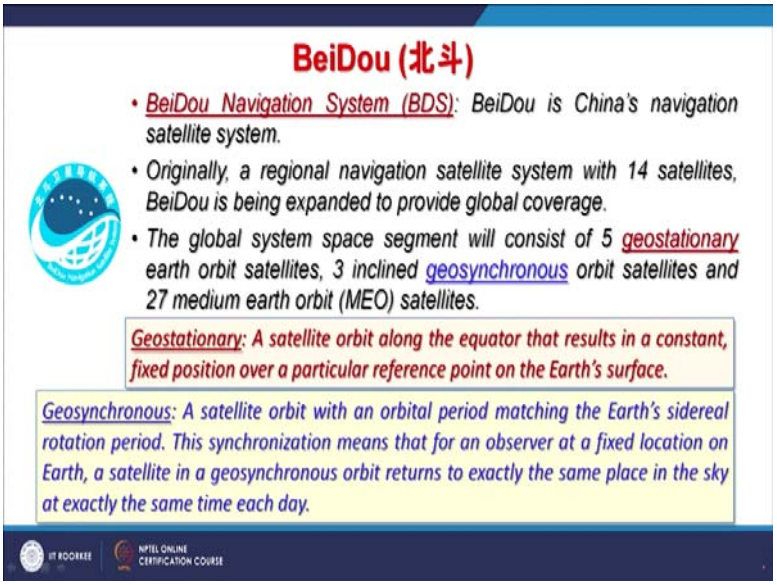
Global Navigation Satellite Systems and Applications
Prof. Arun K Saraf
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Lecture - 07
BeiDou Navigation Satellite System (BDS)

Hello everyone and welcome to 7th lecture of Global Navigation Satellite Systems and Applications. And in this discussion today, we are going to discuss a new system which is BeiDou and which is a Chinese Navigation Satellite System also in short, it is called BDS. As you can see that BeiDou is developed later on after first the GPS that is NAVSTAR, GPS of US and then GLONASS of USSR.

(Refer Slide Time: 01:04)



So, little later after that the Chinese also started developing the system. Originally the system was planned to have a regional navigation satellite system with only 14 satellites and now it has been expanded at global scale.

So, it is also a Global Positioning System like your GPS and GLONASS. And the global system, this consists of 5 geostationary earth orbit satellites. The design of BeiDou is completely different than what we have discussed in case of GPS and GLONASS. Here they are using geostationary orbits as well as geosynchronous orbits and 27 medium earth orbits in which different satellites are there. So, advantage of geostationary orbits that at least 5 satellites access or data from 5 satellites, all the time would be available

over China that is a big advantage. Indian system is also being developed along this line where we will be also putting or have already put some geostationary satellites.

As you know that there are different types of orbits like a geostationary orbit, sun synchronous orbit, geosynchronous orbit, low earth orbit, medium earth orbit or inclined also. So in case of, as you know that in geostationary orbit like Indian examples are there like INSAT series of satellites; mainly the purpose of these satellite earlier was communication but now these satellites have become completely multipurpose satellite. Not only they are providing facility or platform for data communication or telephone communication but same time they are also now being used for this navigation as well as they are also having some camera.

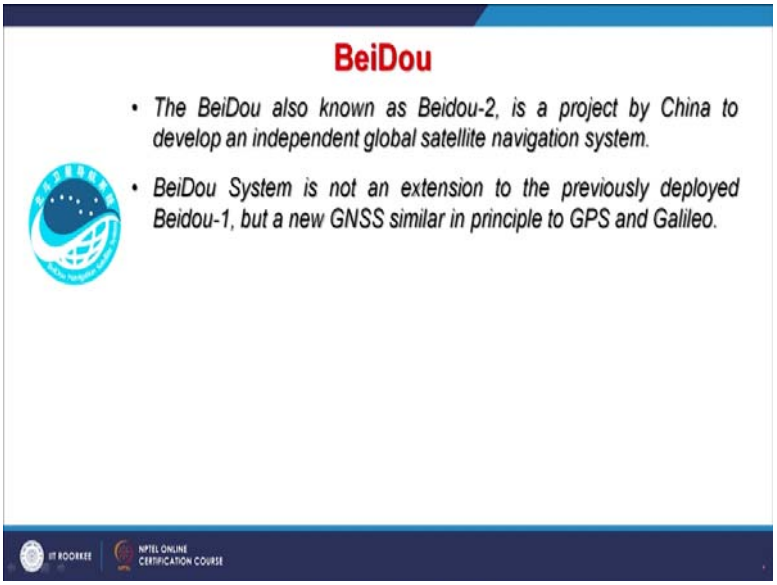
So, they provide data every half an hour and so, of an image or multispectral image. So, those kind of multipurpose applications are there with geostationary satellite. Geostationary orbit is called when your satellite moves as earth moves. So, in a relative sense, it becomes fixed or stationery with reference to the earth. But both things are moving like in our childhood it is said that when 2 trains are going at same speed then in relative motion, they are just having the same speed or they are synchronised. So, here also the movement of the earth has been synchronized with the movement of the satellite or vice versa in that sense.

