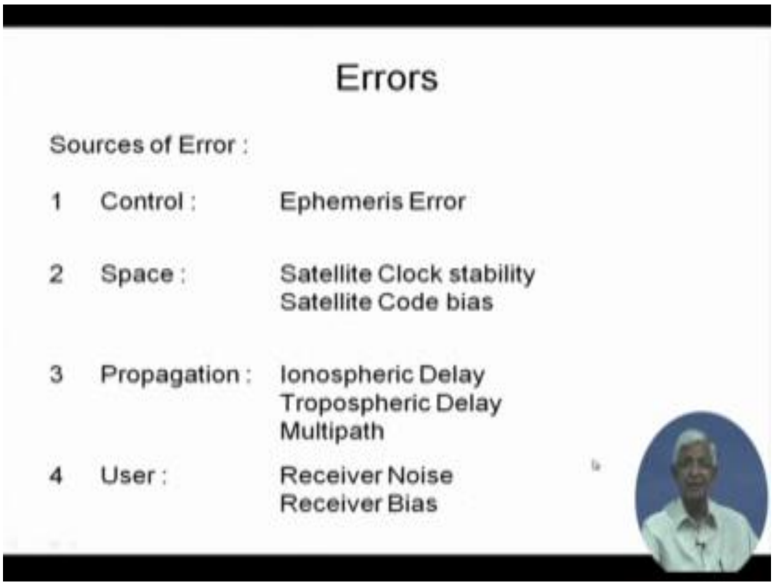

Now, sources of error let us see what are the types of error that can come control error which is the ephemeris error space error it is the satellite clock stability and clock code bias and the propagation error is ionospheric propagation, delay tropospheric delay multipath these are all variables and that the user receiver noise and receiver bias also can have the control and space segment error is ephemeris and clock parameters computed at the control segment and updated at certain intervals when it is visible to the control station satellite is visible.

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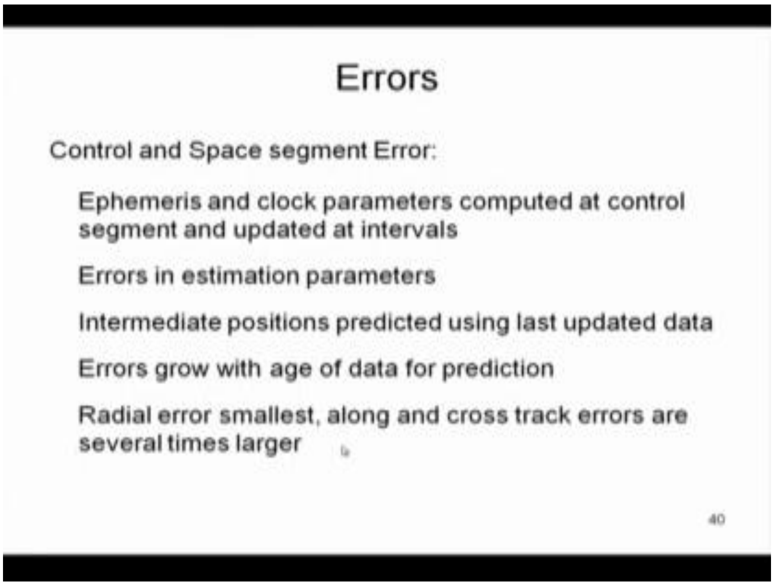

So, in between it will slightly drift. So, that is the control error errors in the estimation of the parameter when you estimate that also there is a model. Because if that some error may come this intermediate positions predicted using last updated data errors grow with age for the prediction and there radial error is smallest along and cross track errors are several times larger is etcetera.

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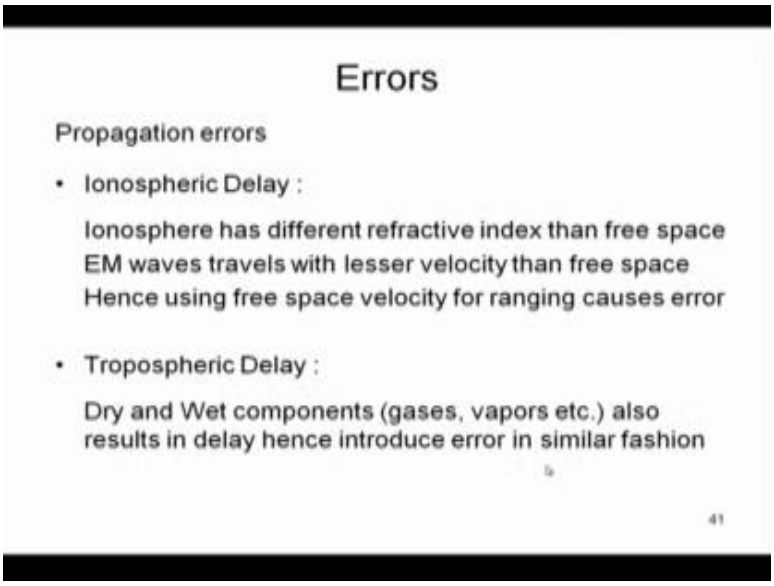

