Volume : 5 | Issue : 7 | July 2016 • ISSN No 2277 - 8179 | IF : 3.508 | IC Value : 69.48

An Analytical Approach to Modify Coupling Length of the Directional Coupler Using External Triggering Technique

Physics

KEYWORDS : Couple mode equation, Directionacoupler,Electro-optic effect.

Dr. Puspendu Kuila
Assistant Professor,Dept. of Physics,Midnapore College (Autonomous),Midnapore, Dist: Paschim Medinipore,

ABSTRACT

Evanescent wave coupling techniques are massively used in photonics technology. The strength of interaction between two wave guides in a directional coupler depends upon the wave guides parameters, the separation between the wave guides, the wave length of operation and also the length of the coupling region. The energy exchange between the wave guide of the coupler is directly depend on the interaction strength. Here a technique is proposed to modify the coupling length of a coupler so that a particular interaction may happen. For this purpose external electric field of specified value is applied to obtain required coupling length

Introduction:

When a plane wave undergoes total internal reflection at the interface of two dielectrics then there is a wave in the rarer medium, which is termed as evanescent wave. Thus evanescent wave is a near field wave exhibiting exponential decay with distance from the interface. Evanescent wave coupling is a term mainly used in optics. In this coupling evanescent waves are transmitted from one medium to another. When two wave guides are placed in such that the evanescent field waves of one wave guide is insignificant at the other wave guide then the interaction between the two wave guides becomes very small and as a result the energy in each wave guide propagates independently even in presence of other waveguides. But if the separation between the two wave guides becomes so small that the evanescent waves of the two wave guides overlap to a considerable extent, then there is an exchange of energy between the two wave guides. In this situation, the evanescent field associated with the propagating modes in the two wave guides interact and lead to a periodic exchange of energy between the two wave guides. Such type of wave guides where coupling between two wave guides occurs is termed as directional coupler. The strength of interaction between two wave guides in a directional coupler depends upon the wave guides parameters, the separation between the wave guides and the wave length of operation and also the length of the coupling length. [3,5]. There is a complete transfer of energy from one to other wave guide will occur if the propagation constant of the modes in the two wave guides are identical and otherwise there is an incomplete transfer of energy. This type of energy exchange can be used in building an optical modulator or optical switch. Optical directional couplers are used in signal routing, in time division multiplexing etc.

Energy exchange in a directional coupler:

Due to evanescent wave coupling, optical energy will be in the wave guide which is in couple with another wave guide where an optical pulse is incident.

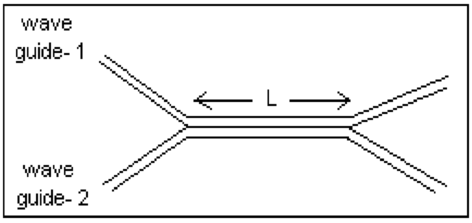

Fig. 1: An optical directional coupler where two wave guides are at close proximity over a length L.

We may write the couple mode equations for a directional coupler coupled over a length L as [as shown in fig. 1] [1,2]

$$\frac{dA_1(z)}{dz} = -iK_1A_1(z) - im_{12}A_2(z) \text{ ,---------- (1)}$$

$$\frac{dA_2(z)}{dz} = -iK_2A_1(z) - im_{21}A_2(z) \text{ --------- (2)}$$

Where, $A_2(z)$ represent the amplitude of the evanescent wave in the wave guide 2 due to optical pulse of amplitude $A_1(z)$ incident on wave guide 1. m_{12}, m_{21} are the strength of interaction between two modes refer as coupling constant. K_1, K_2 are the propagation constants of the mode in the wave guide 1 and wave guide 2 respectively. The block diagram of a directional coupler is as shown in figure (1). The general solution of equations 1 and 2 shows that symmetric and anti-symmetric modes of propagation will be appear in the coupled wave guide . The propagation constants for these two modes are as

$$K_{s,as} = \frac{1}{2}(K_1 + K_2) \pm \left[\frac{1}{4}(K_1 - K_2)^2 + m^2\right]^{\frac{1}{2}} \text{ --- (3)}$$

Where 's' and 'as' stands for symmetric and anti-symmetric modes respectively and $m = (m_{12}.m_{21})^{\frac{1}{2}}$.