And this always keeps looking towards a particular country part of the globe and where as geosynchronous satellites, these orbits have been designed to have a orbital period matching with the earth's sidereal rotation period. This synchronous means that for an observer at a fixed location on the earth, a satellite in geosynchronous orbit returns to the exactly same place in the sky at exactly the same time and each day. So, the designs of these orbits have been like this. So, that you get whenever there is over pass over a fixed location say from Roorkee.

So, whenever it will over pass, it will over pass at exactly at the same time. There are also similar kinds of satellite orbits which are sun synchronous remote sensing satellites like IRS, Cartosat, Resourcesat, and Landsat. All these are sun synchronous, near polar orbiting satellite. So, in which they overpass local time which is almost within 50 minutes or 1 hour time. So the timing, there also is the almost same time, but not exactly. In case of geosynchronous satellite, they pass exactly same time and at each day. So, that

is the advantage with this. So, Chinese have exploited this geosynchronous orbit as well as geostationary orbit and also there are putting 27 satellites in medium earth orbit.

(Refer Slide Time: 05:41)

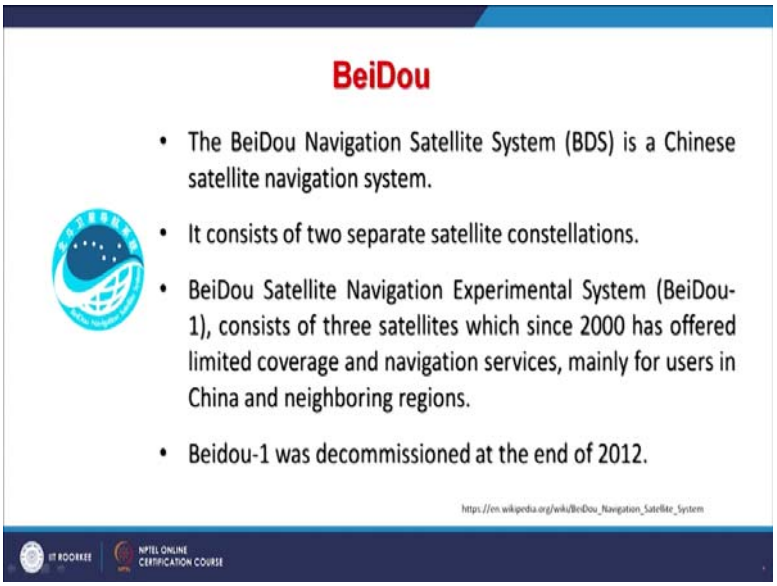


This BeiDou system, this is how it is pronounced. It is a second not the first one because first one initially developed some problems also completely it was planned for regional purposes. Now BeiDou-2 which is the current one is developed as independent global satellite navigation system. So, basically there is no dependency over GPS or GLONASS.

So, it is a completely independent system. When US developed this GPS and Russians developed this GLONASS, their main purpose was the army or for military purposes. Same thing with the BeiDou also that originally it is planned for military purposes, it is being used but now some frequencies have been made available to the civilian use. Even in India, we get the signals easily from BeiDou as well. So, BeiDou system is not basically extension of previously deployed BeiDou-1, but it is new GNSS similar in principle 2 GPS and Galileo.

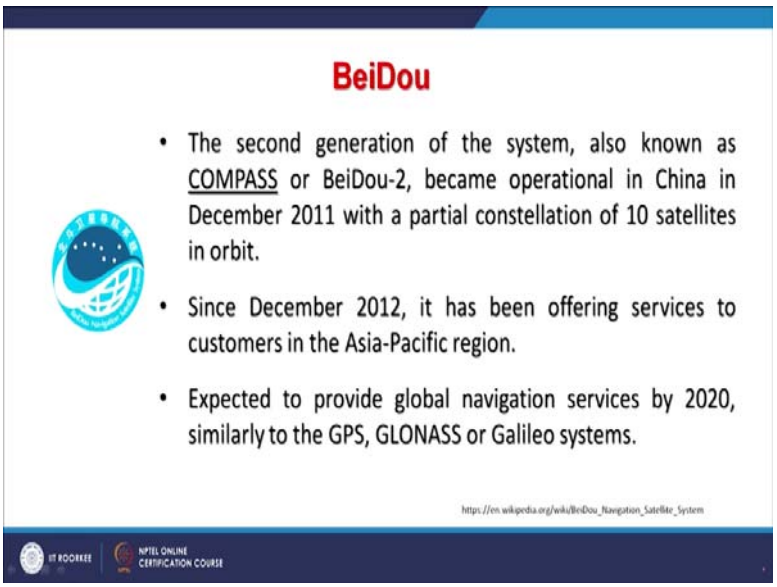
But not really exactly as we have discussed that the orbits of those NAVSTAR satellites are completely different than what we are having in case of BeiDou.

