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Research paper

Optimization noise figure of fiber Raman amplifier based on bat algorithm in optical communication network

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Abstract

Designing Raman amplifier with high On-Off again and low noise figure is required in in optical communication networks, due to wide and tunable amplification and low nonlinearity. This paper proposes a new configuration design to the single mode fiber Raman amplifier using a multi-objective bat algorithm. The main aim of the proposed method is to preserve the values of noise figure and ripple of the amplifier as low as possible while keeping the values of laser wavelength and the amplifier powers are high. The simulation results show that increasing the number of iterations is required, which would result in a flat gain spectrum with a considerable enhancement in the noise figure and minimal gain ripple that reaches to less than 0.18 DB.

Keywords: *Forward Pumping Scheme; Fiber Raman Amplifiers; On-off Gain; Bat Algorithm; Optical Communication Network.*

1. Introduction

The nonlinear effects in optical fiber is a major issue in a Dense Wavelength Division Multiplexing (DWDM) system of optical telecommunication networks related to vibrational excitation modes of silica. Rayleigh, Raman and Brillouin are the three stimulated scattering processes in optical networks. Among the first nonlinear effects studied in optical fibers is the stimulated Raman scattering (SRS) was studied in [1]. From the stimulated inelastic scattering the energy transfer to the linear medium, so the optical fiber serves as a nonlinear gain-amplifying medium.

Spontaneous Rayleigh and Rayleigh wing (very large spectral width) scattering are an elastic process from the local density fluctuations and the fluctuations in the orientation of the molecules of the medium, respectively. The spontaneous Brillouin and Raman scattering are produce a spectral shift of about 10 and 13000 GHz in silica optical fiber with time relaxation of 10-9 and 10-12 Sec, respectively [2, 3].

Due to SRS and SBS restricts the performance of nonlinear devices and limitation of the light power and the bandwidth, such as parametric optical frequency converters and amplifiers. In recent years, there has been many studies in optical communication network order to obtain devices to amplify the light using SRS in silicon [4, 5] and signal processing systems [6-9].

There are many types of optical amplification devices, such as semiconductor optical amplifiers (SOAs), erbium-doped fiber amplifiers (EDFAs) and Fiber Raman amplifier (FRAs) [10]. The spectral shape of Raman gain amplifier depends on the wavelength separation between pump and signal and guides light at both the signal and pump wavelengths by using fibers with low losses [11]. To get high signal to noise ratio, high Noise figure and minimal ripple of Raman gain and flatness in the optical communication network design by optimization the proper pump configuration and other parameters of the amplifier.

2. Theoretical modeling of fiber Raman amplifiers

The signal power $p_S(z)$ with the attenuation constant $\alpha_S$at wavelength λ_s, and the pump power $P_P(z)$ with the attenuation constant $\alpha_P$at wavelength λ_P , propagation differential equations in in Raman amplified medium are expressed as [12]

$$\frac{d}{dz} P_S(z) = \left[\frac{g_R}{A_{eff} K_R} P_P(z) - \alpha_s\right] P_s(z) \tag{1}$$

$$\frac{d}{dz} P_P(z) = \left[-\frac{\lambda_S}{\lambda_P}\frac{g_R}{A_{eff} K_R} P_S(z) - \alpha_P\right] P_P(z) \tag{2}$$

Where g_R is the Raman gain coefficient, K_R is the polarization factor and $A_{eff}$is the effective area.

The design parameters for the optimized the Raman amplifier to evaluate the performance of it is found by [13-17]:

$$P_S(z) = P_S(0)\, e^{\left(\frac{g_R P_P(0)(1-e^{-\alpha_P z})}{\alpha_P A_{eff} K_R} - \alpha_S z\right)} \tag{3}$$

$$P_P(z) = P_P(0)\, e^{(-\alpha_P z)} \tag{4}$$

$$G_{On-Off} = \frac{P_S(L)|_{\text{with pump power}-On}}{P_S(L)|_{\text{with pump power}-Off}} \tag{5}$$

$$NF = \left[\frac{1}{G_{On-Off}} \left(\frac{2\, P_{ASE}}{h\, v\, \Delta v} + 1\right)\right] \tag{6}$$

Where P_{ASE} , Δv, v, G_{On-Off} and NF are the forward amplified spontaneous emission (ASE) noise output power, the bandwith for frequency signal v, the ON-OFF Raman gain and the effective noise figure.

