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Crosstalk Reduction Algorithms Codes in Multiplexer/Demultiplexer Based Array Waveguide Grating in Dense Wavelength Division Multiplexing

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***Abstract*– This paper proposes analgorithms codes whereby a multiplexer/demultiplexer formed of cascaded AWG stages results in total channel accumulated crosstalk reduction which allows for more DWDM channel count. Assuming the transmittance in linear units for each cascade stage, and that each stage has a Gaussian spectral response envelope, obtained an equations of two-stage and three-stage were transformed into Matlab programs these programs transferred into an algorithms steps in order to be used by any other program languages.**

***Index Terms*— Accumulated Crosstalk, Dens Wavelength Division Multiplexer, Transmittance and Array Waveguide Grating**

I. INTRODUCTION

ARRAYED wave guide grating (AWGs) found on silica playing a key role as practical multiplexers and demultiplexers in high-channel-count DWDM systems with a large transmission capacity [1] . The optical performance of AWGs tends to worsen as their scale is increased because the accumulated crosstalk increases in portion to channel number. This means that accumulated crosstalk in large scale AWG obstruct signal transmission even if it has a good background (nonadjacent) crosstalk level around -40dB. The cascade connection techniques are used to avoid this problem with large scale AWGs. It is a way of reducing the crosstalk of conventional AWG filter and it is going to be further pursued in this article. The practical development of cascaded connection technique necessities concerns its application to a large-scale Mux/Demuxin which an accumulated crosstalk is a critical problem [2]. Fore cascaded configuration the planner lightwave circuit (PLC) technique is used to minimize the circuit and provide a low insertion less [3].

II. NONADJACENT CROSSTALK

Total nonadjacent crosstalk level is reduced in order to suit an arbitrary number N of system communication channel. Since the total system crosstalk is:

Total crosstalk = total adjacent crosstalk + total nonadjacent crosstalk (1)

$$x_{tot} = 2x_{adj} + (N-3)x_{nonadj} \quad (2)$$

Where (x_{adj}) is the crosstalk from each of the two channels adjacent to the channel under consideration, and (x_{nonadj}) is the crosstalk from each nonadjacent channel of N-3 nonadjacent system channels. As total crosstalk in such photonic transmission systems must generally be no worse than a certain value (usually around -15dBs) and more stringent levels may also be demanded [4]. Then equation (2) could be written as the following when x_{tot} is equal to acceptable total crosstalk:

$$\text{Acceptable total crosstalk} = 2x_{adj} + (N-3)x_{nonadj} \quad (3)$$

With the acceptable crosstalk of -15dB (10^{-3}) and on typical adjacent crosstalk per channel of -30dB (10^{-3} linear units) [5], [6] and with an N» 3, equation (3) could be written in linear unit as:

$$10^{-1.5} = 2\,x10^{-3} + Nx_{adj} \quad (4)$$

From equation (4) it could be shown that an upper limit in dBs on nonadjacent crosstalk per channel is in the following relationship:

$$x_{nonadj} \leq -15.3 - 10\log_{10} N \quad (5)$$

In a table from relating N (number of channels) to upper limit x_{nonadj} refer to table (1) below for -15dB acceptable total system crosstalk. Matlab program is used for plotting the relation between channels number and its nonadjacent crosstalk in Fig. 1.

