Mine Automation and Data Analytics

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Week-5

Lecture-21

GNSS in Mining

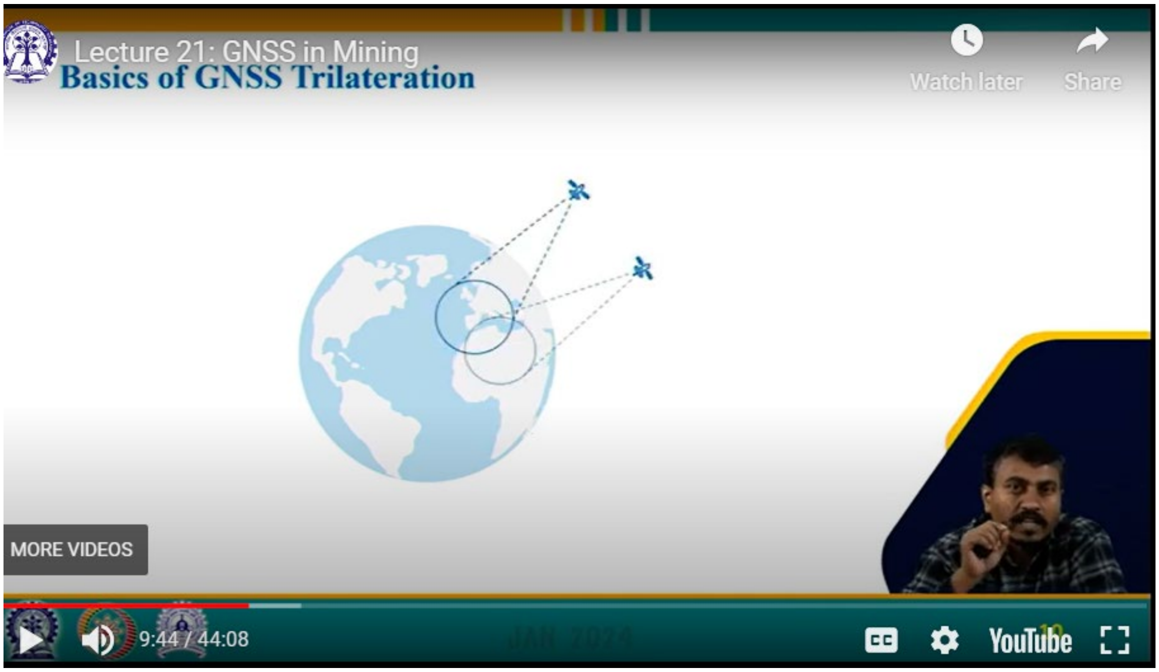
Welcome back to my course, Mine Automation and Data Analytics. Today, we will discuss on the global navigational satellite system or, in abbreviation, the GNSS system, that basically we are using in mining 4.0 in different applications in mining. So, in this lesson, we will cover the following about the introduction to the GNSS system, the primary uses of GNSS system, the basic of GNSS trial iteration method by which we basically calculate the positions of a point in the earth then different GNSS components the type of signals in GNSS the reference systems the observational technique the GNSS positioning techniques the concept of GNSS current and developing status of GNSS the GNSS applications.

So, GNSS is basically stands for the Global Navigational Satellite System. We have seen in many applications in mining, in automated haulage system in fleet management system in automated drilling system ADS system we require a precision positioning of the equipment time to time that positional data of the machines are very essential for the mining operations So due to the advent of this GNSS system nowadays monitoring these machines positions and operating these machines in mines are very easy so we require some good amount of understanding that how this GNSS system is working that is what this relation is all about So this GNSS system is basically consist of a constellation of satellites and those constellation of satellites orbiting around the earth with a very specific trajectory that is more suitable with the algorithms that basically designed by the designers for the overall global coverage and regional coverage as well and it was a primary estimate that 18 to 13 number of satellites is required in a constellation for example on one constellation name is GPS (Global Positioning System) by the NASA. The navigation satellite provides orbital information, orbit information basically and accurate timing and other services to radio receiver. So we have a radio receiver station at the site we have the satellites, and we also have some control points and control stations. So the radio receiver receives the signal and orbital information from the satellite signals, and the receiver decodes the signal what is there on the message and based on the message based on the decoding of the message, it basically tries to understand what is the specific location of the point, and there are some mathematical techniques, it is called trilateration.

So, we should have at least 4 number of visible satellites at the same time at that particular location at least if not most if it is more, it is always good for the accuracy purpose, and basically, the signal sent by the satellite and the pseudo-random codes generated by the receiver there is a time gap and the time gap basically based on the velocity of the signal we can get the distance and different satellite different distance finally the special locations of the point can be estimated very easily.

Primary uses of GNSS system: there are two primary uses: one is the position determination this is very important, and the timing. So, the positioning and timing basically working together. Timing is very important and positioning is also important for us. Position determination, position of an object or a machine is required from the point of view of our operational things. So, the point position is basically its latitude, how far from the equator above or below or the longitude, how far from the greenish mean time right side or the left side and how much it is above or below the mean sea level. So, these are basically the special location of the point. So, this is basically known as the absolute position. So, this absolute position of the GNSS receiver can be determined when the signal from at least 4. It is always preferable that it should be more than 4 Satellites can be seen clearly at the same time and at least some of the satellites in the line of sight, at least 3 to 4.

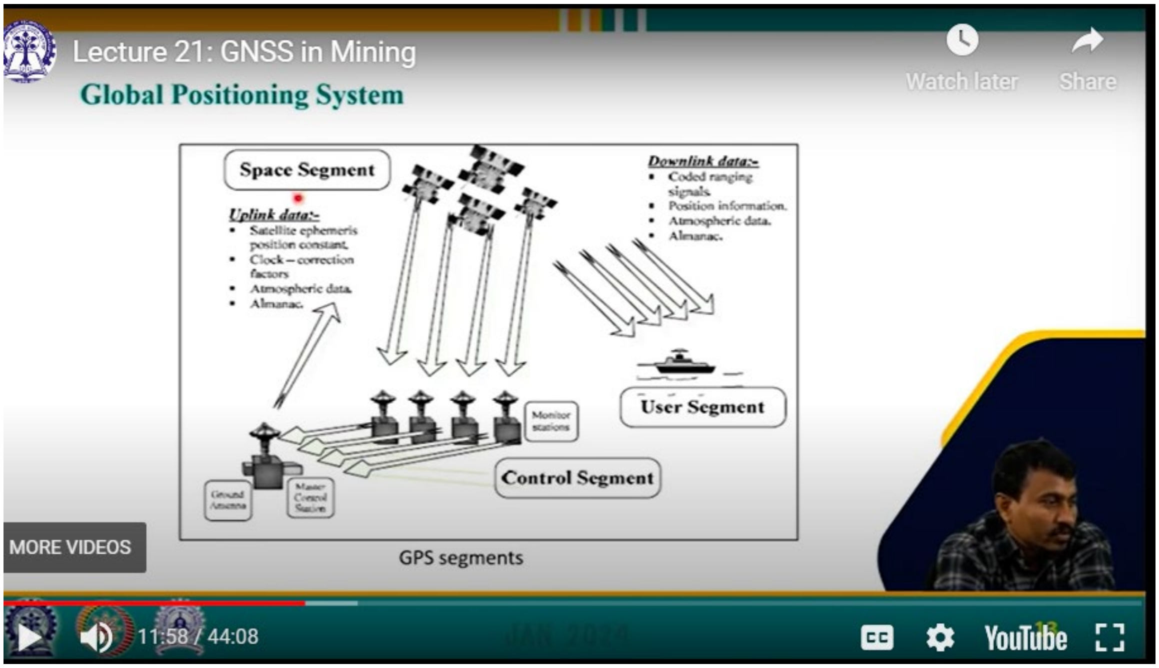
Timing: the signal sent over the radio waves by the satellite on the GNSS satellite is very very consist of very accurate time stamp because these basically have because of the advent of atomic clock that is on board at the satellite system. So, it basically sends a very accurate signal that have a very accurate time stamp and that accurate time stamp is basically decoded by the receiver. So, once the receiver received its position the GNSS receiver synchronize its internal clock with the satellite. By maintaining that synchronization GNSS receiver clock is then considered to have a very accurate timing source. So, the triliteration method is what about So, for example, there is one satellite and that satellite is connected through the radio wave to the receiver. So this is a point, for example. So, what is the exact location of the point from one satellite it would be very difficult, but at least surrounding the point there would be a circular area that, from the receiver point of view it can say it is basically lying within that circular area. So, a single satellite basically covers 35% of the earth surface. So, in a second satellite basically is coming in the coverage and the receiver at the same position. So there would be superimposition of the area that covered by the satellite So there would be the two circular area is intersected there would be two points So the point the receiver may be located at this point or that point.



