Global navigation Satellite Systems and Applications
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Lecture – 05
NAVSTAR – Global Positioning System

Hello everyone and welcome to the fifth lecture on Global Navigation Satellite Systems and Applications. In earlier discussion, we have learnt how position is determined by these navigation systems. Now, for five – six lectures we will be discussing different navigation systems which have been developed by different countries. And, in this series, the first one is a NAVSTAR or typical GPS which we call, Global Positioning System as you know that the system was originally say US Government System or Ministry of Defense of United States.

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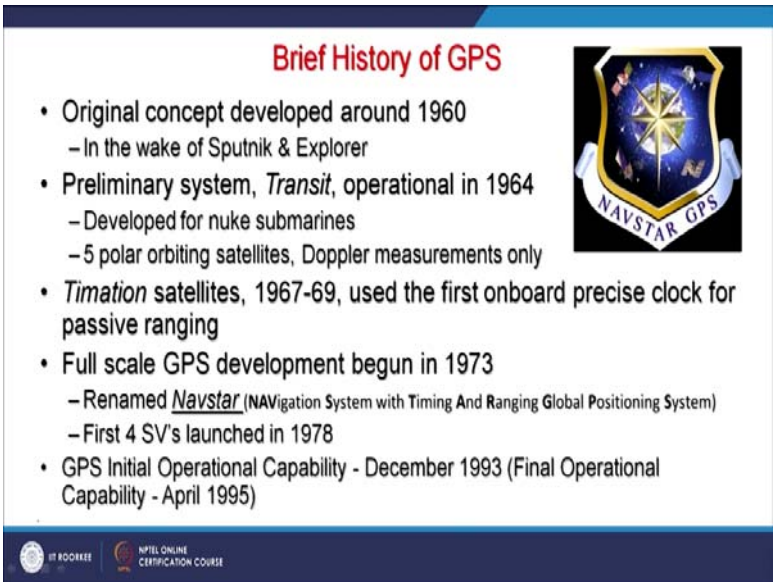

Originally the concept developed around 1960 and it was definitely as earlier also in the beginning of this course, I have mentioned that all these navigation systems basically there are developed for war like or for missiles, guided missiles. But, before that you know the development started in 1960 and when Russian started launching their satellites like Sputnik and Explorer.

And, then in 1964, there were development of nuclear submarines and for that the proper guidance that it should hit the target for which some navigation system was required. So,

initially this was developed and 5 polar orbiting satellites, with Doppler measurements only were, launched by US. Then there were another series of satellites between 1967-69; by Timation satellites used for first onboard precise clock for passive ranging. This was not active ranging, but passive ranging, but concept this is how the entire navigation system or GNSS has evolved.

And, then full scale GPS, which we today see and use that is NAVSTAR GPS of US, development started in 1973 and as you know that this name of the satellites which are in space 24 in 6 orbits that a NAVSTAR stands for NAVigation System with Timing and Ranging Global Positioning System. And, in 1978, first 4 satellite vehicles were launched and then this was fully declared operational in the year 1993 and later on it, was further enhanced in April, 1995. So, it was available to military, started since 1993 and then onward later on, it also made available to the publics. Those details we will be also discussing soon.

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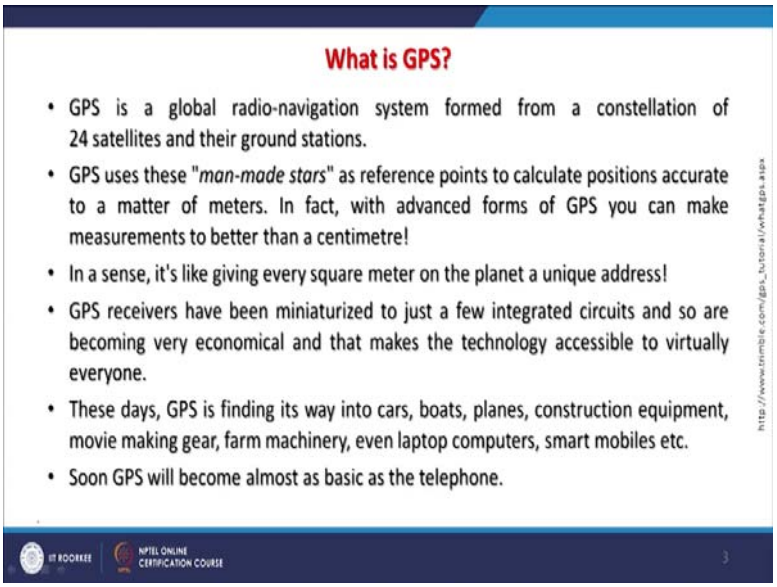

As you know that the GPS constellation consists of 24 satellites and of course, their ground control stations and other things. We consider them as a sort of man-made stars as reference points and the main purpose of course, to all these navigation system is to calculate position, accurately in meters. And, whereas now in after so many years of operation and experience, now because of development of differential GPS technique,

now it is possible to estimate the position or measure the ground deformations up to centimeter or millimeter accuracy. That we will be discussing in differential GPS.

