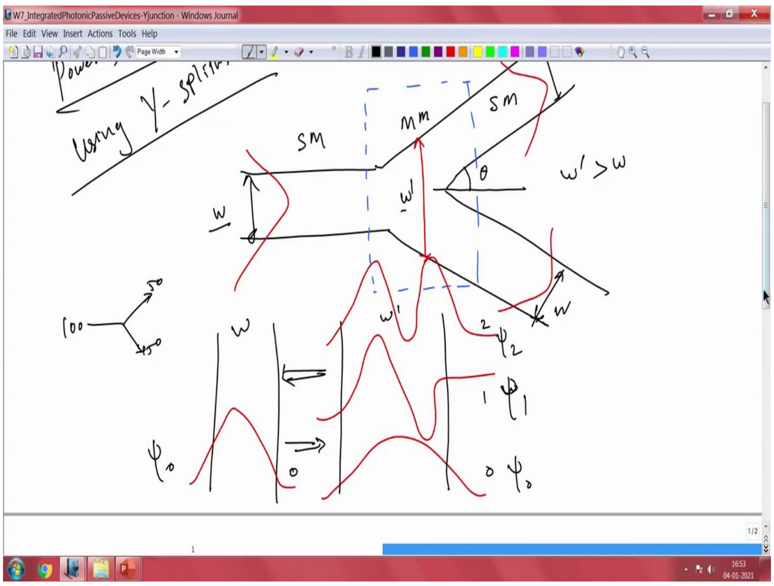
Photonic Integrated Circuit
Professor Shankar Kumar Selvaraja
Centre for Nano Science and Engineering
Indian Institute of Science Bengaluru
Lecture 29
Y-Splitter

Hello everyone, so, let us look at how do we split and combine power. So, in the earlier discussion on directional coupler that is what we discussed. So, how do you take power from one waveguide and put it into another waveguide completely you can transfer or you choose appropriate length where the light is split between the two waveguides. So, you can also do that, so, if you do half the critical length.

So, lc by 2. So, that will give you 50 50 splitting. Is this the only way to split light? The obvious answer to that is no, there should be some other way as well. So, we use even simpler structure to split light instead of directional coupler, thinking about how long it should be? And in and calculating the phase matching and the beat length and so, on we can think about even simpler way.

In simpler way meaning once we understand the modes and more overlap and more interaction, we should be able to come up with some interesting ways of doing this. So, in this particular lecture, I want to introduce you to another type of, power combiners or power splitters. So, we call this as y splitter. The name of the device itself is y splitter, it looks like y, English letter Y with which you could split and combine light. So, let us look at how this particular device works.

(Refer Slide Time: 01:59)



So, power splitting or combining using y splitters or y junction, so, the geometry itself is very interesting, it is a y branch. So, this particular structure looks like y. So, let me draw that. So, you have a waveguide like this and then something like this. So, you have you start with certain waveguide width is W and here again this waveguide width is W and here, the waveguide width is W.

So, what are we looking for here, so, I want to launch a mode here and I want modes here and here. So, this is my intention. So, I put in let us say 100 percentage here. So, I want 50 50 at the output. So, this is this is what I want is a combiner. So, how do you realise this? So, how could one realise such a structure or how do we understand how this thing works? So, you have a single mode coming here we have to concentrate this particular part.

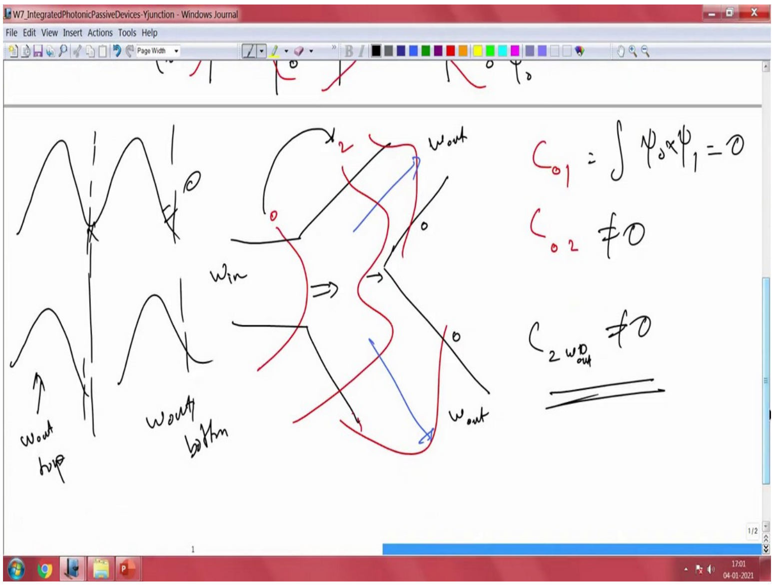
So, when you look at this, the waveguide width here that you have this W dash is much larger than W So, here W dash is larger than W. So, there is there is a reason for this, we can actually make it narrower by choosing appropriate angle here. So, there is a Theta here. So, one could choose appropriate angle to make it really thin, we can split you can make a very large angle here in order to make this W very small, but we are not doing that.