(Refer Slide Time: 07:16)



BeiDou navigation system is as we know that it is a Chinese system, developed by government of China. This consists of 2 separate satellite constellations; one is the BeiDou-1 which consists of 3 satellites which since 2000 has offered limited coverage and navigation services mainly for users in China and neighbouring regions and the BeiDou-1 was decommissioned at the end of 2012.

(Refer Slide Time: 07:46)



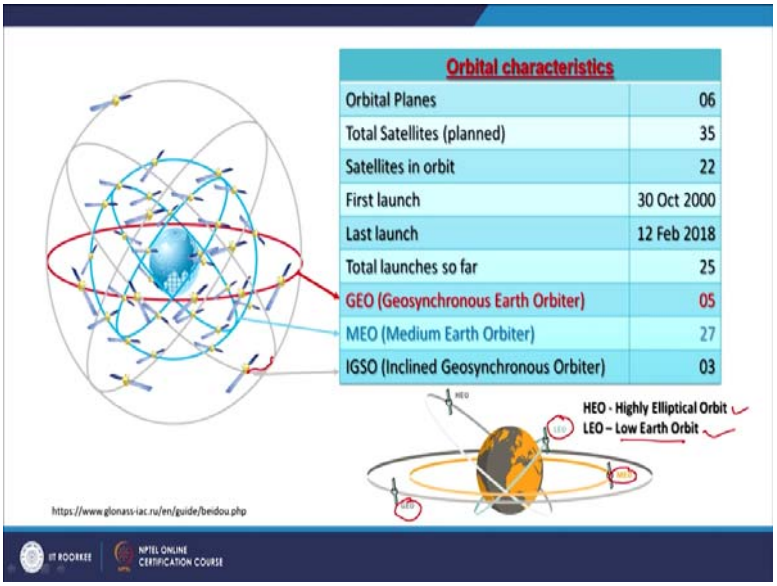
And the second generation of the system that is BeiDou-2 or the current one is also known as COMPASS or BeiDou-2, became operational in China in December 2011 with

partial constellation of 10 satellites in orbit but later on, many more satellites have also been offered the availability of signals that has also widened.

So, since December 2012, it has been offered services to customers in Asia-Pacific region that is why we also get good quality signals from BeiDou. And the main purpose to provide global navigation services by 2020. So, in few year times, it will have a full constellation that is in basically in the year 2020 and for navigation signals point of view, it would be similar or maybe better as we will be seeing in case of Indian system because it is exploiting geostationary satellite and other satellite.

So, for some parts it would be better, may not be for other parts. So, mainly for China or Asia-Pacific region, it may be better; better means that the signals which we will use can give a better accuracy compared to GPS and GLONASS. So, though Galileo here mentioned is completely a regional system and like in India, we do not get signals from Galileo.

(Refer Slide Time: 09:20)



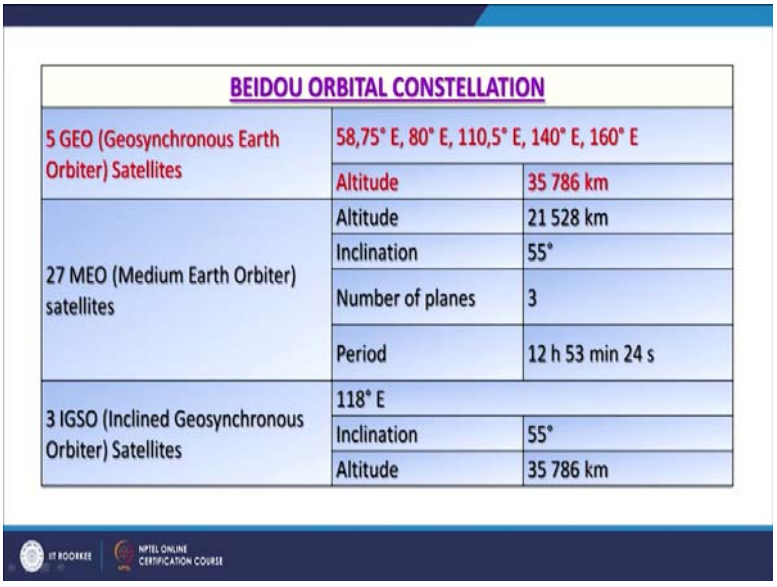
Now these orbits, which we have just discussed and we will be touching one by one that there are 6 types of orbital planes which are being exploited; 6 orbital planes and total satellites planned are 35. By 2020, the full constellation will be there and currently as per the latest information, 22 satellites are already in different orbits. The project started in October 2000 and latest launch was in February 2018, total launches so far 25 and there are 3 orbits which have been mentioned here; the red one is the geosynchronous earth

orbit as mentioned that it over passes or it comes in the sky exactly at the same time every day.

So, that is the biggest advantage of this orbit and there are many satellites in this orbit. When we will have complete installation of the constellation of BeiDou then 5 satellites would be there in this GEO orbit. Then MEO which is Medium Earth Orbit as you can see that these satellites are going to be quite close to the earth and there are going to be 27 satellites in total in MEO orbit which is shown here in the blue colour and then one more orbit, in which 3 satellite will be there which is Inclined Geo Synchronous Orbit (IGSO) as you can see in this grey colour also.

