Switching Circuits and Logic Design

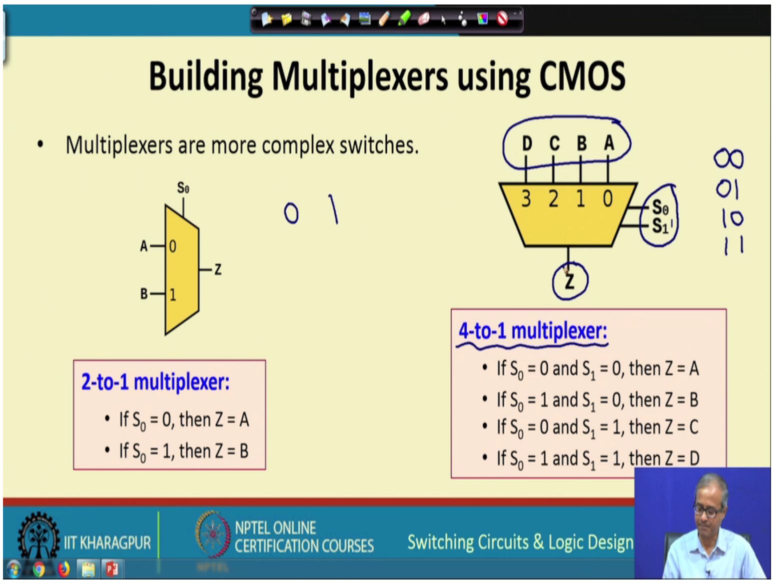
Prof. Indranil Sengupta
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture - 09
Emerging Technologies (Part 1)

If you recall in the last lecture, we are talking about some of the technologies using which you can implement gates like diode transistor logic, transistor-transistor logic and of course, CMOS. Now in the present lecture we shall be continuing our discussion on CMOS and after that we shall be discussing about a few of the emerging technologies. Means emerging technologies are something which is slightly unconventional, but there is lot of opportunities for these technologies for developing future system. So, I feel that it will be interesting for all of us to have some idea about some of these so called emerging technologies.

So, the title of the present lecture is emerging technology the first part.

(Refer Slide Time: 01:15)



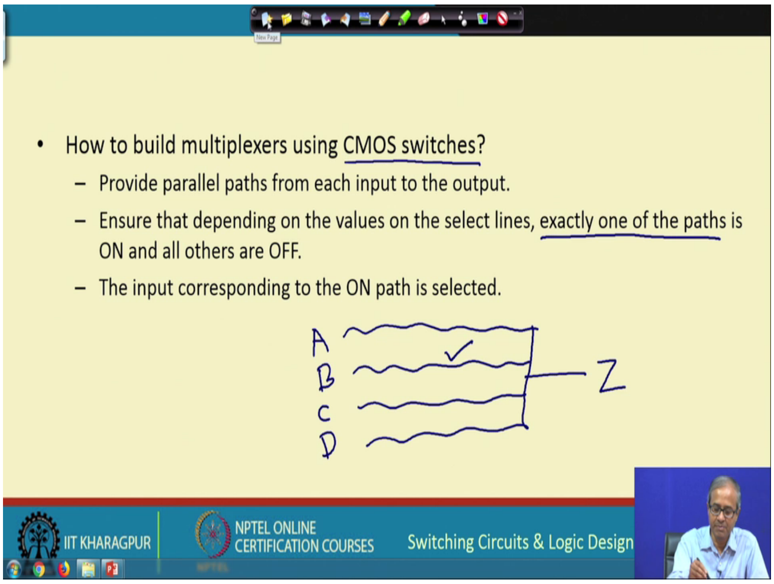
But before we move on to these emerging technologies, we continue a little bit on CMOS. Now here what we say, we are trying to develop some kind of complex switches this complex switches and this complex switches are called multiplexers. We shall be coming back to multiplexer in much more detailed later, but what is a multiplexer like.

Here we have a simple example this is called a 2 to 1 multiplexer. 2 to 1 means there are 2 inputs A and B, there is one output Z.

