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Optimal Design of Flat – Gain Wide-Band Discrete Raman Amplifiers

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***Abstract*—**In this paper, a wide band gain–flattened discrete Raman amplifiers utilizing four optimum pump wavelengths is demonstrated. The pump optimization enabled a gain flatness of less than 0.5dB.

***Keywords*—**Fiber Raman Amplifiers, Optimization, Wave Length Division Multiplexing.

I. Introduction

THE capacity of wavelength–division-multiplexed (WDM) systems is limited by the gain bandwidth of erbium–doped fiber amplifiers (EDFAs). Multiple-pump fiber Raman amplifiers (FRAs) can increase the transmission bandwidth. Moreover Raman amplifiers have better noise performance than EDFAs because the amplification is distributed. While multiple pumps can be used to equalize gain over a large bandwidth, it has been a challenge to design FRAs with flat gain [1]. Recently, six pump power has been used to obtain gain flatting [2]. In this paper optimization procedure chooses optimal pump power for four pump power in order to achieve the best possible gain flatness over 82nm signal bandwidth from 1530nm wavelength for discrete Raman amplifiers. In this paper average power model with better resolution, accuracy, and stability is used which includes pump-pump interactions, Rayleigh Backscattering, and spontaneous Raman scattering to simulate discrete Raman amplifiers (DRA).

II. Theory of Multiple Backward-Pumped Raman Amplifiers

On advantage of Raman amplification is improving gain flatness, it is important that all signal wavelengths have similar optical powers, a flat spectral profile obtained by using multiple pump wavelengths [3]. A more general equation for stimulated Raman scattering in the presence of multiple wavelengths and noise is written as [4]:

$$\frac{dP_f(z,\upsilon)}{dz} = \propto(\upsilon)P_f(z,\upsilon) + \gamma(\upsilon)P_b(z,\upsilon) + P_f(z,\upsilon)\sum\nolimits_{\upsilon<\varsigma}\frac{g_r(\upsilon-\varsigma)}{K_{eff}A_{eff}}\left[P_f(z,\varsigma)+P_b(z,\varsigma)\right] +$$

$$h\Delta\upsilon\sum_{\upsilon<\varsigma}\frac{g_r(\upsilon-\varsigma)}{A_{eff}}\left[P_f+P_b\right]\left[1+exp([h(\varsigma-\upsilon)/KT]-1)^{-1}\right] -$$

$$P_f(z,\upsilon)\sum\nolimits_{\upsilon}\frac{g_r(\upsilon-\varsigma)\upsilon}{K_{eff}A_{eff}}\left[P_f(z,\varsigma)+P_b(z,\varsigma)\right] -$$

$$2h\Delta\upsilon P_f(z,\upsilon)\sum_{\upsilon>\varsigma}\frac{g_r(\upsilon-\varsigma)}{A_{eff}}\left[1+(exp([h(\upsilon-\varsigma)/KT]-1)^{-1}\right]$$

Where υ, ς frequencies (HZ), $\alpha(\upsilon)$ is fiber attenuation (N/m), $\gamma(\upsilon)$ is Rayleigh backscattering coefficient(N/m), $g_r(\upsilon-\varsigma)$ is Raman gain coefficient frequency difference(m/W), $P_b(z,\upsilon)$ is Backward propagating power (W), A_{eff} is effective core area (m^2), K_{eff} is polarization factor, $\Delta\upsilon$ is frequency interval, h is blanck constant, k is Boltzmann constant, and T is temperature in (K).

In this model, pump-to-pump, pump-to-signal, and signal-to-signal Raman interactions, Rayleigh backscattering, fiber loss, spontaneous Raman emission noise, and noise due to thermal phonons are included.

III. Simulation and Optimization Process

Fig. 1 shows the simulation layout of discrete Raman amplifier (10km) comprising four–wavelength WDM pumping, the transmission fiber was counter-pumped to give 82nm flat gain from 1530nm to 1562nm. The number of WDM signals is assumed to be 40 channels in the range from 1530nm to 1562nm with 102-GHZ spacing. The spectral data of the Raman gain efficiency, attenuation coefficient and Rayleigh backscattering coefficient is illustrated in Fig. 2.

