Computer Architecture and Organization
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Lecture - 52
Universal Serial Bus (USB)

In this lecture, we shall be talking about the Universal Serial Bus or USB that has become a real kind of a universal bus standard today. Almost all the devices that we want to connect to the computer system, we will see that there is USB interface available. You compare this scenario with the computer systems that were available let us say 15-20 years back.

There you would see so many different kinds of connectors at the back plane of your PC, the keyboard will be connected using a special kind of a connector, mouse will be connected using another kind of a connector, then the serial port will be RS233 serial port connector, the printer will be connected to your printer port, network will be connected to a different kind of a connector.

So, there will be a lot of connectors. This USB tries to integrate or consolidate all these bus standards into a single bus standard, which is acceptable to almost all different kinds of applications, so that you can have a computer system with a single kind of a port. If you look at a very modern laptop today, you will see that it has only USB ports and nothing else. Everything else you want to connect, you have to connect through USB.

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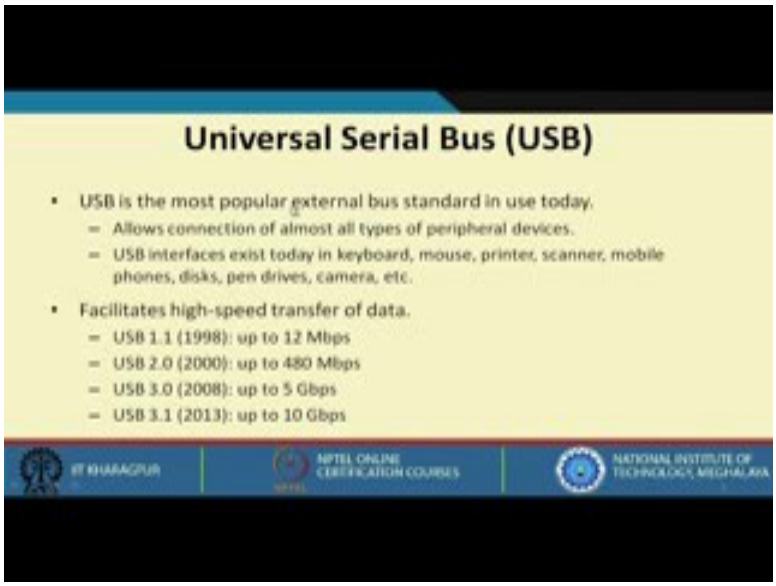

The topic of today's lecture is Universal Serial Bus or USB. USB is the most popular external bus standard. It means, it is not used inside a computer system, but rather this is used to connect some peripheral system, outside the computer.

Today this USB standard allows connection of almost all types of devices. Devices can include keyboard, mouse, printer, scanner. Our mobile phones also have a USB interface, disk, pen drive, camera. Anything you name, you will find that there is an USB interface available.

Now, the advantage of USB is that it facilitates high-speed transfer of data. The standard has evolved over the years. Some of the standards I am showing, version 1.1, 2.0, 3.0 and 3.1, and these are the years when they were proposed.

The first is USB 1.1 version, it worked up to a speed of 12 Mbps. At that time it was considered to be good enough, but USB 2.0 which came in 2000, the speed was jacked up to 480 Mbps, but this 3.0 and 3.1, they have brought it to an altogether different level, 5 and 10 Gbps.

So, with the modern-day USB interface, you can interface virtually any kind of device because 10 Gbps is really fast. There are newer standards available that can go even higher, like 40 Gbps. Whatever kind of device you can think of, you will normally not be exceeding this limit. You can use it for almost all kinds of applications.

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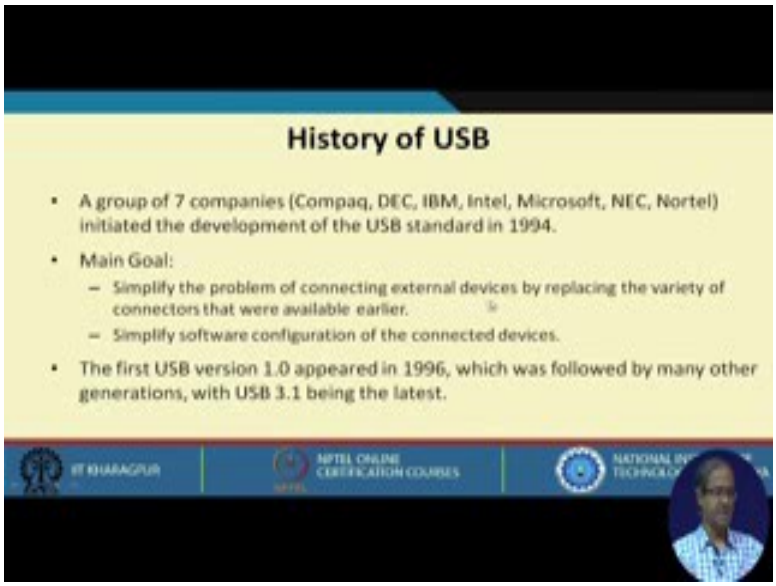

Talking about the history, this was a standard that was jointly formulated by seven companies that included Compaq, Digital Equipment Cooperation which of course today is no longer there. Compaq is also no longer there. Then IBM, Intel, Microsoft, NEC and Nortel. They sat down together and felt that there is a need and necessity to come up with a new standard for connecting peripheral devices.