The general solution of equations (1) and (2) can be written respectively as

$$A_1(z) = A_s \exp(-iK_s z) + A_a \exp(-iK_a z) \text{, --- (4)}$$

$$A_2(z) = \left(\frac{K_s - K_1}{m_{12}}\right) A_s \exp(-iK_s z) + \left(\frac{K_a - K_1}{m_{12}}\right) A_a \exp(-iK_a z) \text{ -------- (5)}$$

Where,

$$A_s = \left(\frac{K_1 - K_a}{K_s - K_a}\right) \text{ ------------ (6)}$$

$$A_a = \left(\frac{K_1 - K_s}{K_s - K_a}\right) \text{ --------------- (7)}$$

Using equations 3, 6 and 7, the equation 5 will be as

$$A_2(z) = \text{m } \frac{Cos(\theta z)}{\theta} \exp\left[-i\left(\frac{K_1 + K_2}{2}\right)z\right] \text{ -- (8)}$$

Where, $\theta = \left[\frac{1}{4}(\Delta K)^2 + m^2\right]^{1/2}$, ---------- (9)

$$\Delta K = (K_1 - K_2) \text{ ----------- (10)}$$

As the optical power in a wave guide is proportional to the square of the pulse inside it, therefore, the power of the evanescent wave in wave guide 2 is proportional to $|A_2(z)|^2$ where,

$$|A_2(z)|^2 = \frac{m^2}{\theta^2} Sin^2 \theta z \text{ ----------- (11)}$$

Similarly, power in wave guide 1 will be as,

$$|A_1(z)|^2 = 1 - \frac{m^2}{\theta^2} Sin^2 \theta z \text{ ----------- (12)}$$

Equations (11) and (12) shows that there is a periodic exchange of energy between two adjacent wave guides in a coupler with a period

$$T = \frac{\Pi}{\left[\frac{1}{4}(\Delta K)^2 + m^2\right]^{1/2}} \quad \text{--------- (13)}$$

The minimum length of inter action of two wave guides in a coupler for which maximum energy will be transferred from one to another wave guide is termed as coupling length (L_c) of the directional coupler which is given as

$$L_c = \frac{\Pi}{2\left[\frac{1}{4}(\Delta K)^2 + m^2\right]^{1/2}} \quad \text{-------------- (14)}$$

Now, if some how we introduce the difference of propagation constant between two wave guides for a mode in addition of its own propagation constant then the coupling length will be modified at the same time. Here, we introduce the extra difference of propagation constant by using the electro-optic effect of wave guide material.[4]. For this external electric field is applied in the coupling region. [as shown in fig. 2].

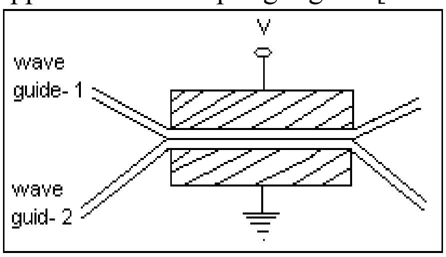

Fig. 2: An externally triggered directional coupler

The extra change in propagation constant in the wave guide is determined by the r_{33} co-efficient of the wave guide material as given by

$$\Delta K = \frac{2\pi}{\lambda_0} n_e^3 r_{33} \frac{V}{d} \quad \text{…….. (15)}$$

Where, V is the magnitude of the applied voltage corresponding to the external signal and d is the distance between the electrodes used to apply triggering signal.

Therefore, the modified coupling length (L_c) of the directional coupler becomes as

$$L_c = \frac{\Pi}{2\left[\left(\frac{\pi}{\lambda_0} n_e^3 r_{33} \frac{V}{d}\right)^2 + m^2\right]^{1/2}} \quad \text{…….. (16)}$$

Hence, different necessary coupling length (L_c) of the directional coupler may be achieved by simply controlling the wave guide externally.

Conclusion:

The evanescent wave coupling between wave guides and electro-optic effect of a wave guide are used here actively to achieve the proposed modification. The main advantage of the proposed technique is that a small voltage is required to obtain the required ΔK , the voltage required to obtain the required values of ΔK can be reduced either by increasing the length or by reducing the electrode gap. It should be mention that if the intensity of the optical pulse introduced into the optical fiber is very high valued then the coupling length will be adjusted according to the non-linearity of the wave guide. Therefore, the energy exchange between the wave guide of the optical directional coupler may be tuned very precisely by controlling the electric signal externally applied in the coupling region.

References:

1. Ghatak. A and Thygarajan, K. (2006), Optical Electronics, Cambridge University Press, New Delhi.
2. Kaminow, I.P. (1974), An introduction to electro optic devices, Academic press, New York.
3. Kogelnik,H. and Schmidt, R.V. (1976), " Switched directional couplers with alternating ", IEEE .J.Quantum Electron QE-12, 396,.
4. Kuila, P., Sinha, A., Bhowmik, H. and Mukhopadhyay, S. (2006), "Theoretical study of using an amplitude modulation scheme with an electro-optic modulator for generation of the proper power shape function of an optical soliton pulse in a nonlinear waveguide." Opt. Engg. 45(4), 045002,.
5. Povinelli, L., Loncar, M., Ibanescu, M., Smythe, E.J., Johnson, S.G., Capasso, F. and Joannopoulus, J.D. (2005), "Evanescent wave bonding between optical wave guides" , Optics Letters, 30 (22), 3042-3044.