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An Efficient Design Technique for the Flattened Transfer Function of Arrayed Waveguide Grating

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This paper describes an efficient optimal design method for an arrayed waveguide grating (AWG) with flattened transfer function. The objective function is the norm of the difference between calculated and target spectra. To analyze the AWG transfer function, the Fresnel-Kirchhof diffraction formula was employed and the design variable was optical path difference of each array waveguide. The (1+1) Evolution Strategy was applied to an eight-channel coarse wavelength division multiplexing (CWDM) AWG as the optimization tool. The optimized transfer function will considerably improve the system performance.

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I. INTRODUCTION

Integrated multiple wavelength filters are being developed for coarse wavelength-division multiplexing (CWDM) telecommunications and computer networks. In particular, arrayed-waveguide gratings (AWGs) have already proven to be critical components for many applications for passive and active routing of optical networks [1,2]. In order to allow the concatenation of many such devices and relax requirements on accurate wavelength control in a network, their spectral response must necessarily be accurately designed. Many techniques that have been introduced in order to design the spectral response of an AWG have been aimed at achieving a broadened or flattened transfer function by use of multimode output waveguides [3], two cascaded grating devices [4], multiple gratings [5], or a multimode interference coupler [6]. Some design methods using an analytic form of objective function have also been proposed [7, 8]. However, these techniques are sequential, that is, physical parameters are determined according to a fixed order one by one or assume a particular mode profile to simplify the problem. Thus, they might be applicable to designing desirable devices in a one-valued optimization method or to those having an particular input or propagating mode profile.

In this paper, an efficient optimal design method for an arrayed waveguide grating (AWG) with flattened transfer function. is presented. The spectral response of AWG was computed by using the Fresnel-Kirchhof diffraction formula. The 1, 3, and 20-dB bandwidths were obtained from the transmission spectrum. The (1+1) Evolution Strategy was employed as the optimization tool. The optimization method presented here is applied to a design of 8-channel CWDM AWG. The design results show that the optimization method presented here is very useful in designing the AWG spectrum and developing some new type of AWG. This algorithm can be extended to another objective function with other weighting factors and optical parameters.

II. SPECTRAL ANALYSIS OF AWG

The Fresnel-Kirchhoff diffraction theory that was applied to an AWG to obtain the transfer function by Parker [8] was employed for the calculation of the spectrum of AWG in this paper. The transfer function for an AWG device is calculated by the following equation :

$$H(\delta) =- C_0\int_{-\infty}^{\infty} \{a(x)e^{j\Phi(x)}\}e^{j\delta x}dx \qquad (1)$$

C_0 is the normalization factor, $(\Phi)(x)$ is the grating phase, the detuning parameter $(\delta)=(\beta-\beta_B)\cos\Psi$, with

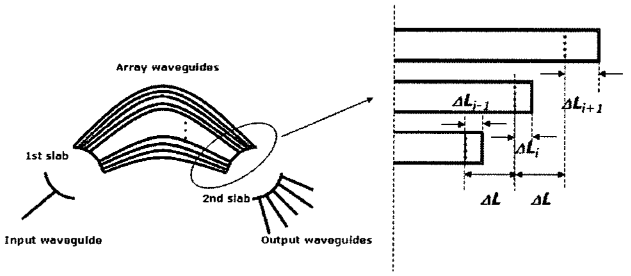


FIG. 1. Schematic configuration of AWG and design varables.

propagation constant $\beta=2\pi n/\lambda$, and β_B corresponding with the wavelength λ_B at the bandpass center of the AWG filter response. a(x) is the variation of electric field amplitude across the waveguide array, and $\cos\Psi$ denotes the direction cosine of the propagation constant in the second slab waveguide.

The phase at the ith array waveguide $\Phi(x_i)$ can be expressed as follows:

$$\Phi(x_i)=\frac{2\pi}{\lambda}n(L_{\min}+\triangle L+\triangle L_i)$$

L_{min} is the shortest length of array waveguide, $\triangle L$ is the conventional optical path difference and $\triangle L_i$ is an additional optical path difference at the ith array waveguide. In this paper, we chose $\triangle L_i$ at each array waveguide as design variables as shown in Fig. 1. The variation in optical path difference at each array waveguide changes the shape of transfer function to obtain the optimal spectrum shape.