So, basically 3 types of orbits are being used. Here there are two more orbits have been mentioned just for completeness because we are using medium earth orbit. There are one more orbit which is Highly Elliptical or HEO orbit is there and there is also of course, low earth orbit which is more close to the earth as you can see here, the low earth orbit and of course, the geosynchronous orbit is also shown here, MEO is also shown here. For completeness this figure is also quite important.

(Refer Slide Time: 11:50)



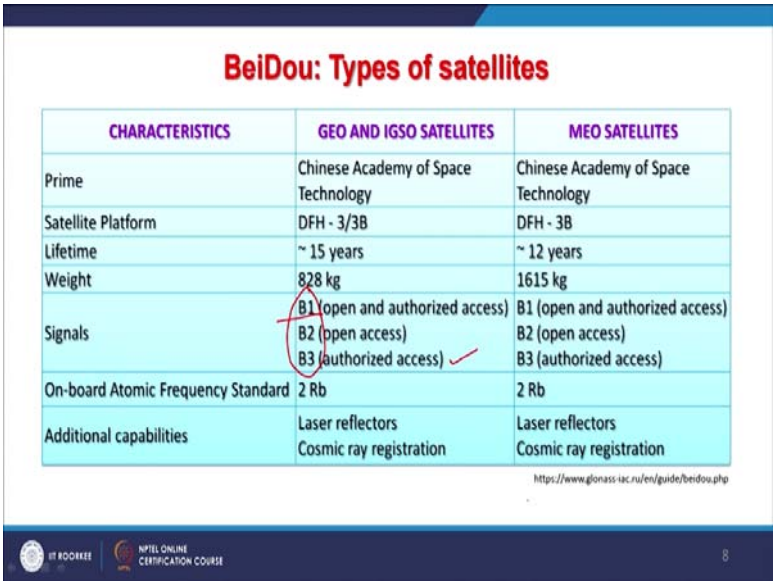
Now, other parameters characteristics of BeiDou are that 5 geo synchronous satellites, they are located at these different locations and which are giving here. And then the altitude is quite high means they are very far from earth; 35,786 kilometre and then 27 MEO satellites which will be once the constellation is completed in 2020 then these

satellites altitude is medium or so, it is around 21,528 kilometre. If you recall that GPS satellites are around 20,200 kilometre so quite close and your GLONASS are 20,000 kilometre. So, it is almost in the nearby envelopes in the space, these satellites are there which are in large number 27.

And the inclination is 55 degree, 3 orbital planes in which these 27 satellites have been put and each satellite will complete cycle or one orbit in 12 hour 53 roughly. So, it is not exactly is coming on the same time because it is 12 hour 53 minutes, but from positioning point of view or getting data and estimating the position, lot many satellites for all locations in Asia-Pacific region would be available from BeiDou system as well.

And also earlier we discussed that there are 3 IGSO that is Inclined Geo Synchronous Orbit satellites are there which is located at 118 degree east, inclination is same as in case of MEO satellites and altitude is almost same as GEO satellite so, 35,786 kilometres. So, this completes the constellation characteristics or orbital constellation of BeiDou.

(Refer Slide Time: 14:10)



Now there are these different types of satellites orbits which we have discussed that GEO, IGSO and MEO. So of course, this agency which is doing this all work; if for China is a Chinese Space technology and these satellite platforms are of 3 by 3B DFH and the design lifetime for GEO and IGSO is about 15 years whereas MEO satellites is 12 years.

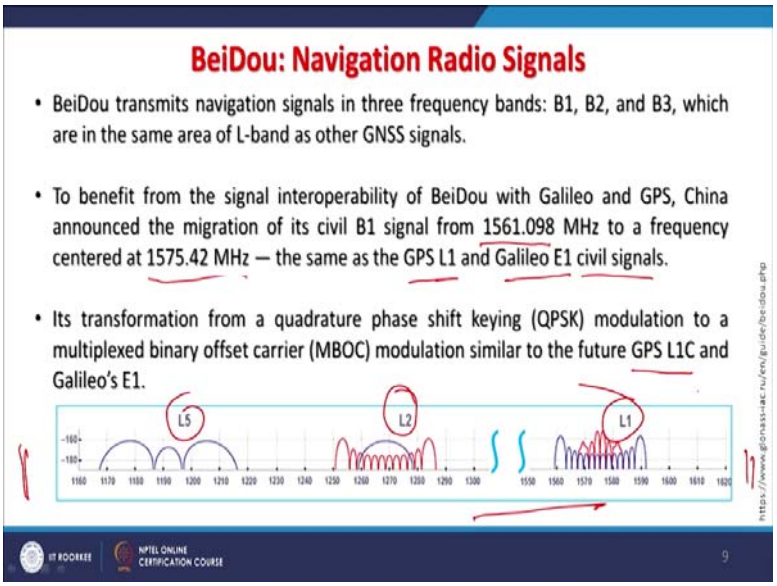
As you know that when they are put in a orbit which is very far from the earth generally the life is more compared to the satellites which are close to the earth and that is why you are seeing that in case of this GEO and IGSO satellites, their life is about 15 years design life because they are at 35,786 kilometre away from the earth and whereas, in case of MEO orbital satellites, the distance is not that much as compared to GEO or IGSO; this only 21,528 kilometre.