Now, in the propagation path there is important thing which is ionospheric delay that is ionosphere has different refractive index than, free space and electromagnetic wave travels with lesser velocity than, free space hence using free space velocity of range for ranging causes error and at this particular frequency normally which is allotted for this satellite navigation which is one band then, ionosphere error is quite dominant at much higher frequency it will much less and tropospheric delay is a dry and wet components gases and vapors they also try to delay the signal.

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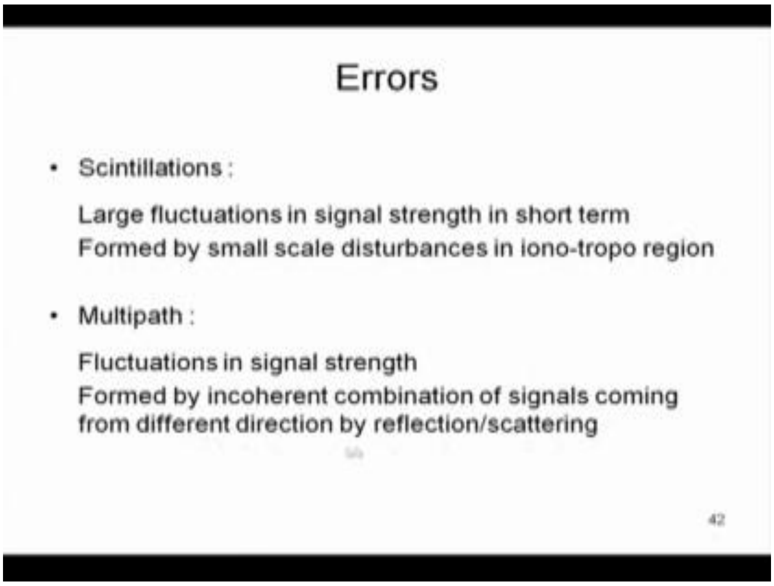

So, therefore, there will be certain error scintillation is a phenomena which is a large fluctuation of signal strength in short term that is formed by this small scale disturbance in ionospheric that is electron or in tropospheric region by the gases etcetera. So, that also affects something multipath is a fluctuation of signal strength due to the reflections the incoherent combinations of the signals coming from different directions reflections and scattering.

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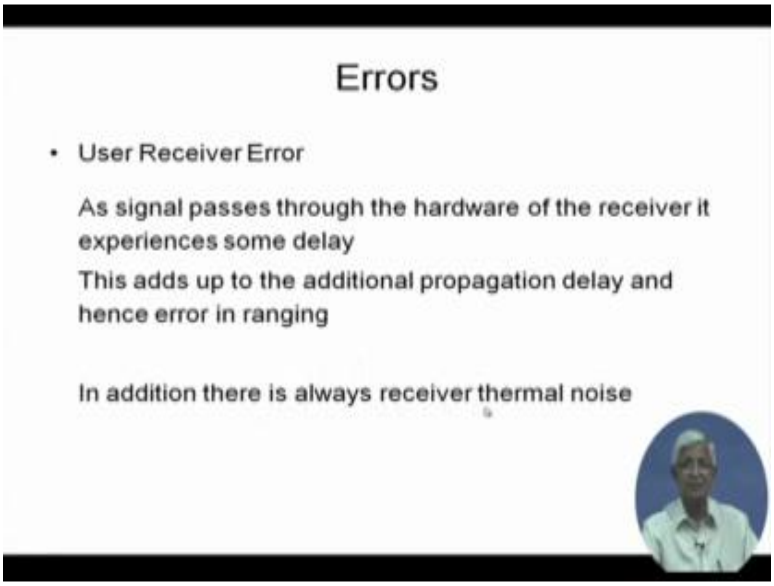

User receiver as the signal passes through the hardware from the antenna to the actual processing receiver. It experience some delay and they add up in additional propagation delay and hence introduce error in ranging in addition there is also the receiver thermal noise that also has to be considered.

