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The effect of fiber length and signal power on the flattened gain Raman amplifier

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تأثير طول الليف البصري وقدرة الإشارة على قيمة الربح ذو الشكل المسطح في مكبرات رامان

الخلاصة :
يمنح مكبر رامان طيف للمكسب يمكن تنظيمه من ناحية سعة الإشارة الموضع ومن ناحية شكل طيف المكسب.
في هذه الدراسة تم التحري عن مكسب رامان عندما يتم الضخ بالاتجاه المعاكس للإشارة باستخدام اثنا عشر ليزر للضخ واختيار قدرة ضخ مثالية للحصول على مكسب بعرض نطاق سعته ٩٤ نانومترمحصور بين الترددين ١٥٢٠ و ١٦١٤ نانومترحاوي على ١٠٠ قناة للاتصال بفاصل ٠.٩٤ نانومتر بين كل قناتين وبربح اضافي قدره ١.٢٨ دسبل حاوي على ترددات النطاقين L و C وبطول ليف قدره ٢٥ كم.
تمت دراسة تأثير طول الليف على تسطح حزمة المكسب كما تم تحليل حالة الاشباع في المكسب.

Abstract:
Raman Fiber Amplifiers offer an adjustable gain spectrum in terms of band width ,gain window and gain spectrum shape ,thus the composite Raman gain can be very flat over a wide band In this work an investigation on Raman gain with backward pumping is introduced using twelve pump lasers with optimum pump power to produce gain flattened for 94 nm band width from 1520 to 1614 nm that contains 100 equal spaced channels, with again ripple of 1.28dB which contain the C-and L-band. Over 25 Km span. Then the effect of fiber length on the gain flatting were introduced and the gain saturation have been analyzed.

Keywords: Raman amplifier, Gain ripple, gain, noise figure, backward pumping

1. Introduction
It is well known that erbium-doped fiber amplifiers operating at 1.55 μm was highly effective in optical telecommunication systems [1]. Because the gain bandwidth of erbium-doped fiber amplifiers (EDFA) is much narrower than the low loss window of standard optical communication fibers, there is growing interest in wideband flat-gain optical fiber amplifiers (OFAs) to exploit more of the available fiber bandwidth and increase the capacity of wavelength division multiplexing (WDM) systems [2]. The fiber Raman optical amplifier is quickly emerging as an important part of long-distance, high-capacity, and high-speed optical communication systems. The decreasing cost of high-

power semiconductor Lasers and the increasing need in optical fiber transmission for more gain bandwidth, lower gain-ripple, and lower noise figures make Raman amplifiers a more attractive technology than the traditional erbium-doped fiber amplifiers[3,4].It can amplify photonic signals at any wavelength by arranging suitable pump source[5]. Pumps used for Raman amplification may be constructed from semiconductor laser diodes or all fiber lasers. Raman amplifier uses the stimulated Raman scattering (SRS) phenomenon, where a strong pump laser at shorter wavelength provides gain to signals at longer wavelengths [6]. In order to construct a Raman amplifier using optical fiber as a gain medium, pump and signal light waves have to be jointly launched into the same fiber for stimulated Raman scattering. As stimulated Raman scattering occurs almost uniformly for all the orientations between the pump and signal propagation direction, this is due to the fact that fiber Raman amplifiers can work both for the counter-propagating and co-propagating pump with respect to the signal [7]. Recently, multiple pump lines can be used to increase the optical bandwidth, and the pump distribution determines the gain flatness [8]. However, the case of multi-wavelength pumps cannot be easily implemented because of the complicated response due to pump-pump, pump-signal and signal–signal Raman interactions [9].