So, this is basically the mechanism how the trilateration technique basically work So initially, there was a coverage then the second satellite another coverage two points, and the third satellite intersect the green point is basically the exact location of the point of the receiver.

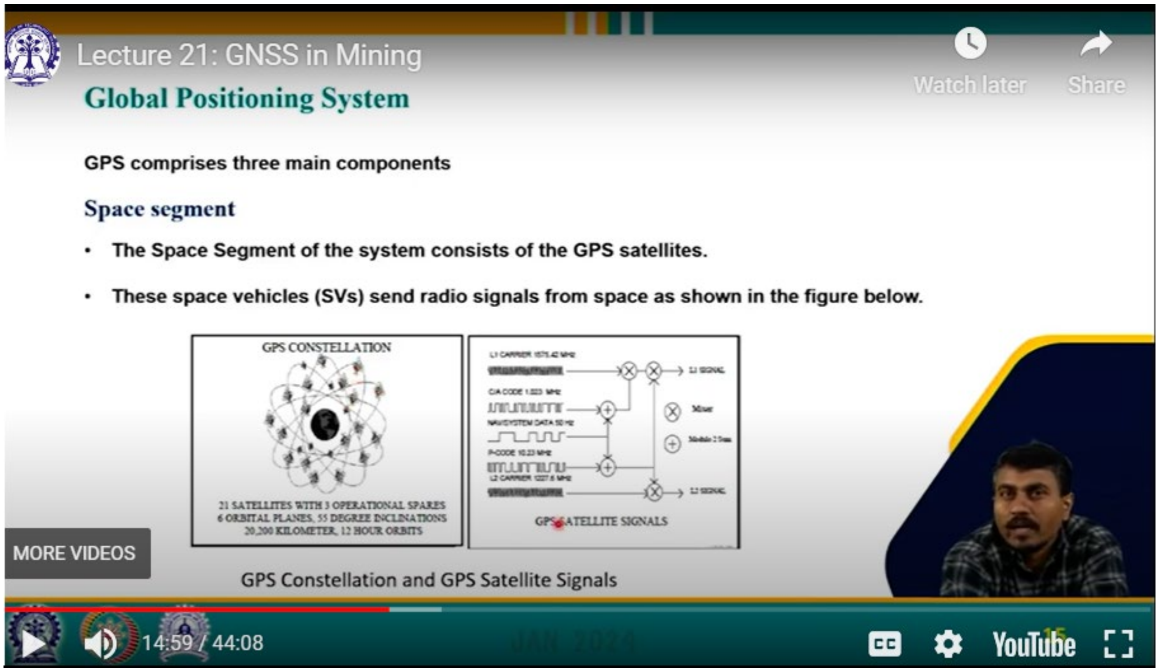
Basics of GNSS trilateration, So when the third satellite is seen the point of intersection of all three-coverage area perimeter will be the location of the GNSS receiver that is an accurate two-dimensional XY positions of the GNSS receiver on the earth surface So that is why the spatial accuracy XY accuracy is very high in the GNSS system So when a fourth satellite is coming to this coverage its altitude elevation is estimated with the trigonometry principle

GNSS components So the GNSS have basically three components particularly one is the space segment second is the control segment, and third is basically the user segment and principally, the GNSS consist of six number of satellite systems. Here we have mentioned the three GPS, GLONASS, GALILEO then we have BIDU then we have GIS and the Indian Navigational Satellite System, NAVIC-C So first component is basically the space segment that is on the satellite constellation orbiting around the earth second is the control segment that is situated at different locations on the spatial extent of earth and third is user segment the receiver that is based on the receiver locations



So, this is basically a typical figure of how these three segments are working hand in hand with each other So this is the space segment of the satellite and there are some control segment monitoring stations spread over all across the world that is basically designed by the agency that they are floating the satellite system in the space based on the mathematical model they will select at which location the control segment will be situated and the user segment maybe it is basically the rail or the sea for the road user will see, user will use for basically location based services location based services is very much now it is used and GNS is basically helping this particular sector to grow So this is basically in the space segment we have the satellites ephemeris, position, constant there are clock correction factors is included we have the, we should have the atmospheric data because whenever these signals are passing through the atmosphere it has several levels of or several components of error basically ingrained with the signal So we should have a pretty good understanding about what kind of error might be So we have a mathematical model we will deliver it on that later how these error can be removed following some specific algorithms.

