OFC '93 655

Erbium doped fibre amplifier with passive spectral gain equalization

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Abstract

We have demonstrated automatic spectral gain equalization due to spatial hole-burning in an erbium doped twincore fibre. Gain equalization rates up to 0.11dB per dB difference between input signal levels are demonstrated and should increase the useful bandwidth of cascaded amplifiers.

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The erbium-doped fibre amplifier (EDFA) is attractive for wavelength division multiplexing (WDM) networks owing to its high gain, low noise and low crosstalk. The 3dB gain bandwidth of EDFAs is typically 3-8nm but can be increased to ~30nm with appropriate techniques[1]. However, in these cases the gain band is not flat exhibiting a small ripple (~ ±1dB). Combined with wavelength dependent losses in the transmission fibre and optical components in the link such variations limit the number of amplifiers that can be cascaded before a significant difference in signal level develops between channels. Ideally the signal levels should be actively[2] or passively compensated after each amplifier to equalize all channels.

The gain available in EDFAs saturates with increasing input signal and provides a self limiting mechanism for the amplifier. However, Er^{3+} in silica based optical fibre is predominantly homogeneously broadened[3] thus the gain spectrum decreases relatively uniformly even if one input signal is substantially larger than the others and no significant spectral gain compensation occurs.

In this paper we demonstrate an effective increase in inhomogeneous broadening in an EDFA by spatial hole-burning. The gain medium is a doped twincore fibre configured such that the intensity of signal light is modulated periodically along its length with period approximately proportional to wavelength. The population inversion in the gain medium, and thus the local gain, is reduced at the peaks of the intensity distribution. The net amplification is a function of the product of the signal intensity at a given point and the population inversion at that point. Since the intensity distribution of separate signal wavelengths differs their gains will be partially decoupled. Thus for the case when one signal is larger than the others spatial hole-burning will preferentially decrease its gain resulting in spectral gain equalization.

The experimental configuration is shown in figure 1. The amplifier consisted of two sections of EDF. The first to boost input signal levels was a 14m length of germano-alumino-silica doped fibre with NA of 0.2, λ_{cutoff} of ~930nm and absorption at the signal wavelength of ~3dB/m. The output was spliced to one core of a 10m length of doped twincore fibre. The twincore was fabricated such that both cores were identical with an index difference, Δn of 0.0258 and core radius and separation of 1.43 and 4.5μm respectively. The resulting coupling length is wavelength dependent and estimated to be 1.26mm at a wavelength of 1.55μm. The absorption at the signal wavelength was ~ 1dB/m. The output from two signal lasers was employed to probe the amplifier gain simultaneously at two closely spaced wavelengths and investigate spectral gain equalization.

Figure 2 shows the amplifier saturation characteristics for the two channels in the new amplifier. Here the pump power is ~50mW at 978nm, signal A input power is held constant whilst signal B input power is increased. The wavelength separation of the lasers is 1nm, close to the gain peak at 1531.2nm. The characteristics are compared with those of a conventional amplifier employing 18m of the initial fibre and ~30mW of pump power. In both cases it can be seen that when the signal B input is lower than that of signal A its gain is increased, whilst, when larger, its gain is reduced. This effect, in the conventional amplifier is due to spectral hole burning whilst for the twincore amplifier the compensation is approximately doubled due to the combined effects of spectral and spatial hole-burning.

Compensation was investigated as a function of wavelength separation and the results are shown in figures 3a and 3b respectively for the conventional and twincore amplifier.

Compensation in the conventional amplifier exhibited a dependence on wavelength separation characteristic of spectral hole-burning with a gain compensation per relative input signal change (maximum slope of fig. 3a) of ~0.046dB/dB observed for a 0.4nm channel separation. In the twincore amplifier the compensation for larger wavelength separations is largely independent of separation with a maximum value of 0.11dB/dB observed. While this compensation is slightly reduced for smaller channel separations (0.2nm) the observed compensation, 0.055dB/dB still exceeds that of the conventional amplifier. By selecting the even mode from the twincore fibre output it should be possible to obtain a wavelength independent output with only a 3dB gain penalty[4].