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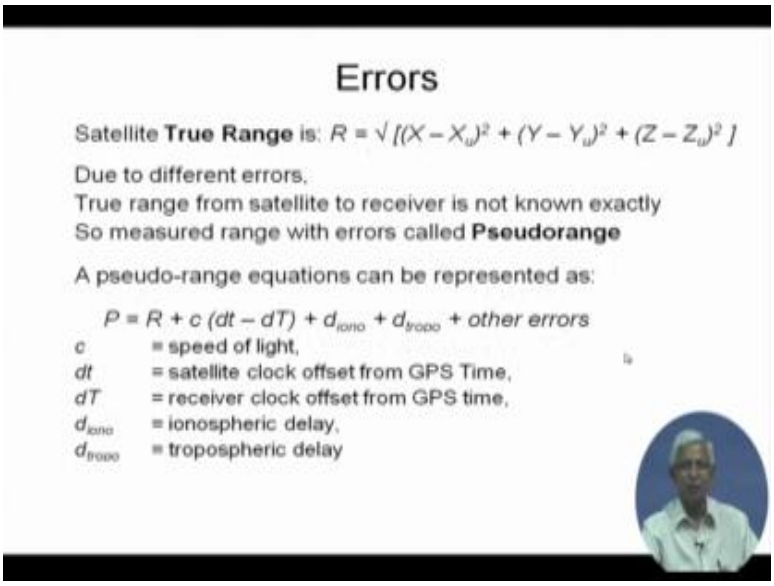

So, the true range if we call it capital r now they due to different errors the true range from satellite receiver is not known exactly. So, this ratio pseudo range we have already used this term.

So, pseudo range is the r plus the clock drift delay clock error iono, error a tropo error and all other errors together.

So, now we have understood that there are certain errors and this has to be estimated modeled or corrected how do you do that that is error correction is the wrong solution of the position.

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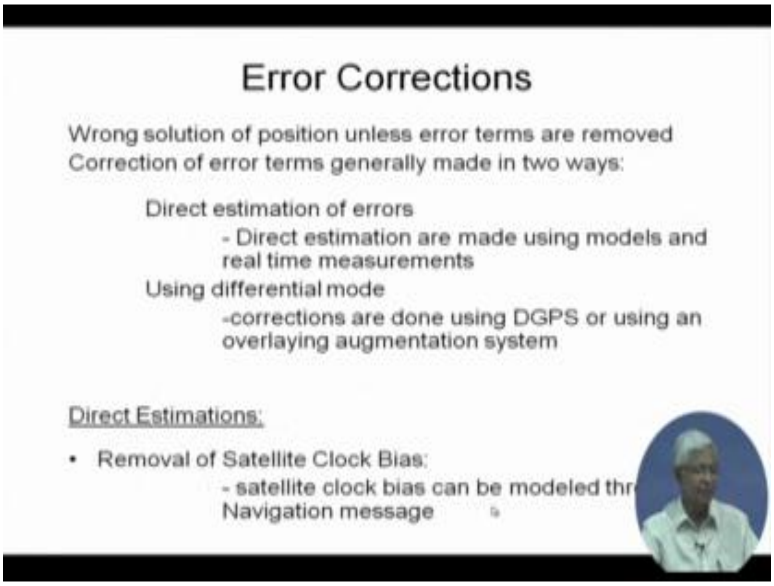

Unless the error terms are removed the correction error term can be done correction can be done in 2 ways either by direct estimation estimate and model it and made use of models or real time measurements all correction can be done with respect to a reference receiver we which is called DGPS, differential GPS. Now direct estimation is clock bias can be removed by the modeling of the clock movement and that can come through the navigation message already, we have said that ionospheric errors can be single frequency users can correct ionospheric errors using a model of the ionosphere at that location because ionosphere varies at different places in the world dual frequency there are 2 frequency receivers can be there.