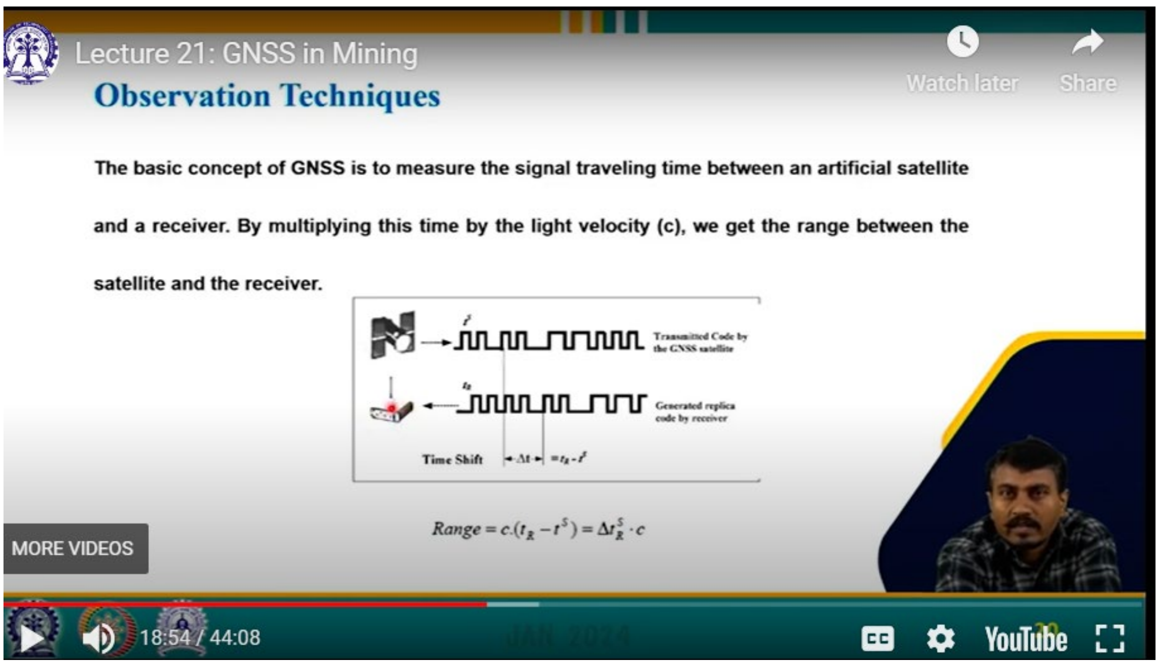
So the US Department of Defense DoD is basically developed the NABSTRAT GPS or popularly known as GPS which is very wall weather friendly and it is a space-based navigational system that basically initially it was designed for the US military forces for their accurate estimation of their position, velocity and time in a common reference system in a geodetic system continuously on the earth or near the earth So the space segment is basically the space segment of the system consists of the GPS satellites so in a constellation 18 to 30 number of satellites is there on an average and these space vehicles sense radio signal continuously on the space as shown in this particular figure So the constellation of satellite is situated around the earth orbiting around the earth with a fixed rotational velocity and there is a fixed time of means orbital period and there are some operational sphere satellites as well that is continuously working as and when demand is there they will work and this is a typical pictures how the signal are being sent and what kind of signals is being sent from the satellite and the receiver receiving the satellite.



So here we have seen the L1 band and L2 band and there are a number of bands GPS signals it is been shown here. Control Segment The control segment consists of a system of tracking station located around the world So the master control facility for the GPS system located at Srivastava Air Force Base formerly Falcon AFD in the state of Colorado, USA The User Segment. The GPS User Segment consists of the GPS receiver and the user community with a large user base basically now a days So the GPS receiver convert the space vehicle signals into position, velocity and time estimates The GNSS Signal So each satellite system has specific signal characteristics But each system attempts to be compatible with the other in order to prevent the interference and attenuation between the signals It is important to consider that the processing of all signals should be performed using the same receiver.

Thus, a complex receiver design is supposed to be designed and built by the manufacturer or the provider of the system So this is basically the different spectrum of frequency of band used in the GNSS system So there are lower L band, there are upper L band and the C bands So of different frequencies spectrum is been shown here Reference System, Coordinate System.

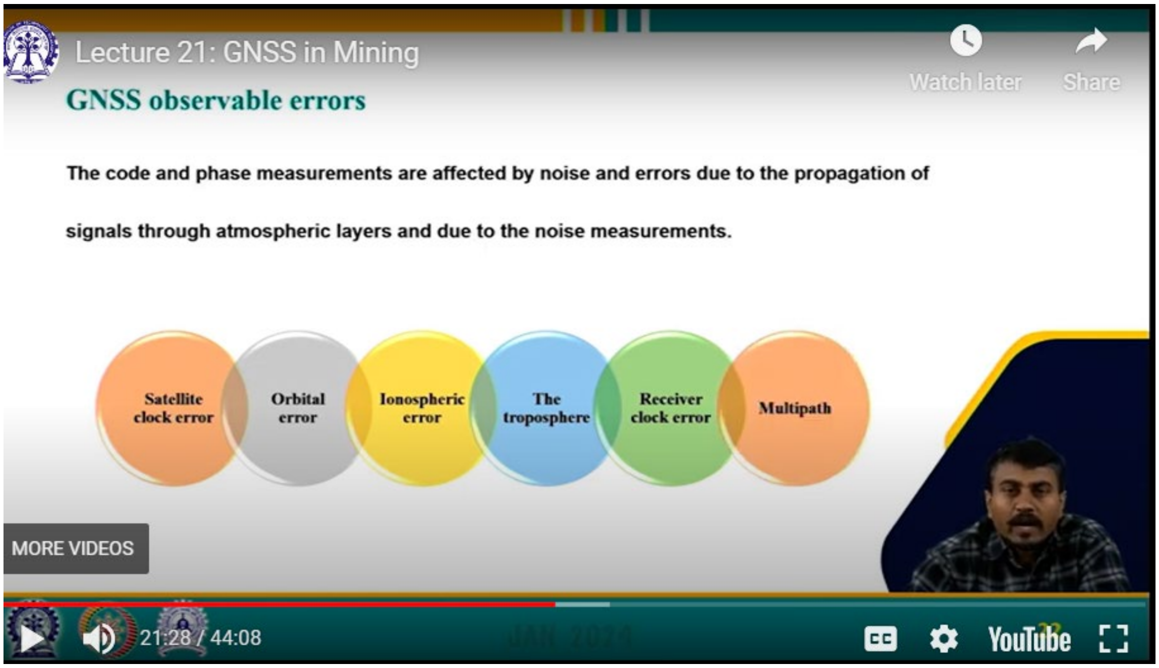
The definition of Reference Coordinate System is crucial for the description of satellite motion. In satellite geodesy, two reference systems are required: One is the Space Fixed Inertial Reference System for the description of satellite motion And B the Earth-fixed terrestrial Reference System for the positions of the observation stations Observational Stations Coordinate System The position of the receiver is calculated with respect to the instant position of the satellite By considering the range vector relation between the satellite and the receiver the coordinate of the satellite and receiver should be expressed in the same coordinate system Observational Technique The basic concept of GNSS is to measure the signal travelling time between an artificial satellite and receiver By multiplying this time by the light velocity C we get the range between the satellite and the receiver.



This is basically the signal sent by the satellites transmitted code by the GNSS satellite system And here is the receiver code, pseudo-random codes generated replica by the receiver So here we can see this is the generated, this is the received one, this is the generated one, and this is replica So this particular ripple is appearing here, and this particular ripple is here So this time gap delta t, time shift is measured tr minus ts, or it is del tsr So this del tsr is a very important component for estimating an accurate range or distance of the receiver from the satellite, and C is the constant, the velocity of light 3 lakhs km per second.