We have demonstrated automatic spectral gain equalization due to spatial hole-burning in an erbium doped twincore fibre. Gain equalization rates up to 0.11dB per dB of relative input signal level are observed and should increase the useful bandwidth of cascaded amplifiers. As an example, if all received signals were required to be within 5dB in a WDM network with 100 cascaded conventional EDFAs then the useful bandwidth of each EDFA would be only 0.05dB. However, this tolerance is relaxed to 0.5dB for the new amplifier since, although the imbalance between signal levels in initial amplifiers would build, signals would be stabilised in subsequent amplifiers. Future improvements in amplifier design should enhance this effect further.

References

1. M. Tachibana et al., in *Optical Amplifiers and Their Applications*, Vol. 13, 1990 OSA Technical Digest Series (Optical Society of America, Washington DC, 1990), paper MD1.
2. S.F. Su et al., in *Digest of Conference on Optical Fiber Communication*, Vol. 5, 1992 OSA Technical Digest Series (Optical Society of America, Washington DC, 1992), paper ThC4.
3. M. Tachibana et al., in *Optical Amplifiers and Their Applications*, Vol. 13, 1991 OSA Technical Digest Series (Optical Society of America, Washington DC, 1991), paper ThB1.

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   E. Desurvire et al., IEEE Photonics Technology Letters, Vol. 4, 246-248, 1990.
4. R.I. Laming et al., UK Patent Application, "Optical Amplifier with automatic self adjusting gain spectrum"

Figure captions

Fig.1: Experimental configuration

Fig.2: Comparison of two channel gain saturation characteristics for twincore EDFA and conventional EDFA. Pump power is 30mW and 50mW at 978nm for the conventional and twincore EDFAs respectively. The wavelengths of signals A and B are 1531.7nm and 1530.7nm respectively.

Fig.3: Gain compensation curves for (a) the conventional and (b) the twincore EDFA for three different signal wavelength separations. Pump power is 30mW and 50mW at 978nm for the conventional and twincore EDFAs respectively. The wavelength of signal A is 1531.7nm.

