Im Grindel 6
8932 Mettmenstetten
Switzerland

Phone: +41 (0) 44 776 33 66
Fax: +41 (0) 44 776 33 65
E-Mail: info@tablestable.com

THE TABLE STABLE LTD.
Vibration Isolation &
JRS Optical Instruments

CHE-101.074.740 MWST/VAT-Nr.

Contrast assessment in the TFP-2 HC spectrometer

The transmission function of single pass Fabry-Pérot interferometer used at normal incidence is theoretically[1]described by the well-known Airy function:

$$I = \frac{I_0}{1 + \frac{4F^2}{\pi^2}\left[\sin\left(\frac{2\pi d}{\lambda_0}\right)\right]^2} \qquad (1)$$

Where I_0 is the peak transmittance, F is the *reflectivity finesse*, d the plate separation and λ_0 the wavelength in use. Looking at the formula one can immediately understand that the contrast, i.e. the ratio between the maximum and minimum value of the instrumental function, is in theory only determined by the coefficient at the denominator in (1). This value is in turn related to the mirrors reflectance R as follows:

$$\frac{4F^2}{\pi^2} = \frac{4R}{(1-R)^2}$$

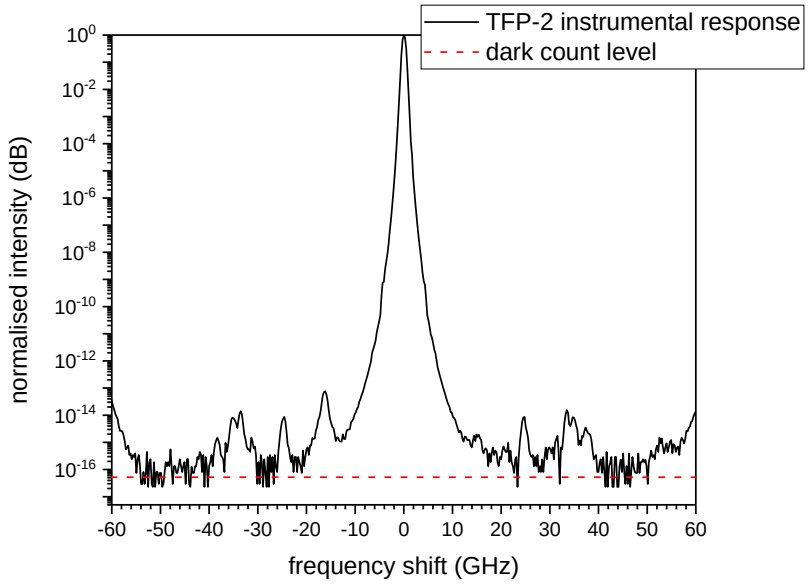
Standard interferometer mirrors provided with JRS spectrometers have a nominal reflectance of about 94% in the wavelength interval 473÷532 nm. The resulting value of contrast for a single pass is close to 10^3.
The main motivation to build multi-pass interferometry setups is the resulting increase of contrast: in theory, the N-pass interferometer transmittance function will correspond to the N^{th} power of the single pass function[1]. In a 6-pass interferometer built using our standard mirrors, the maximum contrast would then be expected to reach 10^{18}.
In a real case, the contrast is significantly lowered by crosstalk between passes, scattering from optics, back-reflected light travelling across the instrument, alignment imperfections and resonances from unwanted optical cavities created by optical components.
The TFP-1 interferometer is affected by all these phenomena, so that the final instrumental contrast is found to be around $10^{10} \div 10^{12}$. The improvements made in the TFP-2 HC layout were aimed at increasing the contrast, reducing all the limiting factors. After the new instrument was born, it was necessary to assess its real contrast, with the expectation that it will lie closer to the 10^{18} level.

The evaluation of such a huge contrast is a difficult task. In order to measure it, one should produce a narrow band signal with an intensity of at least 10^{19} photons in a channel, and then measure the intensity in the neighbouring band, being prepared to gather a few photons in the same amount of time. Considering that the energy of a photon produced by a 532 nm wavelength laser is around $3.7 \cdot 10^{-19}$ J, one easily understands that the best way to do this is to measure directly and quantitatively the spectrum of a narrow line laser, using quite a strong intensity of light at the input.
An incoming power in the order of 1 W or more could be needed to measure a contrast of 10^{18}, and that will be sufficient only if the spectrum of the laser is ideal, so that all the power is sent in a single line. In real world, this is never true: all real laser sources produce unwanted spurious optical emissions in the form of side lobes and broadband noise.

In order to obtain an experimental estimate of the contrast for TFP-2, we used a freshly aligned spectrometer to measure the direct beam of the best 532 nm laser source available. The emission spectrum was purified using two TCF-1 filters in series, both tuned to the laser wavelength. The TCF-1 is a temperature controlled etalon plate, which is expected to reduce up to 600 times the emissions around the laser line, such as (typically) side lobes produced by the laser cavity.
The interferometer's mirror spacing was set at 2.20 mm to match the free spectral range of the TCFs etalons. Several measurements were made in sequence, applying neutral density filters, together with a variable filter to the laser beam. At first an optical density of about 10^{12} was applied,

producing a beam that could be directly measured in terms of several hundreds of counts in a millisecond, then neutral filters were progressively removed and the power was increased, using the instrument shutter to protect the detector from the strong signal close to the laser line. When the variable filter optical density was modified, the power ratio was measured with a power meter. The largest power used was 62 mW, measured at the interferometer's input. The obtained spectra were rescaled considering the acquisition time and the optical density of the filters, and merged together. A high efficiency LaserComponents COUNT® photodiode was used as detector; its dark noise was measured.

At the end of the measurements, the normalised spectrum of the laser emission looks as in the next figure:



The instrumental response function exhibits a remarkably symmetric peak, whose width at half maximum is completely instrumental and much larger than the effective main laser mode. Several residual peaks coming from spurious laser emission are still visible in the 10^{-14}÷10^{-16} region, over a spectrum baseline consistent with the detector's dark noise level. The rise of the first order tandem peaks at about 68 GHz are visible close to ±60 GHz frequency shift.
In first approximation, we are able to assess the contrast to be at least 10^{15}, conservatively considering some uncertainty related to the neutral density filters extinction. Since the lower values in the experimental curve are consistent with the noise, it is likely that this estimate could be improved by using a stronger source power and an even stronger spectral filtering.

A typical application of such a high contrast spectrometer is the observation of spectroscopic signals in presence of strong elastic scattering, for example in the case of turbid samples of biologic interest[2], or to observe lines very close to the main laser mode. In order to get full advantage of the TFP-2 contrast, it is usually advisable to adopt a very narrow band filter device like our TCF in order to suppress spurious emission coming from the source.

[1] J. M. Vaughan - "The Fabry-Pérot interferometer" – Adam Hilger Bristol and Philadelphia, 1989
[2] F. Scarponi, S. Mattana, S. Corezzi, S. Caponi, L. Comez, P. Sassi, A. Morresi, M. Paolantoni, L. Urbanelli, C. Emiliani, L. Roscini, L. Corte, G. Cardinali, F. Palombo, J. R. Sandercock, and D. Fioretto - Physical Review X **7**, 031015 (2017)