Table 1: Relation between channels number and its nonadjacent crosstalk

N	x_{nonadj}(dBs)
1	-15.3
10	-25.3
100	-35.3
1000	-45.3
10000	-55.3

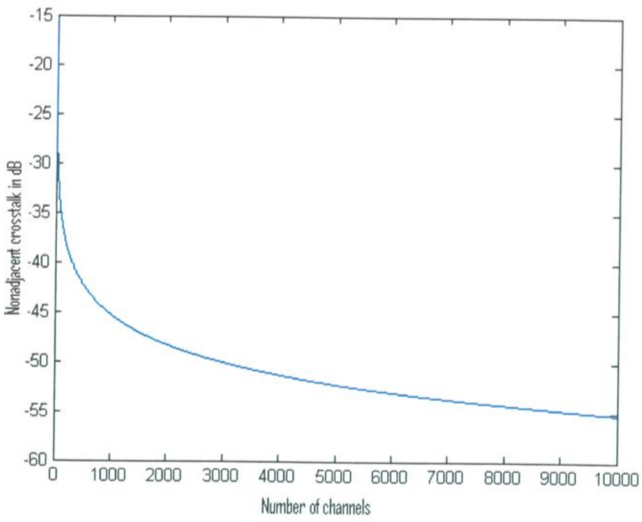

Fig. 1: Relation between channels number and its nonadjacent crosstalk

III. CASCADING TWO STAGES OF AWG

An example of cascading two stages of AWGs as a solution to the problem of crosstalk accumulation in large-scale AWG multiplexers and demeltiplexers is that of a 64-channel cascaded AWG module resulting in a very low background crosstalk of less than -80dB and a total crosstalk of about -34dB.The technique involves optimizing the bandwidth of the bandpass stage (second stage) AWG by estimating the spectral characteristics of the whole cascaded AWG as a function of its bandwidth and its center wavelength difference. Using a Gaussian spectral profile for assumed the transmittance (t_1) equation (6) in linear unit t_1 of the first stage [4].

$$t_1(\lambda) = \exp\left[-\left(\frac{\lambda-\lambda_K}{\sigma_1}\right)^2\right] \text{ for}$$

$$|\lambda - \lambda_K| \leq \sigma_1\sqrt{-ln(x_{nonadj,1})}$$

$$t_1(\lambda) = x_{nonadj,1} \text{ for}$$

$$|\lambda - \lambda_K| > \sigma_1\sqrt{-ln(x_{nonadj,1})} \qquad (6)$$

Using a Matlab program to find the linear unit transmittance (t_1) and its spectral profile figure (2).

Where λ, λ_k, and σ_1 are the wavelength, the i th channel wavelength, and bandwidth respectively for the passband wavelength center at channel k. σ_1 was set so that the first stage AWG had a nonadjacent crosstalk of $x_{nonadj,1}$ therefore σ_1 is defined as:

$$\sigma_1 = \frac{\Delta\lambda}{\sqrt{-ln(x_{nonadj,1})}} \qquad (7)$$

Where Δλ, is the channel spacing.

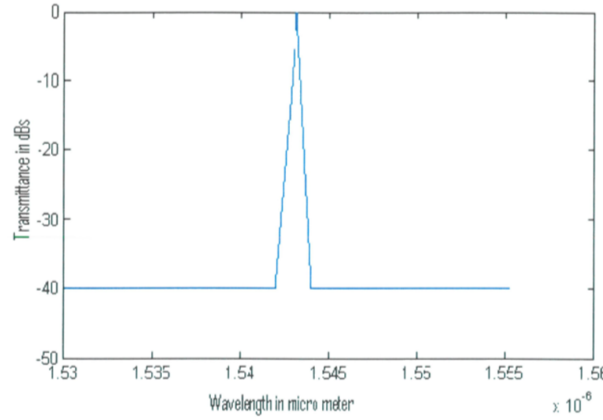

Fig. 2: Gaussian spectral profile of the first (AWG) stage

Also using Gaussian spectral profile of transmittance equation (8) in linear unit t_2 for the second AWG stage is derived.

$$t_2(\lambda) = exp\left[-\left(\frac{\lambda - \lambda_K - \delta_2\lambda}{\sigma_2}\right)^2\right] \ for$$

$$|\lambda - \lambda_K| \leq \sigma_2\sqrt{-ln(x_{nonadj,2})}$$

$$t_2(\lambda) = x_{nonadj,2} \quad \text{for} |\lambda - \lambda_K| > \sigma_2\sqrt{-ln(x_{nonadj,2})} \quad (8)$$

For equation(8) σ_2, is the bandwidth of the second stage AWG and $\delta_2\lambda$ is the center wavelength difference from the channel wavelength λ_k. The lower limit is set so that it had a nonadjacent crosstalk of $x_{nonadj,.2}$ from the product of these two equations (6 and 8) the transmittance (t_c) of cascaded AWG is calculated as in equation (9) and its bandwidth σ_c is defined as in equation (10) [4].

$$t_c = t_1(\lambda)t_2(\lambda) = exp\left[-\left(\frac{\lambda-\lambda_K - (\sigma c/\sigma_2)^2\delta\lambda}{\sigma c}\right)^2 - \left(\frac{\sigma c\delta\lambda}{\sigma_1\sigma_2}\right)^2\right]$$

$$\text{for} |\lambda - \lambda_K| \leq \sigma_1\sqrt{-ln(x_{nonadj,1})}$$

$$t_c = t_1(\lambda)t_2(\lambda) = x_{nonadj,1}exp\left[-\left(\frac{\lambda-\lambda_K-\delta\lambda}{\sigma_2}\right)^2\right]$$

$$\text{for} \sigma_1\sqrt{-ln(x_{nonadj,1})} < |\lambda - \lambda_K| \leq \sigma\sqrt{-ln(x_{nonadj,2})}$$

$$t_c = t_1(\lambda)t_2(\lambda) = x_{nonadj,1}x_{nonadj,2}$$

$$\text{for} |\lambda - \lambda_K| > \sigma_2\sqrt{-ln(x_{nonadj,2})} \qquad (9)$$

$$\sigma c = \frac{\sigma_1\sigma_2}{\sqrt{\sigma_1{}^2+\sigma_2{}^2}} \qquad (10)$$