The way a multiplexer functions that one of the inputs will be copied to the output. Now which input that depends on so, called select line. Here S 0 is a select line, if S 0 is equal to 0, then the value of A will be copied to Z, but; however, if S 0 is 1, then the value of B will be copied to Z. So, you can say that this is like a multi way switch S 0 is the control of the switch. So, either a connect A to Z or I connect B to Z this is the basic idea. Now this concept can be extended for example, we can have a 4 to 1 multiplexer, where we have four inputs let us say A B C and D and we have an output Z. So, now, this is like a four way switch, I am connecting one of these four inputs A B C and D to the output.

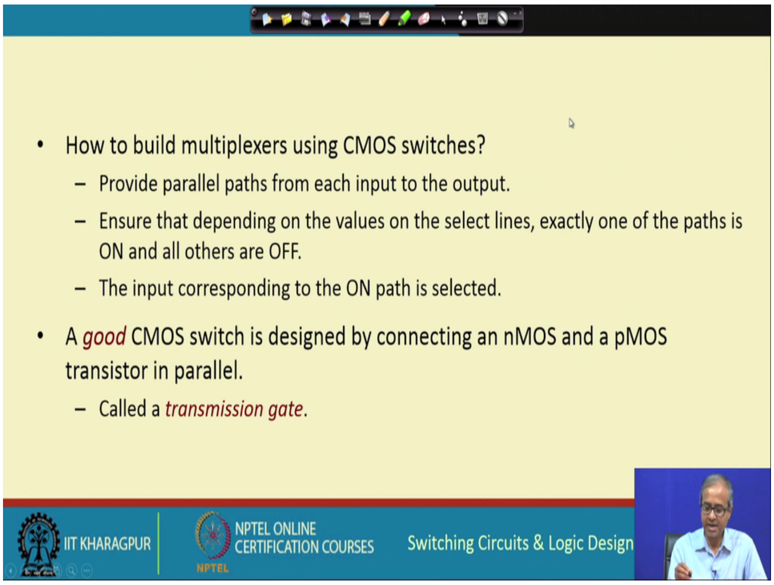
Now to select one of four things, I would clearly required 2 select lines, because in once with one select line I had only combination 0 and 1 two possibilities. So, I have to select one of two. But 2 select lines I have four possibilities 0 0, 0 1, 1 0 and of course, 1 1. So, if S 0 S 1 is 0 0 then A is selected, if it is 0 1 S 1 is 0, S 0 is 1 then B is selected, if S 1 is 1 and S 0 is 0, then C is selected and when both of them are 1 D selected. So, there are many applications where these kinds of multi way switches find lot of interesting uses ok. So, first let us see how we can realize this multiplex so called multiplexer or multi way switches using CMOS transistors.

(Refer Slide Time: 04:31)



So, this is what we are trying to look at how to build multiplexers using basic CMOS switches or CMOS transistors. Now the idea behind is that, from the various input like for example, I can have inputs A B c and D, there will be multiple paths the idea is like this there will be multiple paths, that will be connected to the output let us say Z. Now the using some mechanism we would be selecting exactly one of the path let us say we are selecting the second path. Then B will be connected to Z, A C D will be disconnected. So, here among this parallel path, we have to ensure that somehow exactly one of the paths get selected and once we can do this or multiplexer is implemented let us see how this is done.

(Refer Slide Time: 05:37)