The main goals were two fold. First was there was a big problem as it said that connecting external devices to the computer. Earlier there were so many different standards and that is why the computer systems came up with so many different sets of connectors. Depending on the device, you will be connecting them to one of the available connectors.

So, instead of having so many different kinds of connectors, why not have a single kind of a connector that can connect almost all devices. The second problem is also important to simplify software configuration of the devices you are connecting.

Now, with USB there is a mechanism. If you connect a device through the USB port, the system software will automatically try to find out what kind of device it is, and it will automatically try to locate and install the device driver. You might have experienced when you connect various devices like pen drives and other devices to a computer system, but earlier it was not like that. When you connect a new device, you will have to put in a CD or DVD containing the device driver, and you will have to manually install

the device driver. Then only the device will work. This USB also made the task easier. The first USB version 1.0, appeared as early as in 1996. There are many other versions in between. The latest version is 3.1.

Now, let us look a little bit inside.

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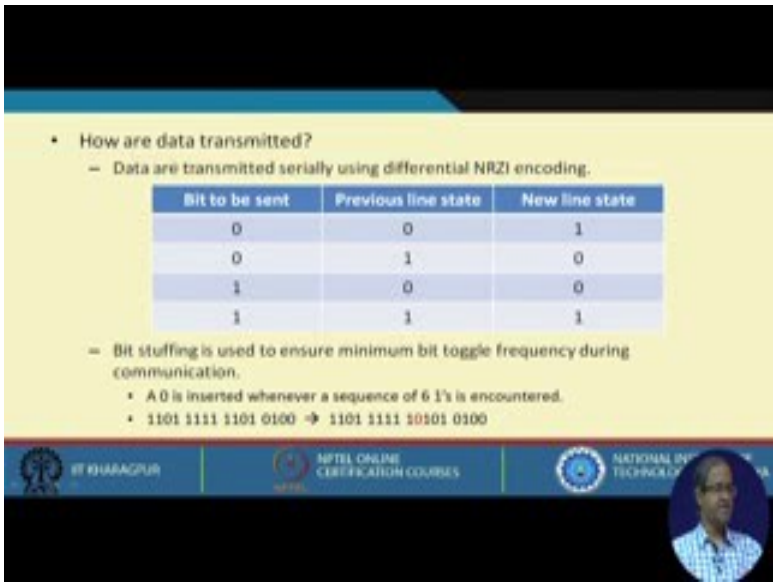

First is that it is a serial bus. Data are transmitted serially and the uses differential NRZI encoding. Now, let me first tell you what is meant by differential. When you carry out communication, suppose I am the sender.

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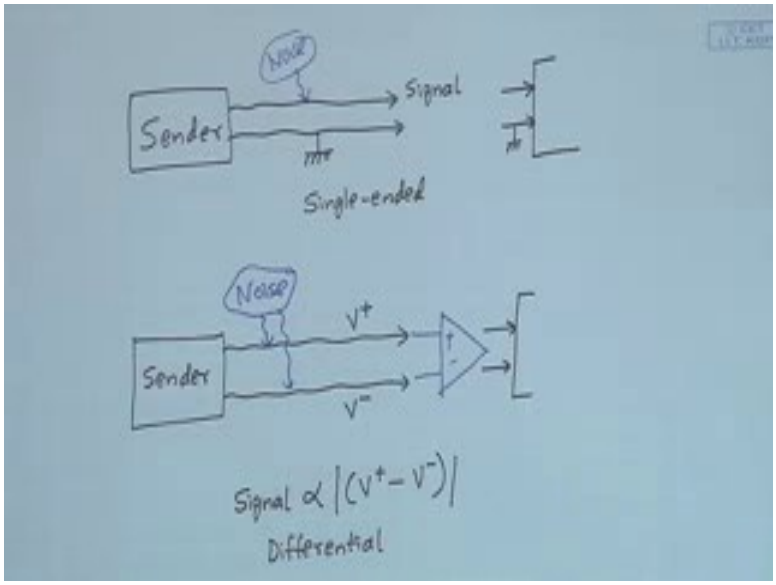

There are two ways in which you can send data. You can have two wires. One wire can carry your signal and the other wire can be ground. When you send the signal to the receiver, receiver should also know that this is your signal and this is your ground. So, you have to connect the signal in the proper order. This is sometimes called single ended connection.

