AM AND FM RESPONSE OF AN ERBIUM-DOPED FIBER AMPLIFIER FOR MODULATION FREQUENCIES UP TO 15 GHZ

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ABSTRACT: We report the first measurement of the AM and FM response of an erbium-doped fiber amplifier. The amplifier gain and phase are constant for signal modulation frequencies between 130 MHz and 15 GHz, for both amplitude modulated (AM) and frequency modulated (FM) signals.

INTRODUCTION: Erbium-doped, single-mode fiber amplifiers[1] [2] [3] have several attractive characteristics for amplifying optical signals at the important optical communications wavelength of 1.53 μm: efficient coupling to single-mode fibers, polarization independence, and high optical gain over a spectral width of about 10 nm. 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 not linear 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. There is evidence of flat response to at least 2 GHz for erbium fiber amplifiers since no signal degradation was observed in a recent 2 Gbit/s direct detection experiment.[5] In order to more fully characterize the high-speed response of erbium-doped fiber amplifiers, we measure the amplitude modulation (AM) and frequency modulation (FM) responses for modulation frequencies up to 15 GHz. Constant magnitude and phase over the modulation frequency range of 130 MHz to 15 GHz for both AM and FM signals are obtained, even with 6 dB gain compression at high input power levels. These results indicate the suitability of erbium-doped fibers for amplifying amplitude modulated and angle modulated signals at data rates in the 10 to 20 Gbit/s range.

EXPERIMENT: The frequency response of the fiber amplifier is characterized using the setup illustrated in Fig. 1. The fiber amplifier consists of a 1.5 meter long alumino-silicate erbium-doped fiber (~500 ppm Er^{3+}), characterized by an NA of 0.15 and a λ_{cutoff} at 1250 nm. A dichroic fiber coupler launches the optical signal and ~300 mW of 514 nm pump into the fiber amplifier. A high-speed DFB laser,[6] followed by ~30 dB optical isolation, provides AM and FM modulated optical signals at 1536 nm. The AM and FM responses are measured with a technique[7] employing a birefringent fiber interferometer followed by a high-speed p-i-n photodetector. A network analyzer directly modulates the DFB signal laser with 20 mA current swing, resulting in a modulation index of ~0.15. The photodetector signal is analyzed for modulation frequencies between 130 MHz and

15 GHz. The measurements are repeated at 1528 nm using a second DFB laser. Fiber couplers, mechanically spliced to both ends of the fiber amplifier, allow measurement of the cw gain by comparing the amplifier input and output power levels. The combined frequency response of the DFB laser and the photodetector is measured separately by connecting the reference signal path (dashed line, Fig. 1) and blocking the pump so that the erbium-doped fiber is dark. The measurement bandwidth is limited to 15 GHz, due to the combined high-frequency roll-off of the transmitter and photodetector. The fiber ends in all mechanical splices are polished at a seven degree angle to minimize light reflected back into the amplifier.

RESULTS: Fig. 2 shows the amplifier output optical spectrum with and without the 1536 nm signal laser. A maximum gain of 21 dB is obtained at this wavelength, at which the gain is approximately 5 dB below the peak gain at 1532 nm. For a high input signal level of -4.4 dBm, a saturated output power of +10.4 dBm is obtained, corresponding to a reduced gain of 14.8 dB.

Fig. 3 shows the gain and phase of the fiber amplifier response versus the DFB modulation frequency at 1536 nm. The AM response is measured for input powers of -27.4 dBm and -4.4 dBm. The FM response is measured for input powers of -11.0 dBm and -2.0 dBm. The gains at 130 MHz are assumed to be equal to the measured cw gains. The magnitude and phase of the optical gain are constant for both AM and FM signals in the frequency range from 130 MHz to 15 GHz. The slight variations in magnitude at high frequencies are probably due to a poor signal to noise ratio for low input signal powers. The only significant change in the amplifier response is the gain saturation which increases at high input power levels. Similar gains with flat AM and FM responses are also obtained using the second DFB signal laser at 1528 nm. The AM response is also measured with frequency resolutions of 5 kHz and 1 MHz over narrow frequency spans of 1 MHz and 200 MHz, respectively. No gain ripple due to reflections from the fiber splices is observed, indicating that travelling wave amplification is achieved.

The variation of gain with wavelength would, in principle, result in FM to AM conversion in the amplifier. However, the maximum slope of the fiber 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: We report the first AM and FM response measurements of an erbium-doped fiber amplifier. Gains as high as 21 dB are obtained at 1536 nm and 1528 nm. The magnitude and phase are flat for modulation frequencies between 130 MHz and 15 GHz for both AM and FM signals, even with 6 dB gain compression at high input signal levels. These results confirm the suitability of erbium-doped fibers for amplifying both amplitude modulated and angle modulated signals for data rates in the 10 to 20 Gbit/s range.