So, in sense it is like giving every square meter on the planet a unique address because as you know each location on the earth is having unique geographic coordinates. And therefore, this statement can be made that each square meter on the earth will have its own address and you know the GPS receivers initially when they were came in 1995 – 96 in civilian domain, they were big size of few kg. And, they used to have a 6 or 8 batteries and these batteries used to last only for few hours and it was not as today what we see even inside our watches or in a smart mobiles. So, the miniature sized has done and it has got now integrated with other circuits and therefore, also it has become economical and this technology is now accessible to almost everyone.

So, as you know that these days, a GPS is finding its way into cars for navigation, boats, planes and construction equipment where earth material or some material has to be moved from one place to another. So, for that GPS based systems have been developed and there are other applications like in field surveying and like geological mapping or in topographic surveying also. Then in movie making gear, farm machinery, where people are having large farms, GPS is playing very important rule. Even now they have been integrated into laptop, computers, smart mobiles etcetera.

And, basically it is something like mobile with everyone. So, it is like a phone for people.

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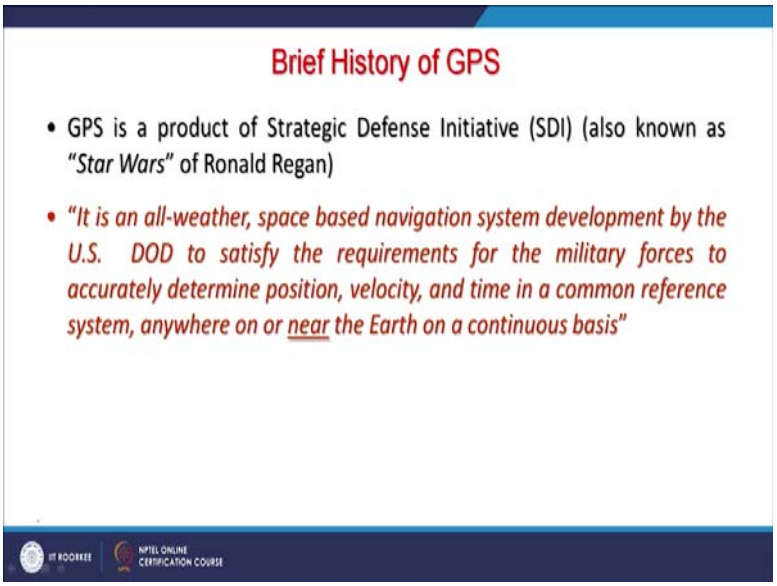

Now, as you know that it was the entire program was conceived as a strategic defense initiative or SDI also it used to known as Star Wars of then President of US Ronald Regan. And, this is how it has been defined that in this was the basically aim of developing the system that it is an all-weather, that in every weather condition, it should work. Space based navigation system developed by US department of defense to specify the requirements for the military forces to accurately determine position, velocity, and time in a common reference system and this is very important, anywhere on or near Earth on a continuous basis.

And, near earth also because when you are using in spacecraft or you know, these missiles. So, they are not exactly on earth, but there are above earth. So, that is why the aim of the GPS, this was also included or near the earth on a continuous basis. So, this signal should be available 24 hours, around the clock, any part of the world. So, that was the main aim.

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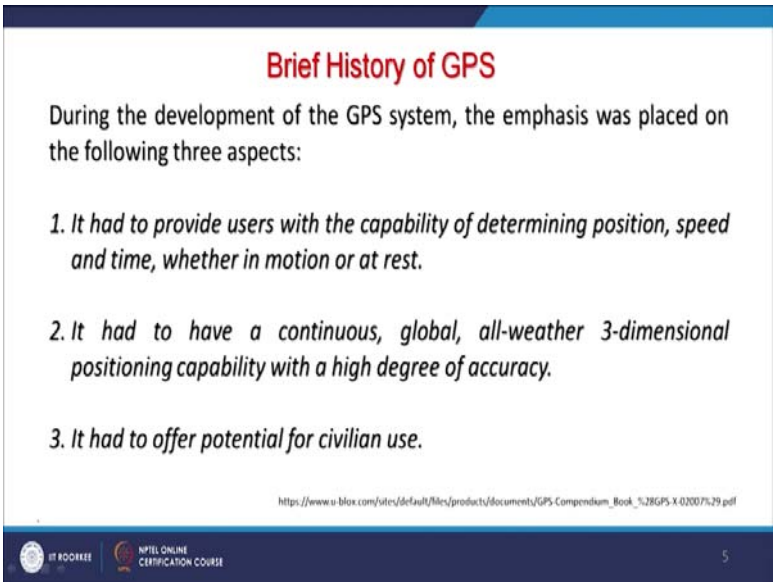

Now, as we go further in the history of GPS that during development of GPS system, main emphasis was placed on these three aspects. The first one; it had to provide users with capability of determine position that is the main aim. Speed, if it has been installed on vehicle or aircraft then you can determine the speed because location will keep changing and by which we can calculate the velocity or a speed. And of course, time because when your receiver is synchronized with the GPS receiver and then you get a very accurate time from GPS.