There is an alternate way of connecting. Here we do not have a separate ground connection, rather signal is sent over two lines. One we call it as V+, we call it as V-, and the receiver receives these two signals. The idea is that the signal that is transmitted is actually represented by the difference of V+ and V-, and modulus of that. This mode of transmission is called differential mode of transmission.

The advantage of differential mode of transmission is that suppose when there is the communication link like this, there can be some nearby sources of noise like power supply lines and other things that will be injecting noise on the communication lines. If it is the pair of wires, the same noise will be injected on both the lines, and if you subtract them, the noise will be cancelled out.

At the receiving end, you will be having some kind of a differential amplifier. It will be finding the difference of the signals, amplifies and feeds it to the receiver, but on the single ended case since one line was grounded, ground line is never infected by noise. Noise will only affect the line carrying the signal. So, the receiving signal will be degrading in quality.

Differential signal has this one advantage. The way the data bits are encoded, there is a standard way NRZ. In USB, we use NRZI. Depending on the bit you are sending and the previous state of the line, you encode the bit to be sent.

Suppose if the bit is 0, the earlier the line was 0, then you send 1. If the bit is 0 and earlier it was 1, you send 0. Let us take an example and see what happens.

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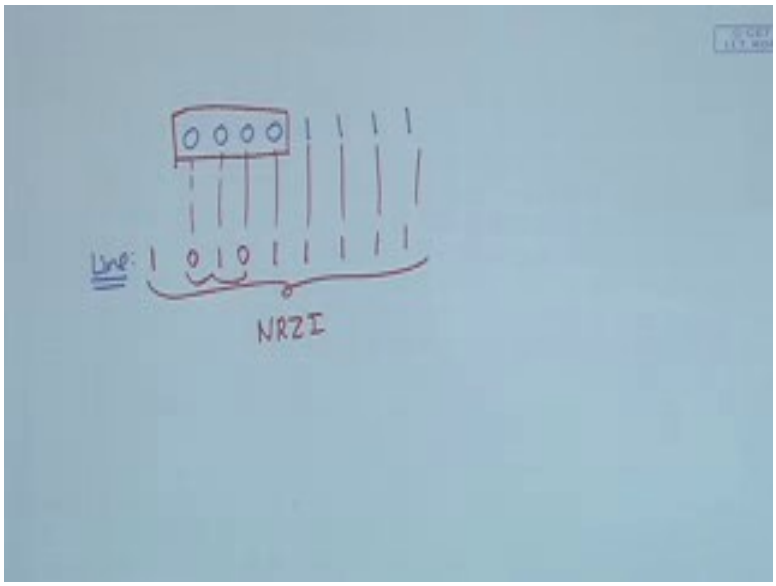

Suppose my data that I am transmitting is 0 0 0 0 1 1 1 1 and let say my line was initially at 1. The previous state was 1 and now this line is 0. You look at this table. Previous line state is 1, bit to be sent is 0, and the new line state will be 0. This way all the other bits are encoded.

NRZI encoding has some good properties that you always inject some transitions 0 1 0 1. Even if your line is continuously at 0, that is a long stream of zeros, but still in the line there will be some transitions.

Transitions on the line are always good because you can synchronize the receiver. If the signal is changing, receiver can synchronize itself. If it is always desirable in a serial communication link, there should be a sufficient number of transitions on the line.

There is another way to ensure that long streams of zeros and ones will never be there. There is a method called bit stuffing that is also used in USB. Bit stuffing says that whenever there is a sequence of six consecutive 1's, then the transmitter will forcibly insert a 0.

After every 6 1's, a 0 is getting inserted. So, the receiver whenever it will receive six consecutive ones, it will drop the next bit. The advantage of bit stuffing is that you will never have a scenario where the line will be having long stream of 1's. NRZI ensures that 0's will not be there. Long stream of zeros and bit stuffing will ensure that long stream

1's will not be there. So, there will be guaranteed transitions in the lines. This is ensured by these two methods.

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Another interesting thing is about USB connectors. You have seen USB connectors yourself because you must have handled all these devices. Well, traditionally the USB connectors come in two kinds, Type A and Type B.

Type A plug has an elongated cross section that inserts into A type receptacle. Receptacle means a Type A plug can go inside A Type A receptacle only. So, there will be like a male-female connector. A type can go inside A type only, but the two connectors are different. The Type A USB connector and the Type A receptacle connectors are different. In a computer system or a laptop, the connectors that are available are the receptacle connectors, and a device when you connect that is your normal Type A connector that goes inside that receptacle.

The Type B plug looks different. It is not elongated and flat. It looks like a square with a top external corners beveled.

