Chapter 8
Optimum Design of Hybrid EDFA/FRA by Particle Swarm Optimization

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ABSTRACT
In this chapter, the authors introduce the hybrid erbium-doped fiber amplifier (EDFA)/fiber Raman amplifier (FRA) and its optimization procedure by particle swarm optimization (PSO). EDFA, FRAs, and their combinations, which have the advantages of both, are the most important optical fiber amplifiers that overcome the signal power attenuations in the long-haul communication. After choosing a proper configuration for a hybrid EDFA/FRA, users have to choose its numerous parameters such as the lengths, pump powers, number and wavelengths of pumps, number of signal channels and their wavelengths, the signal input powers, the kind of the fibers and their characteristics such as the radius of the core, numerical apertures, and the density of Er³⁺ ions in the EDFA. As can be seen, there are many parameters that need to be chosen properly. Here, efficient heuristic optimization method of PSO is used to solve this problem.

1. INTRODUCTION
Fiber optic communication is the key element of the information era. The revolutionarily growth of telecommunication industry during the few recent decades are completely indebted to fiber optic communication. One of the fundamental elements of fiber optic communication, beside the optical fiber, transmitter, and receiver, is the optical amplifier. Most important optical amplifiers are optical fiber amplifiers that use optical fibers as the gain media. Erbium-doped fiber amplifier...
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(EDFA) which uses the rare earth ions of erbium as a dopant of the glass fiber to produce the gain and also fiber Raman amplifier (FRA) that uses the nonlinear effect of the stimulated Raman scattering to produce Raman gain are among the most important optical fiber amplifiers. Hybrid EDFA/FRA is also widely used in the telecommunication systems. Hybrid EDFA/FRAs have low noise figure, large bandwidth and it can be used to minimize the nonlinear impairments (Castanon, Nasieva, Turitsyn, Brochier, & Pincemin, 2005). Without optical fiber amplifiers it was impossible to attain such an extremely high capacity fiber optic communication systems on the extra long-haul distances. So, we can consider the invention of the optical fiber amplifiers as the key invention essential for the telecommunication systems.

The EDFA was introduced in 1980s (Poole, Payne, Mears, Fermann, & Laming, 1986; Mears, Reekie, Poole, & Payne, 1986; Mears, Reekie, Jauncey, & Payne, 1987; Desurvire, Simpson, & Becker, 1987) and practically prevalent on fiber optic communications during 1990s (Headley & Agrawal, 2005). Although, Raman amplification as a gain solution for compensating the signal losses was demonstrated in 1980s (Hasegawa, 1983; Mollenauer, Stolen, & Islam, 1985; Smith & Mollenauer, 1989), FRA was not practically used in fiber optic communications till 2000s (Headley & Agrawal, 2005) after realizing some of its advantages over EDFA in the telecommunication systems. During this period of thriving of the EDFAs and FRAs, numerous efforts have been carried on making more efficient amplifiers. Different engineering designs, system configurations, and parameter arrangements have been used to get better results from EDFA ((Yeh, Lee, & Chi, 2004; Lu, Chu, Alphones, & Shum, 2004; Yamada, et al., 1998; Ahn & Kim, 2004; L., et al., 2005; Yi, Zhan, Hu, Tang, & Xia, 2006; Yi, Zhan, Ji, Ye, & Xia, 2004; Singh, Sunanda, & Sharma, 2004; Liang & Hsu, 2007; Lu & Chu, Gain flattening by using dual-core fiber in erbium-doped fiber amplifier, 2000) (Hung, Chen, Lai, & Chi, 2007; Chang, Wang, & Chiang, 2006; Choi, Park, & Chu, 2003; Pal, et al., 2007; Martin, 2001; Cheng & Xiao, Optimization of an erbium-doped fiber amplifier with radial effects, 2005; Cheng & Xiao, Optimization of a dual pumped L-band erbium-doped fiber amplifier by genetic algorithm, 2006), FRA (Zhou, Lu, Liu, Shum, & Cheng, 2001; Perlin & Winful, 2002; Liu, Chen, Lu, & Zhou, 2004) and hybrid EDFA/FRA (Masuda & Kawai, 1999; Carena, Curri, & Poggiolini, 2001; Li, Zhao, Wen, Lu, Wang, & Chen, 2006).

To recall some of the operation criteria of the optical fiber amplifiers we can include low noise figure, large bandwidth, longer telecommunication spans, minimized nonlinearity impairments, and also flattened gain spectrum. Because of the large number of parameters we have to consider the problem as an optimization problem. Therefore, we need an optimization tool to find the best values for the input parameters. Mathematical optimization means to select the best value from a set of available values. In modeling and simulation of any system, we consider the output or different outputs of the system as the objective function and the system parameters or inputs that evaluate the outputs are defined as the system variables. The complexity of the optimization problem has a direct relationship with the number of the variables. There are some computational optimization techniques such as finitely terminating algorithms, convergent iterative methods, and also heuristics methods that can be used in optimization problems. After the invention of computers the extraordinary improvements in the field of the simulation of the systems and also optimization techniques, let the engineers to design much more effective systems. As expected the simulation and modeling of the optical fiber amplifiers and their optimization had been a hot spot of research during the last few decades. The heuristic method of PSO was introduced in 1995 (Kennedy & Eberhart, Particle swarm optimization, 1995) and it has become popular rapidly because of its merits in dealing with a large number of variables, the