Name	Value	Units	Mode
Length	10	km	Normal
Attenuation data type	Constant		Normal
Attenuation	0.2	dB/km	Normal
Raman gain type	Raman gain efficiency		Normal
Temperature	300	K	Normal
Polarization factor	2		Normal
Rayleigh back scattering d	Constant		Normal
Rayleigh back scattering	2.349e-025	1/km	Normal

Fig. 2 List of parameters used in the simulation

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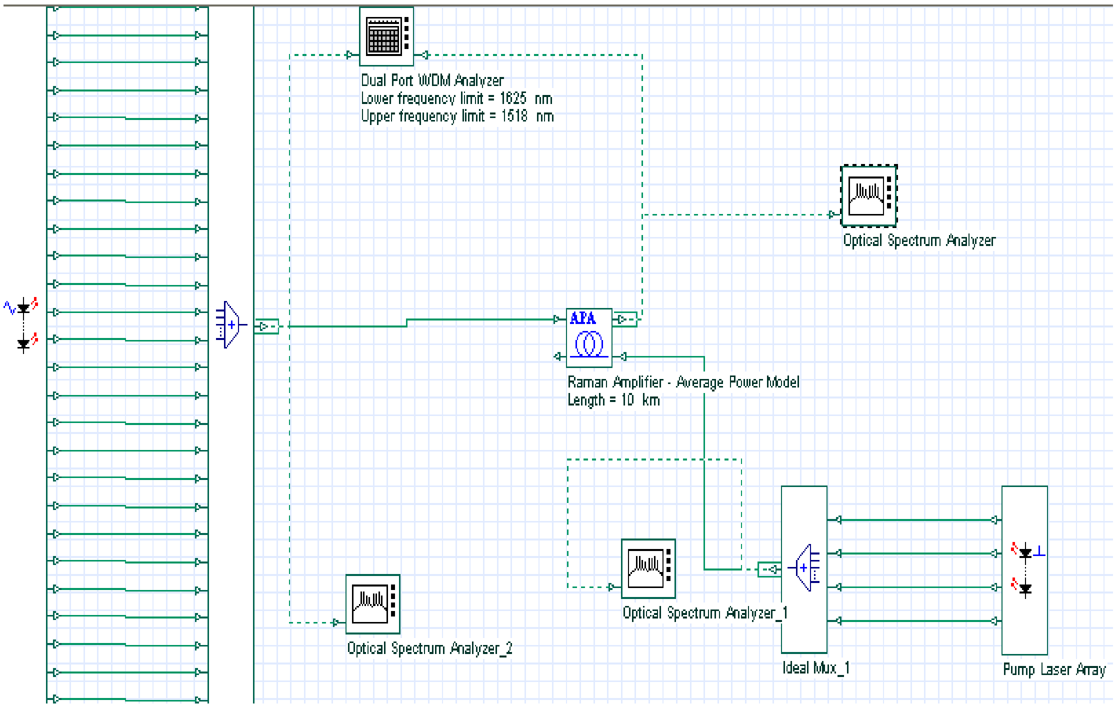

Fig. 1 Simulation layout of the discrete Raman amplifier comprising four wavelengths WDM pumping

Fig. 3 plots the Raman gain spectra for total input signal power of -30dBm before and after optimization, the pump powers of the pumping wavelengths are fixed before optimization which are (375mw, 167mw, 99mw, and 71mw) for (1424nm, 1438nm, 1466nm, and 1495nm) pump wavelengths, respectively. The Raman amplifier is able to achieve a relatively flat gain across the entire signal spectrum after optimization of the pump powers; this is because of interpump Raman amplification in which the short wavelength pumps amplify the long wavelength pumps.

Table I shows the values of the pump powers after optimization.