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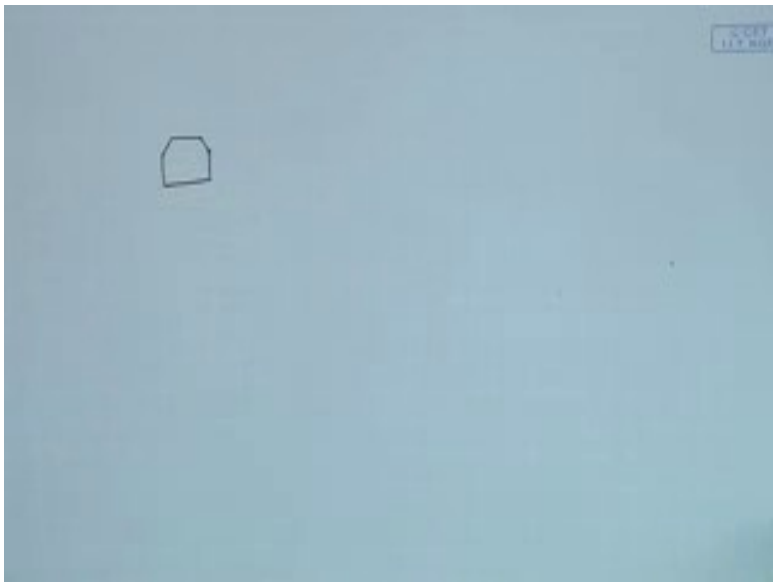

Beveled means it has a shape like this, right square, but the top two corners have a little curve. Now, this Type B plug traditionally was used to insert into an upstream port or a device, let us say printer.

Earlier when you used to connect a printer or plotter to a computer system, you had a USB cable wherein one side you had a Type A plug and on the other side, you had Type B plug. Type B plug will go inside the printer, and Type A plug will go inside the computer system. With the developments in the USB standards, this difference is no longer required. You can have a cable with the same kind of connector on both ends. You can connect the cable in any order you want. It is not that Type B will go into the printer and Type A will go into the computer and not the reverse.

There have been developments where we are now having smaller devices like laptops and tablets, mobile phones, digital cameras. It was felt that Type A and Type B plugs are too large. So, there were smaller versions of USB connectors that came up, the mini USB and the micro USB connectors.

I am showing you some pictures here.

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This picture shows you the Type A connector that you see mostly. It is a little elongated and flat. This is your normal connector and this is your receptacle. The normal connector will go inside the receptacle; and Type B looks like this. This will be your Type B connector and it will go inside a receptacle that looks like this.

For example, if you have a printer with a Type B connector, on the printer you will be having a port like this and on the cable, you will be having a port like this, and this standard USB connector looks like this and the corresponding mini connector looks like this. So, you see it is less than half the size.

Micro USB connector width wise it is almost same, but thickness wise is smaller and is used on our mobile phones today.

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Let us see the connector which we have in the back, this one, this is an example of a micro USB connector. The cable that you connect to it that is a micro USB cable.

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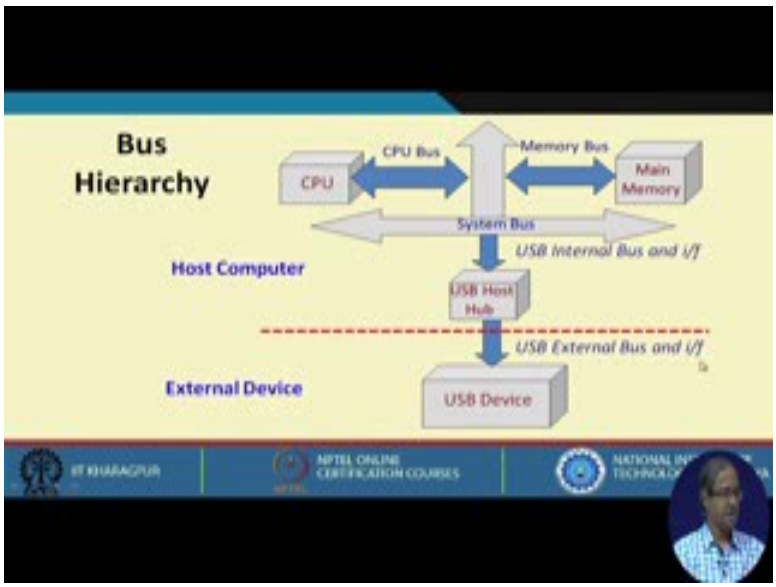

In USB there is a concept of a bus hierarchy; the way the USB devices are connected. Let us look at this picture. On the top part we have a host computer. This can be PC, desktop or laptop. I am not showing the north bridge and south bridge separately; I am just showing it in abstract sense. There is CPU, there is memory, you have CPU bus, you have a memory bus. May be your north bridge is sitting here, then you have a system

bus, may be this is your south bridge. This is connected to a chipset that is your USB host hub.