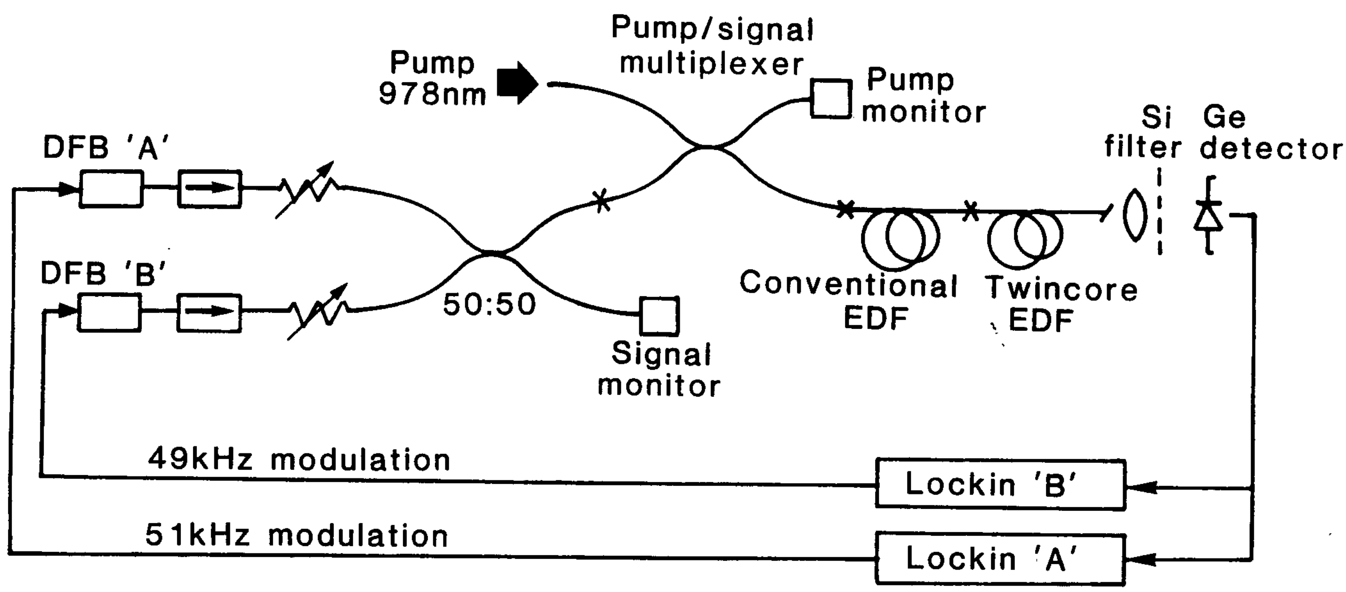

Pump/signal
multiplexer
Pump
978nm
Pump
monitor
Si
filter
Ge
detector
DFB 'A'
DFB 'B'
50:50
Signal
monitor
Conventional
EDF
Twincore
EDF
49kHz modulation
Lockin 'B'
51kHz modulation
Lockin 'A'