So that is why, the age or the design life of these satellites is less compared to GEO and IGSO satellites and weight wise also, there is a lot of difference between weight because some MEO satellites might be multipurpose here. So, there might be more electronics overhead may be scanners and other things. So, that is why when you are having lot of onboard camera and other instruments then weight may increase. Now important part is coming is about signals.

So, instead of calling L1, L2, L3 or L5, they have started calling B1 B2 and B3 for all 3 types of orbital satellites. B1 is open; now authorized access is available. B2 is completely open and B3 is completely restricted. So, restricted or authorized access means it is might be only for the Chinese army. Here sometime they may allow, sometime may not allow in case of B1, but B2 is completely open in all cases and on board atomic frequency standard which they have followed is 2 Rb which is identical in all 3 types of satellites.

Additional capabilities may both or all 3 types of satellites are having laser reflectors, cosmic ray registration and other things because now days it is not the single or uni-purpose of all these satellites. Each country is trying that they should have multipurpose satellite.

(Refer Slide Time: 17:29)

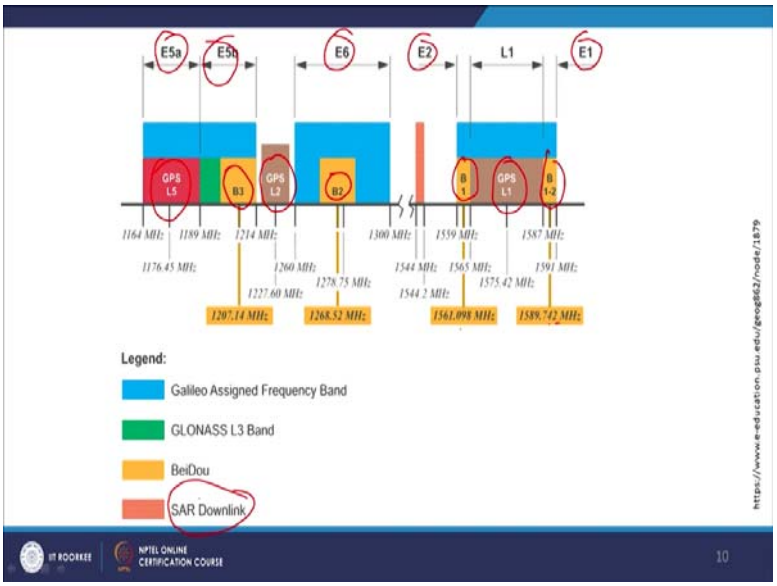


So, they can not only for navigation purposes but forr oother purpose also they can exploit. Now BeiDou transmits navigation signals in 3 frequencies bands B1, B2 and B3 which are in the same area of L band which you are seeing here that L1, L2 and L5 is there in the L band.

So, this covers the entire L band here of other signals, but of course, the frequencies are going to be different. So, to benefit from signal interoperability of BeiDou with Galileo and GPS, China has announced that migration of its civil B1 that is open an authorized access from a 1561.098 Mega Hertz to a frequency centered at 1575.42 Mega Hertz and this would be the same as the GPS L1 and Galileo E1 for civilian.

So, this frequency is completely open for civilians. And the transmission from a Quadrature Phase Shift Key which is QPSK modulation to a Multiplex Binary Offset from Carrier MBOC, modulation similar to future GPS L1C and Galileo E1. When we have been discussing about NAVSTAR GPS of US, we have discussed about L1C also.

(Refer Slide Time: 19:05)



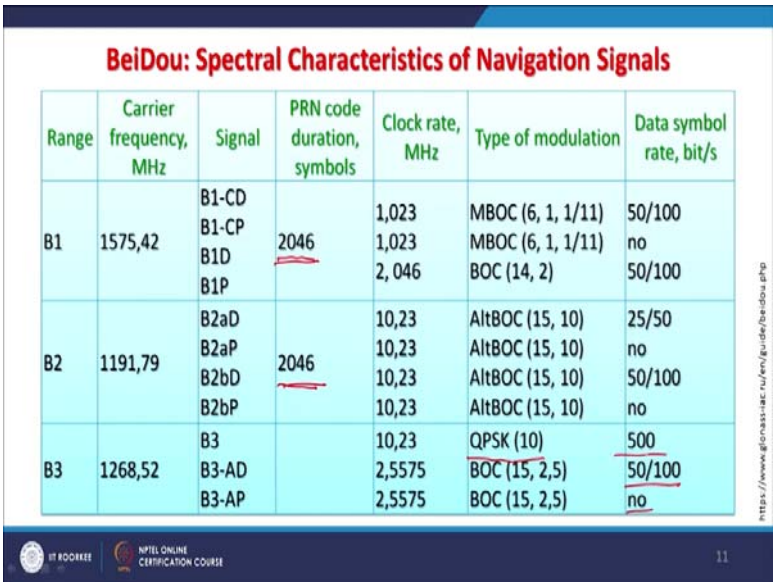
Now, for the comparisons that which navigation system or GNSS is fitting where which frequency they are using. So, say in that sense is a comprehensive picture is here. For as L1, you are seeing for the GPS as you can see here and for L2 also for the GPS and L5.