From the USB host hub, you will have all the USB connectors on your computer on external device. You may be having a pen drive or any other device you want to connect it to the USB host hub, you have the connector here that will be connecting to one of the host computer connectors. The two buses that you have here, system bus and USB host hub, they are connected through the so-called USB internal bus and interface; and when you connect an external device through an external cable, that is referred to as USB external bus and interface.

Now, we look at bus topology.

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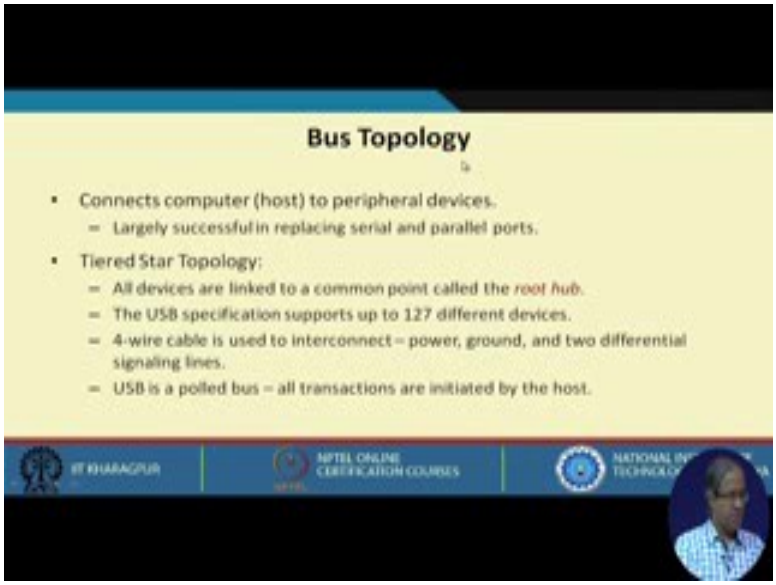

By bus topology what I mean is that how the external devices are connected. Inside the computer system, it is fixed. Now, how you can expand the capability so that you can connect several devices outside. You must have seen there are products called USB extenders available. You plug a device to the USB port and on the other side, you will be getting four USB ports.

So, you have a USB connection topology that is sometimes called a bus topology. I will be illustrating with an example. This bus topology is used to connect the computer system that is sometimes called the host to the peripheral devices. Now, again you think

of the master/slave relationship I talked about earlier, when you connect a computer with a peripheral device like a pen drive. A computer works as the master and your pen drive works as a slave.

A few years back when you would connect a mobile phone to your laptop, your mobile phone can be used only in the slave mode, but nowadays with the advancements in the operating system and the hardware of the mobile phones, you can use mobile phone as the master as well. Like here you have a micro USB connector; you can connect an adapter and then connect a pen drive to this mobile phone also. Then this mobile phone will be acting as the master and the pen drive will be acting as the slave.

This bus topology is typically a star topology. It is a multi-tiered architecture and not a single level. There can be multi-level of hierarchy and it looks like a star. There is no loop or feedback. We will take an example. The devices are all connected to a common point that actually is called a root hub that refers to the master in the star topology. The USB specification is such that you can connect up to 127 devices and each USB connection is a 4-wire cable; just a power supply, a ground and two differential signaling lines V+ and V-.

With the development in USB technology, the power and the ground lines are also such that sufficient power can be delivered over the lines. Nowadays, the external hard disk drives that are available, you can straightway connect them to the USB port without any need to separately connect any power supply.

You recall in an external hard disk, there has to be some motor inside that will be rotating. So, there will be significant power requirement there. That entire power can be drawn from the USB power lines. Lastly, as I had said USB is called a polled bus, where the host initiates all transactions, that is the root.

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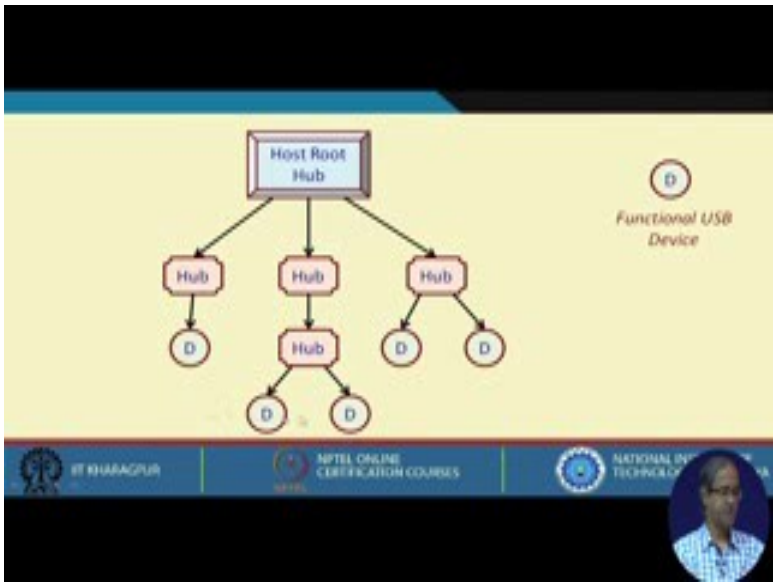

So, this tiered architecture looks something like this. You have a host root hub, this is your host connection, and you can connect the devices D, these are your USB devices. If you want you can connect a device directly through a hub. If you want to extend the capability, you can connect several levels of hubs, and there are hubs that can be having several different connections.

