ORIGINAL ARTICLES

 Interruption Analysis on Two Coupled Waveguide—New Design with New Perspective

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ABSTRACT

A new coupled mode formulation for parallel dielectric waveguides is described. This paper we are reporting the new design to separate two wavelengths based on the coupled mode theory. Due to the channel spacing is too big, the conventional technique is invalid and require a long coupling area to separate the wavelengths. In this paper we introduce introducer as the third waveguide to disturb the propagation profile of two coupled waveguide. The results show by moving the Interrupter, we able to create the valley which can be used to separate the wavelengths. Opti-BPM simulation tool is used to design and assist the analysis. Such proposal is the first reported up to this time which used disturbance concept to achieve the objective.

Key words:

Introduction

Coupled-mode theory (CMT) has had a lengthy and diverse development. It was initially introduced in the early 1960’s for microwave devices, and latter applied to optical devices in the early 1970’s. The theory’s appeal was its usefulness in analyzing devices and predictable fundamental characteristics by simple analytic means, tractable to computational devices of the time. Today, as computer power has increased almost exponentially, the usefulness of CMT has not diminished. Instead, it has become an integral part of the whole design process. This success has resulted from the theory’s wide applicability, intuitive feel, and often surprising accuracy, especially when one considers the simplicity of the governing equations. It is perhaps one of a handful of synthesis tools, since unlike numerical schemes which are analysis by nature, the possibility always exists for inverting the coupling equations and solving for waveguide parameters give some desired response. The essence of coupled-mode theory is clear; one treats the composite or compound waveguiding structure as a collection of simpler waveguides, with the modes associated with each individual (component) waveguide being perturbed by the presence of the others or any additional nonuniformity. These perturbations lead to coupling and exchange of power among the guided modes. Since we are, rather than the whole compound field, this coupling mode formalism represents a rather appealing conceptual framework (Little and Huang 1995).

The term ‘mode coupling’ addresses one of at least three different means of power transfer. These include coupling modes of distinct waveguides by evanescent fields, coupling modes in the same waveguide by longitudinally homogeneous perturbations and co-and contradirectional coupling by longitudinally inhomogeneous, usually periodical perturbations. While one of the example files on magnetooptic polarization conversion addresses the second topic this section is concerned with the first version, i.e. with codirectional light propagation in closely spaced adjacent waveguides. See the paper on radiatively coupled polarization splitters or the theory chapter in the survey for details on the employed formulation of coupled mode theory. However, some remarks on the notion of supermodes in the current framework may be helpful:

Suppose a composite longitudinally homogeneous waveguide is to be simulated. Its permittivity profile shall be such that the propagating light $E, H$ may be reasonably assumed a superposition of a number of known guided mode profiles, $E_m, H_m$ with longitudinally varying amplitudes $C_m$ (Little and Huang 1995):

$$E(x, y, z, t) = \sum_{m} \frac{C_m(z)}{\sqrt{P_m}} E_m(x, y) e^{i\omega t}, \quad H(x, y, z, t) = \sum_{m} \frac{C_m(z)}{\sqrt{P_m}} H_m(x, y) e^{i\omega t}$$

The factors $P_m$ normalize the members of the superposition.

Given the basic modes (propagation constants and profiles) and the total underlying structure, coupled mode theory predicts the following dependence of the coupled mode amplitudes on the propagation distance:

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\[ C_m(z) = \sum_s A^s \frac{1}{\sqrt{P^s}} a^s_m e^{-i\beta^s z} \]

This can be interpreted as follows: A fraction \( a^s_m \) of the basic mode number \( m \) participates in supermode number \( s \) (a superposition of basic modes), which propagates strictly harmonically with propagation constant \( \beta^s \). The supermodes are normalized by factors \( P^s \) and excited with amplitudes \( A^s \). If one defines the supermode profiles \( E^s, H^s \) by

\[ E^s = \sum_m a^s_m \frac{1}{\sqrt{P_m}} E_m, \quad H^s = \sum_m a^s_m \frac{1}{\sqrt{P_m}} H_m \]

and with the two equations above inserted into the ansatz at the beginning, the total guided field can be rearranged as:

\[ \mathbf{E}(x, y, z, t) = \sum_s A^s e^{i\omega t} - i\beta^s z, \quad \mathbf{H}(x, y, z, t) = \sum_s \frac{A^s}{\sqrt{P^s}} H^s(x, y) e^{i\omega t} - i\beta^s z \]

Here the interpretation of the superposed fields as supermodes becomes evident.

**The Art of Design – Determination of Coupling Length:**

Coupling Length is defined as the active area where the signals are alternately migrate from one waveguide to another waveguide. This can be achieved by designing a fundamental of coupling waveguide architecture as shown in Figure 1. Then the coupling length will determine according to the coupling profile that is generated automatically from the BPM software used. The detail of exact coupling length selection is shown in Figure 2.