Whereas, in case of European or GALILEO satellites E,1 E2, E5, E5b and E5a, they are there and these B1 for the BeiDou, B12 again for BeiDou and B3 these are also there. So, each navigation system though they are using L band of EM spectrum but it different locations. So, therefore the frequencies are different within different bands. So, that is why you are seeing here. So in case of BeiDou, that 1561.098 Mega-Hertz for B1 and 15,897.42 Mega-Hertz for B12.

And for B2, is 1268.52 Mega Hertz and for B3 1207.14 Mega Hertz. And GALILEO frequency as you can see, they are using much more frequency almost they are overlapping with BeiDou and GPS, but remember that GALILEO is a regional system. So, here we do not get much problem or issues related with this overlapping. And of course, one this synthetic aperture radar (Refer Time: 21:03) or downlink location is also shown. So, that frequency is also being used by these radar satellites to transmit data towards the earth.

So, a part of a EM spectrum which is specifically part of L band in microwave region has been divided in different components, different sections, different bands and they each country with sort of coordinated manner they are using all this signals.

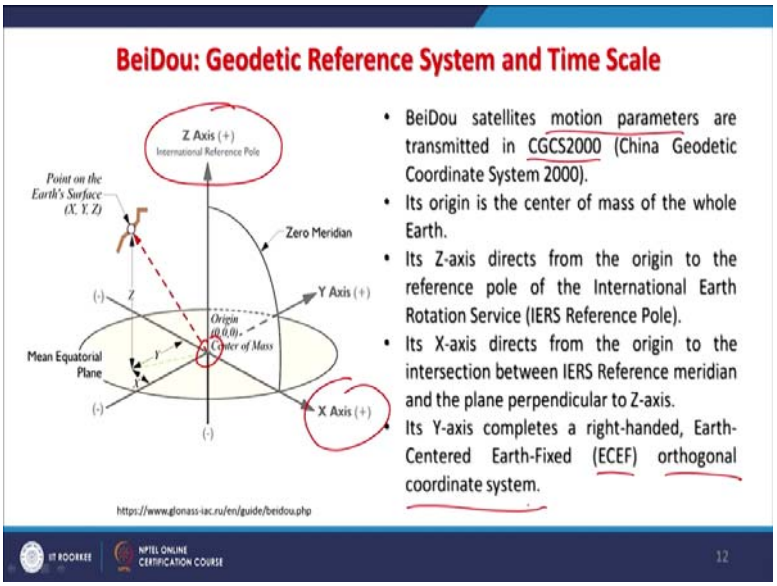
(Refer Slide Time: 21:34)



So, if we look the spectral characteristics of a navigation signals then B1, B2 and B3 which a BeiDou is a going to use or is using that a carrier frequencies in case of B1 is 1575.42, carrier frequency in case of B2 1191.79 and similarly for B3 it is 1268.52. So, you are having signals in B1, you are having signals in B2 and different bands are been assigned PRN code duration and symbols. These codes are assigned. So, sometimes when you plot the location or see a sky plot of these GNSS systems, they are shown as a PRN number because this is the unique ID given for each satellite and this is basically Pseudo Random Noise, but it also identify the satellites.

So, this code is given for these bands also, for B1 and B2. There are different clock rates and type of modulations. We have touched a little bit about this like a QPSK and others. we have discussed about this briefly and data symbol read and bit per seconds are also there as per requirements for. Here see the rate it is much higher as compared to other bands in B1 B2. So, B3 is because as there is only for military purposes as you have seen that B3 is available through authorized access.

(Refer Slide Time: 23:28)



Now, the geodetic reference system, each navigation systems; GPS is using Earth Centric Earth Focus (ECEF) that geodetic reference system, GLONASS is using some other one whereas the BeiDou is using a different one. Only thing as also in our previous discussion, we have seen that some little variations in different parameters are there because earth is not perfect spheroid one and each country would like to have the best for its own locations and therefore they go for their own geodetic reference system.