Suppose this has four connections, you can connect four devices. So, like this you can develop a tree or a star kind of a topology with which you can connect up to 127 USB devices.

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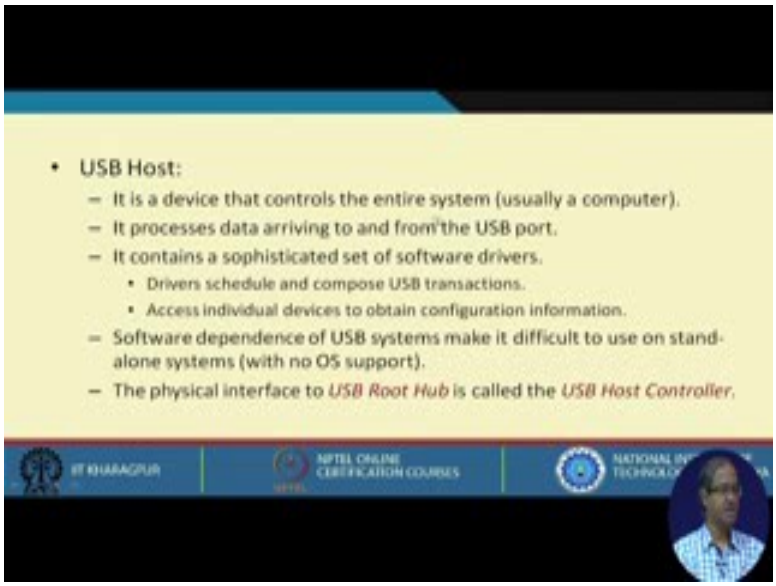

Now, you have host, you have hub, you have the devices. Talking about the host it is a device that controls the entire system, and this host is usually a computer or a laptop. Some mobile phones can also act as the host. It will be processing data arriving to and from the USB port. And it contains a sophisticated set of software drivers. Depending on the kind of USB devices that are connected, the appropriate drivers are selected and they are executed, so that data transfer can take place.

Because of this kind of an operation, USB is not so easy to use in small standalone systems, where there is no operating system support. You need to install the driver software and then only you can use your USB in a proper way.

The interface to the USB root hub is sometimes called the USB host controller.

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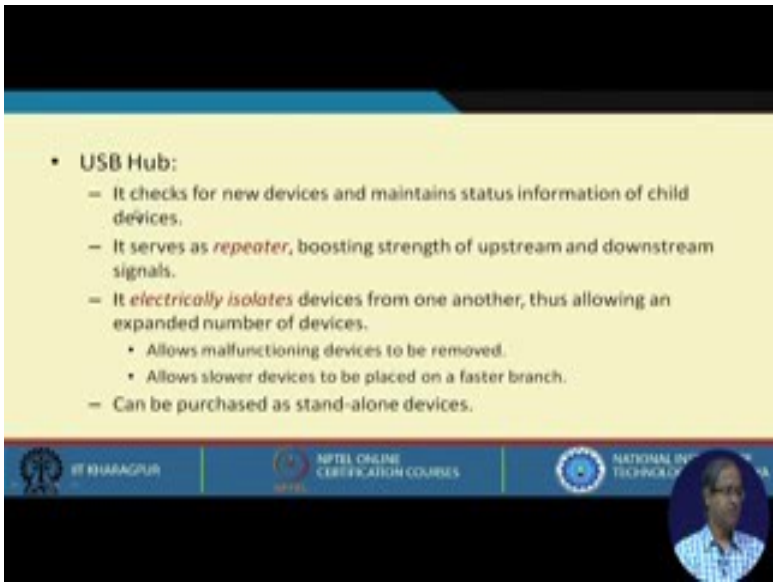

Talking about the USB hub, it checks the new devices that you are connecting to it and maintains status information. Like when you connect a new device to an USB port, that port will check what kind of device it is, and depending on that it will try to locate the driver that needs to be activated. If the driver is not available, the host will try to install that new driver.

The USB hub also acts as a repeater, like it can boost signal strength for both way connection, upstream and downstream. It also serves the purpose of electrically isolating devices from one another, and this allows you to expand to a larger number of devices. You can remove a device if you want to if not working properly. You can have any kind of connection because of those hubs. You can have several hubs and a hub will be isolating the devices that are under it from the rest of the system. Just like a network switch or a network hub we use for connecting computer system, same concept is used here.