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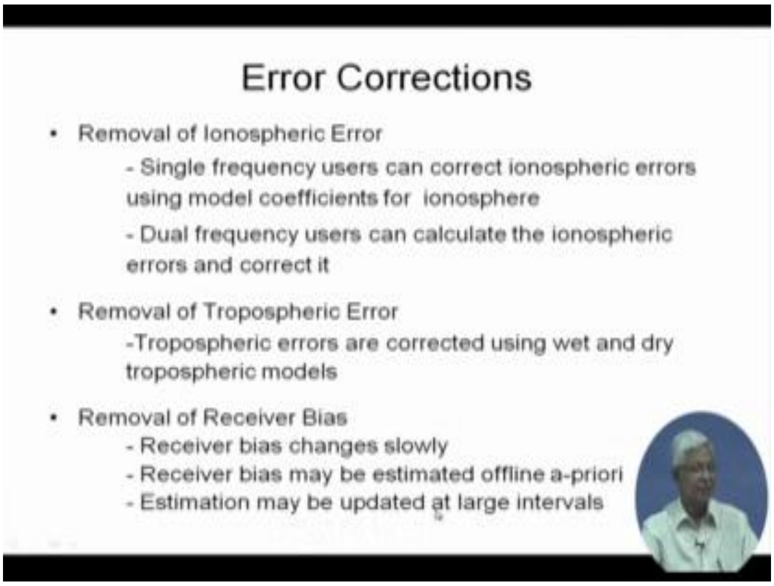

So, dual frequency users can calculate the ionospheric error and correct it because both the frequency will have some similar type of error, that is coming in tropospheric error can be used with within dry tropospheric model and receiver bias error can be changes very slowly, but it has to be corrected it can be corrected by estimated a priori offline measurement of the receiver bias and then, except the interval you can correct it estimation may be updated at large interval.

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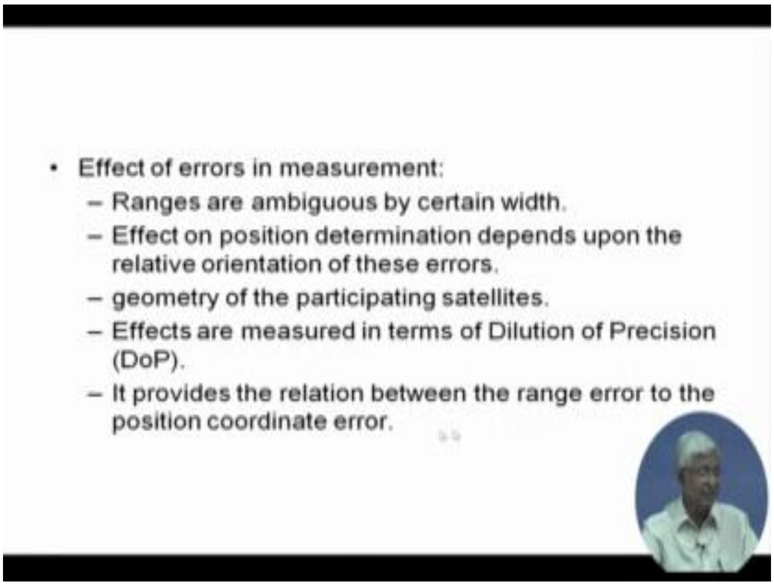

The effect of error in measurement is ranges or ambiguous with certain width effect on position determination depends on the time depends upon the relative orientation of these error geometry of the participating satellites these effects are measured in terms of dilution of precision it provides a relation between the range error and the position coordinate error.

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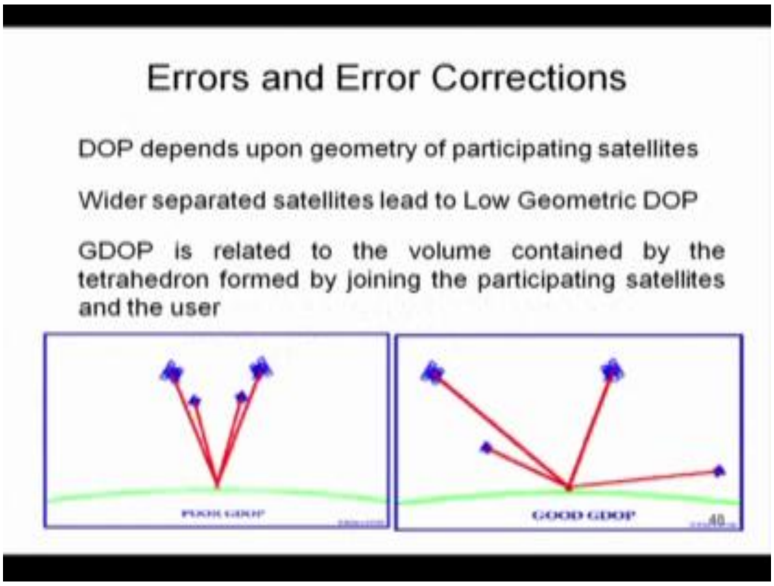

You can see that if the satellites selected for the is located very nearby then you can imagine that cross section points for all the spheres will be slightly fussy if they are away it will much sharper that is what this DOP? DOP depends upon the geometry of the participating satellites wider separated satellites lead to low GDOP geometric DOP GDOP is related to the volume contained by the tetrahedron formed by the joining the participating satellite and the user this is a simpler way of explaining the thing you can mathematically do that we would not going to the details of that.

