0·1–15 GHz AM AND FM RESPONSE OF ERBIUM-DOPED FIBRE AMPLIFIER

Indexing terms: Optical fibres, Optical communications

The AM and FM response of an erbium-doped fibre amplifier has been characterised for signal modulation frequencies in the range 130 MHz to 15 GHz. Both the amplifier gain and phase are found to be constant for both amplitude-modulated and frequency-modulated signals.

Introduction: Erbium-doped, single-mode fibre amplifiers[1,2] are attractive for amplifying optical signals in the third telecommunications window, around 1·53 μm. This is because they are efficient,[3] low-noise, high fibre-to-fibre gain amplifiers, with a large spectral width and polarisation independence. However, the bandwidth of the AM or FM response of an optical amplifier may differ from the spectral width of the optical gain if the gain is saturated, if the phase response is nonlinear with frequency or if there is gain ripple due to residual reflections. Pattern-dependent gain at 2 Gbit/s has been reported for a semiconductor amplifier,[4] due to gain compression with a 500 ps gain recovery time. However, there is evidence of flat response to at least 2 GHz for erbium fibre amplifiers since no signal degradation was observed in a 2 Gbit/s direct detection experiment.[5] Results are reported here which characterise the high-speed amplitude modulation (AM) and frequency modulation (FM) responses of an erbium-doped fibre amplifier for modulation frequencies in the range 0·1–15 GHz.

Experiment: The fibre amplifier consisted of a 1·5 m-long alumino-silicate erbium-doped (~500 ppm Er^{3+}) fibre with a mode field diameter of 8·3 μm at $\lambda = 1{\cdot}53\,\mu m$, and a cutoff wavelength of 1250 nm. A dichroic fibre coupler was used to launch the optical signal and ~300 mW of 514 nm pump power into the fibre amplifier. The AM and FM responses of the erbium-doped fibre amplifier were characterised using the arrangement illustrated in Fig. 1. High-speed DFB lasers,[6] followed by ~30 dB of optical isolation, provided AM and FM optical signals at both 1528 and 1536 nm. These wavelengths were selected to straddle the amplifier gain peak centred at 1532 nm. The AM and FM responses were measured with a technique[7] employing a birefringent fibre interferometer followed by a high-speed *pin* photodetector. A network analyser directly modulated one of the DFB signal lasers with a 20 mA current swing, resulting in an amplitude modulation index of ~0·15 and a frequency deviation of ~5 GHz. The photodetector signal was analysed for modulation frequencies between 130 MHz and 15 GHz. Fibre couplers, which were mechanically spliced to both ends of the fibre amplifier, allowed the measurement of the CW gain by comparing the amplifier input and output power levels at the signal wavelength. The optical power launched into the amplifier was varied between −27 and −2 dBm to measure the amplifier response under uncompressed and compressed gain conditions, respectively. The combined frequency response of the DFB laser and the photodetector was measured separately by connecting the reference signal path (dashed line, Fig. 1) and blocking the pump so that the erbium-doped fibre was dark. The measurement bandwidth was limited to 15 GHz by the combined high-frequency roll-off of the transmitter and photodetector. The fibre ends in all mechanical splices were obliquely polished to minimise light reflected back into the amplifier.

Results: Fig. 2 shows the amplifier output spectrum with and without the 1536 nm signal laser. A fibre-to-fibre gain of 21 dB

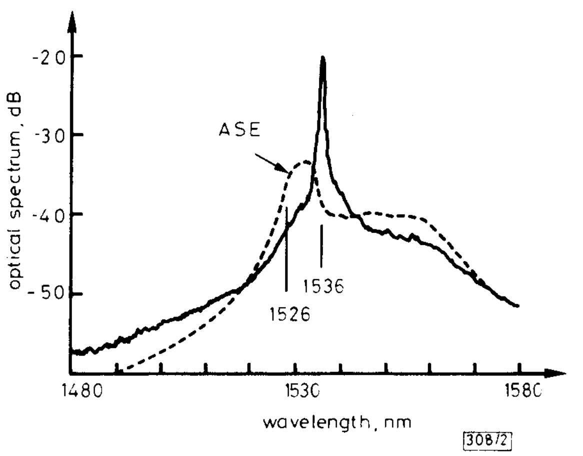

Fig. 2 *Erbium-doped fibre amplifier output spectra with and without 1536 nm signal*

ASE is amplified spontaneous emission

was obtained at this wavelength. This gain value was approximately 5 dB below the maximum gain at 1532 nm. A saturated output power of +10·4 dBm was obtained for an input power level of −4·4 dBm, corresponding to a reduced gain of 14·8 dB.

Fig. 3 shows the gain and phase of the fibre amplifier response against the DFB modulation frequency at 1536 nm. The input optical powers for the AM measurement were −27·4 dBm and −4·4 dBm and for the FM response they were −11·0 dBm and −2·0 dBm. The gain values at 130 MHz are assumed to be equal to the measured CW values. The only significant change in the amplifier response was the gain saturation which increased at high input power levels. Slight variations in magnitude at high frequencies are probably due to a poor signal-to-noise ratio for low input signal powers. Similar gain values with flat AM and FM responses were also obtained using the second DFB signal laser at 1528 nm. In