Four wavelengths of CWDM are injected to the input port. Due to the evanescent field and two very closed waveguide the signal will be migrate to another waveguide alternately. Due to different of wavelength used, propagation constant and wave number has make the signal oscillation and distance of coupling has become different and finally the signal can be separated (Figure 3). In this case wavelength of 1510 nm and 1530 nm together exit from one output port while 1550 nm and 1570 nm exit from other output port. Thus the selection point of coupling length has been determined successfully.

The best and effective point to separate the wavelength is when the signals are engrouped into two parts, Valley and Pulse. The bigger area of this part contributes more efficient of signal separation. The leakage can be avoid and finally improved the value of crosstalk and directivity. This two parameters are important to be controlled to enable the signal can travel longer.

The knowledge of couple mode theory and wavelength separation point determination has been translated to many designs of new optical device. Tilted grating demultiplexer, CWDM WDM coupler, CWDM OADM, 2x3 Optical Moderator, MultiRatio Optical Splitter (MROS) and etc have shown their vast application in optical communication system (Ab-Rahman and Shaari, 2001; Ab-Rahman and Shaari, 2004; Ab-Rahman and Shaari, 2005; Ab-Rahman, et al., 2011; Ab-Rahman, et al., 2009; Ab-Rahman and Wahab 2009; Ab-Rahman and Zaman 2009; Ab-Rahman 2011). As a conclusion, the knowledge of couple mode theory with some creativity is the key of new era of optical device innovation.

![Fig. 1: Designing a fundamental of coupling waveguide architecture to determine the split point.](image-url)
Due to the channel spacing being too big, the conventional technique is invalid and perhaps require a long coupling area to separate the wavelengths. In this paper we innovatively introduce Interrupter as the third waveguide to disturb the propagation profile of two coupled waveguide. As the result, the propagation profile of every propagated wavelength change and we able to observe the new separation point. The results show by moving the Introducer, we able to create the valley which can be used to separate the wavelengths.

Fig. 3: The selection of exact coupling length to separate two wavelength group to be used in Optical Looper.

Two Couple Waveguide Propagation:

Figure 4 shows the propagation profile in two coupled waveguide. The length of device is set 100 um. Two CWDM wavelengths are injected into the input port and the device is designed to separate each wavelength to different output port. Due to spacing between two channel is big therefore it is challenging to separate two
wavelengths. Therefore some initiative has to be introduced to enable the propagation step to be interrupted and able to separate the wavelength eventually. The original propagation profile of two coupled waveguide without any disturbance is shown in Figure 4. According to the graph, both signal exits at different output but there is leakage about 20% which also exit together at other different port for wavelength 1550 nm. After observing the other points as well, there is no suitable point to split the wavelengths. Therefore the interruption has to be introduced to the waveguide to disturb the signal propagation in the waveguide.

**Fig. 4:** Propagation profile with no waveguide disturbance.

**Different Points of Waveguide Interruption:**

The interruption is inserted at point 52500 µm and we can see the three cycles are existed. This is because the signal has to couple to times over three coupled waveguide. By observing the profile we able to define the potential area that can be used to separate these two wavelengths as depicted in Figure 5. When the interrupter starts to move (approximately 500 µm) the value is getting bigger. The area of valley is important to determine the separate point with effectively to avoid any leakages. This can be shown from Figure 6 until Figure 8.

**Fig. 5:** Propagation profile with waveguide disturbance at 52500 µm.

**Fig. 6:** Propagation profile with waveguide disturbance at 53000 µm.
When the interrupter is continuously moved, the valley is expanded and slowly generating the pulse. As a result, the valley is getting smaller. The pulse completely developed and the signal will start again exits at both output port. This is depicted in Figure 9 until Figure 18. From Figure 19. We can see both signal exits at different port but the separation point is difficult to be decided.

**Fig. 7:** Propagation profile with waveguide disturbance at 53500 µm.

**Fig. 8:** Propagation profile with waveguide disturbance at 54000 µm.

**Fig. 9:** Propagation profile with waveguide disturbance at 54500 µm.
Fig. 10: Propagation profile with waveguide disturbance at 55000 µm.

Fig. 11: Propagation profile with waveguide disturbance at 55500 µm.

Fig. 12: Propagation profile with waveguide disturbance at 56000 µm.

Fig. 13: Propagation profile with waveguide disturbance at 56500 µm.
Fig. 14: Propagation profile with waveguide disturbance at 57000 µm.

Fig. 15: Propagation profile with waveguide disturbance at 57500 µm.

Fig. 16: Propagation profile with waveguide disturbance at 58000 µm.

Fig. 17: Propagation profile with waveguide disturbance at 58500 µm.
Conclusion:

A new coupled mode formulation for parallel dielectric waveguides is successfully described. This paper we are reporting the new design to separate two wavelengths based on the coupled mode theory. Due to the channel spacing is too big, the conventional technique is invalid and require a long coupling area to separate the wavelength. In this paper we introduce introducer as the third waveguide to disturb the propagation profile of two coupled waveguide. The results show by moving the Interrupter, we able to create the valley which can be used to separate the wavelengths. Figure 20 shows the overlapped propagation profile for different values of interrupter starting points. We can observe the lines move gradually when perturbation has introduced to the two coupled waveguides.
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