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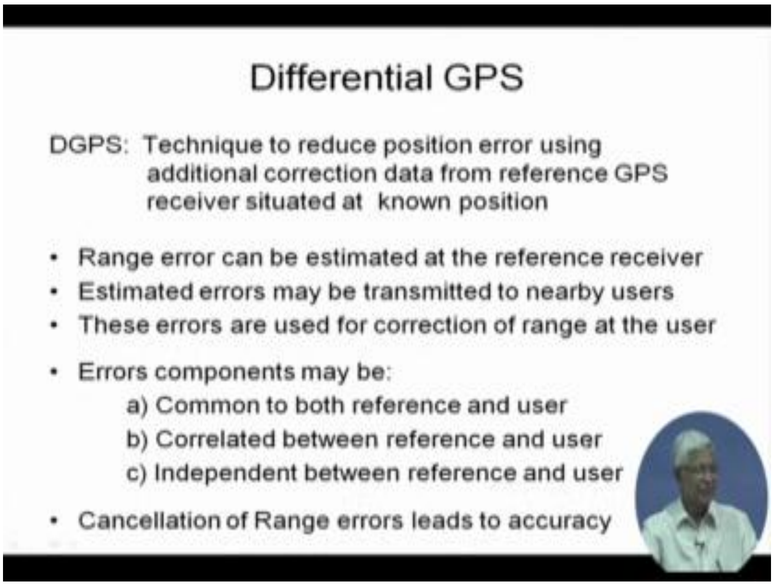

Now, differential GPS techniques are used to reduce the position error using the additional correction data from a reference GPS receiver situated at known position previously known estimated well served point is known range error can be estimated at the reference receiver estimated error be transmitted to the nearby user and these errors are used for correction of the range of the user the error components, may be common to the reference as well as the user it can be correlated or it is independent. Let us see I mean DGPS does not receive a correct all the errors that is what is a meaning there are three types of error components and cancellation of the range is leads to the accuracy.

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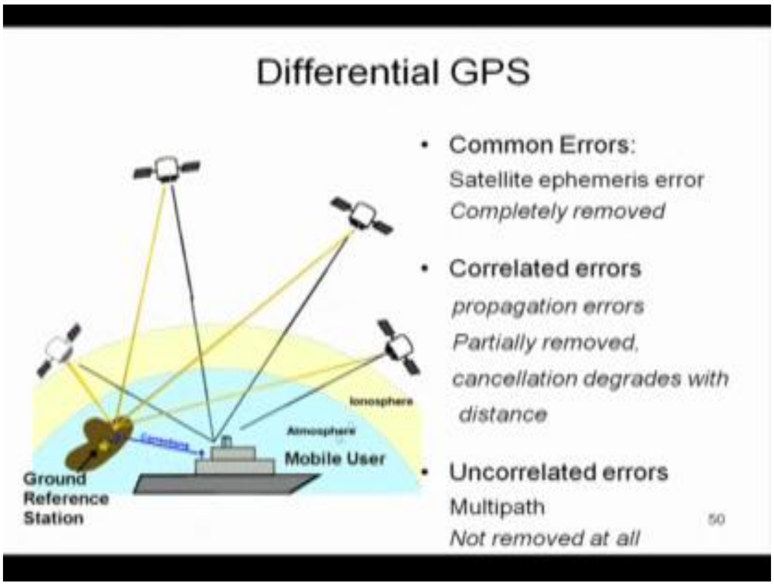

So, how it is done there is a reference at this point which is ground reference well surveyed point and there is a GPS receiver which is receiving from four satellites. Now if user selects the same 4 satellites and he is getting the signal and user get some error since this reference station knows it is own position it is well surveyed previously a priori known. So, he knows what is the error it is getting from these four satellites; in these four propagation path that error term he transmits to the user by another link. So, this correction term comes and user corrects it, but as we said there are certain common errors between these 2 reference station, as well as the user mobile user there are some correlated terms and there are non correlated terms common errors are satellite ephemeris error which is completely removed.