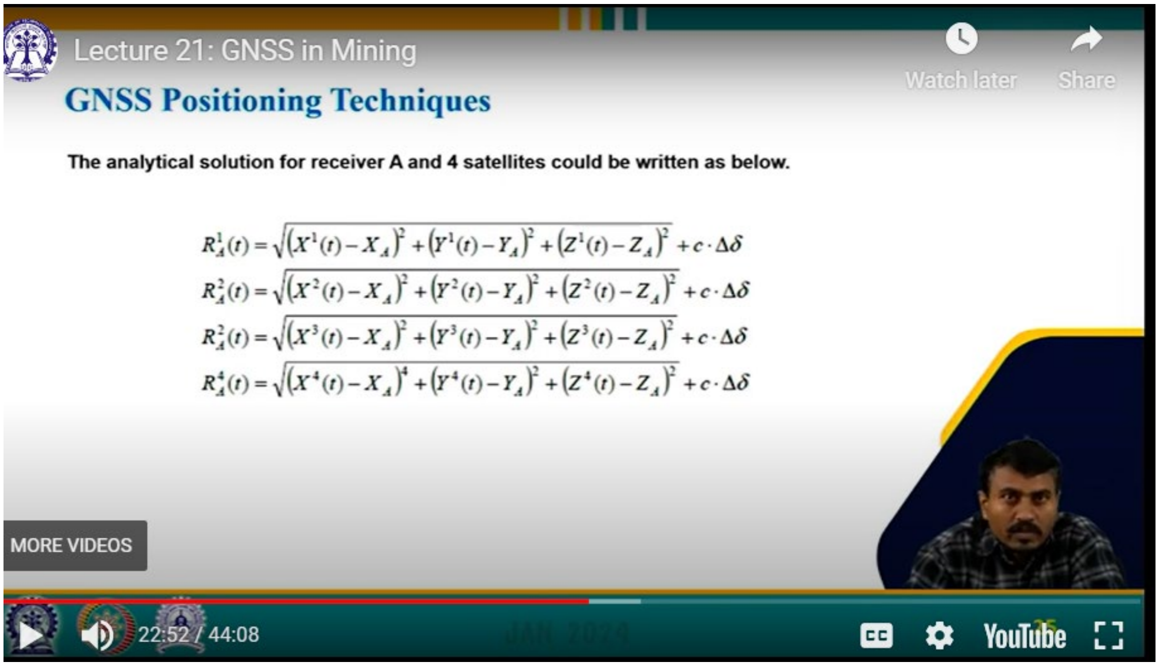
Observational Techniques: So the time or phase measurement performed by the receiver is based on the comparison between the receivers between the received signal at the antenna of the receiver and generated reference signal by the receiver. The two signals are affected by clock errors So. Therefore, the range measure is not true, and it is called pseudo range.

Since the signal travels through the atmospheric layers, further noise should be modeled in order to compute the precise range.

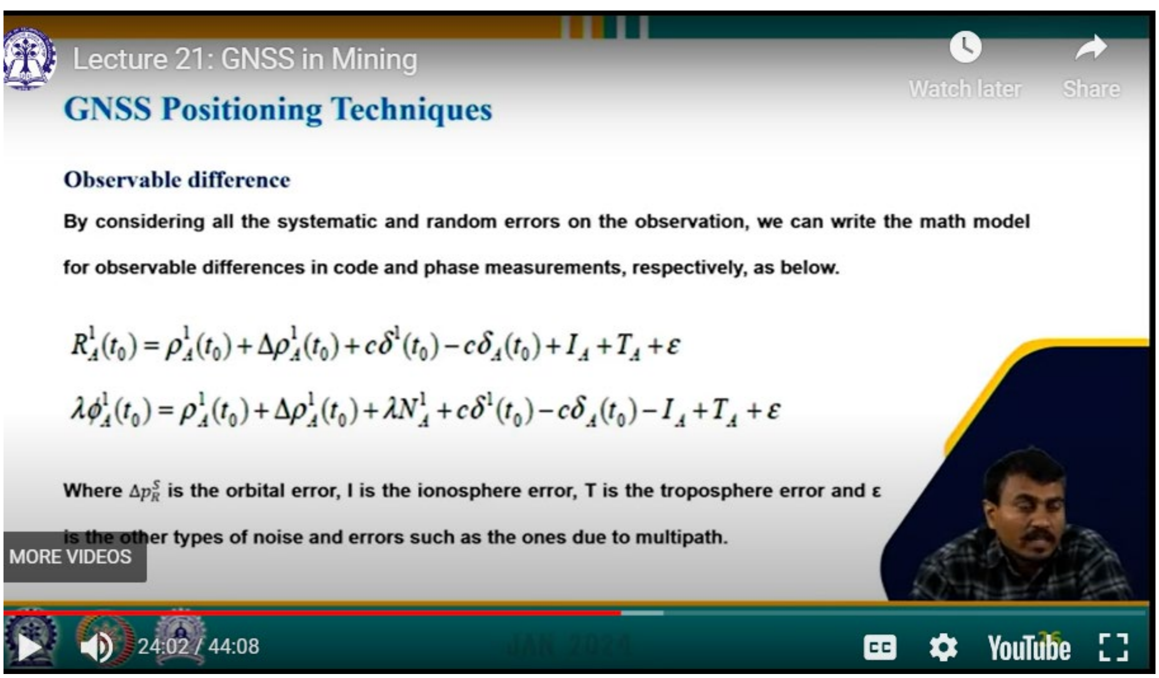


GNSS Observable Errors The code the phase measurement are affected by the noise and errors due to the propagation of signal through atmospheric layers and due to the noise measurements So one error might be satellite clock error Second error is the orbital error because satellites are in dynamic conditions it is not very much stationary So the distance with reference to the earth is always changing by some minute meter or like that The ionospheric error that is basically comes under the atmospheric error the top sphere, then the toposphere error then the receiver clock error and this is very important thing and the multipath error.

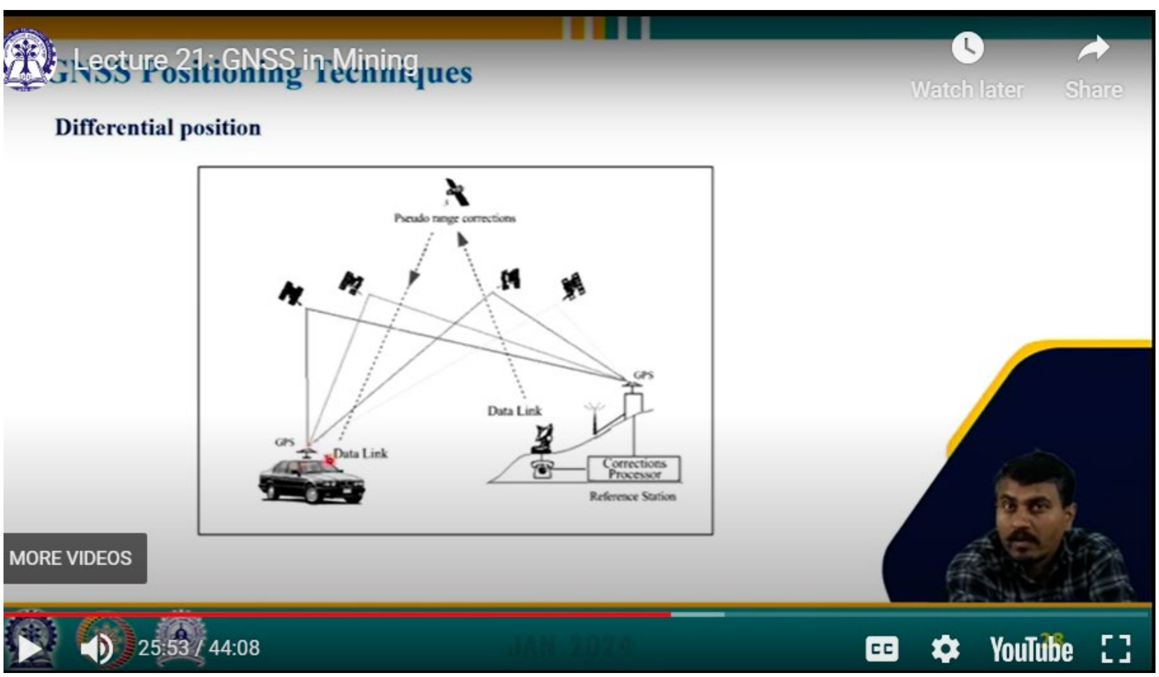
So there are two main types of positioning technique in GNSS measurement. One is the single point positioning, and the second is the differential positioning technique. So most of the cases for now it is for accurate estimation of the point location. We basically use the differential positioning technique, So this is now it is very much used. Single point positioning is basically the basic concept that we have already covered now. So it basically comprises or basically work on the trilateration principle between the receiver and the satellites and the range measurement by using the signals from at least four satellites to estimate the x, y, z, and the receiver clock offset delta.