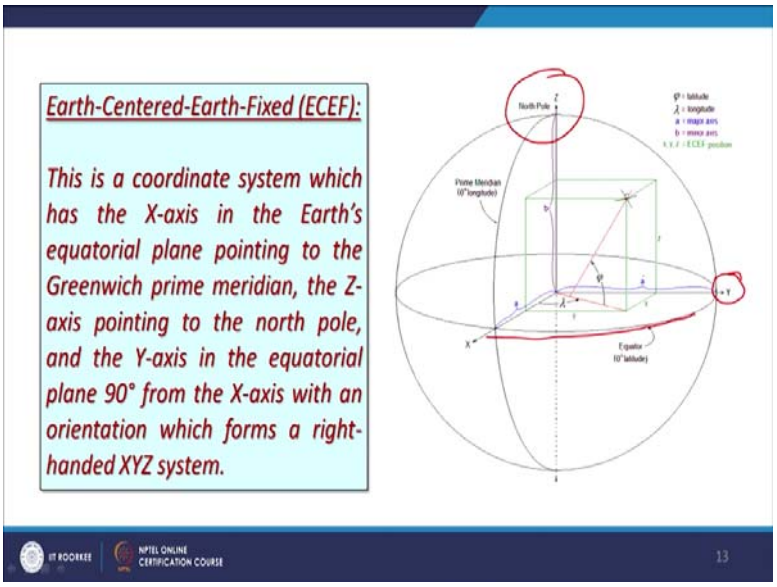
So, in case of BeiDou because the motion parameter is transmitted in IGCS2000 this is China Geodetic Coordinate System and developed in 2000. So, that is why it is being followed for BeiDou. Its origin is the centre of mass of the whole earth and that is shown here and then its Z-axis directs from the origin to reference pole which is also shown here, to the Pole of the International Earth Rotation Service that is IERS Reference Pole or International Reference Pole also called.

So, that means that these motion parameters have been set through this China Geodetic Systems in this manner which are little different than world geodetic spheroid or the other one with the GLONASS and its X-axis as you can see; X-axis here directs from the origin to the intersection between that IERS; International Earth Rotation Service reference meridian and the plane perpendicular to Z-axis.

So, along with this, where it cuts that is the origin of the X-axis in here also. Now the Y-axis completes a right handed, Earth Centred Earth Fixed (ECEF) the same therefore Y-

axis as in case of GPS and which is orthogonal coordinate system. So, some parts are common as I have said that each country is trying to have the best location for themselves and therefore they keep changing little bit in these reference systems.

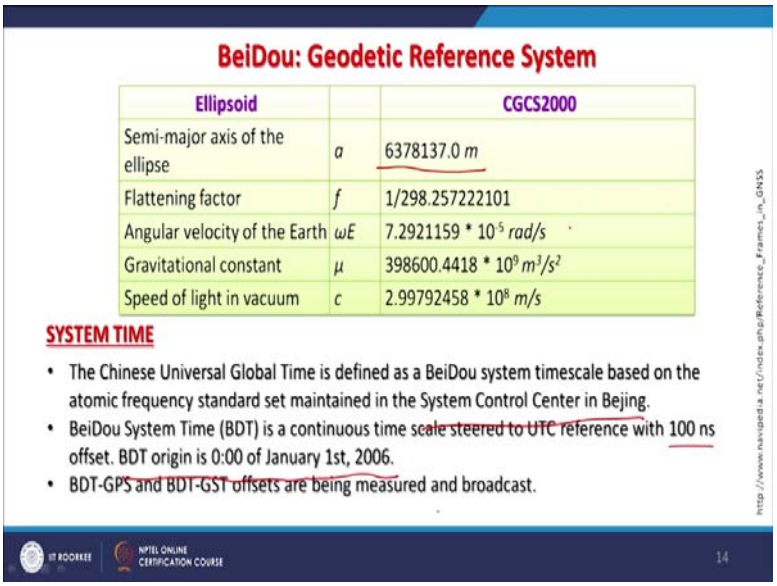
(Refer Slide Time: 26:24)



In the previous lectures when we have been discussing about GPS or GLONASS, we have also touched upon Earth Centred Earth Fixed system, which is a coordinate system which has the x-axis in the earth's equatorial plane. As as you can see here this is earth axis and a pointing to Greenwich prime meridian and the z-axis pointing to the north pole here and the Y-axis in the equatorial plane that is 90 degree from the X-axis with an orientation which forms a right handed XYZ systems.

So, Y-axis is also here as you can see. So, say as it is mentioned that the orientation which forms a right handed XYZ system, which is what followed in the coordinate systems as well.

(Refer Slide Time: 27:31)

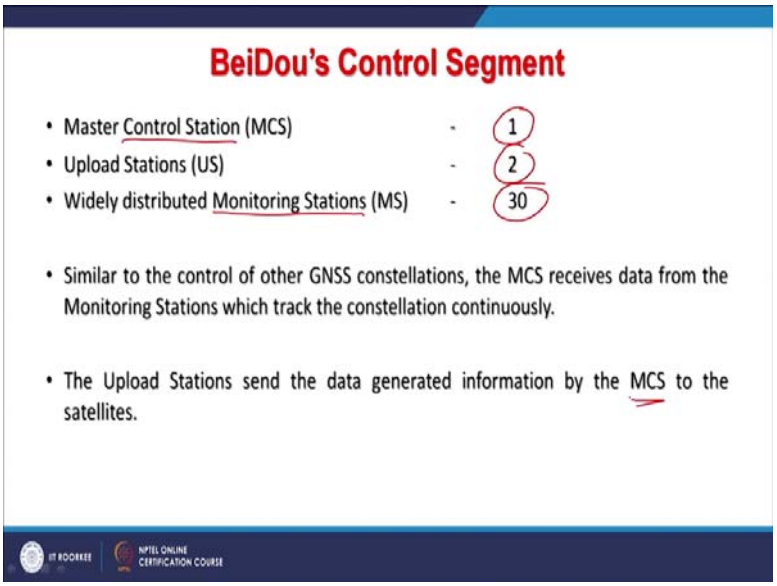


Now BeiDou geodetic reference systems value which are here that the semi major axis of ellipse is having this much of the length, flattening factor has been taken this one, angular velocity has been taken this one, gravitational constant MUE is this one and a speed of light in vacuum is this one.

