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Spectral Broadening Due To Fibre Amplifier Phase Noise

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Erbium-doped fibre amplifiers (EDFA) operating in the 1.5μm [1,2] wavelength region will play an important role in future optical communication systems. Such devices offer large, polarisation-independent gain, low noise and high efficiency [3]. Advanced coherent communication systems employing optical amplifiers in combination with phase or frequency modulation will allow for greatly increased system capacity and are therefore of considerable interest. However, coherent systems may suffer from spectral broadening due to phase noise introduced by the optical amplifiers and this may limit the number of amplifiers which can be concatenated in an optical link. To quantify the effect, we have measured for the first time spectral broadening due to an Er^{3+}-doped fibre amplifier operating at 1.535μm, and have found the amount of broadening to be less than 20kHz for an amplifier operating with 17dB gain.

Phase noise in a fibre amplifier arises due to various effects, but is thought to be dominated by the addition of randomly-phased spontaneous photons to the signal field. These phase variations will add to the intrinsic phase fluctuations of the signal, causing the signal line to be broadened.

Spectral broadening in an EDFA was measured using a Mach-Zehnder interferometer containing the amplifier in one arm, as shown in Figure 1. Provided that the optical paths in the interferometer are matched in length such that the propagation time difference between the light passing through the two arms is much less than the coherence time of the DFB laser source, then the measured power spectral density at the detector is:

$$PSD = \mathcal{F}\left\{\left\langle e^{j(\phi_a(0)-\phi_a(t))}\right\rangle\right\} \qquad (1)$$

where $\phi_a(t)$ is the time-varying phase shift introduced by the fibre amplifier alone. Thus the technique effectively deconvolves the DFB laser spectrum from the amplifier spectral broadening and provides an output which consists solely of the amplifier spectral broadening response to a zero linewidth input spectrum.

The measured power spectral density is shown in Figure 2. For comparison, also illustrated is the delta-function spectrum which resulted when the amplifier was replaced by a length of undoped fibre ($\phi_a(t) = 0$), indicating that the path lengths were accurately matched. The amplifier was an 11m length of Er^{3+}-doped single-mode optical fibre, pumped through a dichroic coupler by a Ti:Sapphire laser operating at 980nm. The DFB laser had a linewidth of ~30MHz at a wavelength of 1.535μm. At a pump power of 20mW and signal input power of 50μW, the amplifier had a gain of 17dB. The spectral broadening gave rise to a PSD with an approximately Lorentzian lineshape (Fig. 2), with a half-power width of less than 20kHz. This corresponds to an increase in spectral width which is negligible compared to typical DFB linewidths of a few tens of megahertz. The result also indicates the extra ordinary efficiency with which the measurement is able to deconvolve the narrow response of the amplifier from that of the broad linewidth diode laser signal source.

The degree of spectral broadening in the amplifier was observed to change with input signal power as shown in Figure 3. The signal power was varied by introducing attenuation while keeping the DFB drive conditions constant. It can be seen that, as expected, the spectral broadening introduced by the amplifier decreases with increasing signal power, as this brings an increase in the ratio of signal to amplified spontaneous emission (ASE). The effect was verified by varying the pump power into the fibre amplifier while keeping the signal power constant, when no change in the spectral broadening was observed, since here the ratio of signal to ASE is unchanged.

The implications for these results in coherent systems are that Er^{3+}-doped fibre amplifiers will introduce negligible penalty as far as phase noise and spectral broadening are concerned, even in chained-amplifier systems. If only spectral broadening in the amplifier is considered, over 1000 amplifiers could be employed before a signal having a 20MHz linewidth was significantly broadened.

References:

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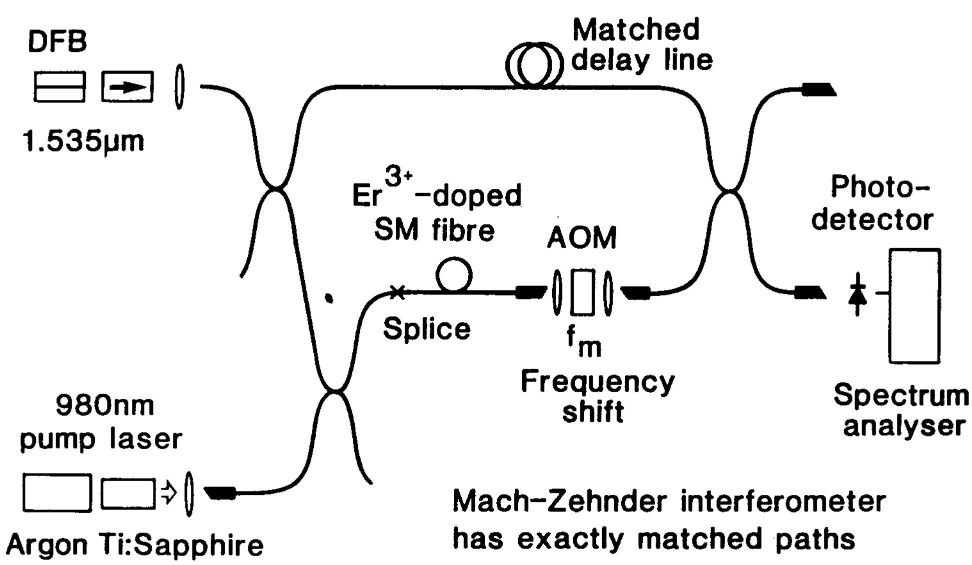

Figure 1. Matched-path Mach-Zehnder Interferometer used to measure spectral broadening.

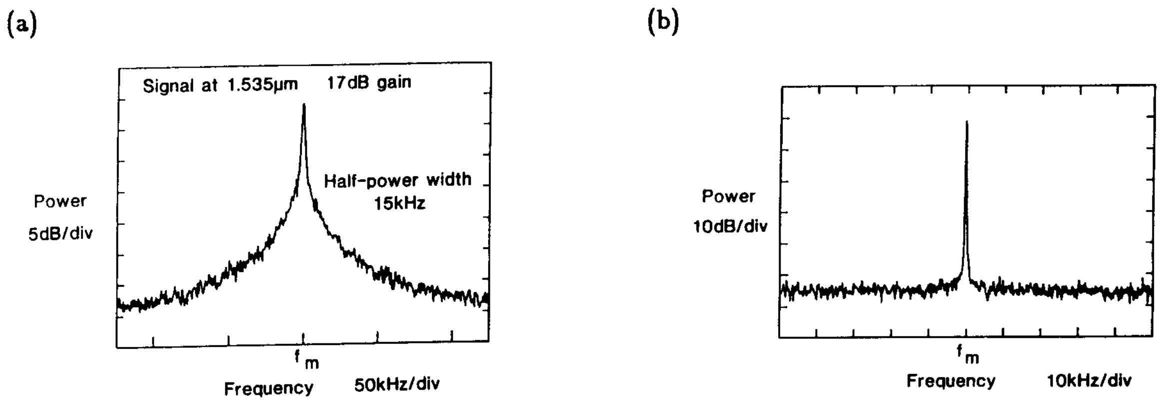

Figure 2. (a) Measured power spectral density. (b) Mach-Zehnder response with amplifier replaced by un-doped fibre.

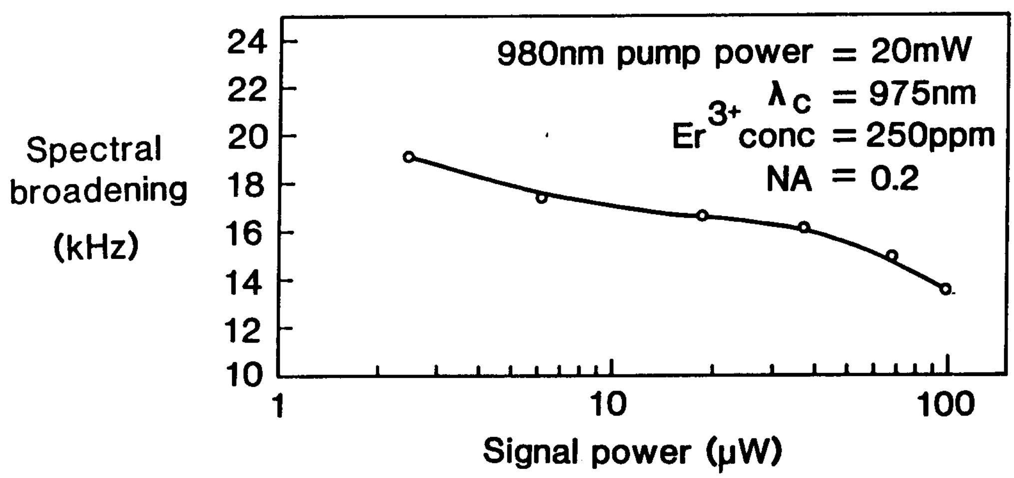

Figure 3. Variation of spectral broadening with signal power.