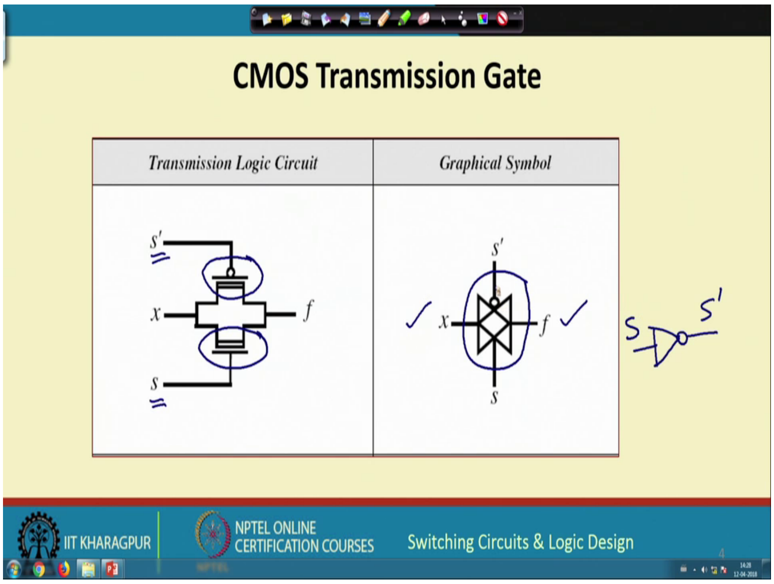


So, we required something called a transmission gate. Let us try to understand what the transmission gate is. You see we have talked about nMOS transistors and pMOS transistors. This is an nMOS transistor this is a pMOS transistor now. So, when the switch is closed say for an nMOS transistor is switch is closed, when you apply a one on the gate this control you put and for a pMOS transistor it is closed when I apply a 0 on the gate. Now some property of this transistor is that if you have our nMOS transistor and if we apply a low voltage here like a voltage close to 0 volts, then the output you get exactly zero volts no voltage degradation.

But if you apply a higher voltage, let us say I apply five volts, then there is a drop across this transistor which is called the threshold voltage. So, in the output let us say will be getting something like 4.2 volts. There will be a 0.8 volts drop, but for a for a pMOS transistor on the other hand, if I apply a 0 and the switch is closed there will be a drop and the output will be 0 point let us say 8 or something, but if I apply a high voltage this will be transmitted without any drop. So, you see the properties are complementary.

So, an n type transistor can transmit low voltage very well, a p type transistor can transmit a high voltage very well. So, if I connect to such transistors in parallel, then I can connect what I can transmit both high voltage and low voltage equally well this is the idea behind transmission gate.

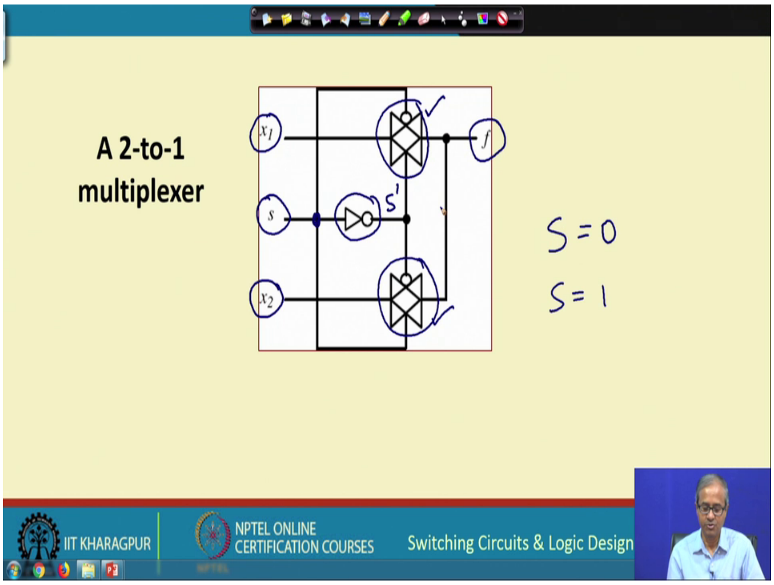
(Refer Slide Time: 07:38)



This is how a transmission gate looks like. Just like I have mentioned you see there is a n type transistor, there is a p type transistor which are connected in parallel and the gates of this transistor are selected together like I connect s here, I connect the not of s. S bar is actually not of S, suppose I have a not gate if the input is S the output will be S prime. So, if S equal to 0, then both this transistors will be off. So, the switch is off. If S is 1 then both the n type and p type transistor will be 1 will be on and so x and f will be connected.

Now, symbolically we represent it like this, this is the symbol of a so called transmission gate where x is the input, f is the output and S is the select lines S and S bar. So, you can see in one case there is no bubble which means if S equal to 1, the n type is selected and the bubble is for the p type transistor, if S bar is 0 then this is selected right.

(Refer Slide Time: 09:03)