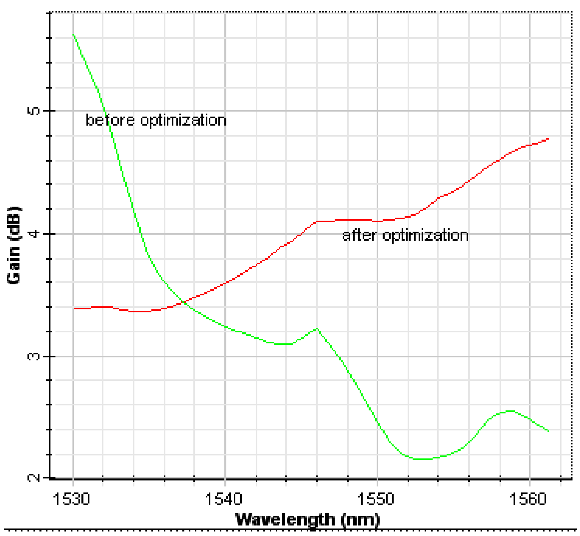

Fig. 3 Gain spectrum before and after optimization

TABLE I
VALUES OF OPTIMIZED PUMP POWERS

Name	Value	Units
Power[0]	99.86070887589	mW
Power[1]	70.007	mW
Power[2]	397.2352188633	mW
Power[3]	70	mW

Figs. 4 and 5 show the output signal spectrum, gain, and noise figure before and after optimization, it is seen that after optimization of the pump powers the power of the signal wavelength remain the same for the entire signal wave length, also optimization yields a gain ripple of 0.5dB as shown in Table II.

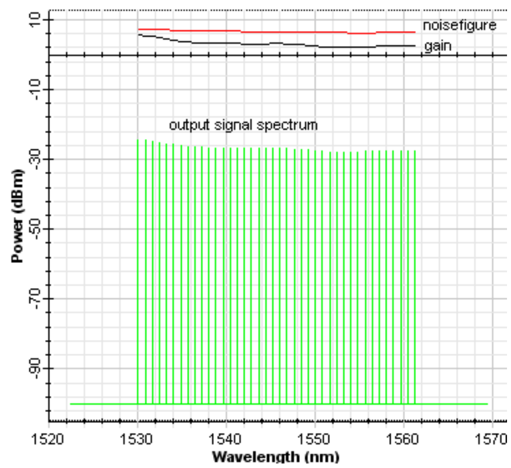

Fig. 4 Output signal power, gain and noise figure relative to the signal wavelength after optimization

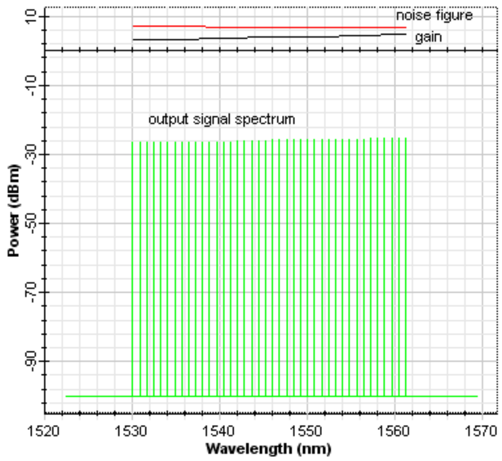

Fig. 5 Output signal power, gain and noise figure relative to the signal wavelength after optimization

TABLE II
FLATTENED VALUE OF GAIN AFTER OPTIMIZATION

Frequency (THz)	Gain (dB)	Noise Figure (dB)
192.027	4.7684685	6.85274
192.125	4.7389999	6.85837
192.224	4.7082665	6.86185
192.323	4.668641	6.86126
192.421	4.6105443	6.85909
192.52	4.5445203	6.85738
192.619	4.4633389	6.85747
192.718	4.3888217	6.85979
192.817	4.3342138	6.86838
192.917	4.2875044	6.8671
193.016	4.2199984	6.86654

IV. CONCLUSION

In this paper a discrete Raman amplifier for 40 channel WDM system with four laser pumps are optimized, the resulted gain ripple is 0.5dB for the entire signal wavelengths. The value of optimized pump powers are (99.8mw, 70mw, 397.23mw, and 70mw) for pump wavelengths (1424nm, 1438nm, 1466nm, and 1495nm) respectively.

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