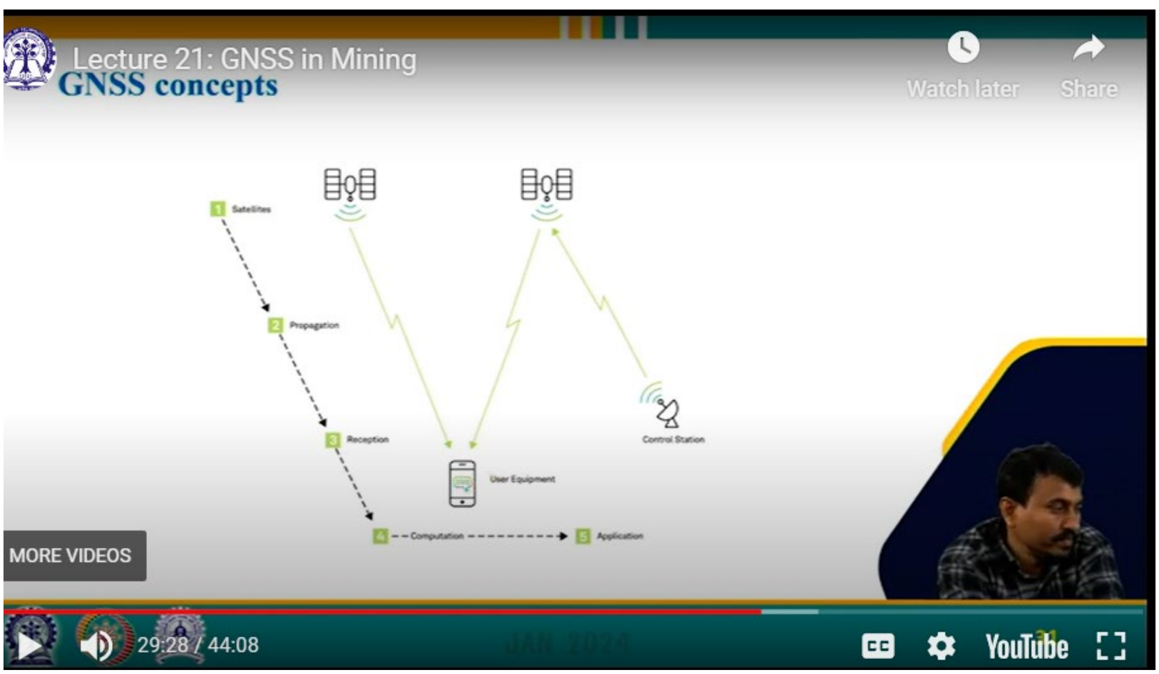
So, there are analytical solutions like this. So for example, receiver A is receiving this data from four satellites. So the R1A, R2A, R3A, R4A is estimated from the base station of the Xa, Ya and Za and the delta time basically the time gap. So by solving this equation, we can get the accurate Xa, Ya, and Za because these three are the unknowns, only Observable differences. So by considering all the systematic and random errors on the observation, we can write the math model for observable differences in code and phase measurement respectively like this.



So the RA comprises of del rho, del a, IA, TA or like this and epsilon So the del p is basically the orbital error, i is the ionospheric error, T is the tropospheric error epsilon is basically the other type of noise and error such as one due to the multipath Geneses positioning technique, differential positions So there is an increase interest in differential positioning due to the numerous advantages of wireless communication and networks So most of the error that affects the Geneses are common between the receiver which observe the same set of satellites So thus by making differential measurement between two or more receiver most of these error can be cancelled So the basic concept of differential position is the calculation of position correction or the range correction at reference receiver and then sending this correction to the other receiver via radio link So this way most of the error can be cancelled So this is the way how this differential positioning system works So here is basically a base station, base GPS station, base receiver and it has a radio module, it has a connection with the satellite So users now use this, users also have a GPS receiver on the vehicle So this vehicle is continuously connected with the station GPS receiver and whatever error is there it is been eliminated Then a very precise location of the vehicle we can estimate from using these two receiver system So earlier for a point positioning system we earlier used to use only single receiver connected with the satellite signal, receiving signal from the satellite Now we are also connected with the ground receiver, another receiver in some distance may be few kilometers away So by that enabling that we are precisely estimating the position of this vehicle with more and very higher accuracy.