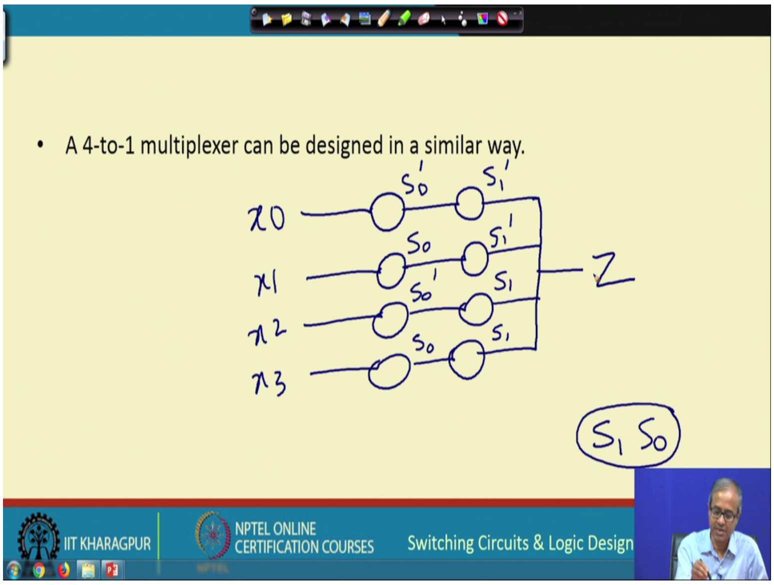
Now using this transmission gates you can very easily implement multiplexers let us look at this. A simple 2 to 1 multiplex, this is a connection fine now, you will see how it works.

There are 2 transmission gates I have used one here and one here at the inputs of the transmission gate at one side I have the 2 input signals x 1 and x 2. And on the other side I have connected them together this is my output f. Now I have selected this 2 transmission gates using a select line s as follows you see s is connected directly here and aft and this is also connected to the inverting input of here and I have a not gate. So, on this side I have s bar, which is not of s. S bar I am connecting to the reverse side to the non inverting part of this and to the inverting part of this.

So, what will happen? If S is 0 you see, then which of the transmission gates will be on. S is 0 means this is 0. So, p type this will be conducting. So, this will be conducting and s is 0 S bar will be 1. So, this n type is also conducting this transistor will be on. So, x 1 will be connected to f, but if S equal to 1 the reverse will happen. S equal to 1 means a one will be connected here. So, this is off this will be 0 this will be off, but on the other hand this one will come here and 0 will come here. So, this will be on.

So, x 2 will be connected. So, in this way I can have 2 to 1 multiplexer very conveniently.

(Refer Slide Time: 11:09)

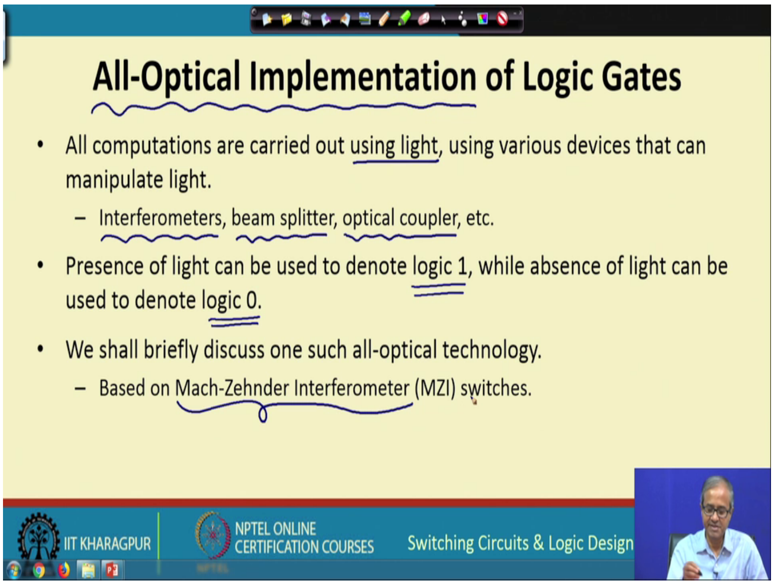


So, using transmission gates it is very easy to do so, you can have a 4 to 1 multiplexer in the same way, I am not showing with the complete diagram, just giving you an idea suppose my four inputs are x 0, x 1, x 2 and x 3 and each of these lines I connect 2 such switches, 2 such transmission gates I am showing it as a circle like this, and the outputs I connect together let us say I call it z this is the output.

Now, there are 2 select lines let us say S 1 and S 0. So, the way I connect them is that this switch is selected by S 0 bar which means when S 0 is 0 this will be selected and S 1 bar. So, when both are 0 0 this first path will be selected. Second row this will be S 1 bar this will be S 0. Third row this will be S 1 this will be S 0 bar and last row both S 1 and S 0. So, depending on the value of S 1 and S 0 you can easily see, that exactly one of the path will be selected that will be conducting both the transmission gate and the corresponding input will be moving to the output right. This is how multiplexers can be conveniently implemented using CMOS transmission gates.