Because the same 4 satellites are selected correlated errors or the propagation errors if they are closed by then the signals from these satellites to the reference as well as to the mobile user are paths are more or less passing through the same part of the ionosphere troposphere. So, they are can be assumed correlated if they are if they are closed by if they are further having it cannot be removed. So, it can be therefore, it can be set partially removed cancellation degrades with distance and non correlated errors multiples will be different to the reference as well as the mobile user it can, cannot be removed at all. So, differential GPS is not the full solution always, but it definitely improves.

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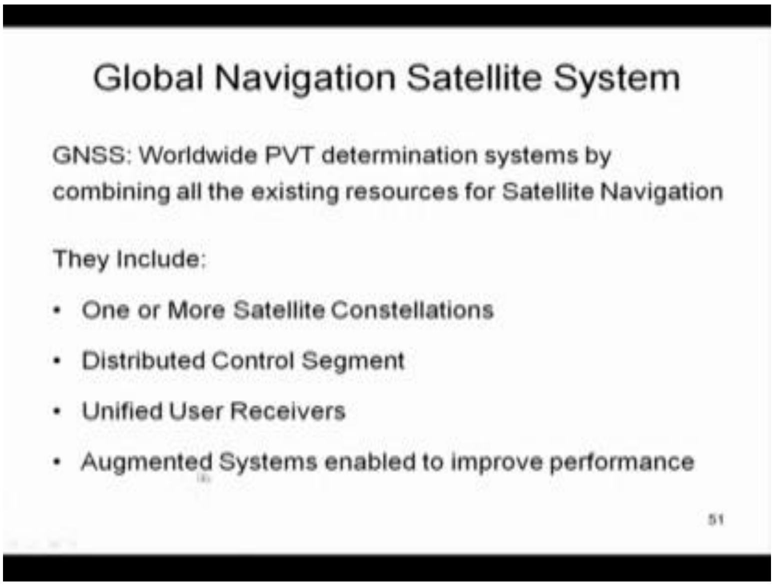

Now, let us talk about global navigation satellites system which is a worldwide PVT determination system by combining all existing sources of the satellites navigation people true to use GPS known as combined receiver Galileo GPS known as combined receiver like that.

So, you have more number of satellites. So, you can select the best satellite looking at the GDOP of different types of constellation satellites. So, one or more satellite constellations are used distributed control segment unified user receiver and there are augmented system enabled to improve the performance.

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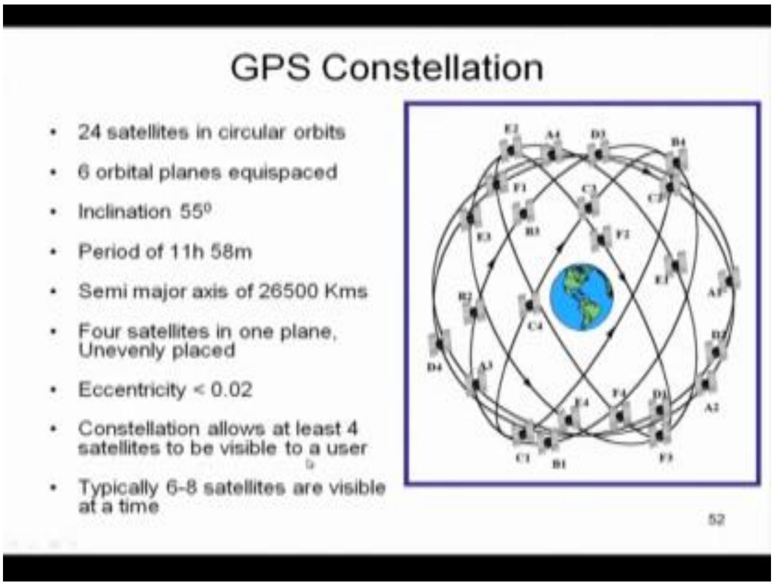

Now, briefly talk about what are some of the some of the parameters in features of the GPS other constellations the GPS constellations has 24 satellites in circular orbit 6 orbital planes at different inclination of 55 degree each and the period of the orbit is 11 hour 58 minutes semi major axis is 26,000 500 kilometers is not geo stationary orbit it is a medium earth orbit 4 satellites in one plane unevenly placed not evenly placed these they did it for that GDOP improvement over the service area what they have looked into and eccentricity is mostly circular. So, eccentricity is very low is 0.02 and constellation allows at least 4 satellites visible to user most of the part of the earth typically 6 to 8 satellites are visible.