III. OPTIMIZATION OF AWG USING (1+1) EVOLUTION STRATEGY

1. (1+1) Evolution Strategy

In this paper, (1+1) ES is employed as a main optimization tool. Among several stochastic methods, ES uses the principle of organic evolution for searching for the optimal values. The ES is widely used because it can find the global optimal solution, the algorithm is simple, and convergence speed is fast. The algorithm roughly consists of four parts : reproduction, mutation, competition, and selection [9,10].

The (1+1) ES is a simple mutation-selection scheme called two membered ES. The "population" consists of one parent only, determined by a certain parameter configuration, creating one descendant by means of adding a normally distributed random vector (mutation) to the parameter values. The 'fitter' of both individuals, obtained by evaluating the objective function, serves as the ancestor of the following iteration (selection). The step width is adjusted periodically (e.g. after 10*np function calls, where np is the number of optimization parameters) in such a way that the ratio of successful mutations over all mutations becomes p. This strategy parameter is usually set to p=0.2. In this paper, an annealing factor is set to be 0.85 and a shaking process is also considered to prevent a solution from converging to a local minimum.

2. Objective Function

In this paper, the objective function of the optimal design of AWG was chosen the norm of difference between the calculated and target (rectangular shape) spectrum. The optimization problem and the objective function are defined as follows :

$$\text{Minimize Objective Function}=\sqrt{\sum_{i=1}^{N}a_i x_i^2} \tag{2}$$

where xi is the difference between calculated transmission and target value at the ith analysis point, as shown in Fig. 2, N is the number of analysis points and a_i is a weighting factor with $\sum_{i=1}^{N}a_i^2=1$.

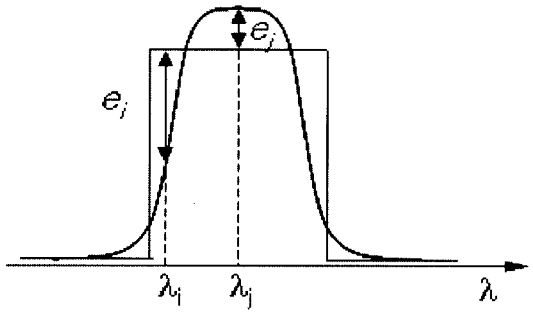


FIG. 2. Comparison between the calculated and target spectrum.

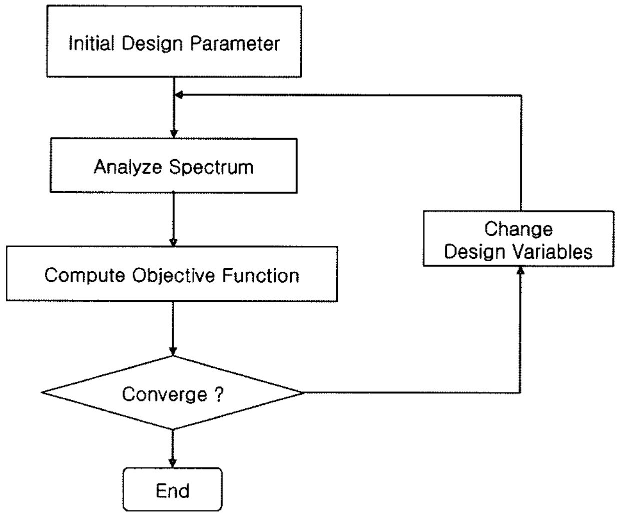


FIG. 3. Optimization procedure for AWG using (1+1) Evolution Strategy

3. Optimization Procedure

Fig. 3 shows the flow chart for the optimization procedure. The optical transmissions are calculated by the Fresnel-Kirchhoff diffraction theory [8]. Then, the objective function is computed by (2). If the objective function is smaller than the specified value, or the relative error between present and previous optimization step is smaller than the predefined tolerance, then the optimization process is terminated.

IV. OPTIMIZATION RESULTS AND DISCUSSIONS

The optimization method presented here was applied to the design of a 8-channel AWG.. The waveguide was assumed a silica-based one. Fig. 4 shows the convergent objective function. The objective function decreased with iteration and after 35th iteration remained constant. Therefore the value converged to a point and the design was optimally designed.

Fig. 5 shows the transmission spectrum at the target and those at the initial and final state. Fig. 5 shows the target rectangular function, the transmission spectrum at the initial and final state. This shows that the shape of transmission was improved and its upper region gets broader to approach the target shape.

