Optimization of Bragg Grating in Optical Fiber Using Modified Fitness Function and an Accelerated Genetic Algorithm

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***Abstract*— This work presents modified genetic algorithm to optimize the fiber Bragg gratings parameters. It is shown that appropriate reformulation of the fitness function and modifications in GA operation are possible to project high quality optical filters and to reduce the computational cost of the technique. The Genetic Algorithm is used to optimize the index modulation profile and geometry of the Bragg grating for application in WDM systems. In theses systems, optical filters with side lobes levels below -30 dB in the 1550-nm window are demanded. Some projects of optical filter are used to compare this new approach with traditional GA.**

***Keywords*— Optics fiber, genetic algorithm, Fiber Bragg grating**

I. Introduction

Fiber Bragg Gratings (FBG) are key elements in optical communications systems due to their unique properties to implement selective devices in frequency, both as an auxiliary component as to execute critical functions in the system [1]-[2]. Some approach of optimization techniques for optical filters applied to WDM systems have been searched to obtain high refletivity optical filter [3]-[5].

Basically, the optimization process of the Bragg grating consists on finding the parameters values of the device (usually those parameters related with the geometry and refraction index of the waveguide), in order to assure performance of this device according to project criterion, such as reflectivity, transmissivity and delay responses along specific spectral region. The optimization process has to take into account the parameters values restrictions of the Bragg grating, i.e., possible physical dimensions and material values of the Bragg grating according to fabrication process limitations [6]-[8].

Once those criteria and parameters were defined, the optimization is carried out minimizing the difference between the ideal response and the calculated response along a spectral region. However the functions involved in those problems are characterized to be nonlinear, discontinuous and multimodals, that present no priori information about global solution. Such characteristics present large difficulty for local optimization techniques, which depends on a quality of the initial solution, i.e., which demands knowledge about search space so that the initial solution (initial guess) is close to global optimum. Thus, other auxiliary techniques can be used to obtain an initial solution in projects of optical filters [9]; however, efforts have been made in order to search efficient global optimization techniques which find optimal global and are independent from the initial guess. Optimization techniques based on population are global optimization techniques and are more appropriate to treat theses problems [5],[10]. In this paper, it is presented a new heuristic applied to genetic algorithm that consists on appropriate reformulation of the fitness function, which presented faster results with more quality. Optical filter project based on FBG is used for testing to show the genetic algorithm efficiency and the quality of the obtained solutions from this new approach.

The remainder of this paper is organized as follows. In section II, modifications proposals in the fitness function are described. In section III, genetic algorithm theory and proposals modifications to improve its performance are described. In section IV, the simulation results are shown and additional discussion about the solution quality between modified GA and traditional GA are presented. Finally, concluding remarks are given in Section V.

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II. Modified Genetic Algorithm

Although FBGs can be considered simple structures, the spread processing time in its synthesis usually justifies the employment of parallel computing. An approach without parallel computing would require large efforts in order to increase the function fitness performance. However, as the fitness function is based on a well defined model of the literature, so that is very difficult to improve it.

The fitness function compares the target and calculated curves of reflectivity and dispersion, which are sampling along the frequency. Thus, the processing of fitness can be faster, reducing the number of samples used in this process. However, a reduced number of fixed samples implicates in larger spacing among the same ones. Thus, as GA evolves the values of the target and calculated curves approach each other, but there is no information about samples between these points. Thus, even it is obtained reasonable estimation in these frequency points, there is no guarantee in all analysis frequency range. Therefore, the solution obtained can present fitness value lower than this same solution evaluated with higher number of samples. In this paper, it is proposed that number of samples is reduced by applying a new heuristic based on stochastic variation of the samples. Basically, a different set of samples is used to evaluate all individuals of the population to each generation and these fitness values are used to apply the selection process. This set of samples is chosen randomly to each generation. Thus, after N generations, it is possible that N different set of points has been tested. But, as explained before, each particular individual can not be a reasonable solution because the number of samples reduced, even with its apparent evolution. Therefore, the individual reference is used to overcome this problem. This individual, also called elite individual, is evaluated with a number of samples enough to obtain reasonable estimation of the error between the target and calculated curves. At the end of each generation, the best individual of current GA population has its fitness recalculated with maximum number of samples. This individual is compared with the reference individual. If this reevaluated individual has fitness larger than the reference individual, this individual comes from being a new reference individual, otherwise the last reference individual is maintained. The function fitness which is calculated using reduced number of samples is called Simplified Fitness Function (SFF) and the function fitness that uses the maximum number of samples is called Extended Fitness Function (EFF).