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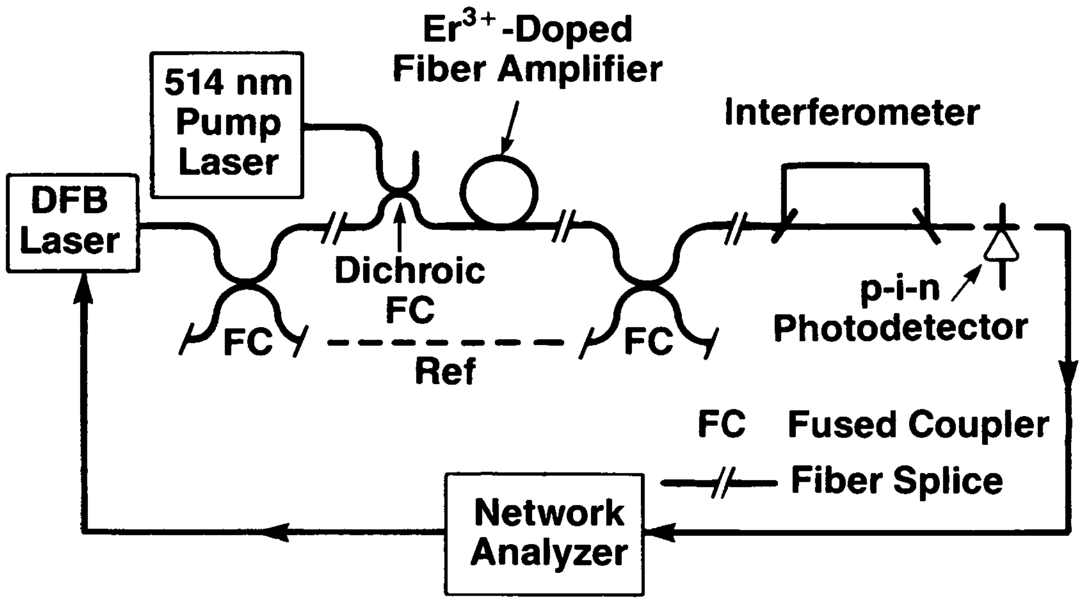

Fig. 1: Experimental set-up for measuring the response of an erbium-doped fiber amplifier. The two paths of the interferometer refer to the fast and slow axes of the birefringent fiber.

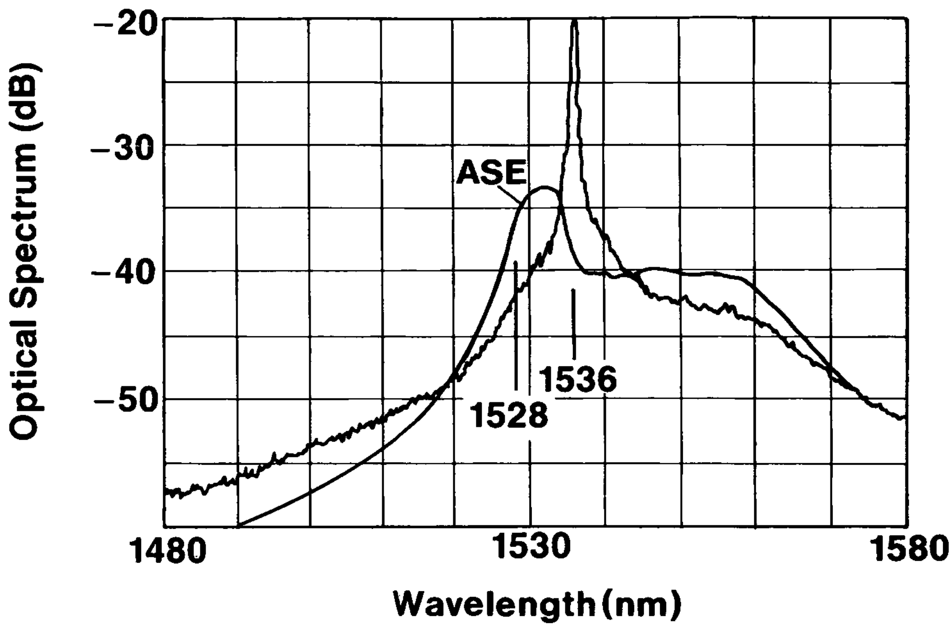

Fig. 2: Erbium-doped fiber amplifier output spectra with and without the 1536 nm signal. ASE: amplified spontaneous emission.

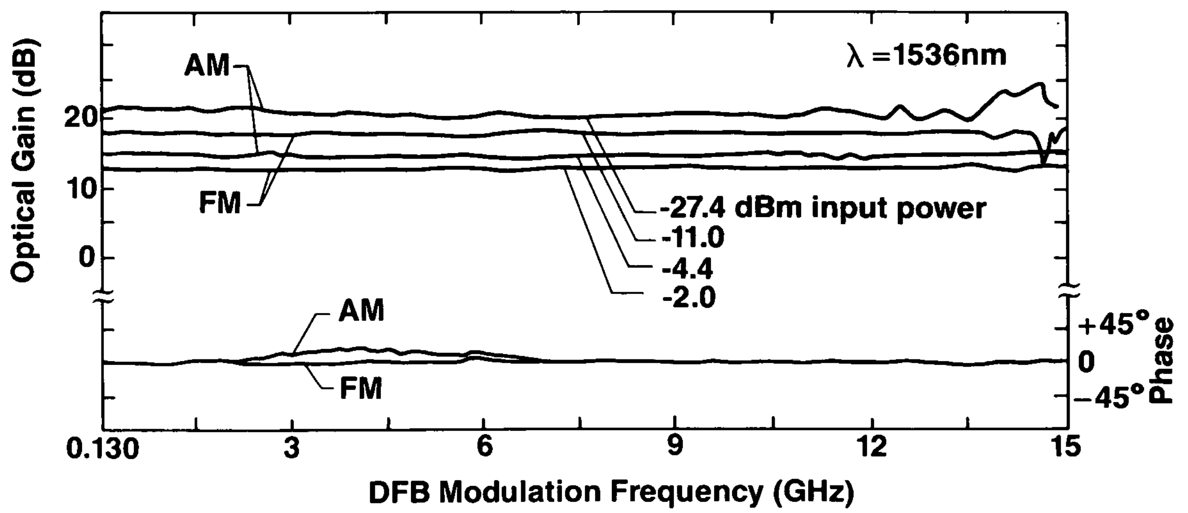

Fig. 3: Erbium-doped fiber amplifier response versus DFB modulation frequency, for AM and FM signals at 1536 nm.