Operational parameter optimisation of MZI-SOA using multi-objective genetic algorithms

R.P. Dionísio, G. Parca, C. Reis and A.L. Teixeira

A methodology for achieving the best-fit set of parameters for a Mach-Zehnder interferometer with a semiconductor optical amplifier (MZI-SOA) static model is proposed. A multi-objective genetic algorithm is exploited and the quality of the approach is validated by applying it in an existing sample. Optimisation of performance and determination of operational limits are enabled by the proposed methodology and good agreement was obtained between simulated and practical results.

Introduction: Mach-Zehnder interferometers with semiconductor optical amplifiers (MZI-SOAs) are well-known devices with potential in a variety of applications. Recently, they have been used as high-speed logical gates [1], multiwavelength converters [2] or signal regenerators [3], making them one of the key components for future all-optical networks. However, integrated MZI-SOAs with hybrid technology encompass several components (couplers, waveguides, phase shifters and SOAs), all with their own tolerances and asymmetries. These issues lead to a very long and difficult initial setup phase [4], which varies from device to device owing to fabrication and integration yields. An MZI-SOA working characteristic is well described with a static model [5], through which we carry out the operational parameters optimisation and the determination of operational limits exploiting a genetic algorithm (GA).

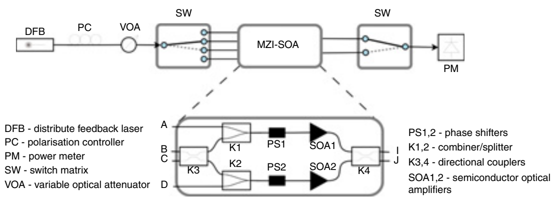

Fig. 1 *Experimental setup and MZI-SOA internal structure*

To evaluate the behaviour of the MZI-SOA depicted in Fig. 1, we use a black box model [5], based on interferometric structure principles. It also considers the internal couplers yield and path length differences between the upper and lower arms. The output powers P_I and P_J are computed as a function of the SOAs' bias current ($Isoa$),

$$\begin{cases} P_I(Isoa_i) = (1-\alpha_4)\,P_1(Isoa_1) + \alpha_4\,P_2(Isoa_2) - \\ \qquad 2\sqrt{\alpha_4(1-\alpha_4)\,P_1(Isoa_1)\,P_2(Isoa_2)}\,sin(\Delta\phi(Isoa_i)) \\ P_J(Isoa_i) = (1-\alpha_4)\,P_2(Isoa_1) + \alpha_4 P_1(Isoa_2) + \\ \qquad 2\sqrt{\alpha_4(1-\alpha_4)\,P_1(Isoa_1)\,P_2(Isoa_2)}\,sin(\Delta\phi(Isoa_i)) \end{cases} \quad (1)$$

$$i = 1, 2$$

where $i = 1, 2$ is an index that identifies parameters from SOA1 or SOA2 and α_4 is the splitting factor of coupler K4. P_1 and P_2 are power levels at the output of SOA1 and SOA2, respectively, and are dependent on current, and their relation can be approximated through a linear curve, derived from experimental data. $\Delta\phi$ is the phase shift induced by SOA current variations. This parameter is modelled through a linear approximation as well, because of the linear relation between SOA induced phase shift and carrier density, through refractive index variation,

$$\begin{cases} P_i(Isoa_i) = gi(p_i \times Isoa_i + q_i) \\ \Delta\phi(Isoa_i) = m \times Isoa_i \pm \dfrac{\delta_i}{2} \end{cases}, \quad i = 1, 2 \quad (2)$$

Parameters p_i, q_i and m are originated assuming a linear dependence of P_1, P_2 and $\Delta\phi$ on SOA bias current; the g_i coefficient takes into account an adjustment of P_i, due to the experimental measurements made; δ_i depends on paths or coupler crossing factors and affects the output interference by means of a reduction of maximum extinction ratio (ER) achievable.

Experimental setup: To experimentally characterise the ER between output ports, the setup depicted in Fig. 1 was used. A continuous-wave laser beam fixed at 3 dBm is injected first into input port B and then into input port C. For each input, we measure the power from output port I and output port J, sweeping SOA1 current ($Isoa_1$) from 150 to 400 mA and maintaining SOA2 current ($Isoa_2$) at a reference value of 200 mA. The previous methodology is repeated once again with the same parameters, varying only $Isoa_2$ and keeping $Isoa_1$ constant at 200 mA. These results are summarised and expressed as four operational settings (OS). They are OS1: input at port B and $Isoa_2 = 200$ mA; OS2: input at port B and $Isoa_1 = 200$ mA; OS3: input at port C and $Isoa_2 = 200$ mA; OS4: input at port C and $Isoa_1 = 200$ mA.