2. THEORY:

Raman amplifier uses the stimulated Raman scattering (SRS) effect in an optical fiber cable, where a strong pump laser at shorter wavelength provides gain to signals at longer wavelengths [10]. A number of factors should be considered while designing a Raman amplifier with multi-wavelength pumps for DWDM systems, which include pump-to pump power transfer, signal-to-signal power transfer, pump depletion, Rayleigh back-scattering, and amplified spontaneous emission (ASE) noise in which loss due to noise emission is described [11]:

$$
\begin{aligned}
\frac{dP_f(z,\nu)}{dz} &= -\alpha(\nu)P_f(z,\nu)+\gamma(\nu)P_b(z,\nu) \\
&\quad +\sum_{\nu\prec\zeta}\frac{g_r(\nu-\zeta)}{A_{eff}}[P_f(z,\zeta)+P_b(z,\zeta)]P_f(z,\nu) \\
&\qquad +2h\nu\frac{g_r(\nu-\zeta)}{A_{eff}}[P_f(z,\zeta)+P_b(z,\zeta)] \\
&\qquad .[1+\frac{1}{\exp(h|\zeta-\nu|/KT)-1}] \\
&\quad -\sum_{\nu\prec\zeta}\frac{g_r(\nu-\zeta)}{A_{eff}}[P_f(z,\zeta)+P_b(z,\zeta)]P_f(z,\nu) \\
&\qquad +2h\nu\frac{g_r(\nu-\zeta)}{A_{eff}}[P_f(z,\zeta)+P_b(z,\zeta)] \\
&\qquad .[1+\frac{1}{\exp(h|\nu-\zeta|/KT)-1}] \qquad \text{……….. (1)}
\end{aligned}
$$

Where $P_f(z,\nu),\ P_b(z,\nu)$ are the forward and backward signal power at frequency ν, respectively, $P_f(z,\zeta), P_b(z,\zeta)$ are the forward and backward pump power at frequency ζ ,α(ν) and γ(ν) are optical loss and Rayleigh scattering coefficients of the fiber at the frequency ν, h is Planck's constant, K the Boltzmann's constant, A_{eff} is the effective interaction area and T the absolute temperature of the medium, while $g_r(\nu-\zeta)$ denotes the Raman gain coefficient between the two frequency components when one at ν gives power to the other one. The terms having a Bose-Einstein distribution are due to ASE in Raman amplifiers and contribute to noise.

3. Results and Discussion

The data, as presented in this work, is obtained by numerical simulations using optisystem 8.0. we designed backward-pumped fiber Raman amplifiers with 25 km length, twelve pumps are injected via DWDM in the right end of the fiber, and signals propagate in the opposite direction to the pumps as shown in fig 1 . The input signal power of 100 WDM channels was -10 dBm/ch, the wavelength range is 1520 nm ~ 1614nm, the channel spacing are equal, and the pump lasers operated with wavelengths (1405, 1412.5, 1420, 1427.5, 1435, 1442.5, 1450, 1457.5,1465,1480, 1495, and 1510) nm.