Fig. 6 (a) and (b) show the transmission spectrum at the target and those at the initial and final state and an enlarged spectrum in log scale. Table 1 summarizes the 1, 3, 20 dB bandwidths at the target and

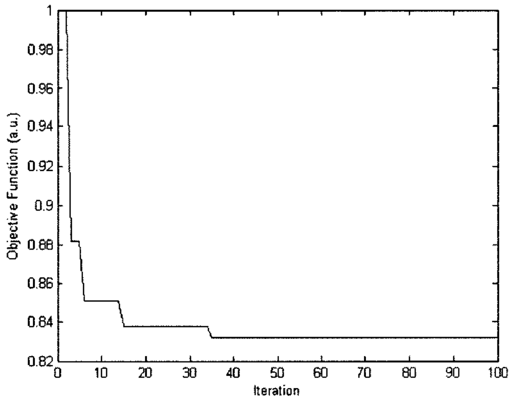


FIG. 4. Convergence of objective function with iteration.

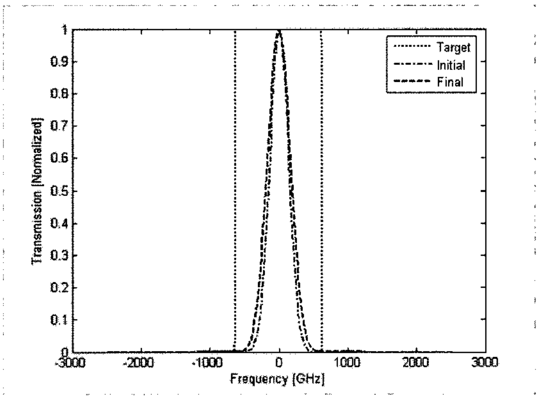
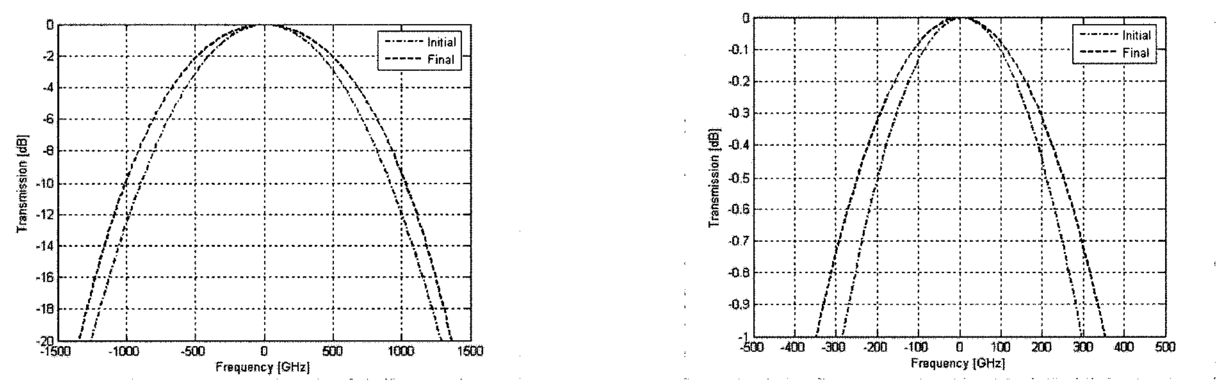


FIG. 5. Target, initial and final spectra (linear scale).



(a) (b)

FIG. 6. (a) The initial and final spectra (log scale), (b) The enlarged initial and final spectra (log scale).

Table 1. Optimization results.

Parameters	Initial	Final	Change
1dB bandwidth [GHz]	586.6	723.8	+23.4%
3dB bandwidth [GHz]	1002.2	1186.9	+18.4%
20dB bandwidth [GHz]	2548.6	2709.5	+6.3%

those at the initial and final state. The figures and table show that the 1-, 3-, 20-dB bandwidths get larger and the increments in upper region of transfer function are more than those in lower so, approach the target shape.

By changing the weighting factors, 'the importance' of the physical parameters can be further emphasized. One may enhance 'the importance' of some physical parameters by increasing their weighting factors and hence, improving the nearness from the target value. Furthermore, there are no limitations or requirements in choice of design parameters and design variables

V. CONCLUSION

This paper presents the systematic optimum design method of AWG to obtain desired transmission spectra. The frequency response of AWG is calculated by the Fresnel-Kirchhoff diffraction theory and from their transmission was obtained. The (1+1) ES is employed as an optimization tool. The optimization method presented here is applied to the design of an 8-channel AWG with the rectangular target transfer function. The design results show that the optimization method presented here is very useful in designing AWG spectrum and developing some new type of AWG. This algorithm can be extended to another objective function with other weighting factors and optical parameters.

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