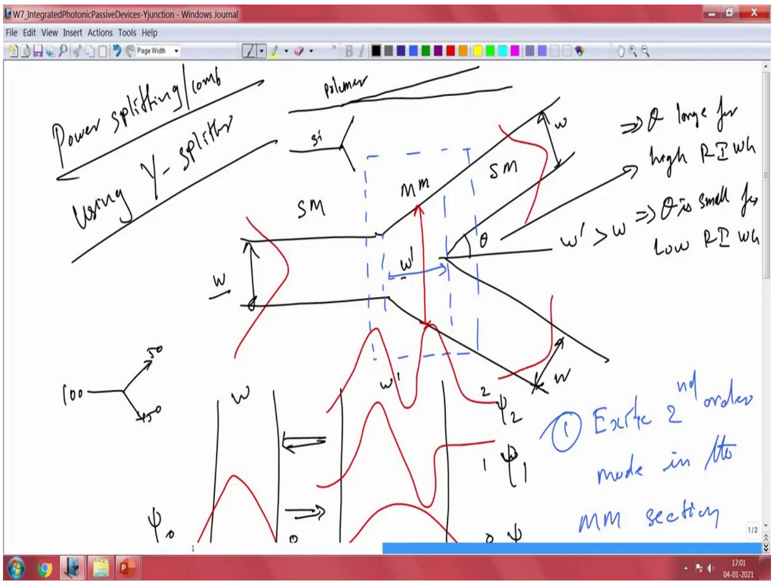
So, what we are trying to do is we want to have certain width W dash here, which is large than W. So, why would we do that? Let us understand from our simple waveguide mode solutions. So, I have W which is a single mode, I only have a single mode here, but then W dash is slightly larger. So, that means, I will have my fundamental mode here and then I will have my first order mode and, and that that is what I want to do.

So, I want to make sure that I get this first order mode into the system. So, the next thing is I will have the second order mode, which is this. So, I have mode 0, mode 1, mode 2 and here I have only 1. So, this is kai 0 and I have kai 0, kai 1, kai 2. So, these are all the possible solutions that I have with when the wave guide width is W dash. So, now, the question is how do I couple this and then go from W, go from W to W dash and from W dash to W.

So, this is my, my whole idea. So, that means, I will also need to not only this way, I have to go this way as well. So, from a multimodal system to a single mode system. So, this area is single mode, and this is multimode. And, again, I have to go to single mode, so, I need to make sure that this happens. So, let us look at how we could realise this, the first thing to look at this, this whole problem is we are looking at these 2 modes. So, these 2 modes should be phased matched with the mode that I am going to generate or couple in this particular multimode region.

(Refer Slide Time: 07:28)





So, let us zoom into that multimode region. So, here, I have my single mode coming in. So, I will be generating this mode and then I also have this mode. So, mode 0, mode 1 and mode 2. So, we all know that from our overlap from the overlap integral C, so, we have to look at C01, C02. And then, so, yeah, C01 and C02. So, let us look at C01 and C02. C01 so, when you have the two the waveguides here kai 0 and kai 1.

So, this is what you are looking at the overlap integral between these 2 whether you will get 0 or non-zero this should be non-zero, but then look at this waveguide, so one is odd and the other one is even. So, you have one like this, the other one is like this. So, when you integrate these 2, what will be the result? The result will be 0 because of the asymmetry that we have in the field.

So, this will be 0. However, when you take a symmetric mode here, the overlap between mode 0 and mode 2 will be non-zero. So, that means you are going to couple light from fundamental mode to the second order mode. So, if that is the case, then we can actually draw it this way. So, maybe I will just use the same graph, just you have to remove this. So, now this is what you will end up with.

So, mode, second order mode is now just coupled into so, we have coupled generated the second order mode, but it cannot propagate further so, that the distance is limited and this is where our next coupling problem comes in. So, you have two modes individual field modes here and here. So, this is this is something you have. Now, the question is these 2 modes will also try to overlap.