And, a second emphasis was to have a continuous, all the time global, all-weather, 3-dimensional position capability; that means, x, y and z; latitude, longitude and elevation and, of course, the aim was to have a high degree of accuracy. And, third emphasis was that it had to offer potential for civilian use ultimate because though it started for military purposes, but later on the emphasis was also put for civilian use. Now, civilians all over the world are using this system.

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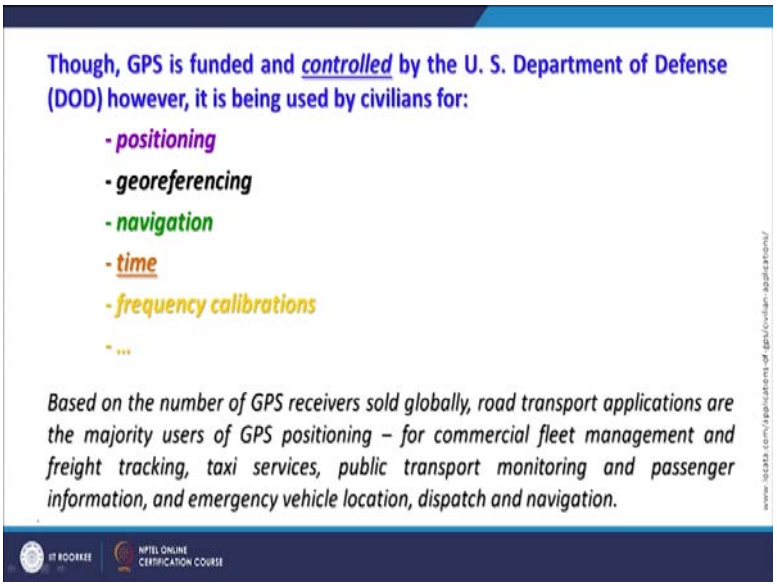

Though, we know that the GPS is funded and control by US department of defense. However, it is available to civilians for positioning, geo referencing because in satellite remote sensing, we want to do the geo referencing specially about high spatial resolution satellite images for which a conventional methods like using some survey toposheets or other approaches were not successful specially for very high spatial resolution satellite images.

So, for high spatial satellite images, for that purpose georeferencing GPS or differential GPS can be used to collect GCPs or coordinates of GCPs. Of course, because position is there, so navigation is also, it is being used, time is very important. So, time is also one of the uses of by the civilians. And, another very important use of such navigation systems is frequency calibrations because in particular frequency as we have seen L 1, L 2.

So, on these frequencies, all the time the data is available. If somebody would like to calibrate their instruments which are based on frequency then they can calibrate using these standard frequencies which are available on any part of the globe. So, and then one can say that I have calibrated with the GPS frequencies. So, it becomes sort of standard for calibrations of frequency of different instruments.

And, there are many other users, people are still developing some uses of navigation systems and most recent development in this regard is about automated vehicles

movement where you do not have the driver or driverless cars which are coming. So, as we know that the number of GPS receiver sold globally, they are used for transport majority of them and of course, for commercial fleet management and freight tracking, taxi services, public transport monitoring, passenger information, emergency vehicle location, dispatch and navigation.

As you know that for like taxi services, these companies like Ola and Uber and many other companies in different countries, they have integrated GIS and GPS together and of course, the communication technology and by which you very quickly get taxis for your location and sometimes they are cheap as well because they do not have to travel much distance to get a customer because of employing this technology and using some centralizer servers to feed a required information.

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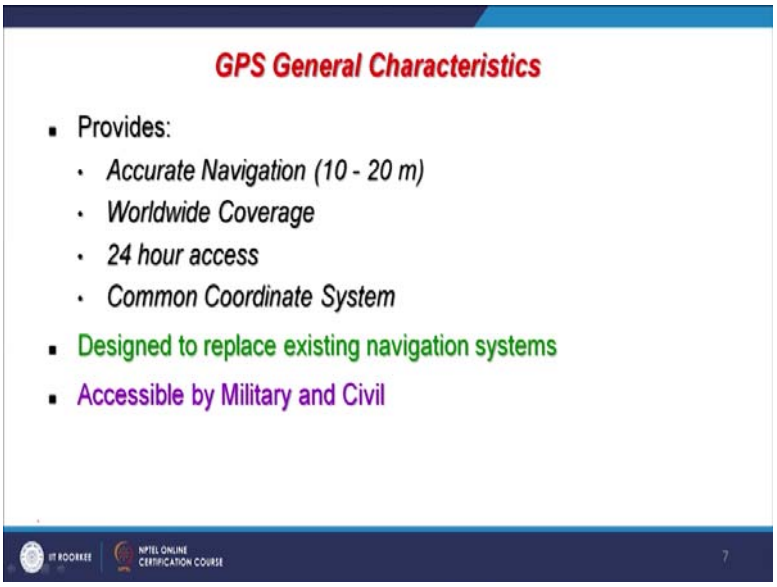

As you know that GPS general characteristics are accurate navigation, one can do standard GPS receivers up to 10 to 20 meter. Of course, it is worldwide coverage. Every part of the globe is covered with this, 24 hours access and it is having a common coordinate system. So, one can compare and use these band. And, of course, it is designed to replace other navigation systems which people used to have or we have discussed in very beginning of this course that earlier navigation like dead reckoning and others were there. And, this is of course; accessible initially it was for military and now for civilians as well.

