path, and rectangular. The simulation is based on the Monte-Carlo method where the channel is constructed from 20 statistically independent partial waves with excess delays that follow a PDF identical to that of $P(t)$.

It is interesting that, even for $S/T = 0.5$, the first order approximation (eqn. 12) yields accurate results. Similarly, Fig. 3 shows that the approximated average phase error [3] $\Delta \phi$ fits the simulation up to $S/T = 0.6$.

Conclusions: We found the error probability to be independent of the delay profile details, as is the case in other digital modulation schemes. Our formula is applicable for delay spreads up to $S/T = 0.5$. It seems that unequalised systems require receiver sampling synchronisation on the instantaneous mean delay, even for indoor operation.

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References


HIGH-BANDWIDTH METHOD FOR MEASUREMENT OF COHERENCE FUNCTION OF LASER SOURCE

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Indexed terms: Measurement, Lasers

The coherence properties of a laser are derived from high bandwidth (with respect to the source linewidth) measurements of the instantaneous output intensity at the output of a two-beam optical interferometer. This technique saves the need to compensate for polarisation and wavefront mismatches and for unequal power splitting between the two interfering beams.

Introduction: The second order normalised temporal coherence function of a laser [1] is of major importance in interferometry and source characterisation [2–3]. Its values for time lags up to a few nanoseconds are usually determined from measurements of fringe visibility in a two-beam interferometer (e.g. Michelson or Mach-Zehnder) [1]. However, to maintain high accuracy, all other factors affecting the observed visibility must be neutralised. Specifically, the interferometer must be carefully aligned so that the two interfering beams have identical wavefronts and polarisation and preferably equal powers (or at last a fixed and known ratio of powers [1]). In this Letter a new technique is demonstrated where a wide band-
width detection system is used to obtain additional information about the interference process, thereby avoiding the need for a precise alignment.

When illuminated by an intensity noiseless singlemode laser, the interferometer input field is proportional to exp \([i(o_0 + \phi(t))]\) [4], where \(o_0\) is the centre optical frequency and \(\phi(t)\) is the laser phase noise. The output instantaneous intensity is then of the form

\[
I(t) = a + b \cos(o_0 t + \phi(t) - \phi(t)_{\text{min}}) \quad (b \leq a) \quad (1)
\]

where \(a\) and \(b\) are constants that depend on the interferometer alignment (e.g. power splitting ratio, wavefront and polarisation mismatch between the interfering arms, etc.). The fringe visibility and its dependence on the delay \(\tau\), are normally determined from low-bandwidth measurements (with respect to the laser linewidth) measurements [1].

The visibility is

\[
\text{visibility} = \frac{(I)_{\text{max}} - (I)_{\text{min}}}{(I)_{\text{max}} + (I)_{\text{min}}} = \frac{b}{a} \quad (2)
\]

The angle brackets denote ensemble average.

The clipping levels for the three settings of the interferometer were used to determine the laser phase structure function and the related second order coherence function. For interferometer delays of 0.5 and 0.89 ns the obtained estimates of \(D(t)\) are 0.73 and 0.79, respectively (coherence function values of 0.73 and 0.79, respectively). To check these numbers, we searched for best fit between the histogram of the instantaneous output intensities in the case of in-quadrature and a numerically simulated histogram, which assumes that the laser phase noise is a Wiener process and uses \(D(t)\) as the fitting parameter. We obtained \(D(t) = 0.50 \pm 0.03\) and \(D(t) = 1.0 \pm 0.06\), which are in reasonable agreement with the previous estimates.

Experimental results: We experimentally tested this high bandwidth technique (see Fig. 1). A 0.8 \(\mu\)m, 40 MHz linewidth AlGaAs semiconductor laser illuminates the Mach-Zehnder interferometer. The interferometer state \(o_0\) is adjusted via slight movement of one mirror using a piezoelectric transducer (PZT in Fig. 1). The output light is detected by an avalanche photodiode (APD) followed by an AC-coupled wideband amplifier, a 1 GHz bandwidth digitising oscilloscope and an RF spectrum analyser. The spectrum analyser is used to measure the power spectral density of the output intensity noise. The 1/1 notch in the power spectral density of the in-quadrature state is used to accurately determine the interferometer delay [5]. The digitising oscilloscope acquires sequences of 70464 8 bit intensity samples at a sampling rate of 1 MHz. These samples are statistically independent as long as the delay between samples is much longer than the laser coherence time and the interferometer delay. Three time traces are shown in Fig. 2. As expected, the trace of the minimum setting is clipped from below by the cosine function, whereas the trace of the maximum setting is clipping levels are shifted, which explains why the trace of the in-quadrature setting does not lie between these two clipping levels. By blocking one or both interferometer arms we estimated the noise sources other than the phase induced intensity noise, and verified that this noise was by far the dominant one.
the phase induced intensity noise is the dominant noise in the system. Our technique saves the need to compensate for polarization and wavefront mismatches and for unequal power splitting between the two interfering beams.

References

CHROMATIC DISPERSION OF ERBIUM-DOPED SILICA FIBRES

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The chromatic dispersion of Er³⁺-doped silica fibres has been measured in the wavelength range 1.2-1.7 μm. The fibre cores were codoped with GeO₂, Al₂O₃, P₂O₅, or a combination of these. It is found that the chromatic dispersion is strongly changed compared to standard singlemode fibres, due to the large amount of codopants which leads to a higher index difference, and due to the small core diameters of Er³⁺-doped fibres.

Introduction: Although much work has already been carried out on the fabrication and characterisation of Er³⁺-doped fibres, little attention has been paid to the dispersion properties of these fibres. Because these fibres are very short compared to the distance of transmission the dispersion seems to be negligible. However, in the field of soliton transmission with either lumped or distributed amplifiers [2] or in the generation of picosecond pulses in actively modelocked erbium lasers [2] the dispersion plays an important role. Also in 1300/1550 nm wavelength division multiplexed systems using Er³⁺-doped fibre amplifiers, the dispersion for the 1300 nm signal must be known.

We present chromatic dispersion measurements on a wide wavelength scale (1.2-1.7 μm) for different Er³⁺-doped fibres which are codoped with Al₂O₃ and P₂O₅. In most cases the Er³⁺-doped fibres are codoped with Al₂O₃ for different reasons [3]: it enables a better incorporation of the erbium ions into the fibre, the pump absorption and the signal gain are less sensitive to wavelength variation, and it is used to achieve a high index difference between core and cladding necessary for efficient pumping. For comparison a small core, high index difference, GeO₂/SiO₂ fibre without any erbium was measured.

Experimental results: Fig. 1 shows the measured refractive-index profile of the five investigated fibres. The measurement was performed by the refracted near-field technique at 633 nm. The core diameters 2a are determined at half maximum points of the curves. The index difference Δn is defined by

$$\Delta n = \frac{n_2^2 - n_1^2}{2 \cdot n_1^2}$$

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