Now, later on we shall see some alternate ways of implementing multiplexers, we shall see that even using gates the and gate or gate not gates NAND NOR we talked about using gates also we can design and implement not only multiplexer any kind of circuit or function that you want to this.

(Refer Slide Time: 13:09)



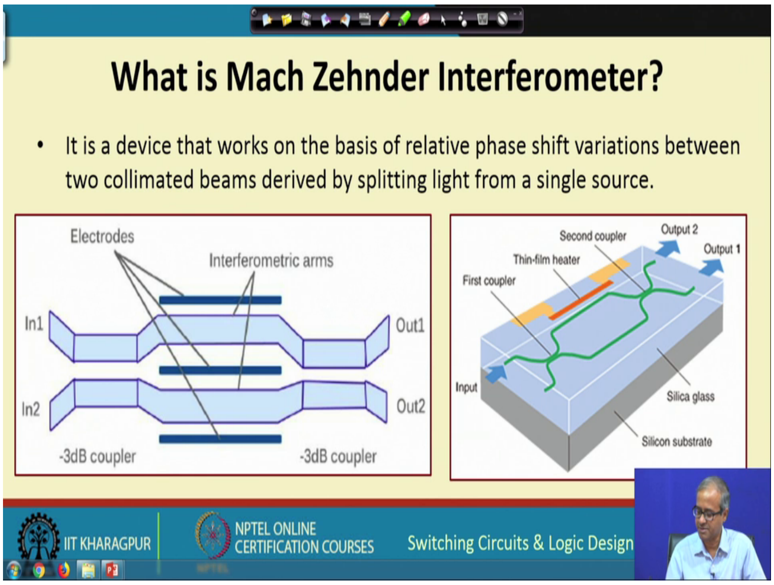
We will see later now let us talk about, I mean one kind of an emerging technology. Here we are talking about all optical implementation. So, what is the basic idea? You see we are hearing that optical fibres are being used for communication, you must have heard there are lot of optical fibres which have been laid under the ocean connecting countries, connecting continents they can communicate very fast, they have very vast fast communication speed and so on and so forth.

Now, here we are saying that can we explore photo mixer optics for carrying out some basic gate operation. Well if we if it is so, then you can also implement some circuits using or using the manipulation of this kind of light or photons. Now as a matter of convention let us say that if there is a light, let us call it logic 1 and if there is no light I call it logic 0. Suppose I have a torch in my hand, I send your signal on off on on off off on on off. So, you can read out the signal on means one off means 0 this is one way of communicating.

So, the idea behind optical communication is very similar, we send digital information using light presence and or absence of light. So, let us see. Here we are saying that all computations are being carried out using light and for that we require various kinds of optical or photonic devices. So, I am not going into the detail just very basic idea, there are some devices called interferometers, beam splitter when one optical beam is divided into 2 beams or more optical coupler reverse 2 optical beams are combined into a single optical beam and as I said as a matter of convention, presence of light will denote logic 1 while absence of light will denote logic 0.

There are several approaches that have been explored; we shall be very briefly talking about one such technology, which is based on something called Mach-Zehnder Interferometer. Let us see what are Mach-Zehnder Interferometer look like and how we can implement some functions out of it well.

(Refer Slide Time: 15:58)



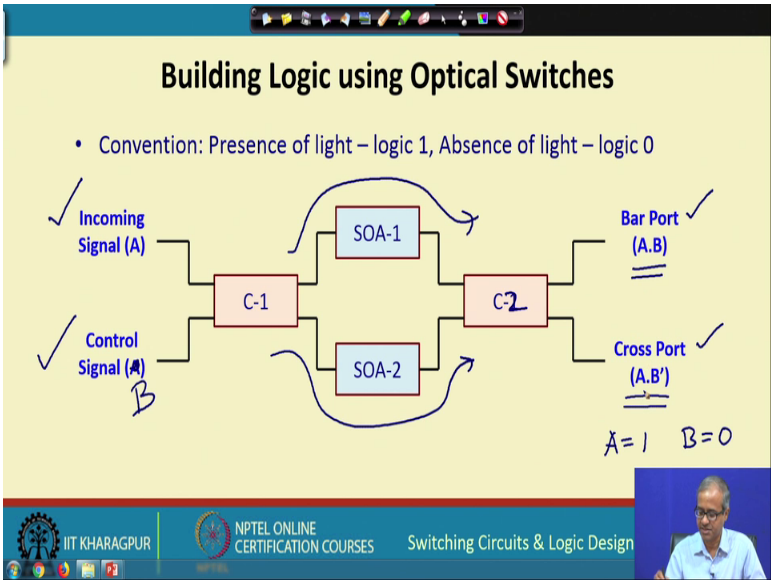
Here we have a very high level schematic diagram of a Mach-Zehnder Interferometer. As you can see it is a device which works on the basis of relative phase shift of 2 beams of light. As you can see in this diagram on the left there are 2 paths which are shown one is wire here other is wire here.