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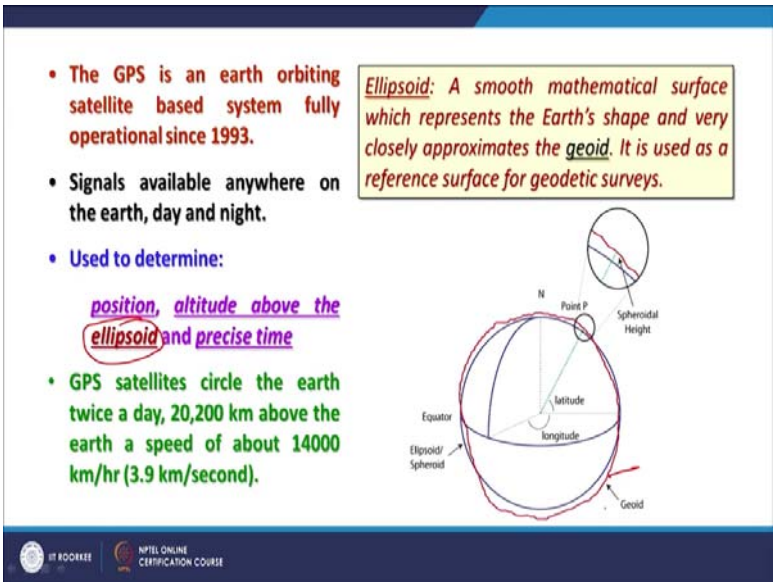

As you know that the GPS in is an earth orbiting satellite based system and fully operational since 1993. Signals available anywhere on the earth, day and night; it is used to determine position, altitude above the ellipsoid and precise time. Now, when we talk about the elevation values which are coming or altitude values which are coming from GPS or such navigation system, some issues are there because that elevation value generally is not very accurate as one would like to have whereas x y positions, we get quite accurate and it is improving.

So, we will be also seen that why elevation values which are determined by or estimated by the GPS or such navigation systems are not accurate that is why here, it has been mentioned that this is above a ellipsoid and not exactly above topographic surface. So, that is one reason, further explanation will come. But before that we would like to understand that what is basically ellipsoid from this GPS reference.

That it is a smooth mathematical surface which represents the earth shape and very closely approximates the geoid. So, it is used as a reference surface for geodetic surveys. So, if we see here that we have used 2 terms ellipsoid and geoid. So, geoid is a, this gravity surface which we see in the red colour, this one which we are seeing and ellipsoid is a mathematical surface which is shown here in the dark blue color.

So, as you know that topographic surface would be another surface which is different than these ellipsoid and geoid. And, the elevation is a basically measured above the

ellipsoid, but we want elevation values above topographic surface. So, that is one of the reasons, why we do not get much accurate values of elevation estimations from navigation systems.

As you know that GPS satellites, these NAVSTAR satellites and these circle the earth twice a day and the distance from the earth of each satellite is about 20200 kilometer and the speed of these is about 3.9 kilometer per second; that means, is very high speed. they orbit the earth and with this speed and that distance, you can think is a huge circle which is made in the space and that is travelled twice in a day by each satellite.

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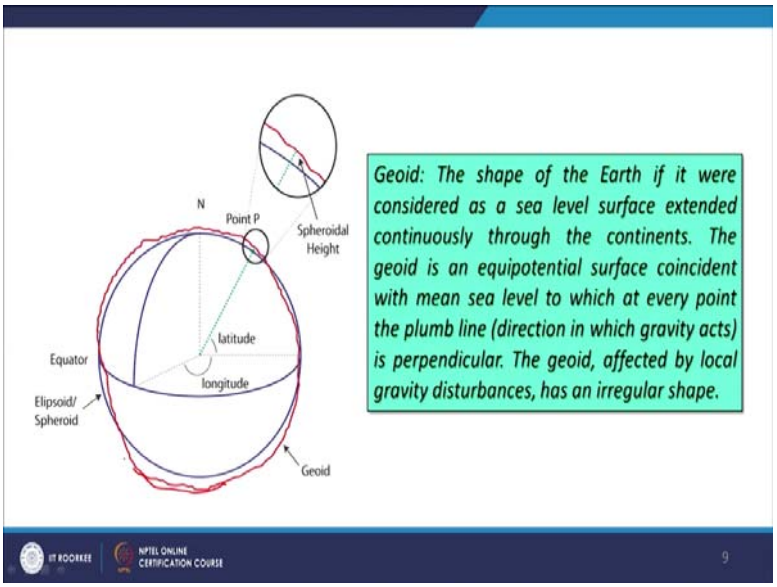

Further we would like to see the geoid part also. Earlier we have seen the definition of ellipsoid or also called spheroid, but let us see the definition of geoid. Geoid is the shape of the earth if it is considered as a sea level surface extended continuously through the continents. So, because for mean sea level or where oceans are there or seas are there is no issue. But, if we assume that it is continuously coming on the land part then that is basically the geoid surface.