Total nonadjacent crosstalk of the cascaded AWG can be estimated from equations (9 and 10).

$$x_{nonadj,1} = \sum\left(\frac{t_c\,(\lambda_i)}{t_c\,(\lambda_k)}\right)$$

i = 1,2,3,…..,k + 2…..N-1,N (11)

IV. TWO-STAGE CASCADED AWG DESIGN

The two-stage design of 64-channel were cascaded AWG multiplexer/demultiplexer using the bandwidth of the first AWG stage as (0.356nm) and the bandwidth of the second stage as (0.2923nm).The bandwidth of the second stage can be normalized by that of the first stage AWG giving three values of center wavelength differences (δλ) 10%, 12%, and 15% of the channel spacing (Δλ).

Using a Matlab program for solving equations (9 and 10) to find the total nonadjacent crosstalk of cascaded AWGs with different center wavelength differences (δλ), the following Table 2 was obtained:

Table 2: Total nonadjacent of cascaded AWGs for different δλ

δλ =	10%$\Delta\lambda$	12%$\Delta\lambda$	15%$\Delta\lambda$
Total nonadjacent crosstalk	-40.1dB	-41.7dB	-44.3dB

Also the spectral of cascaded 2-stage AWG 64-channel was obtained.

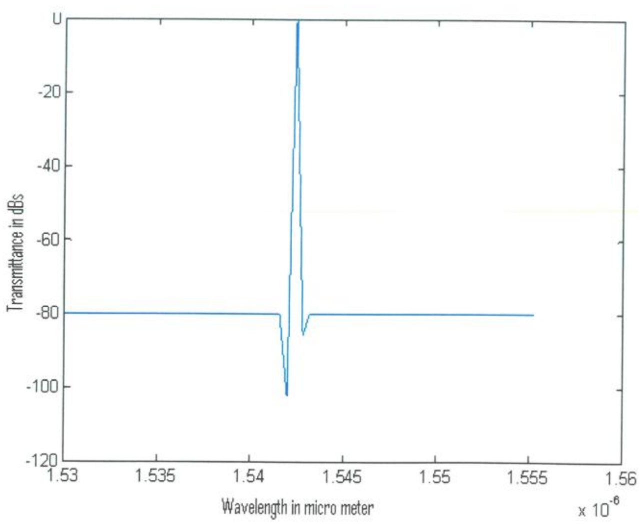

Fig. 3: The spectral of cascaded 2-stage AWG 64-channel

V. TWO-STAGE AWG CASCADING ALGORITHM CODE

The performance algorithm of the 2-stage AWG cascading multiplexer/Demultiplexer based on equation 9 and 10 is presented below:

(1) Specify the wavelength range from channel number one up to the last channel with the slot of 0.4nm

(2) Locate the central wavelength (k)

(3) Calculate the bandwidth of the first AWG stage

(4) Calculate the bandwidth of the second AWG stage

(5) Calculate the bandwidth of the cascaded AWG (2-stage)

(6) Starting from channel 1 up to the last channel (64 channel) d0:

i. Calculate the transmittance when the absolute value of (wavelength (i)) – the central wavelength (k) is less or equal to the bandwidth of the first stage times the square root of (-log (10^ (-4)) and

ii. Calculate the transmittance when the bandwidth of the first stage times the square root of(-log (10^ (-4)) and

iii. Calculate the transmittance when the absolute value of (wavelength (i)) – the central wavelength (k) is greater than the bandwidth of the first stage times the square root of (- log(10^(-4))

(7) Plot the characteristic curve of the wavelength ranges in nm vs the values of transmittance in dB.

(8) Calculate the total non adjacent crosstalk by these steps:

i. Calculate the sum of transmittance from channel 1 up to k-2

ii. Calculate the transmittance of channel k

iii. Divide the result in step one by the result of step2, assume this value is (A)

iv. Calculate the sum of transmittance fromchannel k+2 up to channel 64

v. Divide the result in step four by the result of step 2, assume this value is (B).