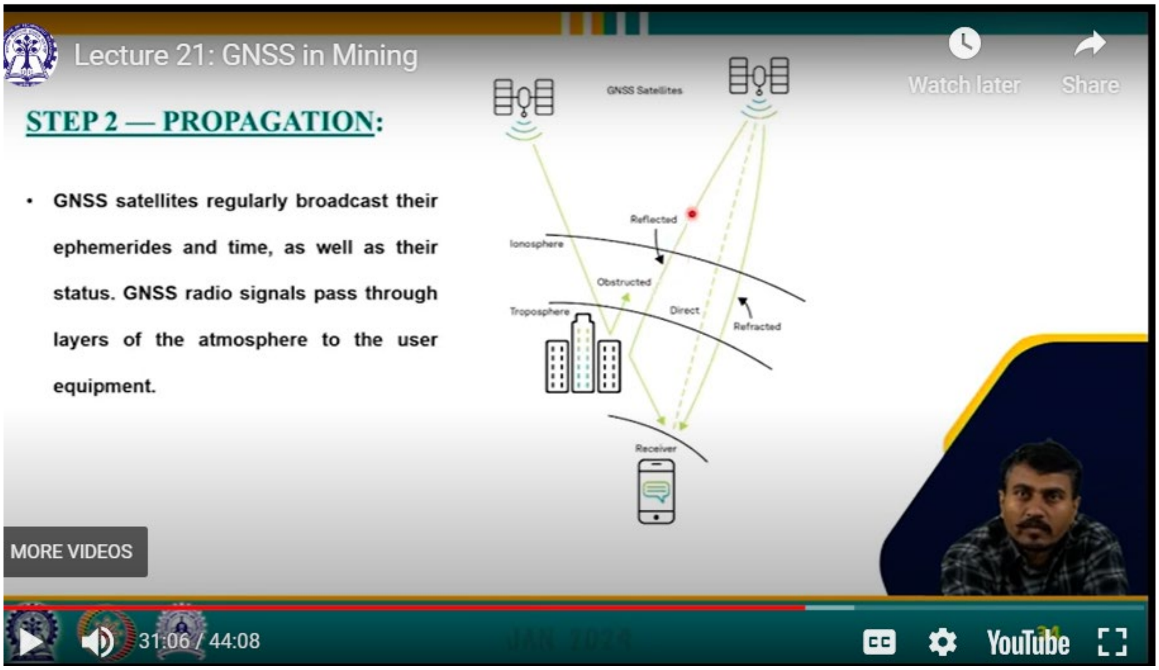


Wide area differential GNSS system So WAD GNSS is a scheme that would allow the user to perform differential positioning and obtain reliable position with high accuracy in real time over a sizeable region So WAD GNSS consist of a master control station and a number of local and global monitor stations and communication link, this communication link is very important The monitor station gather the data from GNSS satellite and then send them to the master control station So the master control basically estimate the ionospheric parameter, tropospheric parameters, satellite FM errors and the clock errors All these connections are transmitted to the user via internet or wireless communication or satellite communications Wide area augmentation system, WaaS is basically a new augmentation of the US Department of Defense of the GNSS That basically designed to enhance the integrity and accuracy of the basic GPS capability This WAAS basically uses geostationary satellites to receive data measured from many ground stations and it sends information to GPS user for position correction Since WAAS satellites are of the geostationary type, the Doppler frequency caused by their motion is very small So thus the signal transmitted by the WAAS can be used to calibrate sampling frequency in GPS receiver So WaaS signal frequency is at 1575.42 MHz and WAAS service will be available on both L1 and L5 band So this is basically the concept how the waves travels, propagates and received at the user device, mobile device or a particular receiver device And then there is a computational phase that calculates based on the trial and error principle and then its uses These uses may be navigational purposes, this may be for the vehicle tracking or this may be monitoring the vehicle So this particular receiver is situated with the machine or inside the machine or inside the vehicle.



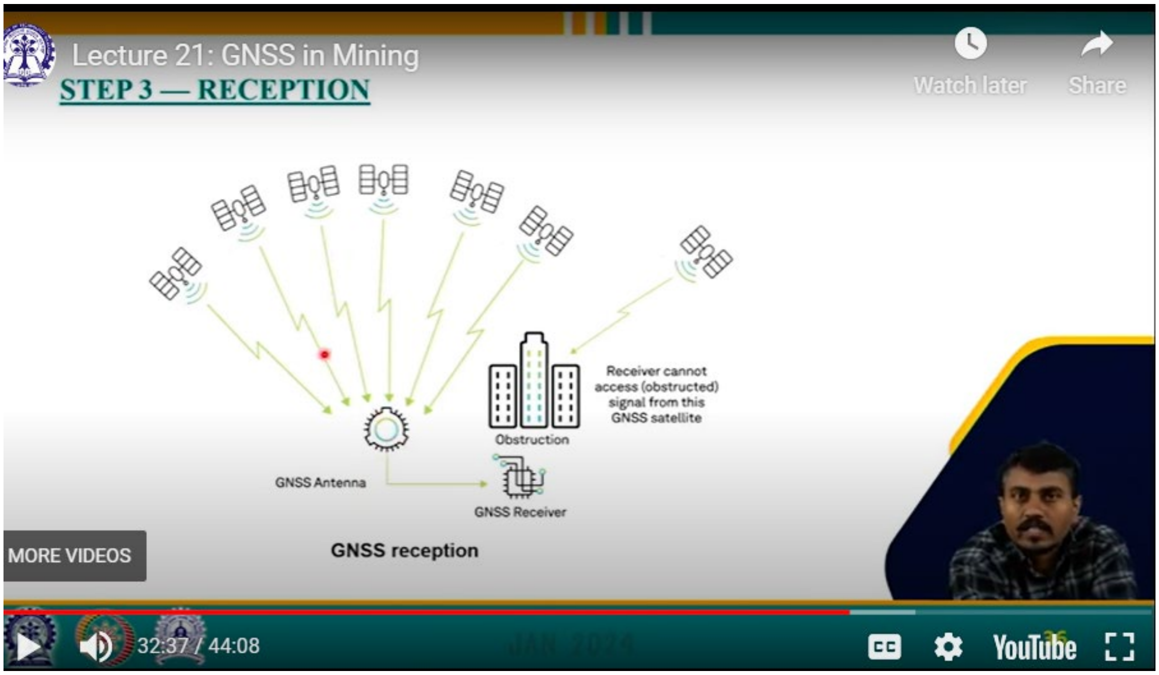
Step 1, Satellites So GNSS satellites orbit around the Earth, and satellite know their orbit ephemerides, the parameter that define their orbit, and the time very accurately Ground-based control stations adjust satellite ephemerides and time as and when necessary.

Step 2, Satellite Orbit GNSS satellite orbit well above the Earth atmosphere. GPS and GLONASS satellite orbit at altitude close to 20,000 km. BIDU operates from 21,500 to 36,000 km, and Galileo operates 20,000 km around the Earth And GNSS orbits are more or less circular, highly stable and predictable. Propagation GNSS satellite regularly broadcast their ephemerides and time as well as their status and GNSS radio signal pass through layers of atmosphere to the user equipment.

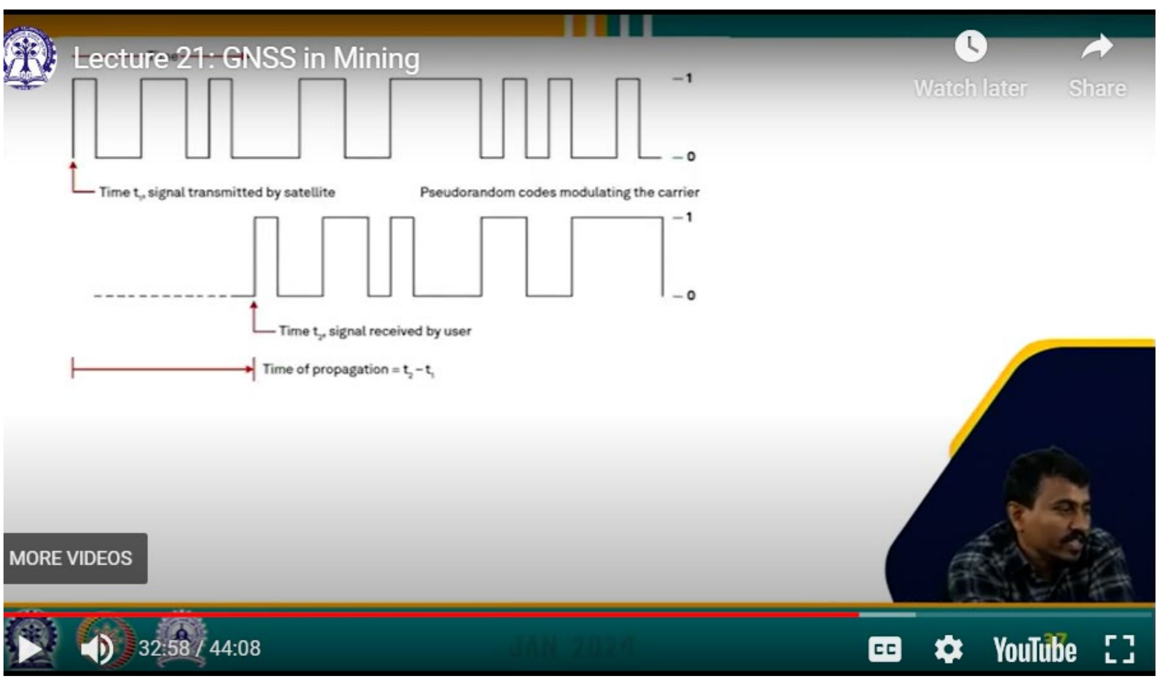


So here, this is basically the GNSS signals, this is basically obstructed due to the presence of buildings, And this is the signal travelling to the atmosphere, initially the atmospheric errors are there due to the ionosphere and the troposphere. Some amount is reflected back, some amount is refracted, and some amount is directly reached to the receiver So these are basically the component how the propagation takes place, and finally it is reached to the user receiver.