So, some optical beam which is coming, they get split into 2 parts and they follow 2 different paths. And in between these 2 different paths there can be some phase shift and on the other side there is a coupler. This coupler depending on the phase shift of the 2 signal, it will be either a constructive interference or a destructive interference. Constructive means the intensity of the light will increase destructive means they will cancel out. So, depending on whether the phase shift is in phase or out of phase, on the output we shall get either a strong light or no light. If it is destructive interference the 2 beams will be cancelling out and we shall not be getting any light in the output this is the basic idea.

So, on a plane on the figure on the right hand side showed you the diagram same diagram, that this is actually you can say your input where you are sending a beam this is a some kind of a splitter, where the beam is being split into 2 paths one is flowing here one is flowing here. Depending on the second input this is also another input; depending on this the phase shift will be determined and on the other side there is a again a some kind of a coupler, which will be coupling the 2 signals in 2 different ways and we generating 2 outputs output 1 and output 2.

Now, this kind of interferometer can be fabricated on silicon just like CMOS gates. Now without going into the details of the optics, let us see functionally how this behaves.

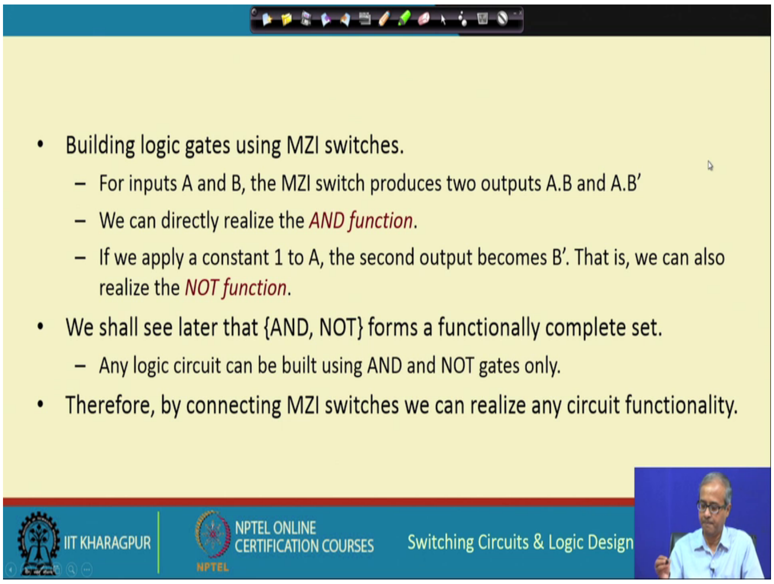
(Refer Slide Time: 18:17)



Functionally it behaves like this; I am showing a schematic diagram. This is my interferometer this is my incoming signal and this is the control signal, let us called them this is not A this is B. Let us call them A and B ok. Here I have a coupler or a beam splitter and here I have another coupler this is C 2 and these are the two different paths. So, one beam will be following this path, one beam will be following this path and depending on the control signal, the phase shift or the phase difference between these 2 beams will be determined. And the why Mach-Zehnder Interferometer works is that, in the 2 outputs which are traditionally called bar port and cross port. In terms of the logic this implements and A and B, which means if there is a light on the input A and also a light on the input B which means A equal to 1 and B equal to 1 only then this output will be 1; that means, some light will come out A and B.

But on the cross port it is A and B bar; that means, if A is 1 ; that means, that is light on A, but there is no light on B then only this output will be 1. So, you can see these 2 outputs are generated. So, logically speaking we can say that Mach-Zehnder Interferometer implements logic function let us call it B again, there is a typo this is B A and B. So, the outputs will be A, B and A, B bar this is what Mach-Zehnder Interferometer is.