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Other Sat-Nav Systems

GLONASS : GLObal NAvigation Satellite System
Proposed by USSR; maintained by the Russian Republic

Constellation	GLONASS
Total Satellites	24
Orbital Planes	3
Plane separation	120°
Satellite in each plane	8
Orbital Radii	25510 Km
Orbital Period	11 Hrs 15 Mins
Inclination	64.8°
Frequency	$f_1 = 1.602 + (9/16)\,k$ GHz; $f_2 = 1.246 + (7/16)\,k$ GHz; $k = 0{:}23$
Ranging Codes	0.511 MHz C/A code in f_1 5.110 MHz P code in f_1 and f_2
Modulation	FDMA

Another constellation GLONASS: Global Navigation Satellite System which is by USSR, now it Russian republic it has also 24 satellites it has 3 orbital planes. Plane separations are 120 degree 8 satellites per plane is also medium earth orbit 25,000 kilometer orbital period is 11 hour 15 minutes inclination is 64 degree at this inclination is selected based on the their service area which is much higher latitude and there transmit into 2 frequencies across.

Now, they have changed now this is a FDMA technique they have used and ranging codes are this ca code is codes acquisition code and p code is precision code these are also used by GPS at not mentioned in the earlier.

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Other Sat-Nav Systems

GALILEO : Proposed, designed and being implemented by European Space Agency (ESA)

Constellation	GALILEO
Total Satellites	27 +3
Orbital Planes	3
Plane separation	120°
Satellite in each plane	10
Orbital Radii	30016 Km
Orbital Period	14 Hrs 22 Mins
Inclination	56°
Frequency	1164 – 1300 MHz; 1559 – 1591 MHz;
Modulation	CDMA

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So, their frequencies are mentioned and modulation is FDMA, but now they are changing over to CDMA Galileo with is European space agency is 27 plus there satellites these 3 is extra satellites on orbit sphere and three orbital plane 120 degree separation of the plane and 10 satellites per plane this is like a higher orbit 30,000 kilometer based on again their requirement and 14 hours 22 minutes is orbital period inclination is 56 degree and frequency is of 2 different transmissions are given and modulation is CDMA.

Now, in addition to that there are compass as well as other satellites India has launched started launching it is own satellite which is regional satellite.

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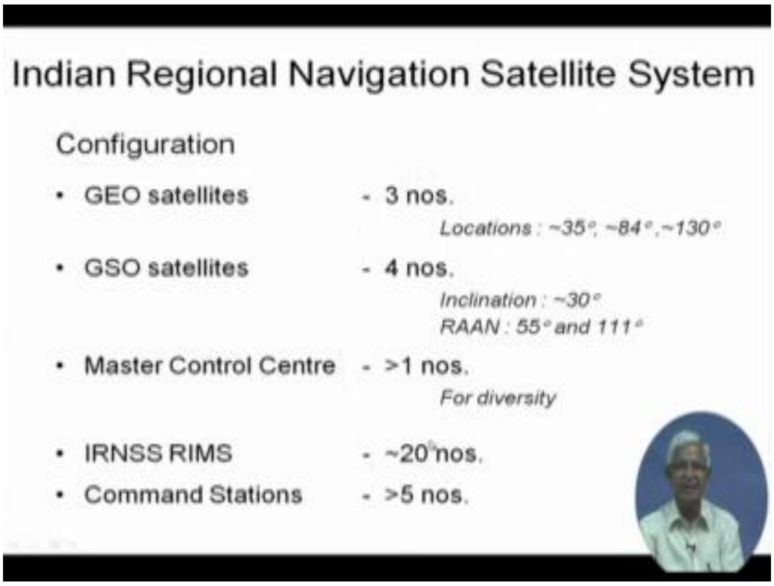

So, it is called Indian regional navigation satellite system IRNS must have seen the announcements advertisements. Whenever they come up any satellites is launched recently they have completed the constellations that is configuration is three geo satellite you try to recollect it is geo stationary satellites.

So, their locations are known which are approximately 35 degree east 84 degrees east and 130 degree east, it is a regional system. So, therefore, it is not covering whole earth only covering only Indian region, India land mass as well as a surrounding ocean I mean and nearby ocean area there are 4 GSO satellites they share geo synchronous satellites.