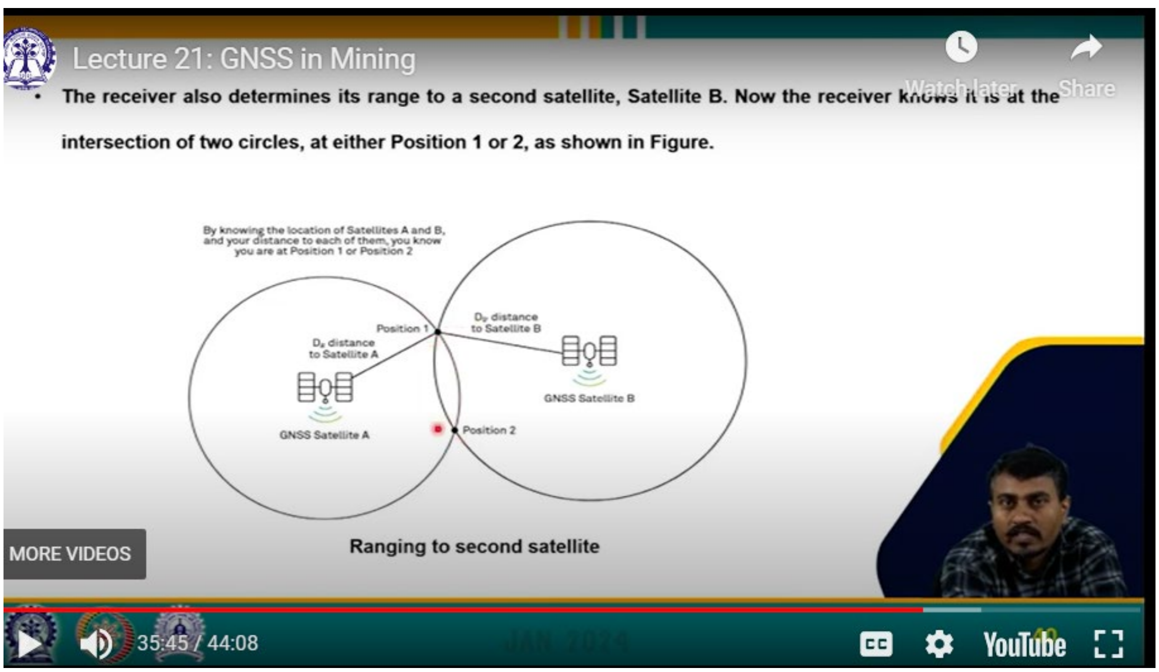
Reception The GNSS user equipment received the signals from multiple GNSS satellites, and for each satellite recovers the information that was transmitted and determined the time of propagation, The time it takes the signal to travel from the satellite to the receiver. To determine a position and time, GNSS receiver needs to track at least four satellites from one of the GNSS constellation And preferably from the same GNSS constellation so this means there needs to be a line of sight between the receiver antenna and the four satellites



This is basically the principle the GNSS antenna: the receiver is connected with at least four satellite systems, and some of the signals is obstructed due to the presence of buildings but. However it is now connected with at least four number of satellites, and based on that, it basically computes to the next stage.



So this is how, this is basically the generated satellite signal sent by the satellite, this is the signal and this is basically the generated replica at the receiver point So the same thing is generated if you see the pattern of the curve, pattern of the data, so this is basically the gap and this gap is basically the time of propagation, t_2 minus t_1 So this figure illustrates the transmission of pseudo random code, a series of 0s and 1s since the receiver knows the pseudo random code for each satellite It can determine the time it received the code from a particular satellite By comparing the time the signal was received with the transmission time stored in the satellite message, receiver can determine the time of propagation Now the computation, GNSS equipment uses the recovered information to compute time and position So if we know the exact position of three satellites and the exact range of each of them we would geometrically be able to determine our location So we have suggested that we need range to four satellites to determine the position So for each satellite being tracked the receiver calculates how long the satellite signal took to reach it as follows Propagation time is equal to time, signal received that is reached to the receiver and the time signal left the satellite And multiplying by the c or the speed of light is basically says the distance of the satellite So the satellite A is communicated its location determined from the satellite orbit, epimedes and time to the receiver.

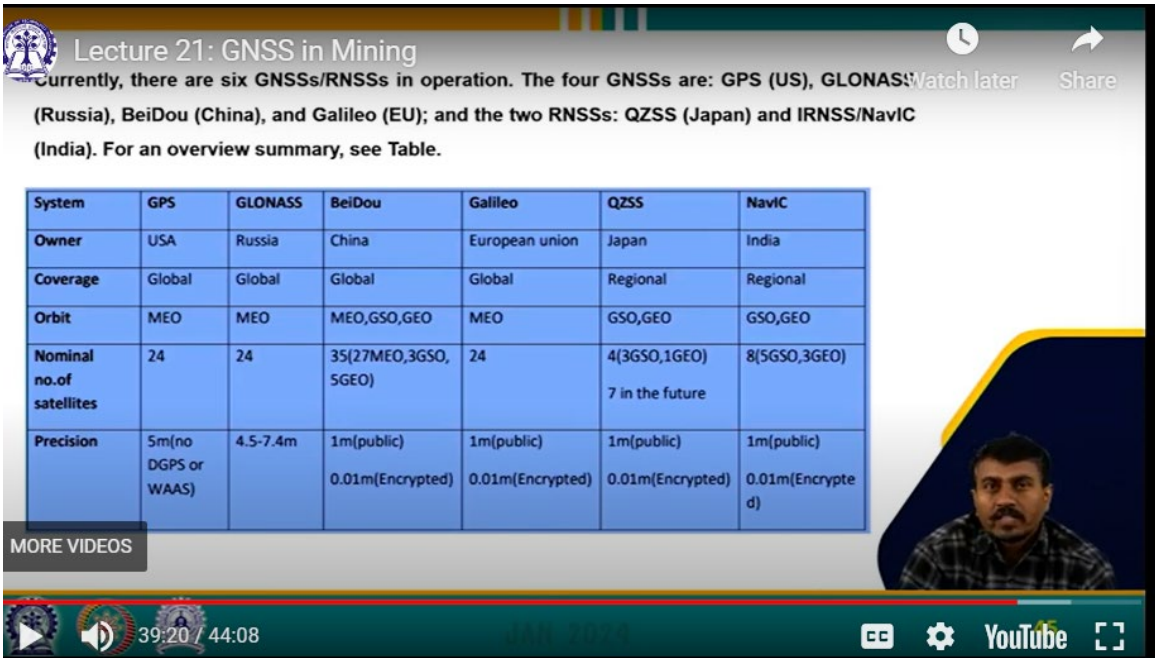


So the receiver knows it is somewhere on a circle with a radius equal to the range and centered at the location of the satellite A illustrated like this So based on the single satellite data we very much know the location of the point will be here, around here So now when another satellite is come into in the connection in the picture in the coverage So there is an intersection of the common area so these are the two points position one, position two When the third will come, so based on the third we will be pretty sure this is basically the location that covers the range from the satellite A, satellite B, satellite C, the three number of satellites and we can very well estimate the position of that particular point So the GNSS user equipment provides the computed position and the time to the end user application for use in navigation, surveying, mapping and more Once the error has been accounted for in the GNSS equation the receiver can determine its position, time and pass this information to the end user application.