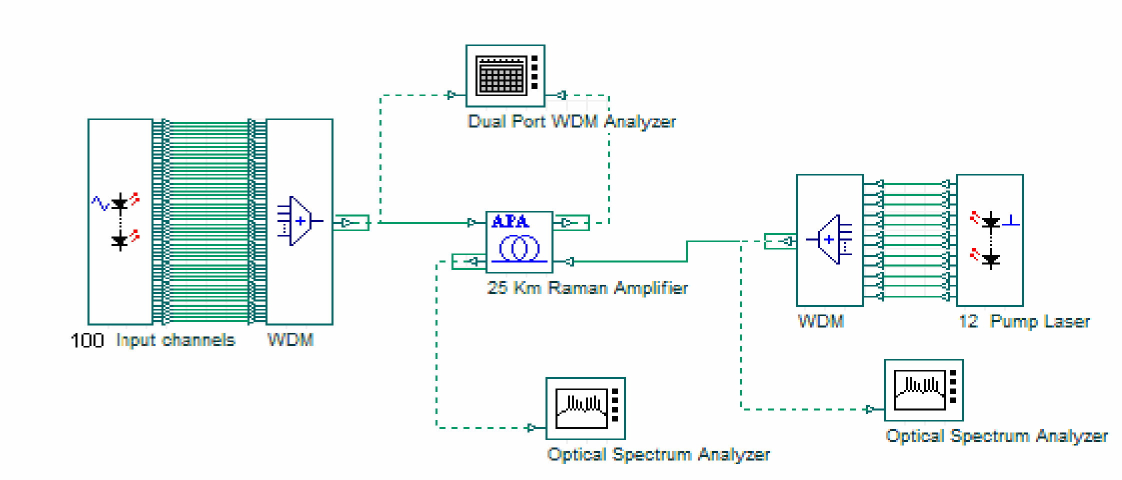


Figure (1): Schematic diagram of backward Raman amplifier

3.1 Gain flattening:

The primary calculations of Raman amplifier was with a twelve backward pumps, pump power of 100mw per pump is chosen.

Figure (2) shows the behavior of pump power with 100 mw on gain spectrum. When it uses individually they produce small gain (a). But if they act together with the same pump power it's seen that the significant amount of gain with 6.7 dB tilt comes from the longest wavelength pump as shown in curve (b). This is because of the inter pump Raman amplification in which the short wavelength pumps amplify the long wavelength pumps (pump –pump interaction),

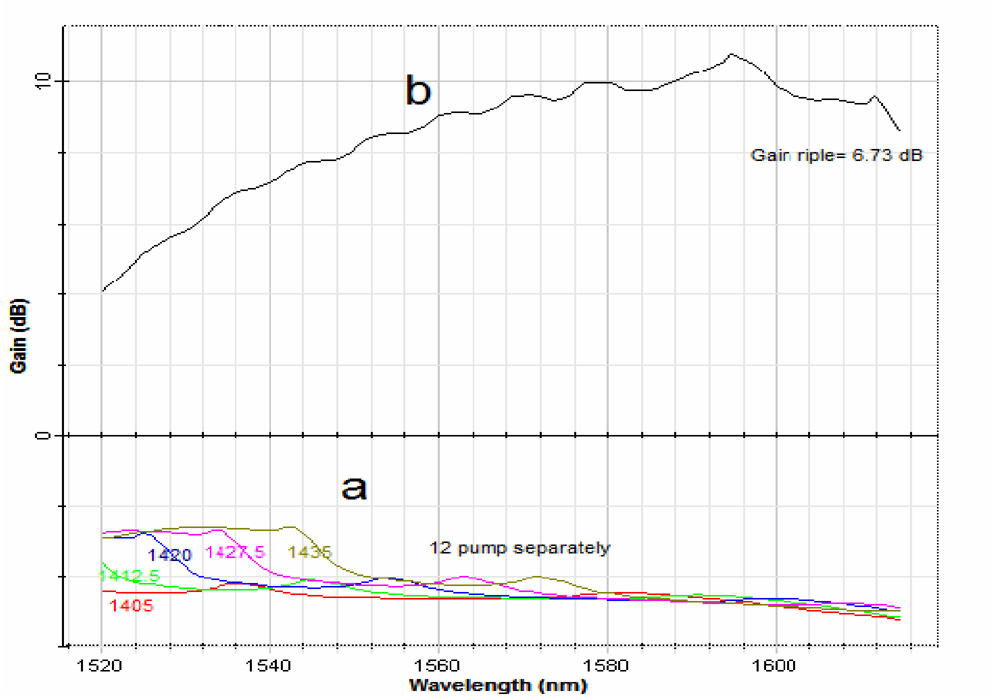


Figure (2) gain characteristic for 12 backward pumps with 120 mw for each pump. (A) individual pumps, (B) the resultant gain with pump-to-pump interaction

To reduce the gain ripple the optimum value of pump powers is determined by the simulation program as shown in the below table.