Figure 1

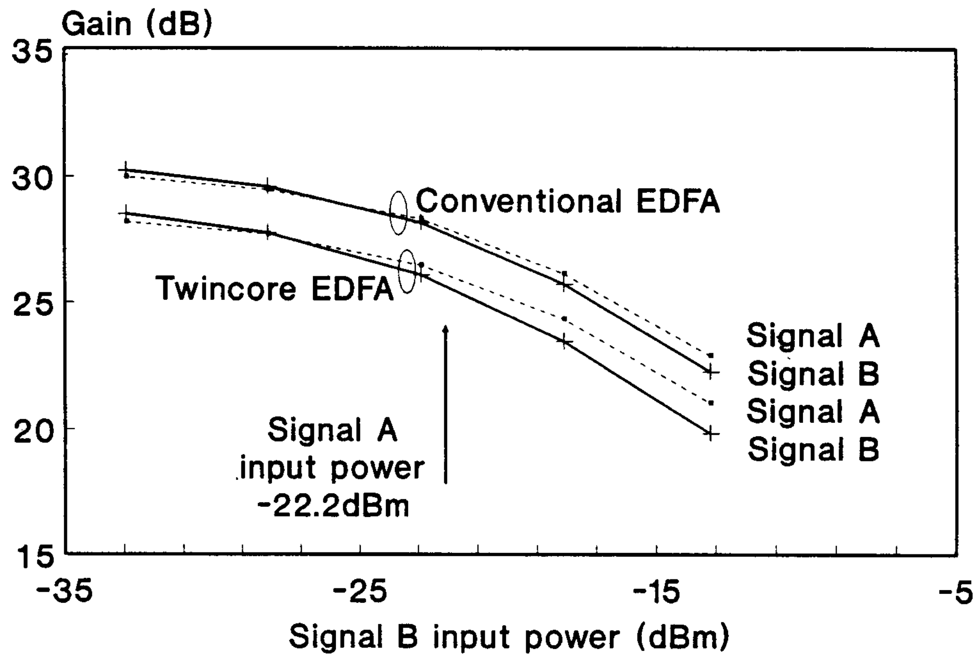
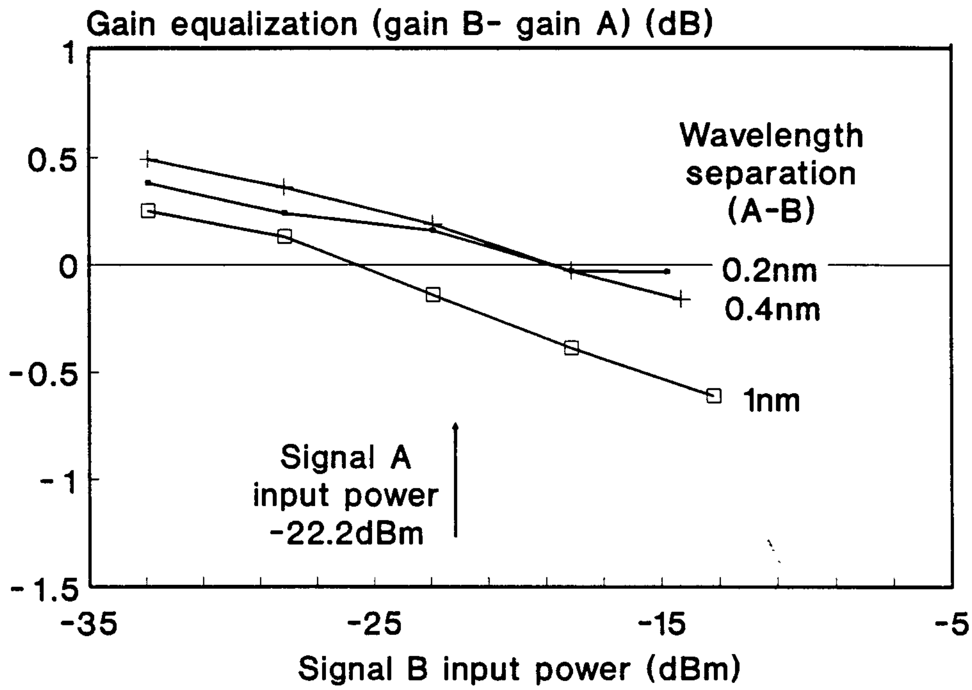
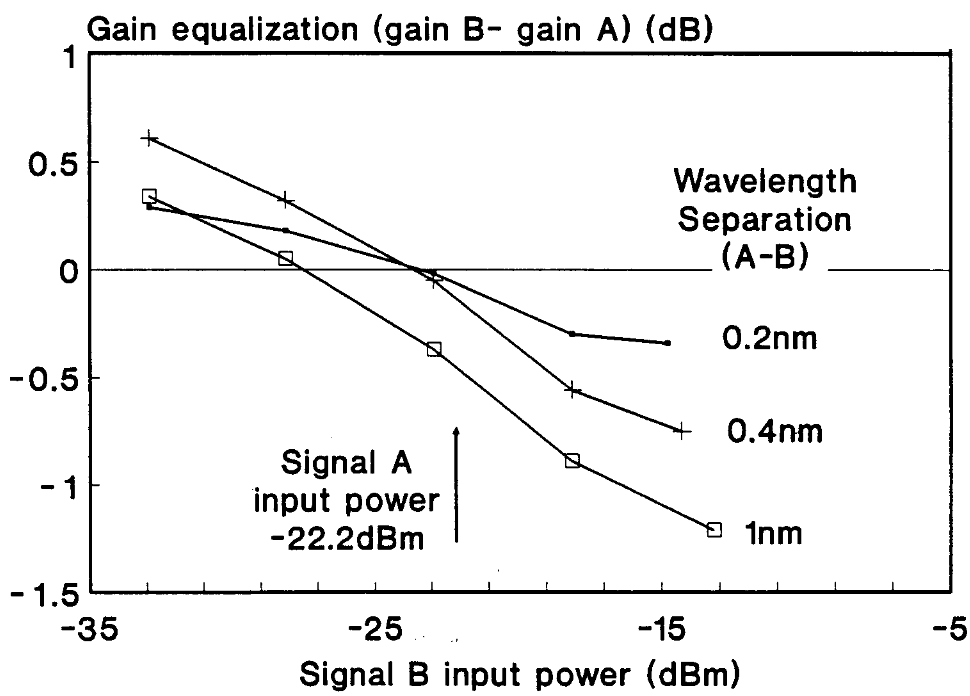

Gain (dB)
35
30
25
20
15
-35
-25
-15
-5
Signal B input power (dBm)
Conventional EDFA
Twincore EDFA
Signal A
Signal B
Signal A
Signal B
Signal A
input power
-22.2dBm

Figure 2


Gain equalization (gain B- gain A) (dB)
1
0.5
0
-0.5
-1
-1.5
-35
-25
-15
-5
Signal B input power (dBm)
Wavelength
separation
(A-B)
0.2nm
0.4nm
1nm
Signal A
input power
-22.2dBm


Gain equalization (gain B- gain A) (dB)
1
0.5
0
-0.5
-1
-1.5
-35
-25
-15
-5
Signal B input power (dBm)
Wavelength
Separation
(A-B)
0.2nm
0.4nm
1nm
Signal A
input power
-22.2dBm