The geoid is an equipotential surface coincident with mean sea level to which at every point, the plumb line; the direction in which gravity axis perpendicular and the geoid affected by local gravity disturbances and therefore, does not have the regular shape. And, that is why you are seeing very irregular shape all along this geoid which we see, say gravity controlled basically surface.

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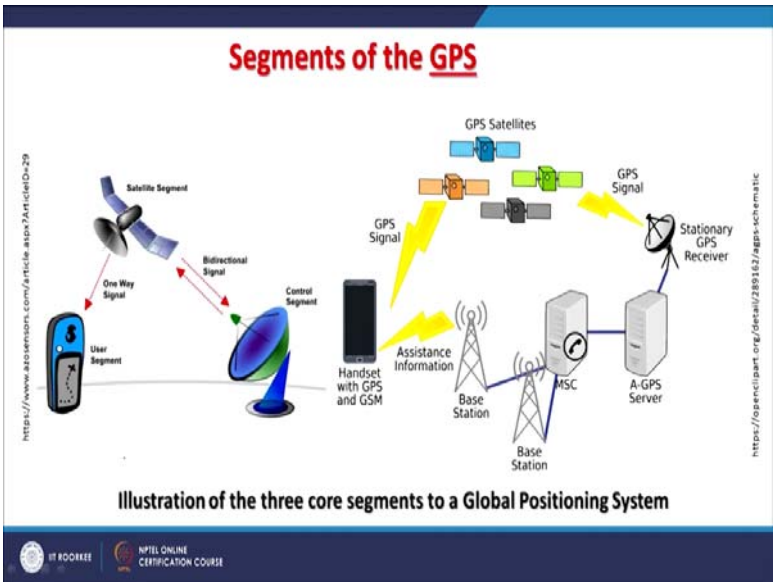

Now, we are going to see that different segments of a GPS NAVSTAR system. So, as you know that most of these navigation systems are having three basic segments. The first segment is satellite segment which we further will be seeing in detail; then second segment is the control segment by which these satellite which are orbiting the earth and providing data to the receiver, they are controlled from control segment and then last segment in this one is of course, the important one is the user segment.

So, the three important segments are there and as you can see that the satellites keep communicating to these antennas for Augmented GPS that is AGPS servers. And, base stations are also there and lot of information is then collected and then that assisted information is transmitted to the handset which we are having.

So, sometimes when you see in the specifications of mobiles, they mentioned that AGPS. AGPS is basically assisted GPS because using towers, their locations that information is also fed through your mobile towers and using that that information, you also get the GPS location rather than directly from satellite or if both locations are coming, you may get a better positioning estimation. So, that is why this discussion is required that AGPS is a assisted GPS which is coming through locations of mobile towers and then transmission is coming towards your mobile.

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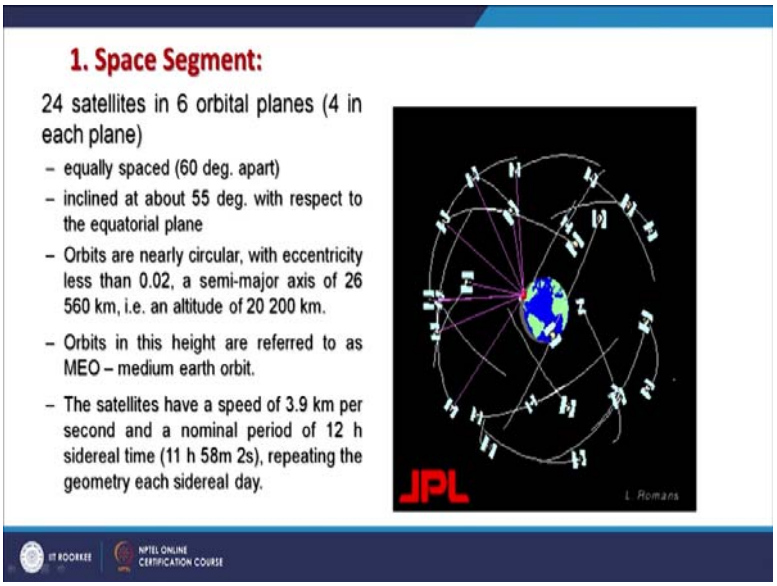

As you know that the entire constellation, the space segment of GPS is having 24 satellites in 6 orbital planes and; that means, that in each orbital plane we are having 4 satellites and they too are at equal distance of 60 degree apart. So, these satellites as you can see in this animation that they keep moving and one location is also shown that red dot. So, for that if we are keeping our receiver at that point as you can see through this animation that every time that location or that receiver is getting signals from at least 5 – 6 satellites all the time. As you can see it is in the west coast of US, that location has been shown in this animation.

And, these satellites are inclined at 55 degree with respect to equatorial plane and these orbits basically are nearly circular and there eccentricity which is less than 0.02 and semi major axis of 26560 kilometer and altitude as I have already mention of 20200 kilometer. So, all the satellites are equal distance from the earth and these satellites be considered as a MEO orbit that is Medium Earth Orbit. And later on, in discussion we will be seeing the other types of orbits as well like LEO and others which we will discuss there.