This USB hubs are available as separate systems that you can purchase and connect to your system to expand the number of ports and the USB devices.

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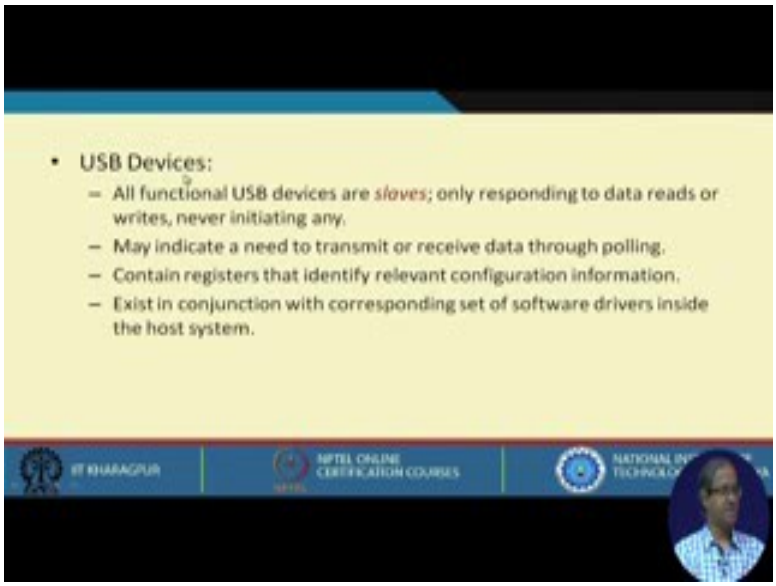

Conventionally all of the USB devices work as slaves. They cannot initiate any operations, they can only respond to operations that are initiated by the host. There are some registers inside the USB devices that can identify what kind of device it is and what kind of drivers it require, and so on.

A device can work only when the corresponding set of software drivers are there and are installed in the host system. This is a requirement.

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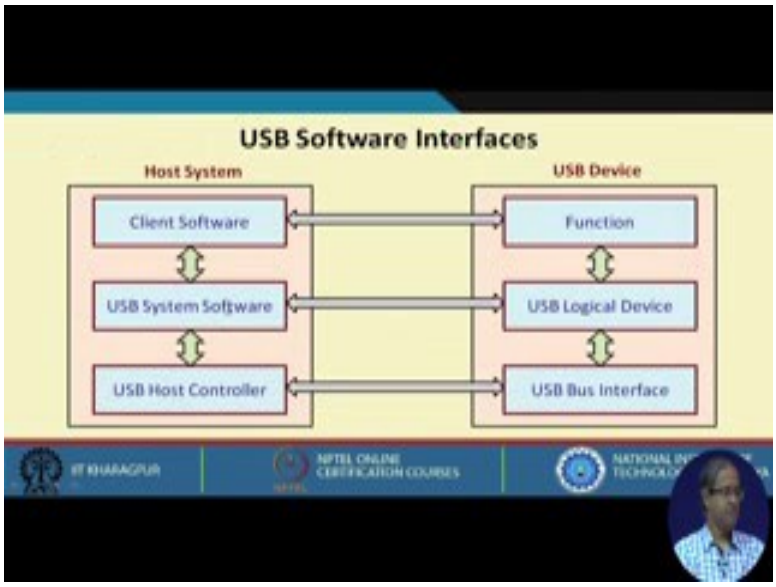

Pictorially for the host system and USB device, the connection is like this. You see in the host system, you have the USB host controller that is the connector; and in software part, you have the USB system software. And in a highest level, you have the client software. On the other side, they interact with the USB bus interface because host controller directly connects to the USB bus interface by a cable and these are virtual connections. USB system software interacts with USB logical device, and client software interacts with the USB device function whatever it is.

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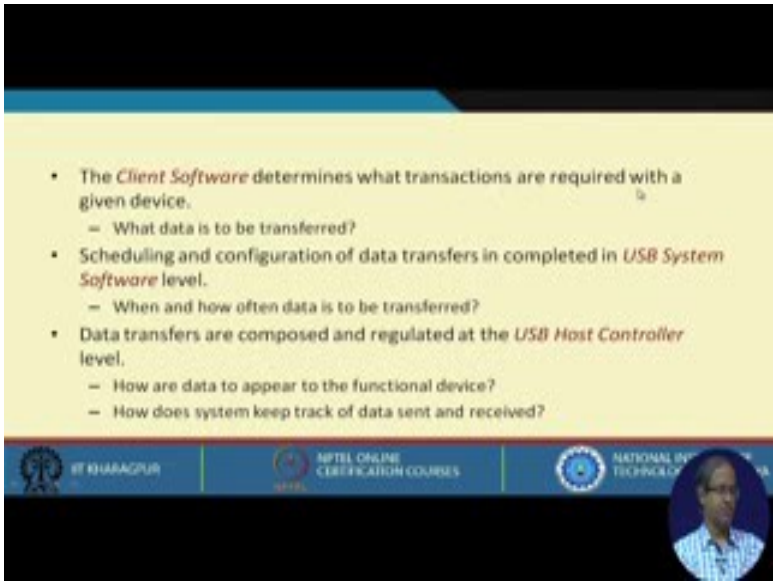

The client software determines what transactions are required with the device, what data is to be transferred. Scheduling and configuration of data transfer is completed in USB system software level. All data transfer gets completed here logically. When and how often data is to be transferred that is decided there, and either lowest level USB host controller data transfers are composed and regulated.