So, you have to find the overlap integral between the 2 modes here. So, this is W waveguide in and W out and this is also W out. Now, the question to ask is what is my overlap integral 0 sorry between 2 and W out 1? So, this is W out 0. So, this is your zeroth order mode here you have and again zeroth order mode. So, what is the overlap integral between these two? And what is the overlap integral between these two?

When you look at that, that will also be non-zero because they are phased match. So, if I have to draw it here, so, we have this particular mode generated. Now, I have mode like this, so, this is for W out top and then this is W out bottom; so, top and bottom. So, when you look at the integral between these two, it will not it will not be 0. So, there will be a non-zero overlap integral between these two.

So, because of this non-zero overlap, because of this non-zero overlap, you will be able to couple light to this particular waveguide and to this particular waveguide. So, this is how you are going to split the light. So, you just create a multimode section. So, you create a multimode section of a certain length l so, this is something that we need to design it for a certain length l and certain width W.

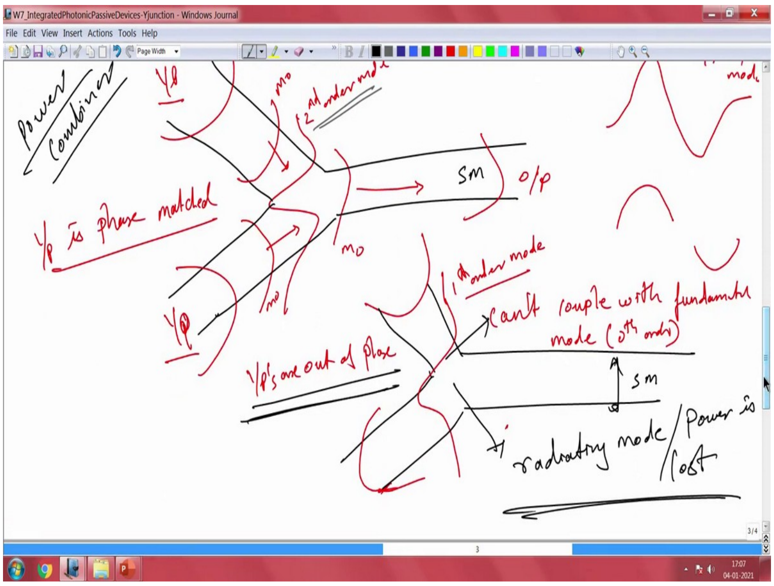
So, that you create the second order mode that is very important. So, important thing to notice is here excite second order mode in the multimode section. So, this is a very important message to carry. So, you when you are designing your y splitter make sure that you create this multimode section, so that it couples.

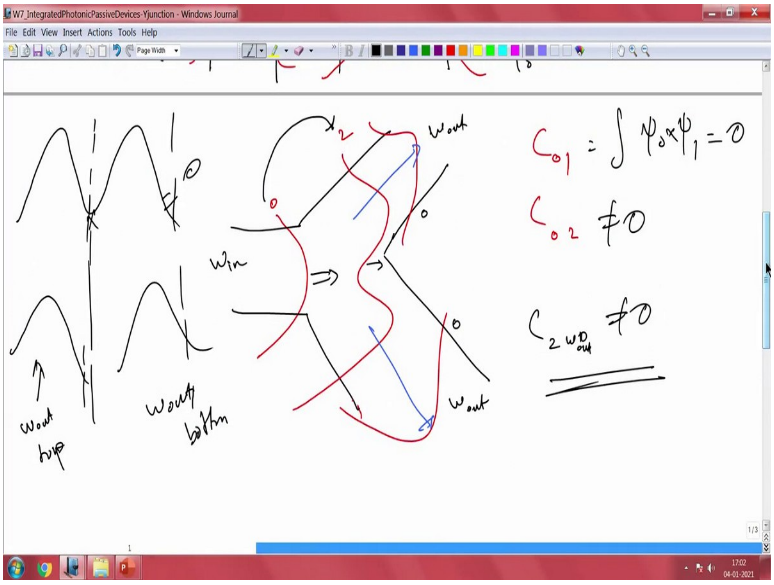
And also you should make sure that you do not make this length too long, if you make this length too long, then you will have phase difference or phase accumulation that may or may create a loss in the overlap integral. So, this is something that one can take and that is where this theta comes in. So, your theta will make sure how long it takes for this. So, normally this particular theta.

So, this particular theta is small for high refractive index and theta is large for sorry, it is other way round, theta is large for this. So, theta is small for low refractive index waveguides. So, a good example would be between polymer and silicon. So, if it is a polymer waveguide then your theta will be very small.