Application of GA: The problem considered in this study is to establish a best-fit parameters vector, $\{p_1, p_2, g_1, g_2, q_1, q_2, \delta_1, \delta_2, m\}$, to minimise the error between two sets of measured and estimated curves, simultaneously. Two main approaches are used to overcome this problem in the literature. The first one consists of the combination of the different objectives into a single one, and then using one of the techniques for single objective optimisation [6, 7]. In such cases, the compromise between the objectives is *a priori* determined through the choice of the combination rule. The main criticism addressed to this approach is the difficulty to choose *a priori* the compromise. Another method is to postpone this choice after having several candidate solutions. This is the goal of the Pareto-based method using the notion of dominance between candidate solutions. Among the methods that can be used, a multi-objective genetic algorithm (MOGA) [8] was adopted, using MATLAB environment with optimisation library functions.

For the computation of parameters for both equations in (1), two objective functions, F_I and F_J, must be minimised. These functions are given by the following equation:

$$F_v = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(P_v^m(k) - P_v^c(k))^2}, \quad v = I, J \quad (3)$$

where $P_v^m(k)$ is the kth measured power value for one output port. $P_v^c(k)$ is the computed value of the power output for the unknown parameters of (1) and N is the number of measurements.

Results and discussion: For each OS, the MOGA has been run for 2000 generations, using a population size of 100 individuals, i.e. parameter vectors. From the resulting Pareto fronts, the best individual was chosen finding an average from the minimum values of F_I and F_J, given by $F = (F_I + F_J)/2$. The optimised parameters obtained for each OS are given in Table 1, together with the resulting fitting error F.

Table 1: Set of solutions for optimised fitting for each OS

	g_1	g_2	p_1	p_2	q_1	q_2	m	δ_1	δ_2	F
	–	–	W.A^{-1}	W.A^{-1}	W	W	rad.A^{-1}	rad	rad	mW
OS1	0.05	0.14	−1.49	0.20	0.60	0.13	1.63	0.53	2.20	0.19
OS2	0.10	0.16	0.43	−0.41	0.36	0.17	1.14	1.02	1.98	0.64
OS3	0.12	0.21	0.40	0.27	−0.03	0.02	−2.79	0.55	−0.27	0.33
OS4	0.10	0.06	0.57	−0.31	0.20	0.25	−1.97	2.60	−1.29	0.48

Fig. 2 shows common graphs of experimental data measured from output ports I and J, and estimated output powers using model (1) with the optimised parameter from Table 1. The result shows good agreement between measured and simulated curves, which validates the proposed approach.

From the curve fitting obtained with MATLAB, $Isoa_1$ and $Isoa_2$ were computed to maximise the ER between output ports. Numerical results obtained and presented in Table 2 show that ER depends both on the bias currents and on the chosen input port. Moreover, owing to the misalignment of the two complementary output curves, maximum ER is attained when both bias currents are different, as a consequence of the device internal asymmetries.

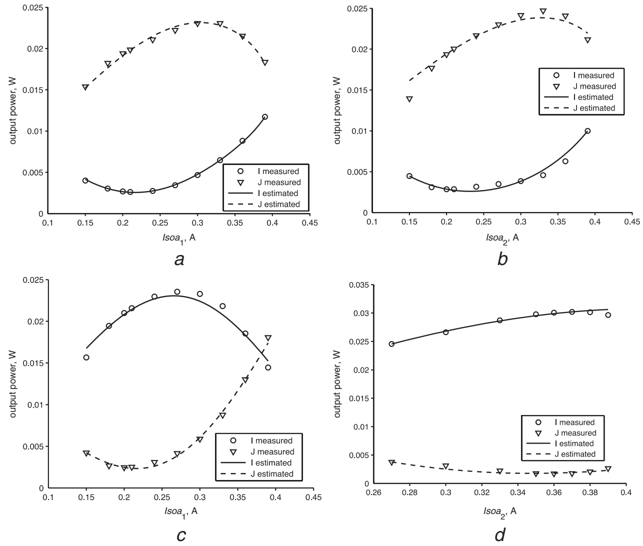

Fig. 2 *Measured and estimated power levels on output ports I and J*
a OS1
b OS2
c OS3
d OS4

Table 2: SOA bias currents for maximum ER between MZI-SOA output ports

	MZI-SOA input	*Isoa*$_1$ (mA)	*Isoa*$_2$ (mA)	Maximum ER (dB)
OS1	B	227	200	9.04
OS2	B	200	242	9.19
OS3	C	221	200	9.72
OS4	C	200	352	12.21

Conclusion: An MOGA has been successfully implemented to reach a best-fitted set of parameters of a model for an MZI-SOA. The practical and simulated results for the output power show good agreement and confirm the validity of the approach. The proposed process allows the user to quickly and effectively find the optimal operating point for maximal ER between output ports or any other specific target.

Acknowledgments: The authors acknowledge the BONE and EURO-FOS networks of excellence. R. Dionísio gratefully acknowledges FCT grant SFRH/PROTEC/50015/2009 for funding his PhD.

14 January 2011
doi: 10.1049/el.2011.0128

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