3. Experiment setup to the simulation structure

The basic layout of Raman Amplifier shows in Figure 1, which is used to characterize and optimize it with co-pumping scheme. Table (1) illustrates the simulation parameters values.

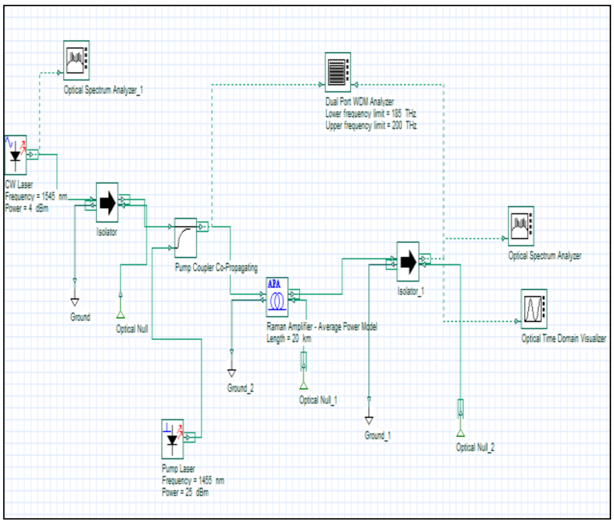


Fig. 1: Layout of Raman Amplifier.

Table 1: The Simulation Parameters Values

Property	Values
Wavelength (nm)	1535-1565
Pump Power	10 dBm, 25dBm, 30 dBm, 35 dBm and 40 dBm
Length	4 km to 20 km
Input Signal Power (dBm)	-2, 4 and 12

A setup configuration consists of Continuous Laser Unit (CLU), Raman Pump Unit (RPU) (Setting RPU Power. Wavelength stability ± 100 MHz/h, Wavelength = 1455 nm, Linewidth < 2 nm, Polarization State = Random, Output Power Stability = < 1%, Relative Intensity Noise = < - 110 dB/Hz), optical isolator, optical coupler, optical time domain visualizer, dual port WDM analyzer (lower frequency limit= 185 Thz and upper frequency limit= 200 Thz) and two Optical Spectrum Analyzers (OSA) (Setting input parameters at OSA, Measurement wavelength range = 600 to 1750 nm: Wavelength linearity: ± 0.01 nm). The setup configuration includes co-pumping scheme; when the propagation direction relation between the pump wave and signal wave in forward are coupled into the gain medium of Raman amplifier.

4. Implementation of bat algorithm optimization

The performance of the Raman amplifier setup is investigated for different Raman fiber length as a gain medium, Raman pump power and wavelength. Bat algorithm is implemented with the aim to optimize and characterize the On-Off Raman gain and the effective noise figure of FRA.

Nature inspired optimization algorithms such as colony optimization (ACO), artificial bee colony (ABC), harmony search; cuckoo search (CS), particle swarm optimization (PSO) and bat algorithm (BA) are becoming powerful methods for solving many tough optimization problems. The metaheuristic algorithms can be summed up in optimization problem in the in the field of business, artificial intelligence, engineering technology and other applications have been derived from the social behaviour of biological systems (animals). Bat algorithm (BA) is a novel feature; biological algorithm developed by Xin-She Yang in 2010 [18], depending on the echolocation behavior of bats and uses a frequency-tuning technique with varying loudness [19-24].

Initial population of the bats is performed randomly generated from real-valued vectors. Bats fly randomly is defined by: the velocity v(i) at its location x(i); fixed frequency (varying wavelength), the emission pulse rate r(i) and loudness A(i) according to the equations (7a-e) with the bat algorithm flow chart and the proposed methodology in figures (2 and 3):

$$f_i = f_{min} + (f_{max} - f_{min})\beta, \tag{7-a}$$

$$v_i^t = v_i^{t-1} + \left(x_i^{t-1} - x_*\right) f_i \tag{7-b}$$

$$x_i^t = x_i^{t-1} - v_i^t, \tag{7-c}$$

$$A_i^{t+1} = \alpha A_i^t, \tag{7-d}$$

$$r_i^{t+1} = r_i^0 [1 - e^{-\gamma t}] \tag{7-e}$$

Where $\beta \epsilon [0,1]$ is a random vector, α and γ are constants. In this work we set $\alpha = 0.9$ and$\gamma = 0.8$.

