Photonic Integrated Circuit
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Lecture No. 27

Phase Matching

Hello everyone, let us look at a crucial phase matching condition that one should achieve in order to make sure that you have efficient coupling. So, far we have been discussing quite a lot in depth into the coupling mechanism in how and how to achieve this coupling to start with and then how to increase the coupling efficiency and how to understand co and counter-propagating coupling schemes and so on.

But then all of this discussion hinges on one key requirement and that is the phase matching. So, if you look at our phase matching rather coupling equation, we you find this delta, so this delta captures the phase difference, so we want the phase difference to be 0 and how do we achieve that and also what is the implication of having this phase matching on the coupling itself? So, let us do a summary of this phase matching itself. So, let us look at the phase matching concept.

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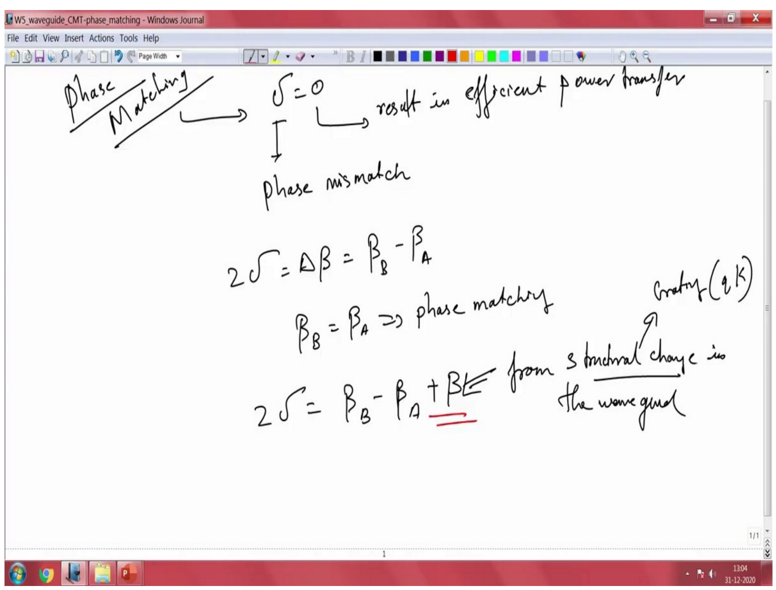

$$\delta = 0$$

$$2\delta = (\beta_b \pm K_{bb}) - (\beta_a \pm K_{aa})$$

$$2\delta = \Delta\beta = \beta_b - \beta_a$$

$$\beta_b = \beta_a$$

$$2\delta = \beta_b - \beta_a + \beta$$

So, phase matching is essential to get efficient coupling, so what we mean by phase matching is delta equals to 0. So, this is the most efficient way of power transfer, so this result in efficient power transfer, so this delta is nothing but phase mismatch is basically this called phase mismatch is what we call this one. And how did you how did we arrive at this phase mismatch? Initially we had this idea between the propagation constant, it is a difference between the propagation constant of let us say wave B and wave A.

The phase matching allows you to make sure that these two waves are traveling to the same beta, so this is what we call phase matching. So, in case that delta includes the contribution from additional structure, it is not necessarily coming from the difference, but you could add geometrical changes in the structure and then the phase matching of these two waveguides will be now in should include this factor from our structures also, so that is something that we should do.

So, we need to consider all the contributing parameter, so that is what this delta is all about. So, we should be able to not only take betas, beta different but then you could have structure dependent phase changes, so just to give you a recap, so we did this and there could be some other beta will just say some beta, it is possible that this could be from structural change. And this structural change could be a grating, let us say, I will, we will quickly look at the grating as we move on, but you could get this additional phase that one can bring in by changing the structural property.

So, that is something that we have seen earlier, so for a grating we know that it will be q times k, so that is an additional phase factor that this grating is going to bring. So, we should not leave those out. So, the important thing is just make sure that any phase component that you are structure may bring in should be incorporated. So, let us summarize some of the important concept in this phase matching.

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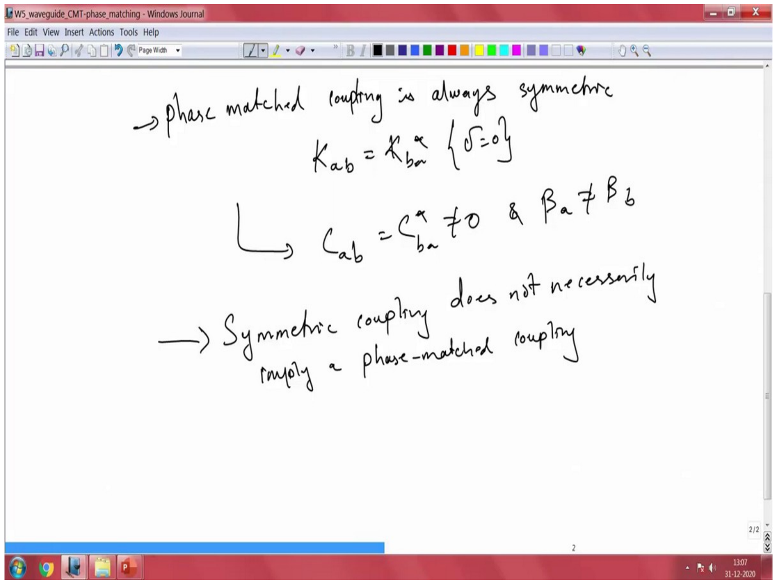

