# Broadband Lossless Dispersion Compensating Fiber

M. R. X. de Barros, J. B. Rosolem, M. L. Rocha, A A Juriollo, M. R. Horiuchi
mbarros@cpqd.com.br - phone 19 3705.6163 - fax 19 3705.6119
*CPqD, Rodovia Campinas-Mogi Mirim, km 118, Campinas, SP, 13086-902 Brazil*

**Abstract: We demonstrate a broadband low loss dispersion compensating fiber, using Raman amplification. The device is optimized for the L and L+ bands. Only two pump sources have been used. Pump power and pump wavelength are varied in order to reduce and flatten the dispersion compensating loss. This device should prove useful for upgrading bit rate of WDM systems.**

## I - Introduction

Dispersion compensation fibers (DCF) are the usual solution to compensate for chromatic dispersion when upgrading the bit rate of installed DWDM transmission systems [1]. However, DCFs present high loss (~0.5 dB/km @ 1550 nm), imposing power budget limitations for the bit rate upgrade. In the L and L+ bands (1570-1610 and 1610-1650 nm), the DCF loss is even higher than for the C band, in such a way that we have an unequal loss over the three bands.

It has been demonstrated recently that the dispersion compensating unit loss can be compensated by using Raman amplification in the DCF[2]. Due to its small effective area (~25 $\mu m^2$), this fiber provides very high Raman gain [3],[4].

Recently many configurations of dispersion compensating Raman amplifiers have been demonstrated [5]-[11]. Most of them either cover a single wavelength band (C or L band), or use compex pumping schemes and multiple amplification stages in order to reduce the DCF loss over a wide bandwidth.

We present here an element, which provides dispersion compensation over the L and L+ bands with low flat loss, obtained by Raman pumping the dispersion compensating fiber. A simple pumping scheme composed by two lasers is used. The gain flatness was optimized by tuning one of the pump sources and adjusting the power level of the second source. We have measured on-off gain, effective noise figure, and reduced attenuation for three different dispersion compensating fibers which were Raman pumped.

## II – Experimental Setup

The schematics of the broadband dispersion compensating fiber is shown in figure 1. The DCF is backward pumped by two different sources. One pump source is a tunable erbium doped ring laser. This laser can be tuned over the entire erbium wavelength band, but the WDM coupler used to launch it into the DCF limits its tunability to the range between 1527 and 1539 nm. The second pump source is a commercial cascaded Raman laser (a double clad fiber laser pumped by an array of multimode pump modules) at the wavelength of 1480 nm. A WDM coupler was used to couple light from this source into the DCF, while measuring the output spectrum by using an OSA.

The backward pump configuration was selected because it provides higher gain and lower noise than the forward pump configuration, as observed in previous experiments. [11]

We have performed gain measurements using three different DCF´s. The dispersion of the DCF´s are -700, -900 and -1600 ps/nm.

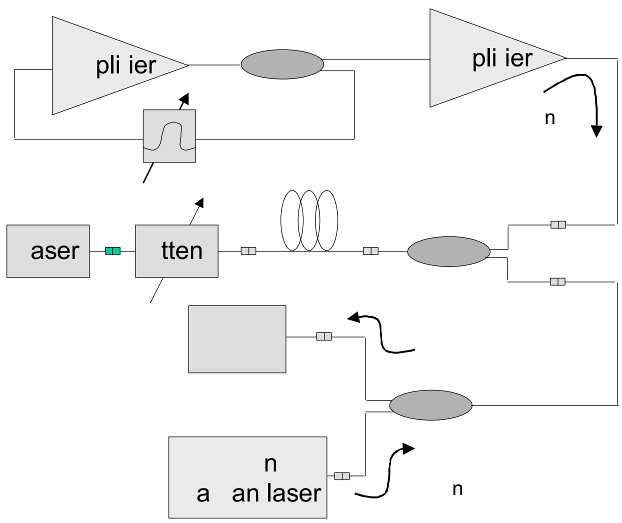


Figure 1 – Schematic diagram of the broadband dispersion compensating Raman amplifier pumped by two lasers, an erbium doped fiber laser and a Raman.