And, these satellites as also mentioned earlier that is speed is having 3.9 kilometer per second and one complete orbit of the earth takes about 12 hours. So, every day each satellite is orbiting two times around the earth.

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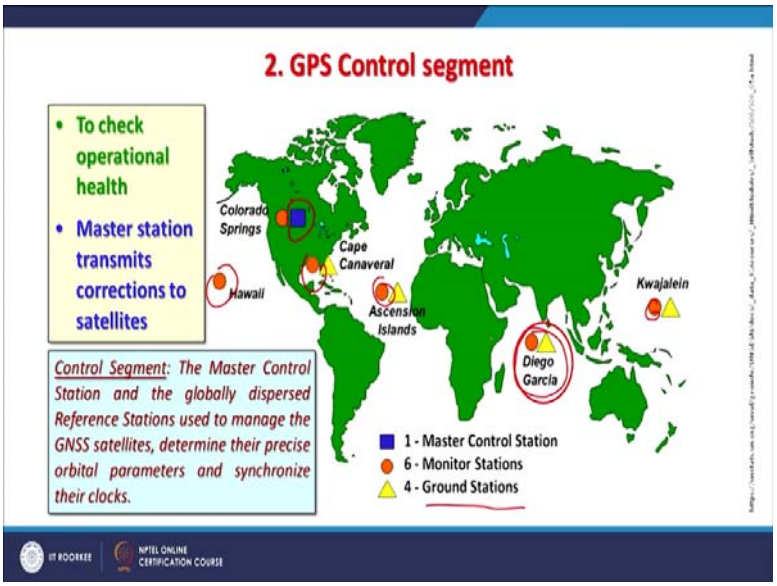

Now, this second segment which is another very important segment is control segment and as you can see that this is in for GPS, master control station is there which is in Colorado, springs and then, monitoring stations are also there all over the globe as you can see. And, then also ground stations are there at few locations and as you can see that these monitoring stations are spread all over the world, also ground stations.

But, important thing about the monitoring stations because after all the satellites are moving objects and sometimes they deviate from their designed orbit. And, therefore, in order to bring to their designed orbit, they have to be monitored whether they are orbiting properly in their designed orbit or not. if not then corrections are made through master control, but monitoring stations all over the world are required to monitor the movement of these satellites.

Important thing is this, it is in our Indian Ocean, Diego Garcia which used to be small island of India, but it is currently occupied for all this purposes by US or some other countries and basically control segment purpose here is to check the operational health; how these satellites are functioning, whether their data is in proper order or not and if some corrections are required that is there, if some satellite is not working properly then spares are put into the orbits for service. And, these monitoring stations or ground stations, they cannot transmit anything towards the satellite except the master control

station. For GPS, it is in Colorado Springs which transmit the corrections to the satellite in order to put into their designed orbit.

So, if we want to basically define the control segment which is the master control station and the globally dispersed Reference Stations as we have seen through this globe map or world, used to manage the GNSS satellites, determine their precise orbital parameters and synchronize their clock. Because as you know that the GPS is a global positioning system, there are some other positioning systems like our IRNSS or GALILEO which of European, they are regional systems for which you do not require these monitoring stations or ground stations all over the world. Only for in that region if you are having this stations that would be sufficient. So, when discussion will come we will see that one

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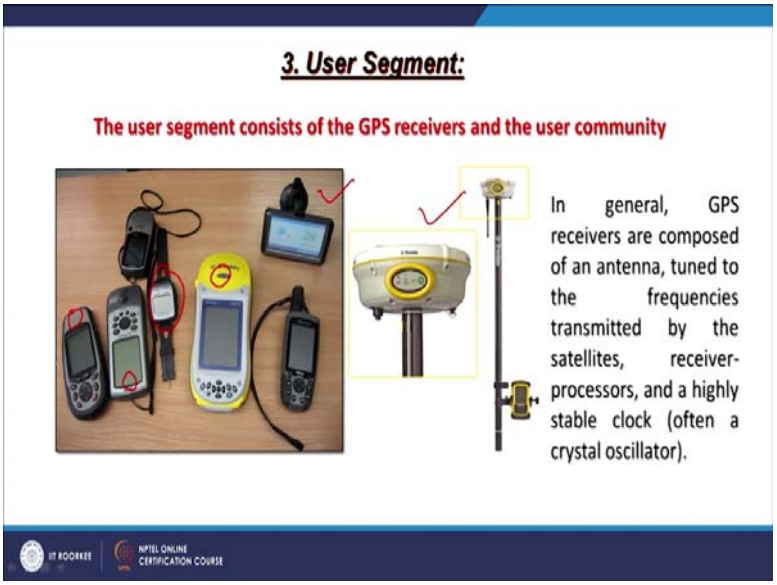

Now, the last component in this one is the user segment where we are basically. We are not in a space segment; we do not have much roll there and neither in the control segment. But, we are user and here it is our role is very important here. So, the user segment basically consists of receivers and the user community, various types of receivers exists as shown handled receivers are there, in car navigation receivers are there or in a wrist watch also you can see the receivers.