Table (1) optimized pump power data

W(nm)	1405	1412.5	1420	1427.5	1435	1442.5	1450	1457.5	1465	1480	1495	1510
Power (mw)	195	190	185	160	85	90	75	70	65	35	17	55

It is clear from table 1 that the power of shorter wave length pumps is greater than the power of the longer wavelength pumps because the long wavelength pumps amplify the short wave length pumps as the radiation propagate along the fiber

Figure 3 shows the gain figure for the optimized pump scheme. It is obvious that a better peak-to-peak gain ripple of 1.28dB over C+L band was obtained.

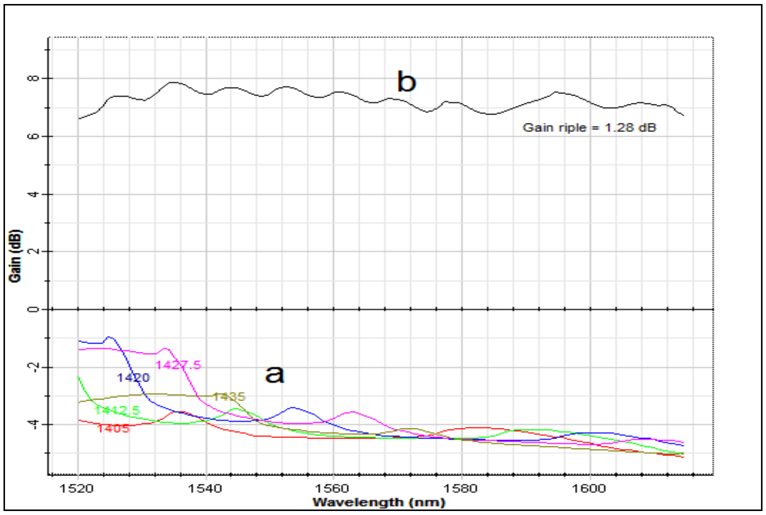


Figure (3) : Gain characteristic for 12 backward pumps with optimum powers, (a) Gain for individual pumps, (b) the resultant gain with pump-to-pump interaction.

In figure(4) the shape of noise figure is significantly tilted ,and it tends to be worse at shorter wavelengths this phenomenon mainly arise from pump-to-pump Raman interaction and double Rayleigh back scattering which is large at short wave length tends to increase the noise in Raman amplifier at shorter wavelength , to solve this problem we must use co-propagating pump configuration for short wave length pumps, However the co-propagating pump has lower noise than the counter-propagating pump, the noise of the co-propagating pump will transfer to the signal. in other word the longer wavelength signal Channels, which receive more gain from the longest wavelength pump will have a gain that is more evenly distributed along the length of the fiber and hence better NF than that of the shorter wavelength. However we compare the gain ripple between the initial design and the optimal design

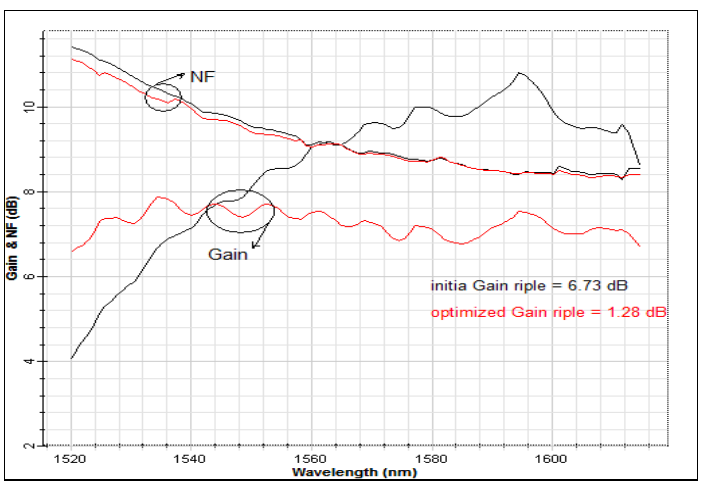


Figure (4) Gain and NF characteristic for 12 backward pumps with optimum and individual powers

3.2 Effect of amplifier length on gain &NF

Figure 5 and 6 show the characteristic of gain and noise figure spectra for different amplifier lengths

Figure 5 shows the characteristic of gain for different amplifier lengths. It's clear that the value of the gain changed at different fiber lengths. By increasing the fiber length, gain of shorter wavelength channels is slightly increasing but for longer wave lengths the gain improvement is more pronounced. because along the amplifier length the power transfer from short wavelength pump to long wavelength pump this cause more gain in longer wavelength channels and less gain in shorter one.