So, they have such an inclination you can imagine that tetrahedron all of the satellites if they are on the same plane you would not get the proper GDOP. So, therefore, they are has to be some satellites which are away from the equatorial plane. So, that is why this inclinations given 4 satellites are there with 30 degree inclination at 55 degree distant 100 and 11 degree is across the equator that is total 7 satellites and there are master control center has to be more than one. Because if one fails the other one takes place the takes care and that range integrated monitoring system which is the required for the control segment IRNSS RIMS are almost about 20 numbers I am not sure exact number and there are command stations more than 5 numbers these are data I have collected just sometimes back. So, may be may have a varied now.

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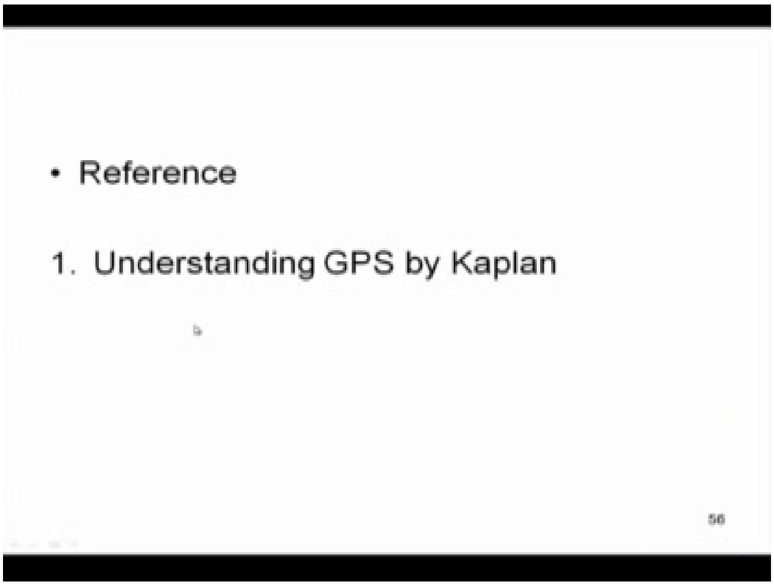

So, we have mostly taken the reference of this linearization technique it is available in many books and these here we have referred to the book which is understanding, GPS by Kaplan. So, with this we have covered the what is meant by PVT and what is the trilateration technique used in the satellite and the time and velocity how it is estimated in addition to the position and then the basic functions of GNSS receiver very briefly you can see it in PRATT also the book text book satellite communication. There also is chapter there also you will get some of the information and errors and mitigation yeah we talked D GPS and other module technique and some existing Sat Nav system. So, with this we complete this satellite navigation which is has application of the satellite communication.

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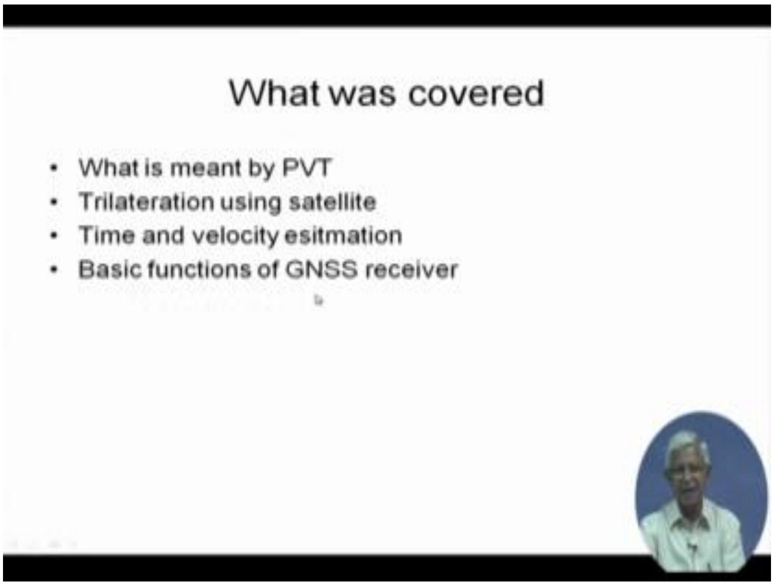

So, till now we have covered almost all the topics what we announced that is our initial part is introduction then orbit then the space segment the linked budget then, the propagation and then multiple axis then the linear that is non-linearity and certain issues and like non-linearity and synchronization issue and then, of course, the higher layer effect the higher layer is couple of issues and briefly touched and of course, one of the application, but it is a vast subject in this such short time everything cannot be covered I hope you enjoyed the course.

Thank you very much.