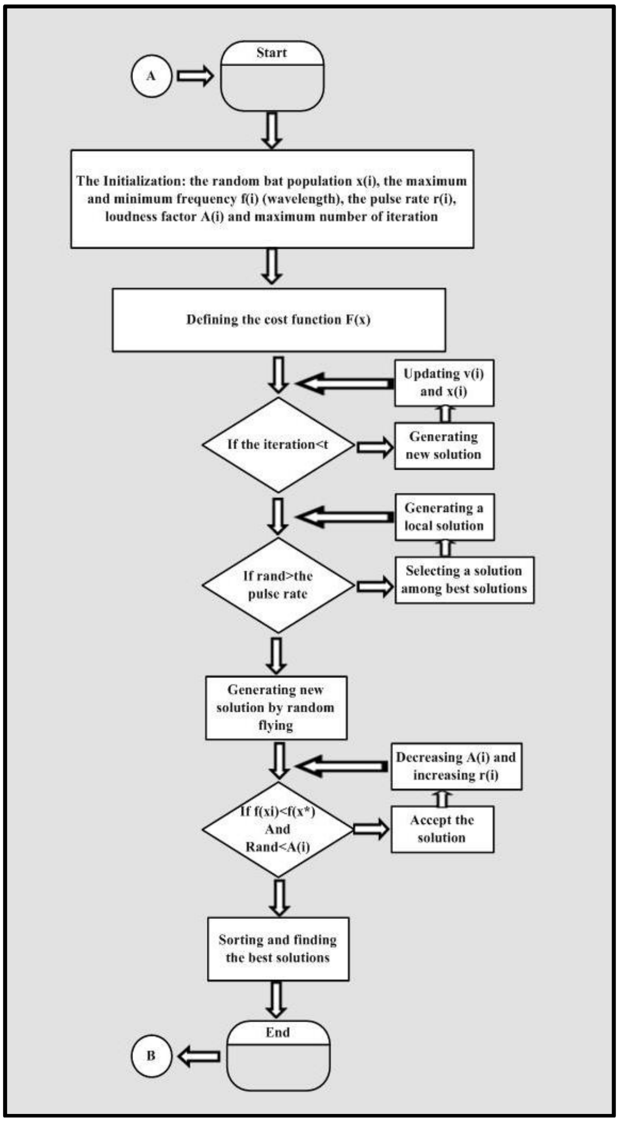


Fig. 2: Bat Algorithm Flow Chart.

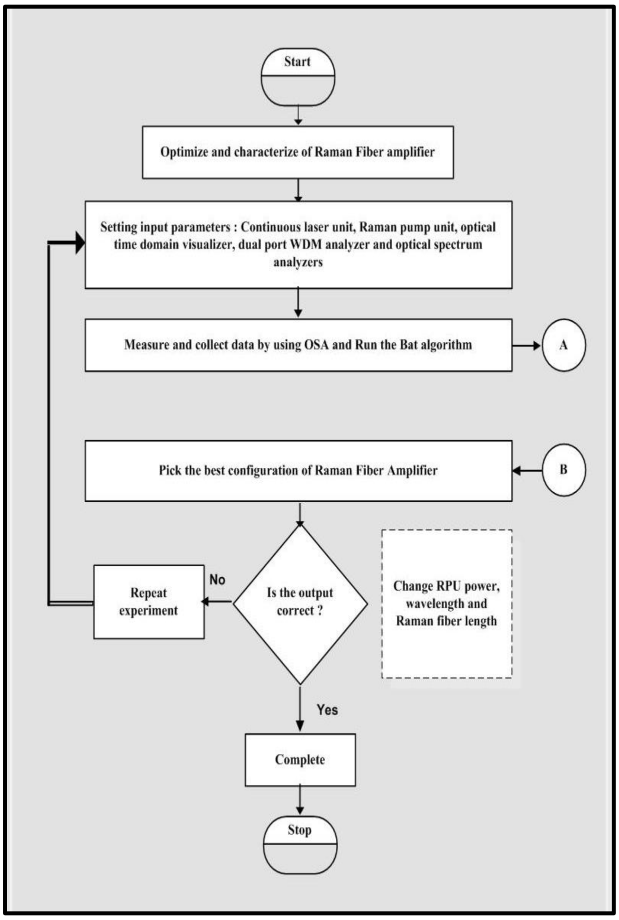


Fig. 3: The Methodology Flow Chart to Optimize and Characterize Fiber Raman Amplifier Using Bat Algorithm.