III. The Modified Fitness Function

The choice adequate fitness function is important in the optimization process, because this function is the connection between the physical problem and the optimization technique. There are in literature other fitness functions for optimization of optical filters. The most used function is root mean square error, which is used in this paper. The error between calculated reflectivity and target reflectivity is calculated using the following equation:

$$F(X) = \left\{ \frac{1}{S} \sum_{k=1}^{S} \left[\Gamma(\lambda_k) - \Gamma_R(\lambda_k) \right]^2 \right\}^{-1} \quad (1)$$

where X is $X = X_L | L = 1, 2, ...N$, N is the number of variable and X_L presents values between x_{Lmin} to x_{Lmax}. S is the number of samples used for comparison among the relativities curves. This parameter can present values of S_e or S_r for SFF and EFF, respectively, where $S_e \gg S_r$. $\Gamma(\lambda_k)$ and $\Gamma_R(\lambda_k)$ are values of calculated and target reflectivity for the wavelength k, respectively. The parameter k is the wavelength for arbitrary sample k, which is between the sample $k = 1$ and $k = S$, $F(X)$ is the value of the fitness function of the solution X. The reflectivity grating is calculated by matricial form and based on coupled-mode theory [9]-[10]. The values of k are distributed uniformly along the wavelength interval $[\lambda_{min}; \lambda_{max}]$. SFF and EFF can be calculated by the following expressions, respectively:

$$\lambda_k = \lambda_{min} + k\Delta\lambda \quad (2)$$

and

$$\lambda_k = \rho\Delta\lambda + \lambda_{min} + k\Delta\lambda, \quad (3)$$

where ρ is a uniform randomly variable in $[0; 1]$ and $\Delta\lambda = (max - max)/S$, where S is defined such as (1).

It is possible to estimate how these modifications can improve the GA performance using the processing number of samples. The traditional GA uses just EFF, which is used m times for each generation, where m is the population size. However, modified GA uses the SFF m times for each generation instead of EFF. On the other hand, EFF is used just once to each generation - it is only used to evaluate the best individual of the GA population which will be compared to the reference individual, as it was explained before. Therefore, it is possible that the modified GA is faster than traditional GA by a factor f:

$$f = \frac{S_e m}{S_e + S_r m} \quad (4)$$

Besides adaptation proposals for GA acceleration, it was carried out modifications in fitness functions in (1). The modified equation is shown as follows:

$$F(X) = \left\{ \frac{1}{S} \sum_{k=1}^{S} \left[10\log\left(\Gamma(\lambda_k)\right) - 10\log\left(\Gamma_R(\lambda_k)\right) \right]^2 \right\}^{-1} \quad (5)$$

The reflectivity response presented improvements in side lobes levels with the application of this equation, because in this scale, the errors come from being more considerable and more perceptible, so that the genetic algorithm can find an optical filter with lower side lobe level.

IV. Result Simulations and Discussion

In this section, a project of fiber Bragg grating is used for optimization with the aim to evaluate the effects of the proposals improvements for the fitness function and genetic algorithm. Thus, the results of traditional GA and modified GA are compared to show benefits to the adaptations proposals. The processing time and quality of the solution were compared. The computer used to run results was a PC with processor AMD Athlon 1800+. The codes were compiled using GNU GCC/G++ version 3.4.4 and executed in the Linux operational system.

The project consists of a fiber Bragg grating projected to operate in the third operation window of 1.5493 mm to 1.5509 mm, total reflection between 1.5499 mm and 1.5503 mm and null reflectivity out of band. The index modulation (or fringe visibility) was equal to 1 and the number of section is equal to 120. The effective refraction index of the fiber core was 1.45. The imposed constraints are the wavelength of project from 1.5501 $\leq \lambda_{Bi} \leq$ 1,554 mm, section thickness from 70 $\leq \Delta_{zi} \leq$ 100 μm and induced index from 0.0$\leq \delta_{neff} \leq 4 \times 10^{-4}$. This project was testing the performance of the traditional GA and modified GA. Modifications at the fitness function in (5) were not used yet. For modified GA, it was used 50 points for SFF and 1000 points for EFF, and traditional GA was just used 1000 to analyze the reflectivity curve. Both GA used 15000 generations. In Figure 1, it is shown the reflectivity results obtained from traditional GA and modified GA (with acceleration technique). Both spectral responses presented about -10 dB side lobes, but with significant difference in time-processing. In that case, the modified GA of mean time-processing was 1h56min, while for the traditional GA, the mean time-processing was 7h46min. Fig. 2 shows the comparison of the evolution curves of traditional GA and modified GA. These curves are average of 10 simulations to each GA - traditional and modified. In Figs. 3 and 4, it is shown the profile of induced refraction index obtained in the optimization process for the traditional and modified GA execution. The dispersion for optimized gratings are in Fig. 5.