(9) Add (A) and (B) and the result is the total nonadjacent crosstalk of Mux/Demux based on AWGs.

(10) Find (-log (A+B)).

The 2-stage cascade AWG consist of AWG_1,and AWG_2 connected in series using PLC-PLC technique. The combination of these 2-stages solve the problem of accumulated AWG crosstalk, by reducing the total nonadjacent crosstalk to the value less than -40dB in order to enhance the performance of large scale AWG.

VI. THREE STAGES AWG CASCADED

Using the transmittance in linear units $t_1(\lambda)$ for first cascading stage, and the transmittance in linear units $t_2(\lambda)$ for second stage, and the transmittance in linear units $t_3(\lambda)$ for the third is obtained.

$$t_3(\lambda) = exp\left[-\left(\frac{\lambda-\lambda_K-\delta_2\lambda-\delta_3\lambda}{\sigma_3}\right)^2\right] \quad for \quad |\lambda-\lambda_K| \le \sigma_3\sqrt{-ln(x_{nonadj,3})}$$

$$t_3(\lambda)=x_{nonadj,3} \text{for} |\lambda-\lambda_K| > \sigma_3\sqrt{-ln(x_{nonadj,3})} \qquad (12)$$

Where σ_3 is the bandwidth of stage three, and $\delta_2\lambda, \delta_3\lambda$ are second and third AWGs center wavelength differences from the channel wavelength (λ_K).

The product of the transmittances($t_1(\lambda), t_2(\lambda), and\ t_3(\lambda)$) of the three AWGs representing the cascaded transmittance $t_c(\lambda)$. To do this the 3-stage cascade is visualized as a 2-stage cascade whose first stage is formed of two stages allowing the really stage be stage two in visualized cascade. Then the relationship of the first composite stage and that of the second stage (the third in reality) to σ_d, their overall bandwidth is calculated [7].

It is worthy of mentioning that the total bandwidth equation of a 3-stage cascade is similar to that of the impedance of 3 conductors connected in parallel only that the impedances in the denominator are replaced by the square of their corresponding bandwidth and the summed up denominator is square-root.

Cascade transmittance $t_c(\lambda)$ = ($t_1(\lambda)$($t_2(\lambda)$($t_3(\lambda)$

$$t_c(\lambda) = exp\left[-\left(\left(\frac{\lambda-\lambda_K}{\sigma_1}\right)^2 + \left(\frac{\lambda-\lambda_K-\delta_2\lambda}{\sigma_2}\right)^2 + \left(\frac{\lambda-\lambda_K-\delta_2\lambda-\delta_3\lambda}{\sigma_3}\right)^2\right)\right]$$

For $|\lambda - \lambda_K| \leq \sigma_1\sqrt{-ln(x_{nonadj,1})}$

$$t_c(\lambda) = x_{nonadj,1}\ exp\left[-\left(\left(\frac{\lambda-\lambda_K-\delta_2\lambda}{\sigma_2}\right)^2 + \left(\frac{\lambda-\lambda_K-\delta_2\lambda-\delta_3\lambda}{\sigma_3}\right)^2\right)\right]$$

For $\sigma_1\sqrt{-ln(x_{nonadj,1})} < |\lambda - \lambda_K| \leq \sigma_2\sqrt{-ln(x_{nonadj,2})}$

$$t_c(\lambda) = x_{nonadj,1} \times x_{nonadj,2} exp\left[-\left(\frac{\lambda-\lambda_K-\delta_2\lambda-\delta_3\lambda}{\sigma_3}\right)^2\right]$$

For $\sigma_1\sqrt{-ln(x_{nonadj,1})} < |\lambda - \lambda_K| \leq \sigma_3\sqrt{-ln(x_{nonadj,3})}$

$$t_c(\lambda) = x_{nonadj,1} \times x_{nonadj,2} \times x_{nonadj,3}$$

$$for|\lambda - \lambda_K| \leq \sigma_3\sqrt{-ln(x_{nonadj,3})} \quad (13)$$

$$\sigma_d = \frac{\sigma_1\sigma_2\sigma_3}{\sqrt{\sigma_1{}^2\sigma_2{}^2 + \sigma_1{}^2\ \sigma_3{}^2 + \sigma_2{}^2\sigma_3{}^2}} \quad (14)$$

VII. THREE –STAGE CASCADE DESIGN

This three- stage design of 64-channel cascaded AWG multiplexer and demultiplexer assumes a bandwidth of (03499nm) for the first AWG stage, (0.999nm) for the second stage and (0.4333nm) for the third stage.