5. Results and discussions

A typical spontaneous Raman gain spectrum g_R of standard single mode silica glass fiber and Raman gain profile $\eta g_R, 0 < \eta < 1$; for Stokes noise are shown in Figure (4) [25], [26]. The normalize Raman gain in pure glass equal to 1 as maximum.

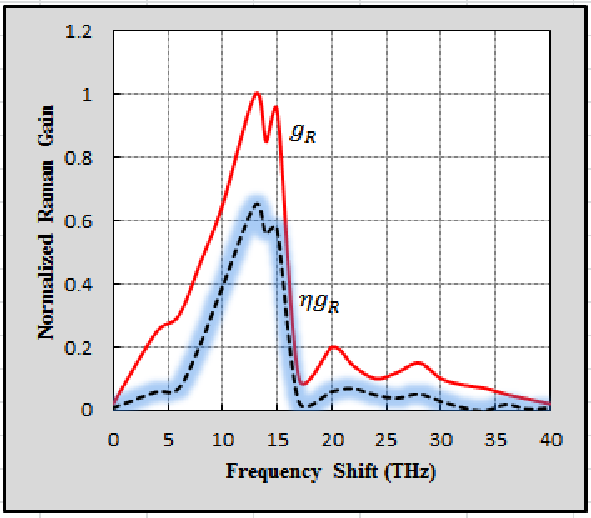
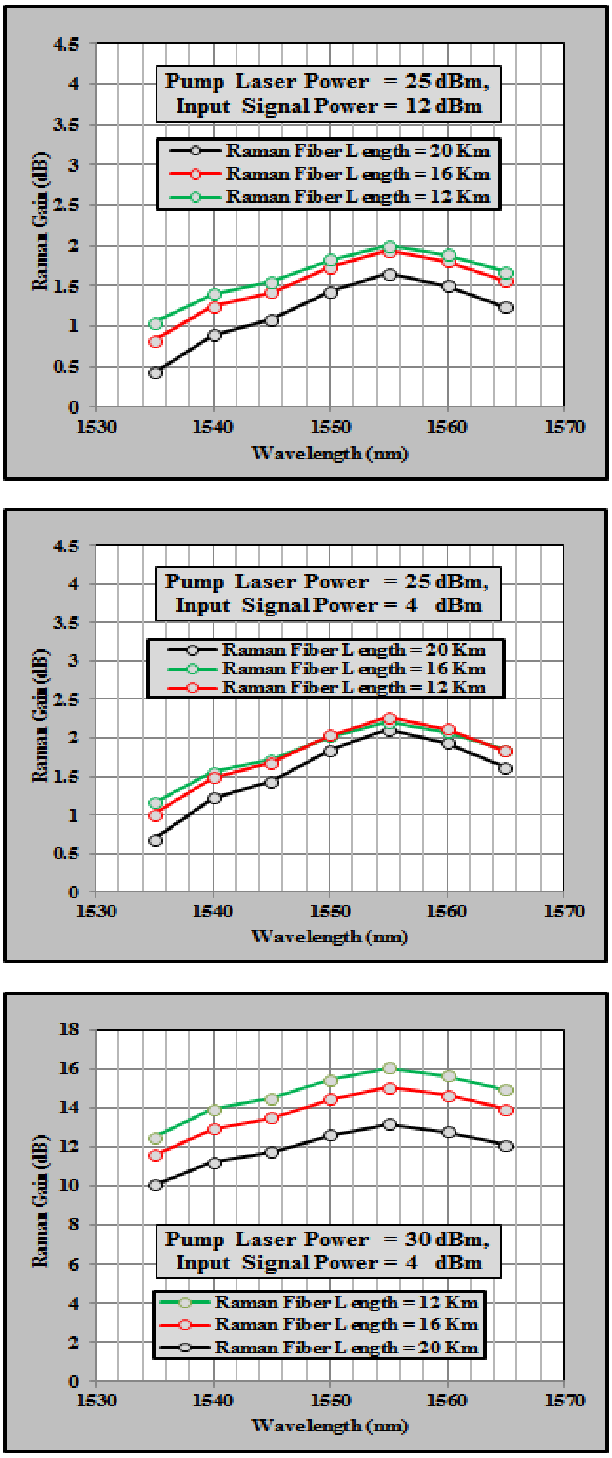