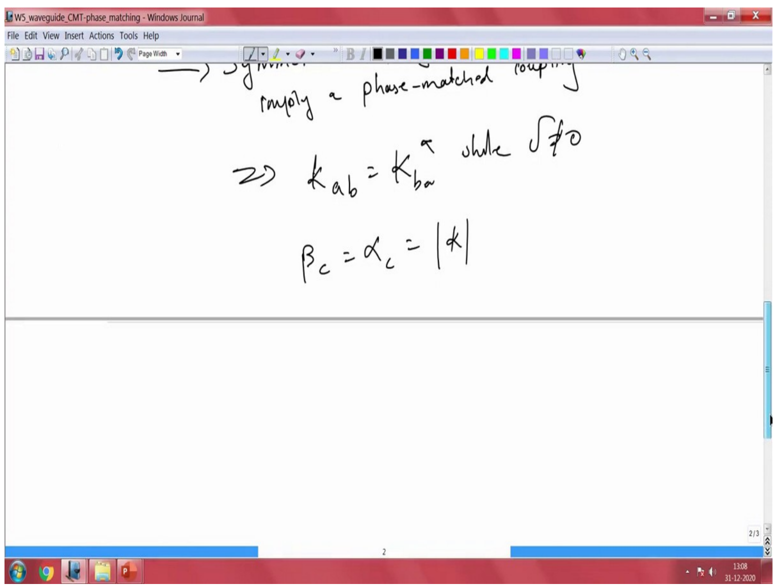

$$K_{ba}{}^* = K_{ab}\{\delta = 0\}$$

$$C_{ba}{}^* = C_{ab} \neq 0 \;\&\; \beta_b \neq \beta_a$$

$$K_{ba}{}^* = K_{ab}\{\delta \neq 0\}$$

$$\beta_C = \alpha_c = |k|$$

So, the phase matching is always symmetric, the phase matching or rather phase match or say phase matched coupling is always symmetric, so what that means is kappa ab will be equal to kappa ba star, so the condition here is delta should be equal to 0, so that is the perfect phase matched coupling, so this is also true, even when you have C a equal to C ba star is not equal to 0 and beta a is not equal to beta b. So, this is also true when you have these conditions. So, when you have a perfect phase matching we should be able to have symmetric.

So, symmetric coupling does not necessarily imply that the you have phase matched condition, so this is something that we should also keep in mind, the symmetric coupling does not necessarily imply a phase matched coupling. So, when there is a symmetric coupling then it does not imply that the phase match, we have a phase matched coupling, so when we say symmetric coupling it is nothing but kappa aab equals kappa ba star.

So, this is what we mean by coupling between two different modes that is phase match, so the coupling could be symmetric, so symmetric coupling is achievable but it does not mean that you have a phase matched coupling, so you can go back and have a look at the equation, so this is this possible. And it is also possible, so this implies it is also possible that kappa ab could be equal to kappa ba while delta is not equal to 0. So, the coupling between two phase mismatched modes in the same waveguide, so you could have phase mismatch and you could still have coupling between these two.

So, the other important thing is when you have the coupling in the forward and backward coupling you will eventually end up, you know making beta c will be equal to alpha c which is nothing but kappa. So, this is the condition that one could use in order to exploit and find this coupling constant. So, for a co coupling co directional coupling for a perfectly matched per phase matched propagation.

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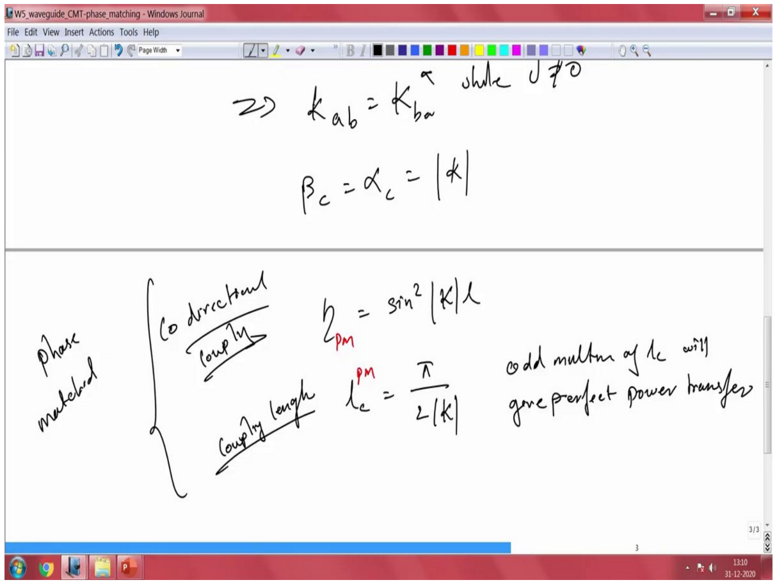