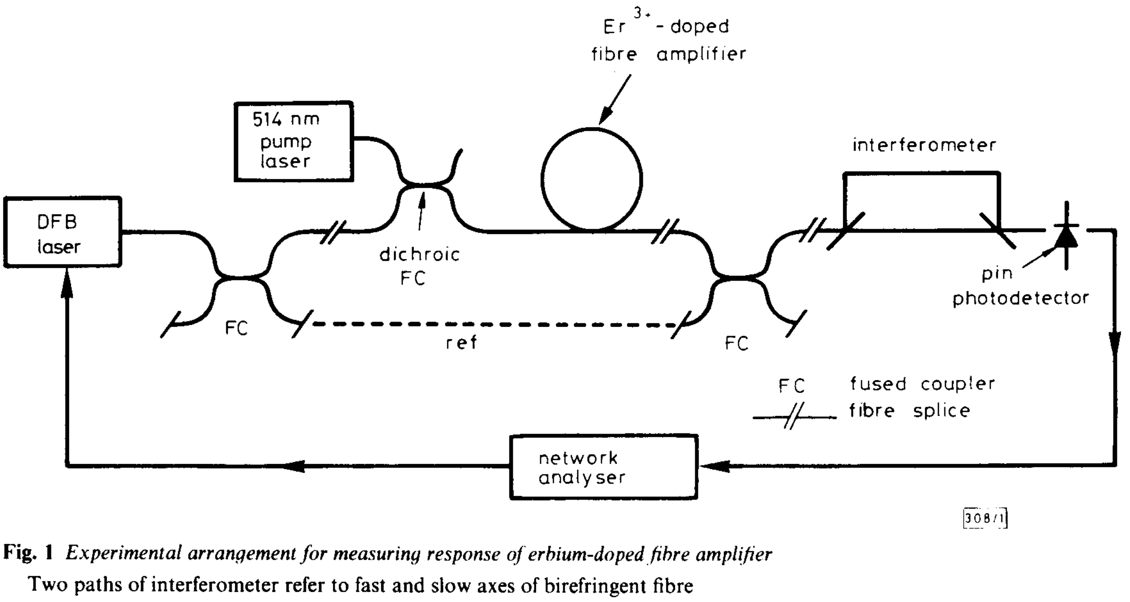

Fig. 1 *Experimental arrangement for measuring response of erbium-doped fibre amplifier*

Two paths of interferometer refer to fast and slow axes of birefringent fibre

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addition, the AM response was also measured over frequency spans of 1 and 200 MHz, with corresponding resolutions of 5 kHz and 1 MHz. No gain ripple due to reflections from the

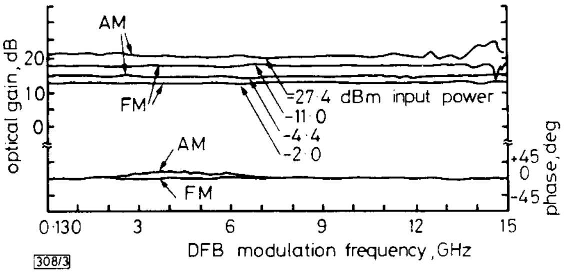

Fig. 3 *Erbrium-doped fibre amplifier response against DFB laser modulation frequency, for AM and FM signals at 1536 nm*

fibre splices was observed, indicating that travelling-wave amplification was achieved.

The variation of gain with wavelength would, in principle, result in FM/AM conversion in the amplifier. However, the maximum slope of the fibre gain curve is about −1 dB/nm at 1536 nm, which corresponds to a negligibly small 0·1 dB gain variation over a 15 GHz bandwidth.

Conclusion: The AM and FM responses of an erbium-doped fibre amplifier have been characterised for modulation frequencies up to 15 GHz. Gain values as high as 21 dB were obtained at 1536 nm and 1528 nm at either side of the gain peak. The magnitude and phase response are flat for modulation frequencies between 130 MHz and 15 GHz for both AM and FM signals, even with up to 6 dB gain compression at high input signal levels. These results confirm the suitability of erbium-doped fibres for amplifying both amplitude modulated and angle modulated signals for data rates in the range 10–20 Gbit/s.

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References

1 MEARS, R. J., REEKIE, L., JAUNCEY, I. M., and PAYNE, D. N.: 'High gain rare-doped fibre amplifier operating at 1·55 μm'. Proceedings of the Conference on Optical Fiber Communications, OFC'87, Reno, 1987, pp. 167

2 DESURVIRE, E., SIMPSON, J. R., and BECKER, P. C.: 'High gain erbium-doped travelling wave fiber amplifier', *Opt. Lett.*, 1987, **12**, pp. 888–890

3 LAMING, R. I., FARRIES, M. C., REEKIE, L., PAYNE, D. N., SCRIVENER, P. L., FONTANA, F., and RIGHTETTI, A.: 'Efficient pump wavelengths of erbium-doped fibre amplifiers', *Electron. Lett.*, 1989, **25**, pp. 12–14

4 MARSHALL, I. W., SPIRIT, D. M., and O'MAHONY, M. J.: 'Picosecond pulse response of a travelling-wave semiconductor laser amplifier', *Electron. Lett.*, 1987, **23**, pp. 818–819

5 GILES, C. R., DESURVIRE, E., TALMAN, J. R., SIMPSON, J. R., and BECKER, P. C.: 'Characterization of high-speed signal amplification at λ = 1·53 μm in an erbium-doped single-mode fiber'. Proceedings of the Conference on Lasers and Electrooptics, CLEO'88, Anaheim, 1988, paper PD9

6 VODHANEL, R. S., and TSUJI, S.: '12 GHz FM bandwidth for a 1530 nm DFB laser', *Electron. Lett.*, 1988, **24**, pp. 1359–1360

7 VODHANEL, R. S.: 'Frequency modulation response measurements to 15 GHz using a novel birefringent fiber interferometer'. Proceedings of the Conference on Optical Fiber Communication, OFC'89, Houston, 1989, pp. 114