So, this is Chinese Geodetic Reference System is there of 2000. Now, time because in each system, it have to a synchronized clocks and sometimes with some reference time. So, Chinese Universal Global time is defined as BeiDou system time scale based on atomic frequency standard set maintained in the System Control Centre in the Beijing and this BeiDou system time BDT, is continuous time scale steered to UTC reference with 100 nanoseconds offset.

So, it is not exactly UTC time but little having offset of 100 nanoseconds. So, every GNSS system will have their origin of the time. So, they have fixed the origin with 00 hours on January first 2006. So, this is how, it basically completes in that sense the Reference System as well as Time Reference which they have been following and BDT-GPS and GST offsets are being measured and broadcast so that we get the correct signals.

(Refer Slide Time: 29:14)

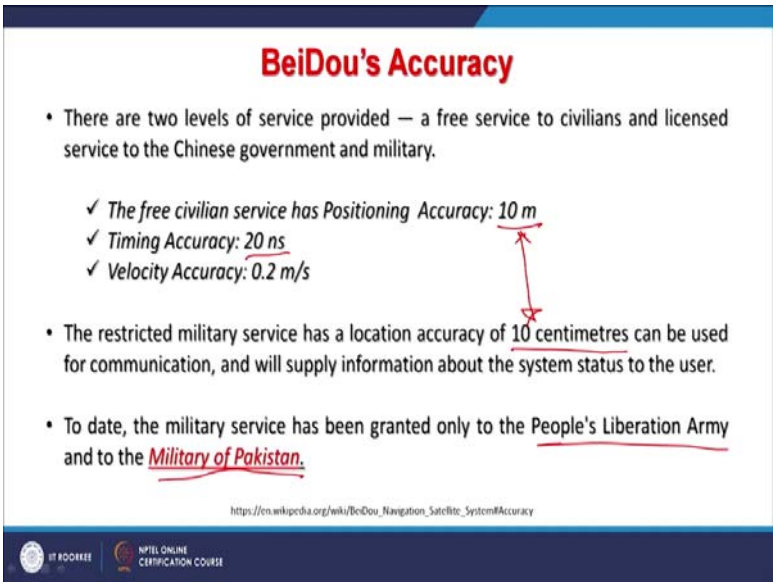


Now, as we have also seen in case of GPS and GLONASS, there are segments. All GNSS are having 3 major segments; first one is control segment. Now we are going to discuss about the control segment. So, control segment includes a Master Control Stations and for Uploading Stations, Up-linking Stations, Widely Distributed Monitoring Stations. So, each GNSS will have Control Stations, Monitoring Stations, Up-linking Stations and they have planned for 30 monitoring stations from different parts of the globe and only 2 Up-linking stations and of course, all the systems are having 1 Master Control Station.

So, similar to the control of other GNSS constellations, the MCS; Master Controls Station also receive data from monitoring stations which track the constellation continuously and if these satellites, though they are in different types of orbits, if they deviate that information is fed to the Master Control Station and then corrections are sent through this Uplinking Station.

So, this upload station send data generated information by monitoring stations to the satellites and then satellites are brought back in the corrected designed orbit.

(Refer Slide Time: 30:45)



There are two level levels of service provided by BeiDou; open access or also called free service to civilians and licenced or through the authorized access service to Chinese government and military which is definitely is more accurate than what we get to the civilians.

So, free civilian service has positioning accuracy of 10 meter as you can see, timing accuracy of 20 nanoseconds. For most of the applications in the civilian domain, this clock accuracy is quite good, 10 meter for positioning accuracy may not be good, but if we use the signals from other constellations or other GNSS systems then this can be improved and it is being done also and velocity accuracy is 0.2 meter per second again it is quite good in that sense and restricted military service has a location accuracy of 10 centimeter.

See the compare with 10 metre and 10 centimetres. So, as mentioned already that the restricted in the B3 band, they are having this 10 centimeter accuracy which can be used for communication and will supply information about system status to the user. To date the military service has been granted only to the People's Liberation Chinese army and this is very important; to the Military of Pakistan.

Because Pakistan do not have their own GNSS system neither they have planned anything. So, by because of some agreements or geopolitical reasons they are getting the same accuracy as Chinese Army Organization. So, this point is important to note. So,

this brings to the end of discussion related with BeiDou and as usual normally I am leaving with some cartoon to enjoy and have a fun after each lecture.

Thank you very much.