Data appears on the functional device like the voltages, encoding everything and how the system keep track of data sent and received, so those low level functionalities are handled by the lowest level.

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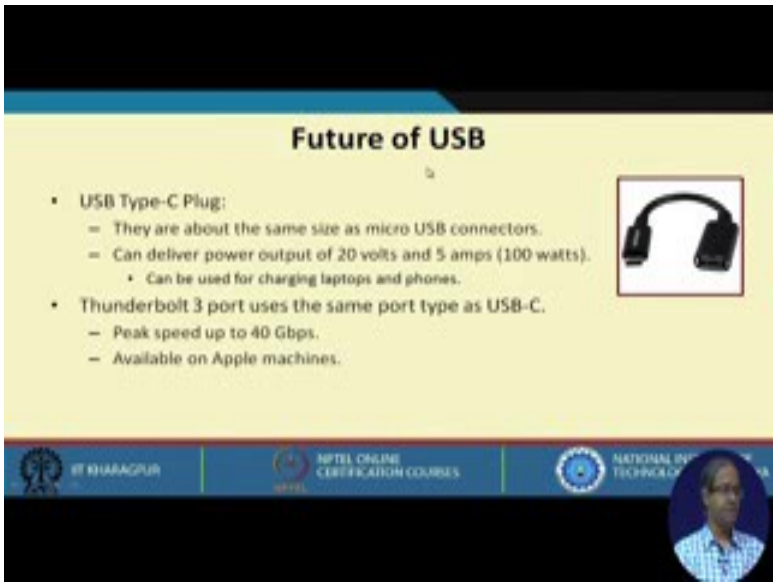

Talking about the future of USB, you might have seen a third kind of USB plug that is available on Macbook Air. The recent versions that are there, they have come up with a new USB port called Type C port. Type C port looks a little circular; they are symmetrical. The plug that you are putting in, you can reverse it also without any problem. So, the direction is not important. You can put the plug in any way you want.

This is the Type C plug, and you can say a small version of that same size is micro connector. You can put it in any direction you want, and they can deliver pretty high power; 20 volts and 5 amperes, it comes to 100 watts. You can use these ports as your charging points also. You can connect these ports to a charger for charging laptops and phones as well.

Thunderbolt is a standard that is also very specific to the Apple systems. Thunderbolt 3 port also uses the same kind of USB C connectors, where the speed can go up to 40 Gbps. So, you see in the future you have the same kind of USB ports with smaller feature factors coming up with higher and higher speeds. Almost any kind of applications that demands high speed communication, can be handled by this kind of interfaces.

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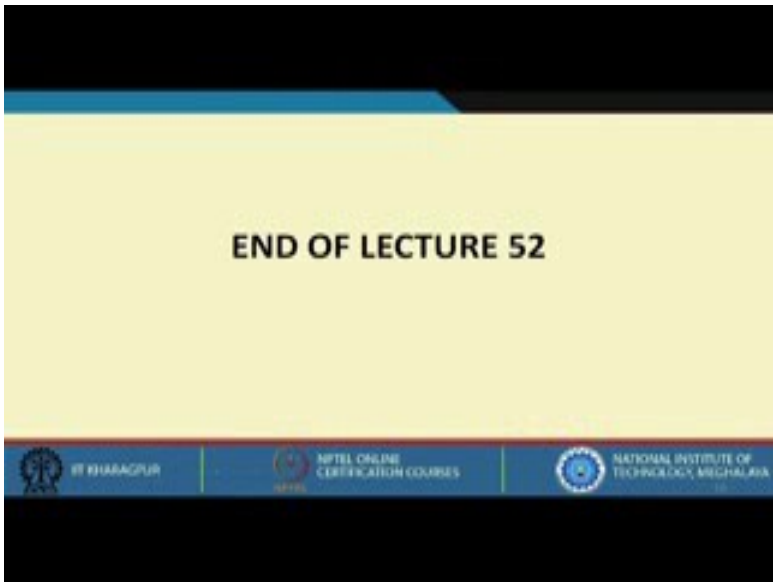

With this we come to the end of this lecture, where we talked about various bus standards and one of the very important bus standard which is there with us today, USB.

Thank you.