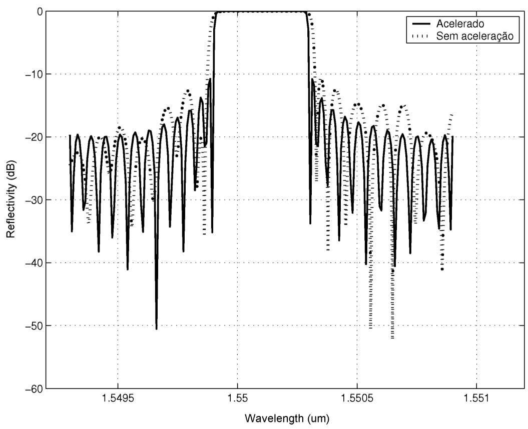

Fig. 1. Comparison of the reflectivity curve of the traditional GA and modified GA.

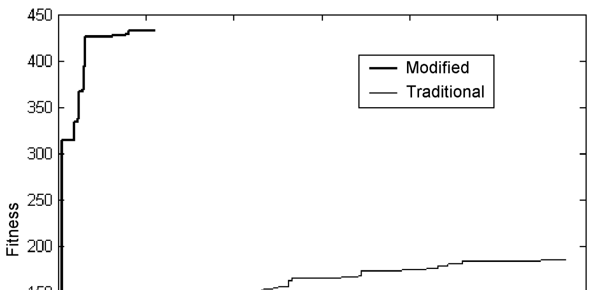

Fig. 2. Fitness functions of the time-processing in seconds.

For second test, the same parameters were used of the previous project, but, in this case, it was used the fitness function defined by Eq. (5), where the reflectivity values are used in dB. Thus, the target is defined considering 0 dB into the band and -40 dB out of the band. For this project, modified GA with acceleration technique was used. For SFF it was used 50 samples and EFF was used 1000 samples. The aim was to verify the effect as both techniques were used jointly. The results can be seen in Fig. 6, where it is shown the reflectivity spectrum of the optimized grating by GA. The side lobes presented values minor than -30 dB, improving the quality

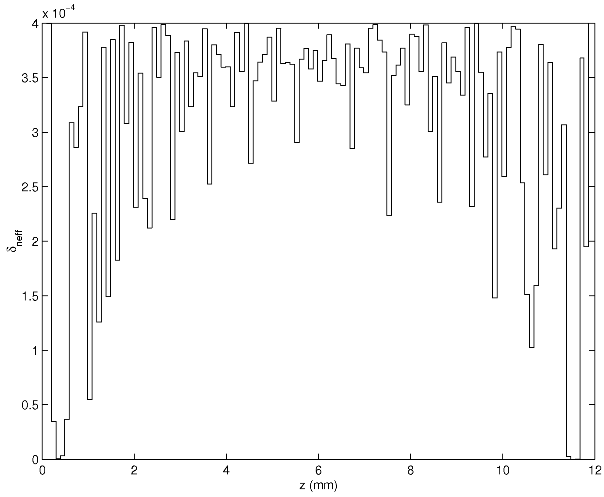

Fig. 3. Profile of induced refraction index of the grating obtained with traditional GA.

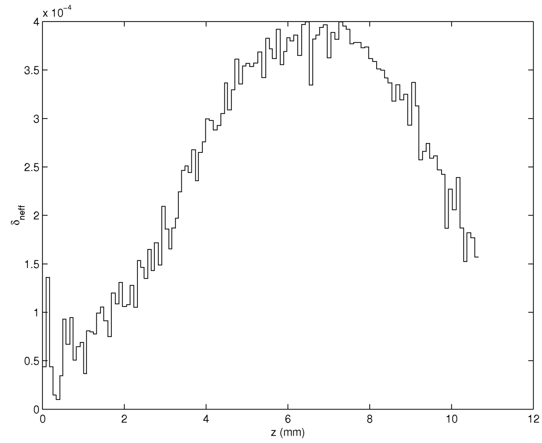

Fig. 4. Profile of induced refraction index of the grating obtained with modified GA.