In order to optimize the gain width and flatness, two parameters were varied, pump wavelength of the first source and pump powers of both sources.

## III - Results and discussion

Figure 2 shows the On/off gain and effective noise figure curves measured for the –900 ps/nm DCF. The curves were obtained by tuning the signal wavelength. Each curve was obtained for a different erbium pump laser wavelength, 1527, 1533 and 1539 nm. The pump power for both pump sources was kept at 21.5 dBm.

The two peaks observed in the on-off gain curve are associated to the pump wavelengths. The peak centered at 1590 nm is due to the 1480 nm pump and the peak on the right side changes depending on the second pump, ranging approximately from 1630 to 1650 nm. As a consequence, the wider on/off gain is obtained for pump wavelengths more wide apart, 1480 and 1539 nm. However, wider gains imply in reduced flatness.

Due to the broadband nature of Raman gain, both pump sources contribute to the gain in both peaks. The evidence for this is that the on-off gain in the 1590 nm peak decreases as we tune the long wavelength pump source to even longer wavelengths.

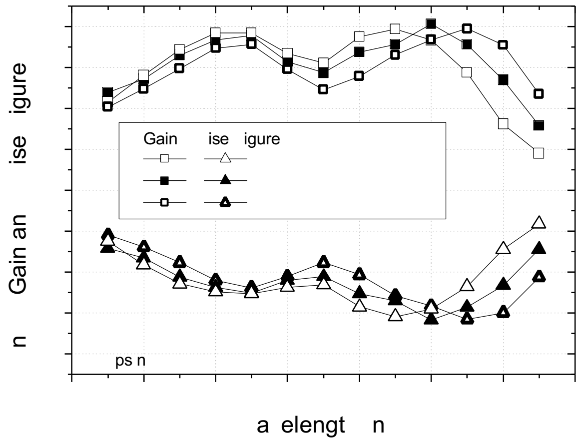

Figure 2 – On/off gain and effective noise figure for the –900ps/nm DCF, keeping one pump wavelength fixed at 1480 nm and tuning the other (1527, 1533 and 1539 nm). Both pump power levels are 21.5 dBm for all three curves.

Figure 3 shows the on/off gain and effective noise figure curves obtained by varying the pump powers. In these measurements, the pump wavelengths were kept at 1480 and 1539 nm. Each curve in this figure correspond to one of the three power level conditions: 21.5 dBm for both wavelengths, 21.5 dBm for 1539 nm, 24.5 dBm for 1480 nm and 24.5 dBm for both wavelengths.

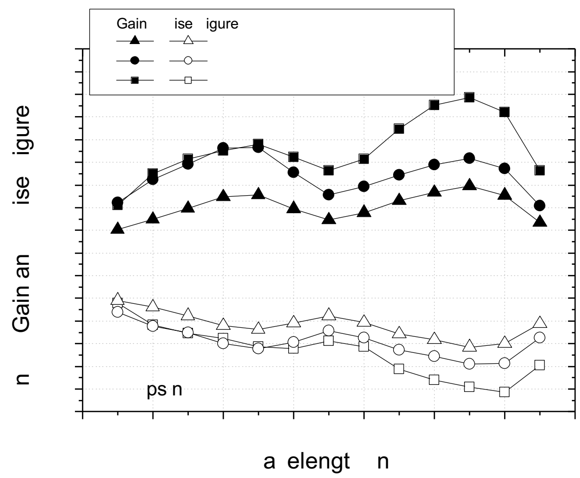

Figure 3 – On/off gain and effective noise figure for the –900 ps/nm DCF, keeping both pump wavelengths fixed at 1480and 1539 nm and varying pump powers. ▲ 21.5 dBm for both wavelengths, ● 21.5 dBm for 1539 nm and 24.5 dBm for 1480 nm, ■ 24.5 dBm for both wavelengths.