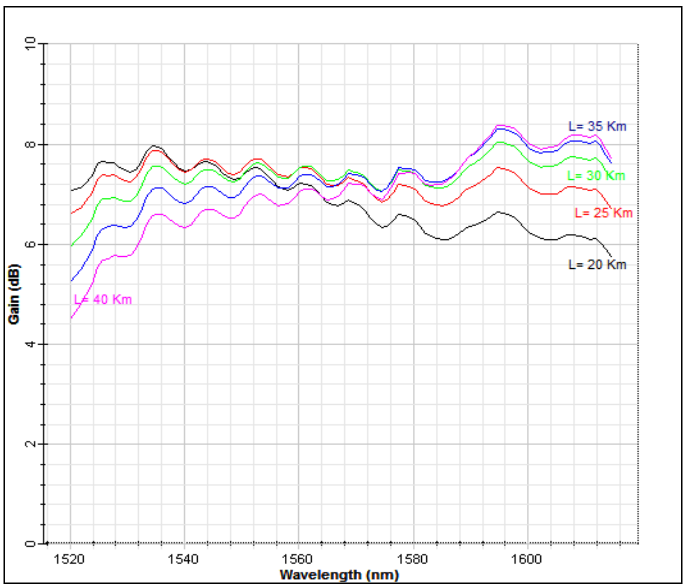


Figure (5) Gain characteristic for different fiber length

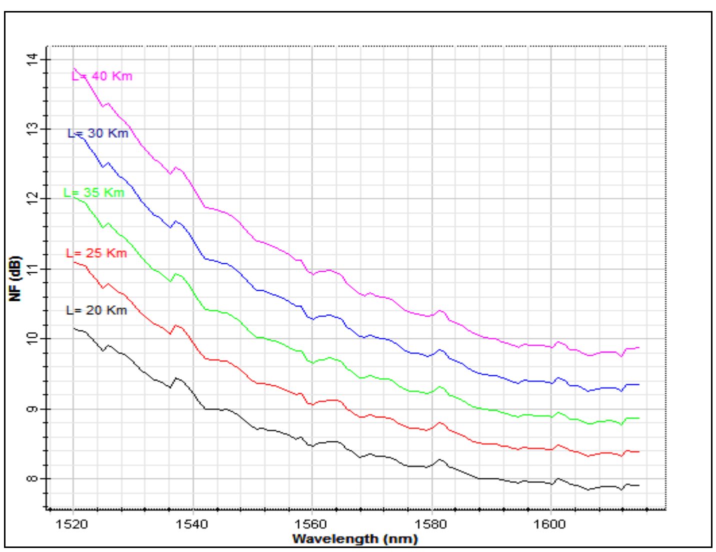


Figure (6) Noise figure characteristic for different fiber lengths.

Figure.6 shows that by increasing the fiber length NF increased. This is due to the effect of the length of the amplifier on the efficiency and spontaneous noise performance. Another possible explanation is that for the longer fiber length double Rayleigh scattering DRS noise become worse and for shorter fiber lengths the DRS noise performance improves rapidly as the fiber length is decreased [12]

3.3 Effect of signal power (Ps) on gain &NF:

Gain saturation is characterized by a reduction of the gain with increasing input signal power in the amplifier [13]; Figure.7 shows the gain characteristics of the Raman amplifier for different signal input powers, where the pump powers are maintained under the same conditions. It can be seen that gain was saturated with decreasing the signal power, this is due to that at high signal power the amplified signal intensity become so high since it lose its power as a result of higher order stokes generation. further more the Stimulated Brillion Scattering(SBS) induce output signal power loss[14]. This saturation has almost no wavelength dependence. Another important thing is that by decreasing the signal power to (-24 dBm), the gain remains almost unchanged. . Consequently by increasing the input power the NF increased.