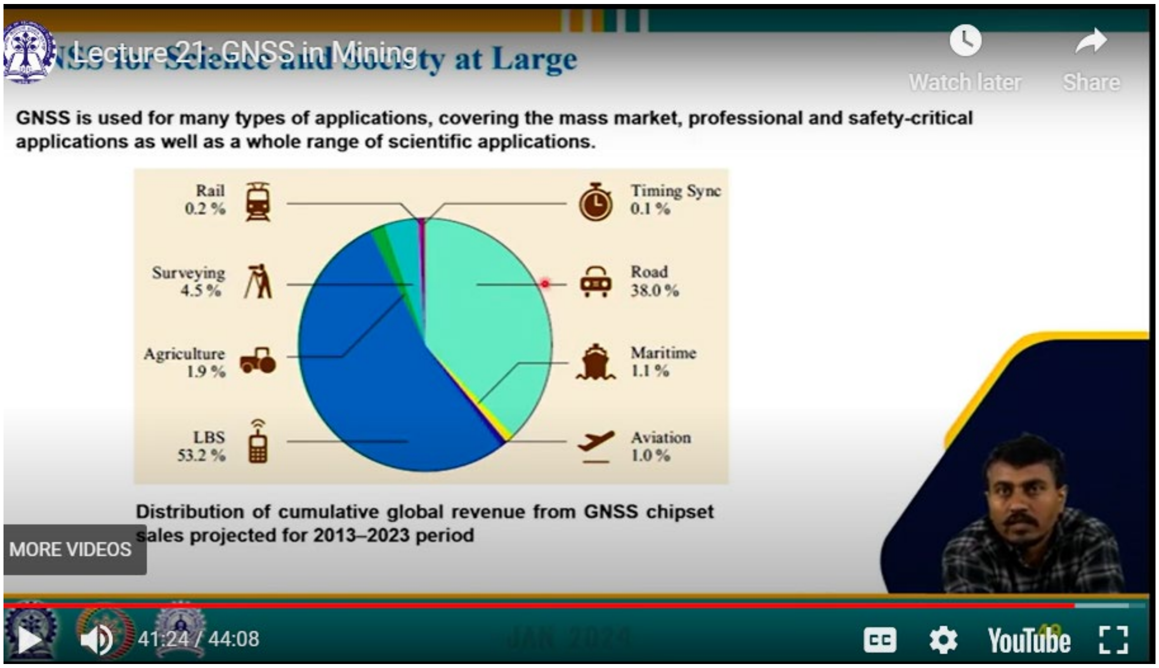
So nowadays, the GNSS industry is a multi-billion dollar industry and the application range from simple handheld meter level accuracy navigational to the centimeter level positioning solutions for the survey, military and autonomous applications.

GNSS measurement pseudo range measures the difference between the receiver clock at signal reception and the satellite clock at signal transmission. The satellite clock at signal transmission scaled by the speed of light it reflects the satellite receiver distance with precision in range, and considering clock, asynchrony and other delays Doppler, the Doppler effect induced change in received frequency indicates range rate or line of sight velocity. This provides valuable information about the velocity component along the line of sight GNSS measurement, carrier phase, so it measures the instantaneous bit phase and accumulated zero crossings after mixing with reference signal Changes in carrier phase over time reflect that is the pseudo range change with exceptional precision approximately to two order higher than the pseudo range Interrupted tracking may lead to cycle slip in measurements Current and developing status of the GNSS system, so these consist of different GNSS and regional navigational satellite system So the space segment comprises of a constellation of satellite orbiting above the earth surface, the transmit ranging signal on at least two frequencies in the microwave part of the radio spectrum And the control segment is responsible for maintaining the health of the system by monitoring the broadcast signal and computing and uploading to the satellite required navigation data It consists of a group of globally or locally dispersed monitoring stations, ground antennas for communicating with the satellites and a master control station with a backup facility at a different location.

So, currently, we are having six number of GNSS, RNSS in operations and GPS, GLONASS, BIDU, GALILEO, RNSS and QZSS and the IRNSS So these are the different data about the GPS, GLONASS, BIDU, GALILEO, QZSS and NAVIC-C



Principally earlier, GPS and GLONASS was on air. Later, it was GALILEO was on air, later BIDU was on air, and now Japan QZSS and NAVIC-C Indian system is also on air and it is in working So this is basically provided by the China, People's Republic of China, the BIDU, it has currently 35 satellites on air GALILEO have 24 number of satellites on air, this is basically maintained by the European Union GLONASS is fully operational since 80s and it has 24 number of satellites Indian Navigation satellites now it is in working, it is covering 1500 km around the Indian mainland, and it consists of 7 satellites And the QZSS is a regional global navigational satellite system operated by the government of Japan and it has basically total 11 number of satellites on air.



So GNSS for science and society are large, so this is basically the data now currently available. The distribution of cumulative global revenue from the GNSS chipset sales projected for 2013 to 2023 periods If you see this graph, 53% is used for the location based services and 38% for the road services for the vehicle movement and tracking And 1% is aviation, 1.1% is meditime, timing synchronization 0.1, rail is using 0. 2, surveying 4.5 and agriculture have substantial use 1.9% So there is a big market of GNSS not only in the mining in other industries for accurate mapping, location mapping and navigations.

GNSS is used for many type of application as well in the mass market and professional safety-critical applications. For example, here we are showing this is GNSS used in the vehicle, this is on the sieve, this is on the aviation, this is on the rail, this is on the space, this is on the sieve, this is on the transmission of electrical tower, this is on the location particularly where we are doing the surveying, and this is basically in the traffic So this is the different applications of the GNSS. So, in the next lecture, we will cover the GNSS application specific to the mining industry.

So, these are the references. So let me conclude with few sentences what we have covered in this lesson So we have provided a brief about the GNSS system, global navigational satellite systems and the primary uses of the GNSS system and how these trial iteration technique are basically executed and position is estimated And we have explored the different constituents of the GNSS system and how that signal transmitted, what kind of signal transmitted for the position and navigations And we have used the reference system used in the GNSS for accurate position measurement We have explored the methodologies and technique employed to observe and analyze GNSS signal for navigation and position purposes And we have provided the fundamental concept of GNSS technology which enables precise positioning and navigation using the satellite signals We have introduced the concept of determining precise positioning using the GNSS technology We have discussed the existing and emerging GNSS system And we have explored the diverse practical applications of the GNSS technology across various industries.

Thank you