We observe that when we increase the short wavelength pump power, both gain peaks increase. And when we increase the long wavelength pump power only the long wavelength gain peak increases significantly. This difference is associated to the fact that light generated around 1590 nm provides Raman gain around 1650 nm.

We have measured the on/off gain and effective noise figure curves for –700 and –1600 ps/nm DCFs and they present similar trends as for the –900 ps/nm DCF.

Figures 4, 5 and 6 show the effect of the Raman gain on the DCF attenuation in the L and $L^+$ bands. The three DCF´s measured have total dispersion of -700, -900, and -1600 ps/nm. In each figure, we show the loss of the DCF alone and the new reduced loss by Raman pumping them.

For the three DCFs, the wavelengths and pump power selected are 1480, 1539 nm and 24.5 dBm for both wavelengths. The higher gain at 1650 nm is necessary to compensate for the high coupler attenuation in the $L^+$ band.

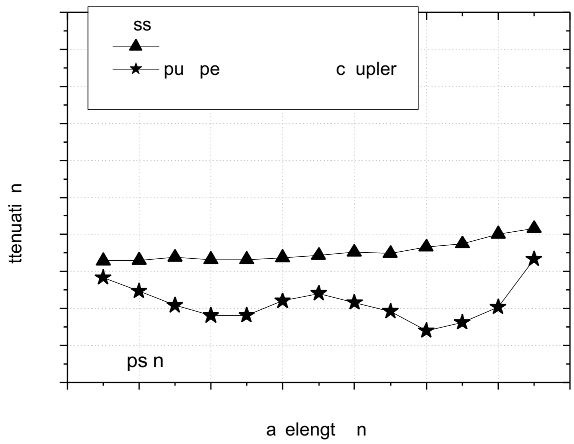

Figure 4 - Attenuation with and without the Raman pump for the DCF with -700 ps/nm.

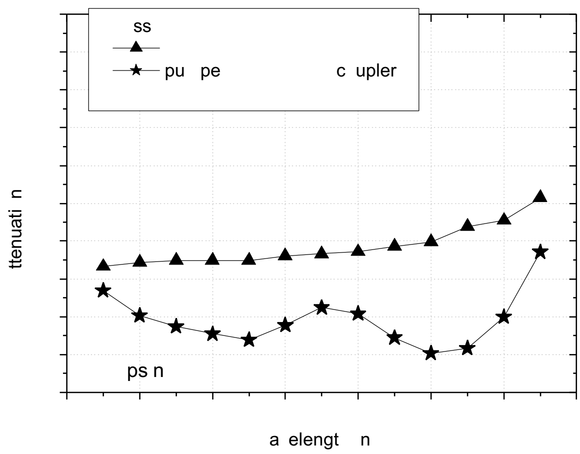

Figure 5 - Attenuation with and without the Raman pump for the DCF with –900 ps/nm.

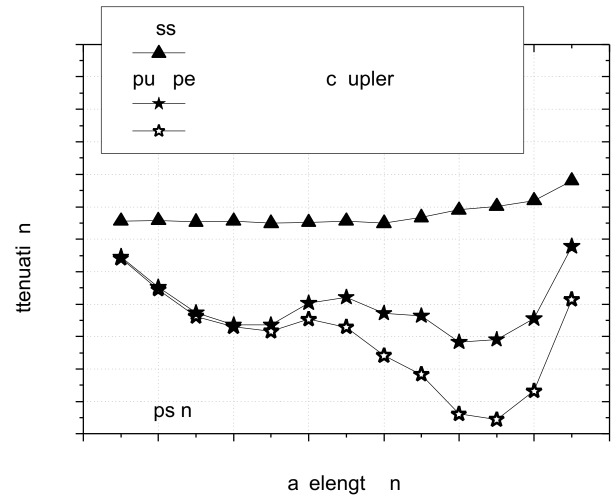

Figure 6 - Attenuation with and without the Raman pump for the DCF with -1600 ps/nm.