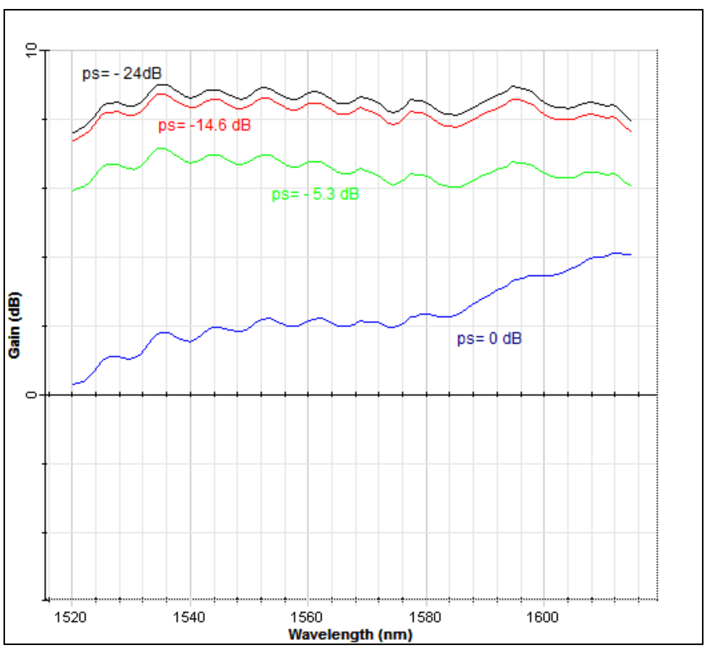
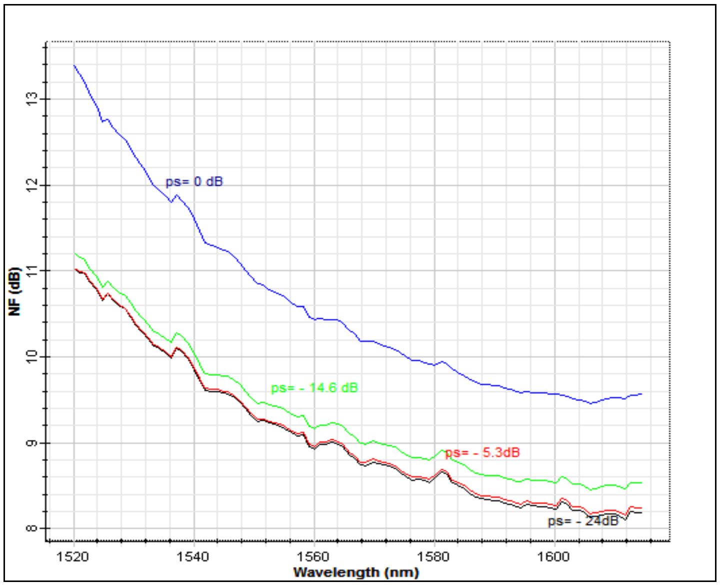


Figure (7) Gain characteristics for four different input signal powers (Ps).

Figure.8 shows the noise figure characteristic for different signal powers, its clear that NF increase by increasing the signal power.



Figure(8) Noise figure characteristics for different input signal powers (Ps).

4. Conclusion:

the results presented for finding the optimal pump power spectrum for the best flattening Raman gain with 94nm in C+L communication band, by using 12 pumps in backward configuration with 100 WDM signal channels. It was found that the gain increased by decreasing the input power of the signal, but the noise figure was found to increase with increasing the input power of the signal. We demonstrated that to avoid gain saturation the input power of the amplified signals must be controlled. The Noise figure was increased by increasing Raman amplifier length and the shape of the gain contour was distorted, which reveal the fact that for each length there is optimal set of pump power spectrum to obtain flattening gain.

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