And, some advanced one for differential GPS then you are having a large antenna on a pole and then other communication apparatus are along with there. So, in general, the

GPS receivers are composed of an antenna. Here the antenna is external; in this one you see but here in these cases everywhere the antenna inside this handled unit.

So, say very small size antenna and which is basically tune to the frequencies which are transmitted by these NAVSTAR satellites. And, then you are having a processor which process the data of these satellites, the ephemeris and then highly stable clock within these units and generally it is a crystal oscillator are there or some time we call that quartz clock. So, these clocks are there inside all these units whether it is a large or a small.

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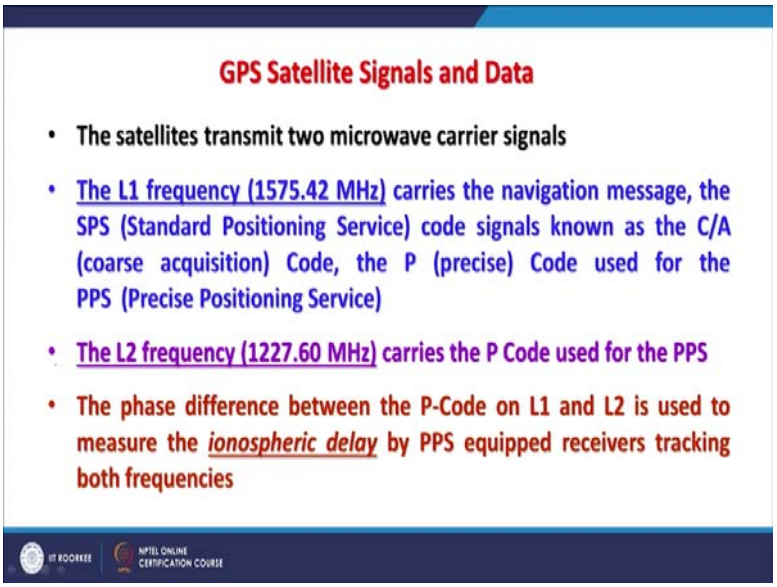

Now, as you know that GPS satellite signals, these are transmitted in two microwave carrier signals; one is the L1 frequency that is 1575.42 megahertz which carries the navigation message, the SPS the Standard Positioning Service code signals known as the C/A or coarse acquisition, not for very high accuracy and then other is the P code used for Precise Positioning Services; two services Standard Positioning Services and Precise Positioning Service.

Whereas the L2 frequency in the microwave region of the electromagnetic spectrum this L 2 frequency is 1227.60 megahertz carries the P code used for specially for Precise Positioning Service. And, if we are having receivers which can receive signals from these two frequencies then this phase difference between P code on L1 and L2 is used to measure ionospheric delay by this Precise Positioning Service equipped receivers

tracking both frequencies. So, you implying differential GPS, it is possible to measure the ionospheric delays as well.

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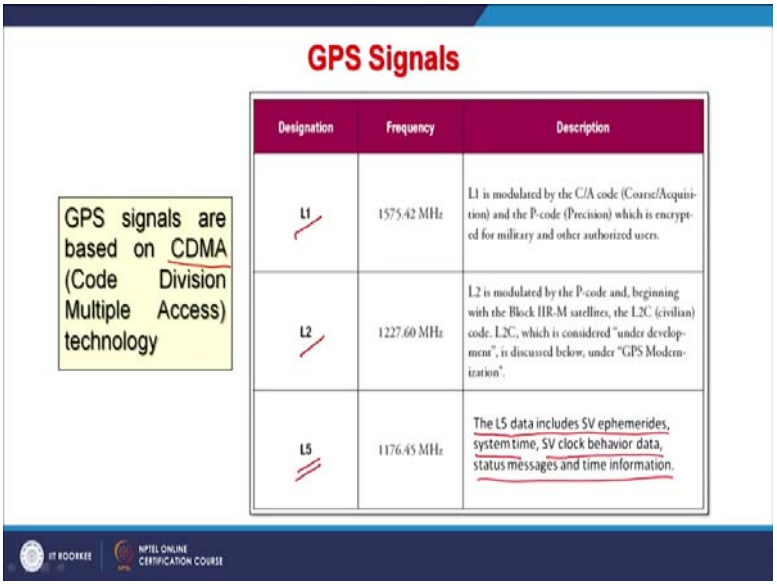

Now, as you know that L1 frequency is there, L2 frequency is there and also L5 frequency which is at 1176.45 megahertz and this data includes your ephemeris, or space vehicles system time, space vehicles clock behavior data, status message and time information. So, likewise different frequencies, these different bands L1, L2, L3, they carry different kind of information which are used and as you know that the GPS signals are based on CDMA, many of our mobiles are also using the same technology that is Code Division Multiple Access technologies there.