Fig. 4: Raman Gain Spectrum and Raman Gain Profile for Stochastic Noise in Fiber Raman Amplifier.

The used physical parameters to characterize fiber Raman amplifier are α_s and α_p are the magnitude of the signal and pump loss coefficients as 0.24, 0,34 and 0,49 and 0.36 dB/km at λ_s =1500 and 1300 nm, with g_R / α_p equal to 121 and 102 mW, respectively. Figure (5) shows the relation between the Raman gain and the wavelength; of three Raman fiber lengths vary from 12 to 20 Km step 4 at input signal power 4 dBm and 12 dBm, with different two pump power; 25 and 30 dBm, respectively. The lowest gain curve denotes the Raman gain profile for input signal power equal to 4 and 12 dBm less than 2.27 dB. With the pump power increasing to 30 dBm, the Raman gain corresponds to the input signal power equals to 4 and 12 dBm is more than 12.62 and 16.03 dBm, respectively. With an increase of the Raman fiber length from 12 to 20 km; the On-Off Raman gain still declines and gradually to a values of 1.616, 1.232, 12.102 and 10.657 dB at input signal power equal to 4 and 12 dBm; the pump power of 25 and 30 dBm obtained on the wavelength of 1565 nm.



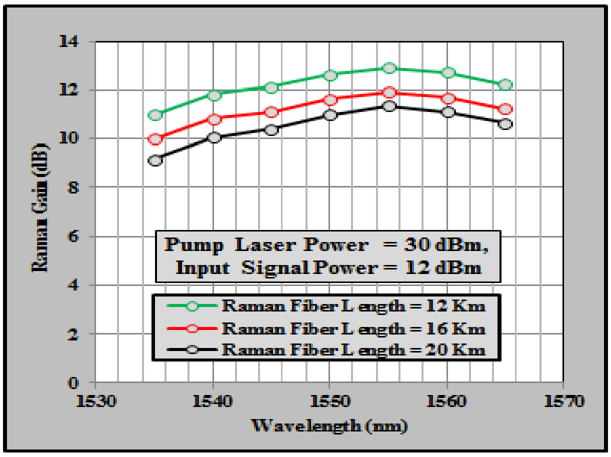


Fig. 5: Raman Gain Spectrum Characteristic of the Amplifier.

In order to evaluate the performance of our design, Bat algorithm is used with three cases of iterations, which are 100th, 500th, and 900th. Figure 6 shows the mean values of 50 trials of each iteration case of On-Off Raman amplifier with co-pumping power versus the Raman ripples. The On-Off Raman amplifier values are almost close to each other at iterations 500th and 900th; however, the best solution/optimized value shows in the 900th iteration. Therefore, the Bat algorithm required 900 iteration to ensure better coverage (0.13) and to have better values of On-Off Raman gain (16.21 dB) and insignificant gain ripple (0.18 dB).

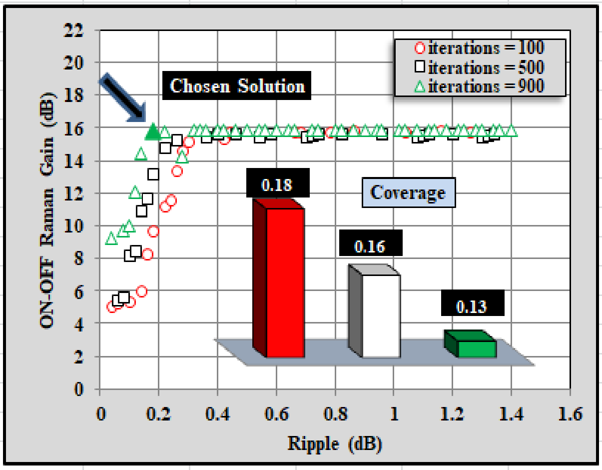


Fig. 6: Evolution of Bat Algorithm for on-Off Raman Gain.