Using a Matlab program for solving equation (13) to find the total nonadjacent crosstalk of proposed cascaded AWG with different center wavelength differences (Table 3). Also the same Matlab program used for plotting the response curve of the cascading 3-stage AWG 64-channel.

Table 3: Total nonadjacent of cascaded AWGs for different $\delta_3\lambda$ and $\delta_2\lambda$

$\delta_3\lambda$ and $\delta_2\lambda$ =	**9%Δλ**	**10%Δλ**	**11%Δλ**
Total nonadjacent crosstalk	-40.32dB	-41.42dB	-42.5dB

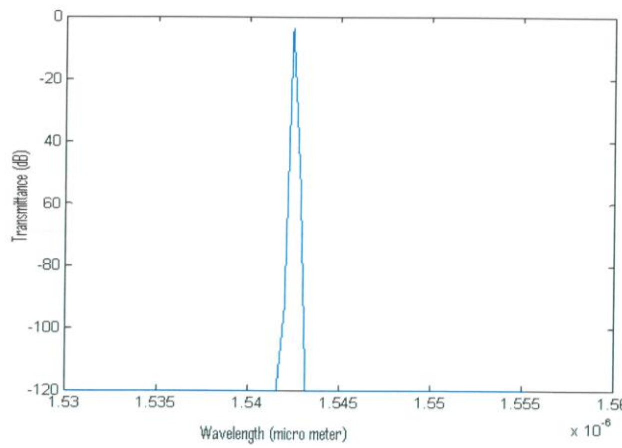

Fig. 4: The spectral cascaded 3-stage of AWG 64-channel

VIII. THREE- STAGE AWG CASCADING ALGORITHM CODE

The performance algorithm of the three-stage AWG cascading Multiplexer/Demultiplexer based on equation13 and 14 is represented below:

(1) Specify the wavelength range from channel number one up to the last channel with the slot of 0.4nm.

(2) Locate the central wavelength (k).

(3) Calculate the bandwidth of the first AWG stage.

(4) Calculate the bandwidth of the second AWG stage.

(5)Calculate the bandwidth of the third AWG stage.

(6) Starting from channel 1 up to the last channel (64 channel) do:

i. Calculate the transmittance when the absolute value

of(wavelength (i))-the central wavelength (k) isLess or equal to the bandwidth of the first stage times the square root of(-log(10^(-4)) and

ii. Calculate the transmittance when the bandwidth of the first stage times the square root of (-log(10^ (-4)) is less than absolute value of (wavelength (i)-the central wavelength (k) and this is less or equal to the bandwidth of the second stage times the square root of (-log(10^ (-4)) and

iii. Calculate the transmittance when the bandwidth of the first stage time the square of the (-log(10^ (-4)) is less than absolute value of(wavelength (i))-the central wavelength (k) and this is less or equal to the bandwidth of the third stage times the square root of (-log (10^ (-4)) and

iv. Calculate the transmittance when the absolute value of(wavelength(i))-the central wavelength (k) is greater than the bandwidth of the first stage times the square root of (-log (10^ (-4))

(7) Plot the characteristic curve of the wavelength in nm vs the values of transmittance in dB.

(8) Calculate the total non adjacent crosstalk. For that do:

i. Calculate the sum of transmittance from channel 1 up to k-2
ii. Calculate the transmittance of channel k
iii. Divide the result in step one by the result of step 2, assume this value is (A).
iv. Calculate the sum of transmittance from the channel k+2 up to channel 64.
v. Divide the result in step four by the result of step 2, assume this value is (B).

(9) Add (A) and (B) and the result is the total nonadjacent crosstalk in absolute units of Mux/Demux based on 3AWGs.

(10) Find (-log (A+B)).

The three 3-stage cascaded AWG consist of $AWG_{1,}$ AWG_2, and AWG_3 connected in series using PLC-PLC technique. The combination of these three stages reduces accumulated AWG crosstalk, by reducing the total nonadjacent crosstalk to the value less than -40dB in order to enhance the performance of large scale AWG.

IX. CONCLUSION

The most popular optical structure used for multiplexer/demultiplexer these DWDM numerous channels are AWG. These channels are affected by the level of channel crosstalk. 2-stage and 3-stage cascade configuration of AWG using PLC technique were introduced to reduce accumulated crosstalk. Matlab programs based on AWGs equations were converted to algorithm steps to be used by any program languages.

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