Over the bandwidth measured, the attenuation ranges for the -700, -900 and -1600 ps/nm DCFs are 5 to 9 dB, 5 to 13 dB and 10 to 15 dB, respectively.

We observe that in all cases the Raman gain brings the attenuation to a level near 0 dB, making the device lossless over a bandwidth of approximately 100 nm, including L and $L^+$ bands. Depending on the wavelength range, negative attenuation is measured, which corresponds to a positive net gain.

In particular for the -1600 ps/nm DCF, the net gain obtained can be as high as 14 dB in the $L^+$ band, when the power level of both pump sources is 24.5 dBm. However, the best condition to obtain flatness is with pump power levels 24.5 dBm at 1480 nm and 21.5 nm at 1539 nm.

## IV - Conclusions

We have demonstrated a broadband low loss dispersion compensating fiber, using Raman amplification. The device was optimized to cover the L and $L^+$ bands and only two pump sources were used to provide a reasonable flat spectrum. Three different dispersion compensating fibers were Raman pumped and had their attenuation brought down to near 0 dB over 100 nm bandwidth. The broadband lossless dispersion compensating fiber should prove a useful element for upgrading bit rate of WDM systems.

## Acknowledgements

The authors would like to acknowledge Funttel for financial support of this research.

## References

[1] Massimo Artiglia, "Upgrading installed systems to multigiga bit-rates by means of dispersion compensation", European Conference in Optical Communications ECOC'96, paper MoB.4.1 (1996).

[2] P.B Hansen, G. Jacobovitz-Veselka, L. Grüner-Nielsen and A. J. Stentz, "Raman amplification for loss compensation in dispersion compensating fibre modules", *Electronics Letters*, 34, 11, pages 1136 – 1137, (1998).

[3] M. L. Rocha, M. R. X. de Barros, J. B. Rosolem, M. R. Horiuchi, M. A. D. dos Santos and A. A. Juriollo, "L-band distributed Raman amplification using a bi-directional C-band Erbium-doped fiber laser pumping scheme", $19^{th}$ SBrT (2001).

[4] V. L. da Silva and J.R. Simpson, "Comparison of Raman efficiencies in optical fibers", *Proceedings of Optical Fiber Communication Conference*, 1994, paper WK13, 1994.

[5] Y. Emori, Y. Akasaka, S. Namiki, "Broadband lossless DCF using Raman amplification pumped by multichannel WDM laser diodes", *Electronics Letters*, V. 34, N. 22, pages 2145 – 2146, 1998.

[6] Y. Emori, S. Matsushita, S. Namiki, "Cost-effective depolarized diode pump unit designed for C-band flat-gain Raman amplifiers to control EDFA gain profiles", Optical Fiber Conference'2000, paper FF4 (2000).

[7] Y. Emori, S. Namiki, "Broadband Raman amplifier for WDM", IEICE Trans. Electron., E84-C, 5, 593 (2001).

[8] W.-Y Oh, S.-S. Lee, H. Lee, W. Seo, "16-channel C-band hybrid fiber amplifier comprising an EDFA and a single diode laser pumped dispersion compensating Raman amplifier", European Conference on Optical Communications, ECOC'2000, paper 4.4.5 (2000).

[9] S. Kinoshita, K. Otsuka, T. Chikama, "Raman amplification of dispersion compensating fiber for loss reduction and enlargement of WDM wavelength range", 2nd Optoelectronics and Communications Conference OECC '97, p.412-13, (1997).

[10] S.A.E. Lewis, S.V. Chernikov, J.R. Taylor, "Broadband high gain dispersion compensating Raman amplifier", Optical Fiber Conference OFC´00, paper TuA2, (2000).

[11] M. R. X. de Barros, M. L. Rocha, J. B. Rosolem, M. R. Horiuchi, "Dispersion Compensating Raman Amplifier for the L-Band", $19^{th}$ SBrT, 2001.