Figure 7 displays the effect of our proposed method on the noise figure, i.e. the figure shows the change in the NF values before and after using the Bat optimization algorithm. The simulation setup of this figure is as the following: the input signals power is -2 dBm, the number of iteration of the algorithm is 900, and the pump laser power is 25 dBm. The simulation results demonstrate that a credible enhancement in the NF occurred after running the optimization algorithm. Besides, NF in fiber Raman amplifier increases with extending Raman length and it becomes smaller at high wavelength.

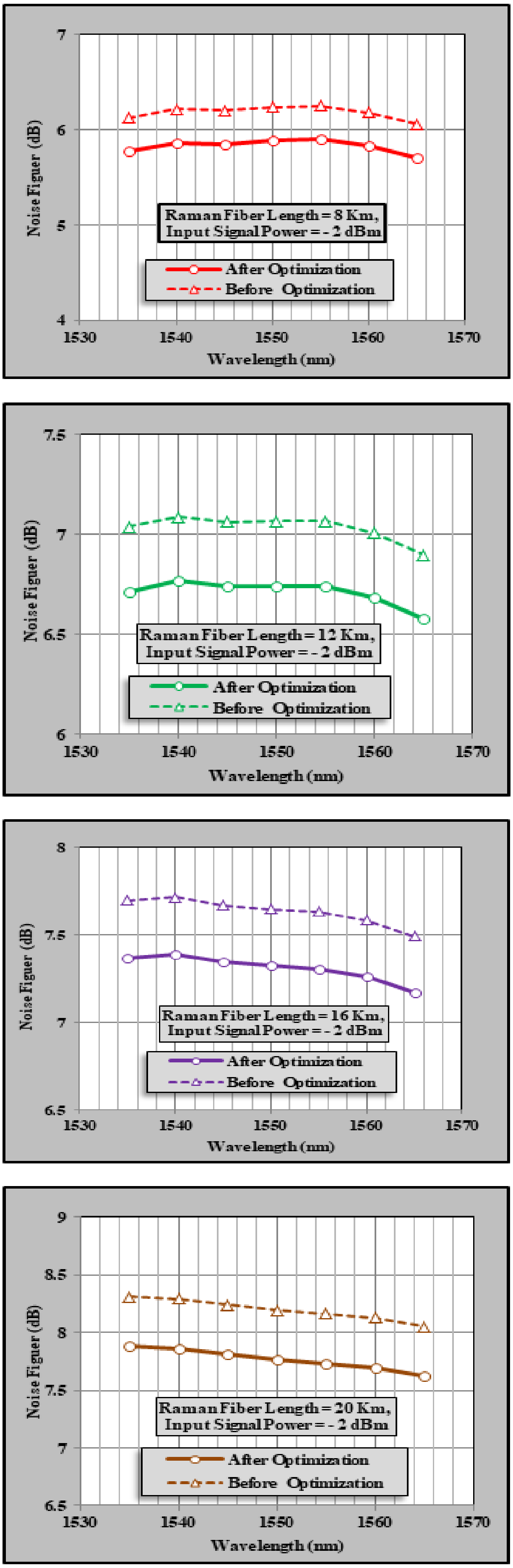


Fig. 7: Evolution of Bat Algorithm for Noise Figure.

Figure 8 depicts the NF value at different input signals power with an increase of the Raman fiber length (8, 12, 16, and 20 Km). The simulation setup of this figure is as the following: the number of iteration of the algorithm is 900, and the pump laser power is 30 dBm. The simulation results show that our design remains stable on enhancing the NF value even with the increase in the input signal power and increase the pump laser power.