So, you will have a directional coupler that is like this. It is very long, but then when you have, let us say this is polymer and when you have silicon for example, you can have something like this very sharp. So, this is on silicon. So, your theta will have will have an implication based on the platform that that you are using. So, this is all about, designing your y splitter and how y splitter would split the light? So, now let us look at the combining action now.

(Refer Slide Time: 15:09)





So, it is the inverse. So, now, I am going to take light from this waveguide. So, this is going to be input, this is input, and this is my output. So, this is what I want. So, this is a power combiner. So, how do we achieve this? Again, it is it is reciprocal. So, it is a reciprocal device. So, the 2 individual wave waveguide modes here should generate the second order mode that is obvious.

So, you when the wave is coming close to this and close to this and then you know the second order mode looks like this. So, this is your mode 2, this is a second order mode. And these two are mode 0 and this is also mode 0. So, now, these 2 will make sure that the second order mode is generated, but then the second order mode would couple to mode 0 here and then it is propagated.

So, this is simple, beam combining, it is a reciprocal, there is nothing big. So, there is an interesting fact of this. So, what happens when you have a phase shift here. So, the 2 input modes here or phase match. So, here the input is phase matched. So, I am going to give a scenario where the input is of opposite phase now. So, let us take that example now. So, now, from the input side, I have a wave like this there is one input.

The next input it is completely, pi phase shifted, So, that means the mode would look like this. So, it is just phase shifted now, so, the input is out of phase. So, the inputs are out of phase. So, the inputs are out of phase, then look at the junction here. So, we talked about the second order mode here. So, the second order mode is going to be generated here, but when you look at this, because of this difference in the phase, so, look at this carefully one is like this, the other is like this.

So, the best possible, overlap that this is going to have is with the first order mode. So, this is the first order mode. So, the first order mode in this section, so, you are going to generate the first order mode in this particular section. So, now, these two modes are going to generate the first order mode here. So, this is what you are going to generate first order mode, but this is not good.

The reason for that is we know from our overlap integral with the overlap between the 0 and the first order mode, you remember this the overlap between 0 and first order mode is 0. There is no coupling that is going to happen. So, when you have this first order mode it is coupled into the system, it will not be a propagating mode. So, this mode cannot couple with fundamental mode and that is our zeroth order.

So, it cannot be coupled to this fundamental mode it, this cannot happen. So, when this is the case, then this mode particular mode will radiate into the sides. So, there is then this becomes radiating mode, that means power is lost. Power is lost when you have out of phase light coming and interfering in this particular case, it is basically interference is what you can say here.

So, there are two way, 2 modes that are opposite in phase and that will generate the first order mode. So, since the first order mode cannot couple into the waveguide with the fundamental mode, again this is single mode, you remember, this is single mode and this is also single mode, there is only one mode allowed, the fundamental mode is the only one that is allowed there and because of that reason, you will actually radiate this first order mode and this will result in loss of that particular light.

So, we will use this in building Mach-Zehnder interferometer later on, but this this gives you an idea about how one can understand power splitting in this particular y junction. So, y type waveguides and also power combining and power combining strongly depends on the phase of the 2 beams or the 2 waveguide modes that we have, if there is a phase shift in one of the modes, then you will have issues coupling it to the propagating mode.

So, this will result in loss of power. So, these are all the two ways how you could use very simple y junction in order to split the light and combine the light. The takeaway message from this understanding is you can use the same device for splitting and combining, but when you are combining, one should take care of the phase difference between the 2 modes. So, if they are in phase, then you will be able to combine those.

So, you will end up with adding those these 2 powers together. So, when there is a phase difference between these 2 waves, if there is a pi phase shift between these two, you will not be able to combine it, you will just combine it to the first order mode, but this first order mode will not be propagating through the waveguide and it will radiate. So, in the earlier case when you are splitting it, you are taking the zeroth order mode or the fundamental mode and coupling it to the second order mode.

So, it has to be symmetric. So, the symmetric coupling would happen, but then when you are coming back again you should couple back to the symmetric mode that is this second order more, but because of the phase difference if you come by if you combine and excite the first order mode, you will not be able to get the light out, it will be lost. So, this is the operation principle of a very simple y junction which you can use it in many places.

It is not just a single y splitter, if you want 1 to 10 splitters, you can put them in series. So, 1 splitter gives you 2 outputs. So, that each output could be then serially connected with another 1 by 2 splitter. So, 1 by 2, 1 by 2, 1 by 2, you can keep on increasing your number of branches that you need. So, we can call it as a tree branch. You create a tree network just by putting this, 1 by 2 splitters or y splitters that you may use. So, with this, we have a better understanding of y splitters now. So, hopefully we will use this later on to build some interesting interferometers, thank you very much for listening.