(Refer Slide Time: 20:19)

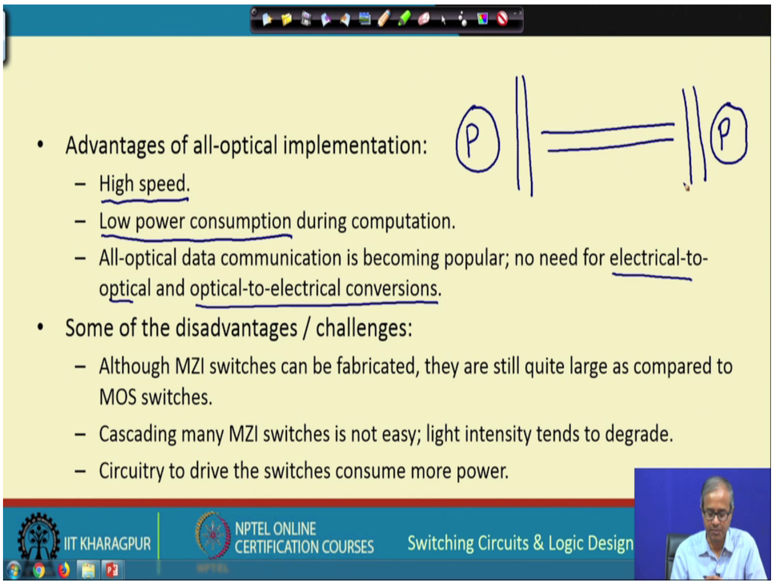


So, if I treat this as a black box, there are 2 inputs A and B, there are 2 outputs which are A and B, the other one is A and B bar. Now see on the first output A B A A and B are applied we will get A and B; that means, we can implement the and function. Let us also assume that I apply a constant one on the input A that means, there is a constant light here then what will be the output? The first one will be B and the second one this A is 1, we shall talk about this operations the next lecture this will be B bar.

Because A is always one something and something is the other one it will be B bar. So, we can also implement the not function B not of B. And we shall see later that this and not this set forms something called a functionally complete set, which means that if I can implement and not, I can implement any function I want. This implies that Mach-Zehnder Interferometer can implement a functionally complete set and we can realize any circuit functionality, this is the basic idea behind Mach-Zehnder Interferometer. This is one of the all optical technologies that I have talked about, where the input data as well as the outputs they are represented as lights.

If there is a light I say it is logic 1, if there is no light that is logic 0. So, this is a futuristic technology because already optics or light is used for long distance communication using optical fibres even inside a VLSI chip, inside a circuit chip there are high speed interconnects that are implement using optical technologies today. So, this can be the next step forward that we can also implement some logic circuits, some functions using all optical technologies also.

(Refer Slide Time: 23:07)



So, some of the advantages here, because light is very fast you can have high speed computation. Power consumption will be low, because everything is depending on the flow of light only no other circuits are required and because we are already doing communication. So, electrical to optical and optical to electrical conversions are not required if you are can do everything in optical.

Because you see normally, you have a processor you are doing some calculations on the other side there can be another processor doing some calculations and your communication medium can be all optical. So, here you need to convert electronics to optics and on the other side you need to convert optics to electronics. So, here what is says that if this processing can also be done in the all optical domain, then these conversions will not be required.

But the things are not that simple there are lot of technological challenges still remaining; till today this MZI switches a relatively large in size as compared to the MOS switches, which we used in our circuits and connecting many such switches in parallel is also not so, easy because the intensity of the light tends to fade away or decrease as we connect more number of such switches in cascade one after the other ok. And the associated circuitry to drive the switches the switches do not consume much power, but the circuits that may be required to drive the switches, they can still consume significant power. So, these are some of the drawbacks. So, once is drawbacks are addressed by researchers possibly you can have a feasible technology for implementing logic.

So, with this we come to the end of this lecture, where we talked about firstly, how we can use CMOS transistors to build something called transmission gates and implement multi way switches or multiplexers using such transmission gates, then we talked about one of the emerging technologies the all optical way to implement logic functions we talked about one such method using Mach-Zehnder Interferometer. Now in the next lecture we shall be talking about another such emerging technology called Memristors.

Thank you.