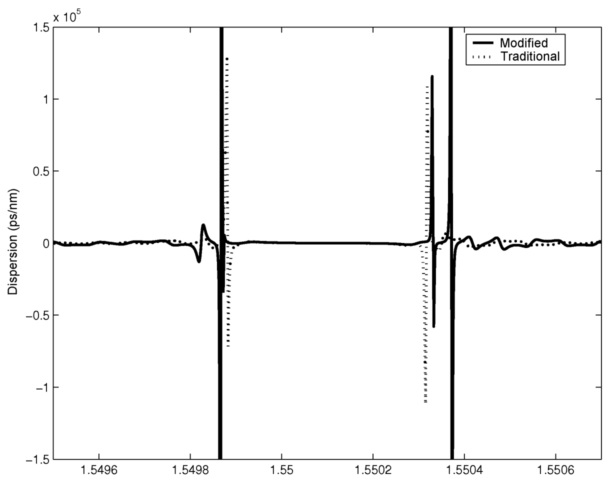

Fig. 5. Curve of dispersion for project using traditional GA and modified GA

of the optimized reflectivity response. In Fig. 8, it is shown the induced index profile obtained by optimization process. The execution time was 4h30min, after executions of 20000 generations. The dispersion curve of the grating by GA is shown in Fig. 7.

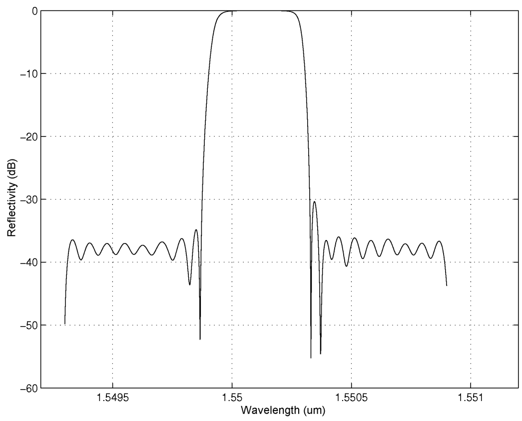

Fig. 6. Reflectivity of obtained grating with acceleration technique and fitness function in **??**.

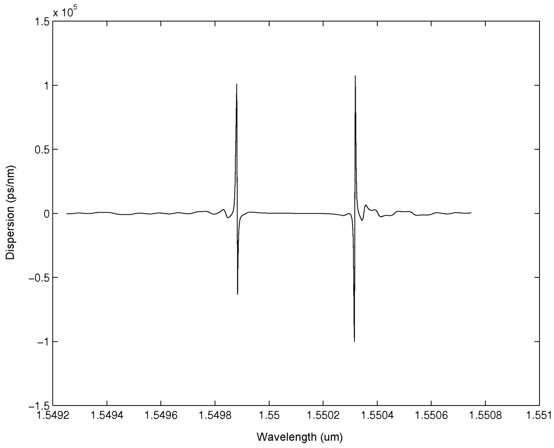

Fig. 7. Curve of dispersion for project using traditional GA and fitness function in dB.

V. CONCLUSION

In this paper, it was shown a new fitness function and modifications in the genetic algorithms for the optimization problem of optical filter using fiber Bragg gratings. Through simulated results, it was possible to show that modifications in the genetic algorithms were possible significant reductions of the time-processing, which is a critical problem in this technique, while the modification in fitness function allowed the reduction of the side lobes to satisfactory levels for the WDM systems specifications. Finally, it was shown that both modifications in the genetic algorithms and fitness functions allowed to find solutions with high quality and with reduced time-processing.

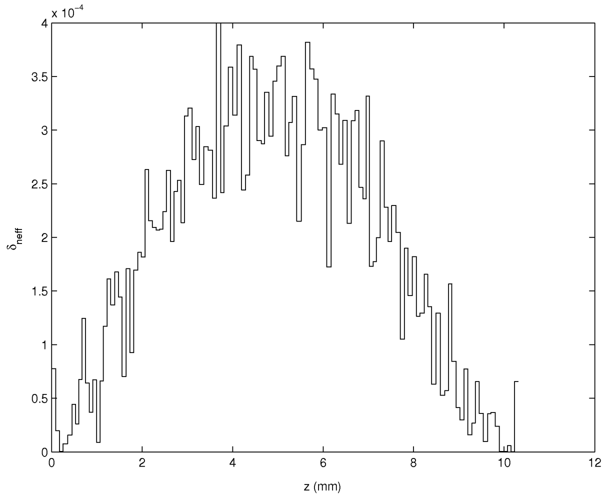

Fig. 8. Profile of induced refraction index f the grating.

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