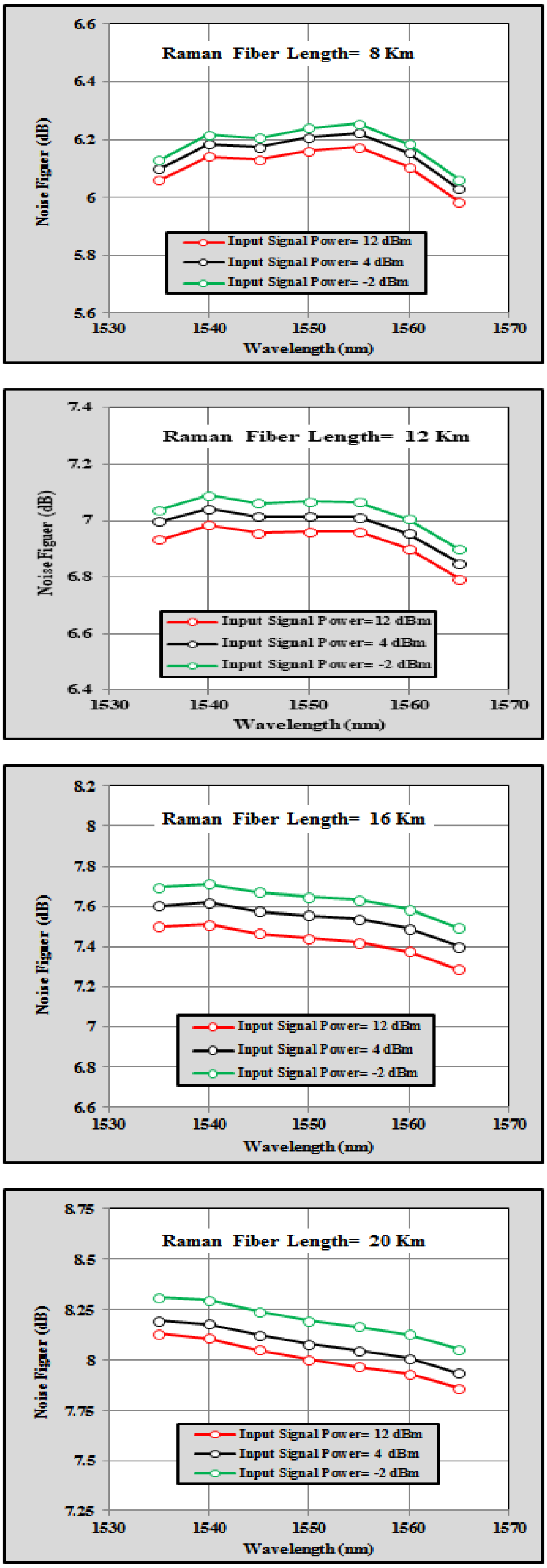


Fig. 8: Evolution the NF Value at Different Input Signal Powers.

In the co-pumping scheme in this work; signal power is high because the propagation of the input signal and the pump signal are in the same direction. So, high signal power leads to high signal to noise ratio at output and then from low Noise Figure. The obtained results of the proposed metaheuristic optimization algorithm (Bat algorithm) show that it is much more robust and efficient with error ratio of less than 3.1%, 3.2%, 3.4% and 4.2% for Raman fiber length 8, 12, 16 and 20 Km at input signal power -2 dBm. Increasing the Raman pump power or using a shorter span length will result in a slight higher Noise Figure and still the performance of co-pumping fiber Raman amplifier is good.

6. Conclusion

In this work, we proposed a novel method to lay and characterize a single mode fiber Raman amplifiers with co-pumping power scheme based on using a multi-objective bat algorithm. The method obtained a high signal to noise ratio and low Noise figure, while keeping the flatness On-Off and the ripple of the Raman gain as small as possible, over the used transmission bandwidth in the optical communication network. The experimental results showed that the gain ripple is less than 0.18 dB when the input signal power is over 10 dBm at pump wavelength bandwidth and optimized NF value (8.197 dB) for Raman span length (20 km). Simultaneously, the optimization algorithm exhibited a high efficiency and robustness such that the error ratio is less than 3.1%, 3.2%, 3.4% and 4.2% for Raman fiber length 8, 12, 16 and 20 Km respectively.

In the future work, different pump configurations can be used with the same optimization algorithm and be comparing their results to end up with the best design of the pumping lasers of Raman amplifier.

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