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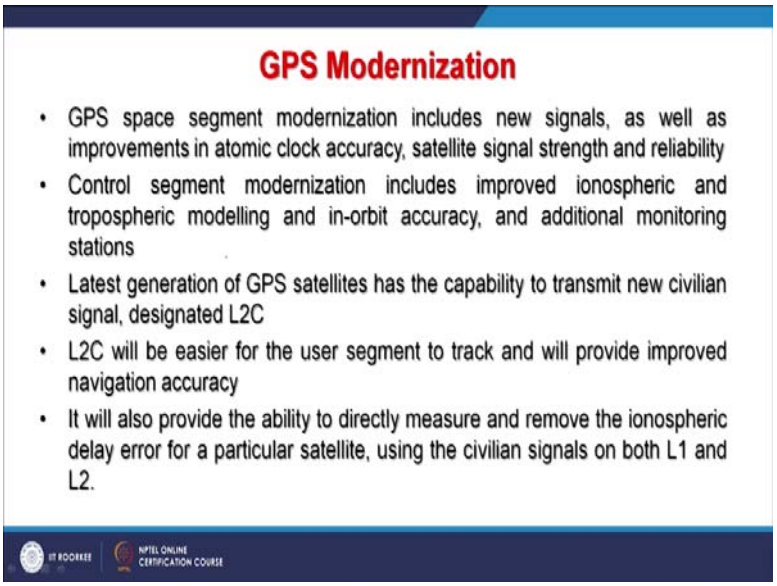

Now, what is the future about GPS? So, because as you know that the system started developing in 1973 and now about 3 decades have passed so, modernization is definitely required. So, first of all it was maintaining the complete orbits means 24 satellite constellation that was a challenge so, which has been done quite successfully. Now, modernization; that means, the main target is to improve the accuracy or you know the position data which you get from these receivers.

So, this GPS space segment modernization basically includes new signals, as well as improvements in atomic clock accuracy, satellite signal strength and reliability because between 1993 to now things have really improved. And, this control segment modernization includes improved ionospheric and tropospheric modeling so that when these models are used before the position is shown on a receiver then we get a more accurate position. So, development of more improve models is very much required and in orbit accuracy; that means, the less deviation of the satellites and additional monitoring stations which this in orbit accuracy can be achieved if you are having more monitoring station. So, that is part of the modernization of GPS system.

And, this latest generation of GPS or NAVSTAR satellites has the capability to transmit new civilian signals that is a designated as L2C. So, earlier L1, L2 and L5; now, another frequency at L2C and, this L2C will be easier for user segment to track and will provide improved navigation accuracy. So, the main purpose from user perspective point of view,

the main aim of this modernization should be that our receiver should give us better accuracy not only about x, y, but also about the z or elevation values.

And, it will also provide the ability to directly measure and remove ionospheric delay. As I have already mentioned that once these models are implemented, more refined or high resolution models are or accurate models are incorporated, then we will be getting better positions and of course, using the civilian signals which are both L1 and L2 and exploiting that phase difference concept.

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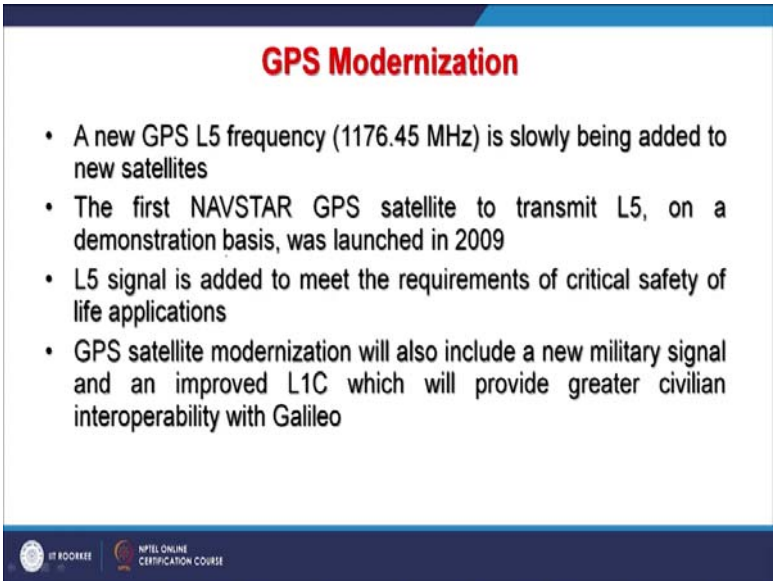

Now, in a modernization of GPS, a new GPS L 5 frequency we have already discussed that 1176.45 megahertz is slowly being added new satellites. And, the first NAVSTAR GPS satellite to transmit L5 on a demonstration basis was launched in 2009 and L5 signal is added to meet the requirements of critical safety life applications because in case of emergencies, people are also implying GPS or such navigation devices. So, for that purpose the accuracy becomes prime importance.

So, GPS satellite modernization will also include a new military signal and a improve L1C like L2C; L1C which will provide greater civilian interoperability with GALILEO. So, in European countries with the L1C band, one can have better accuracy of position estimation. So, this brings to the end of the discussion on NAVSTAR GPS of US.

I am leaving with this a cartoon it says that, face it, we are lost and in this world of computers, a smoke signals will bring the authorities faster than GPS signals. This is just for humor.

Thank you very much.