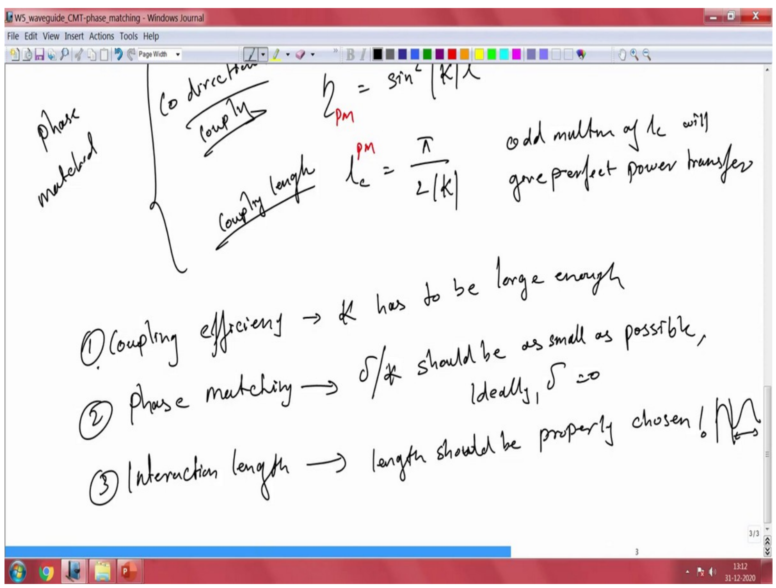

$$\eta_{PM} = sin^2(|k|l)$$

$$l_c{}^{PM} = \frac{\pi}{2|k|}$$

So, then you could have for co-directional coupling your coupling efficiency equal to Sin square kappa l and the coupling length lc is pi over 2 kappa. So, this is perfectly phase match, so all these things is phase matched, so we would add everywhere phase match, so the 100 percent transfer from one mode to the other will be a odd multiple of (())(10:02). So, this is nothing but odd multiple of lc will give perfect power transfer and there are 3 terms that we should all keep in mind when it comes to coupling.

One is coupling efficiency which is nothing but kappa has to be large enough, you should have large enough coupling that is point 1, next is phase matching, so phase matching is nothing but you should have very low mismatch, the phase match has to be minimized, so that means you are delta over k should be as low as possible. So, instead of as low I will say it as small, as small as possible, so that means ideally your delta should be equal to 0. So, that is what you want, so this is kappa, so kappa has to be high, delta has to be very low.

And finally interaction length, so here we have co-directional coupling and counter directional coupling, so in either case particularly in co-directional coupling length should be properly chosen, this is very important because you have periodic changes, so you have a periodic change, so you do not want your coupling to be too long. So, you want to keep it short enough, so that you have the required coupling. So, if your lens are not properly chosen your coupling will also be different.

So, these are all the 3 important factors that you should consider in mind when we talk about coupling in the waveguide at between the waveguides, so that you can do a lot of engineering based on this coupling transferring energy between the modes and manipulate the propagation. So, with that we have come to the end of this whole series of coupling lecture.

So, we started off with a couple more theory had a complete understanding of the coupling coefficient how this coupling coefficients are defined, we took the field, so overlap and also phase content, so this is the propagation constant, so we decide to take these two together and then made the condition for coupling, it is not just a beta your field should also overlap. So, when the fields do not overlap the overlap integral if it is 0, then you do not have much to say that though you have reached beta there.

So, that is not the only condition, this is one of the necessary condition but not the only condition. So, we looked at that and then we took that kappa and then looked at how we can use this kappa when the waves are you know there are two waves and how the field is going to evolve, as it moves through the waveguide. And then we also looked at single wave guide and multi-waveguide coupling and how one can numerically solve this.

And finally, we looked at co and counter-propagating waves and one of the important thing there is phase matching and finally we looked at the essential condition for phase matching and summarize the 3 key requirements that is the coupling coefficient the phase matching and the length the interaction length. So, these 2-3 gives you a hold on controlling your coupling between different modes, so with that we end this discussion on coupling, I hope you have a better understanding now in light coupling in this waveguides. Thank you.