Production and detection of phase modulation of matter waves

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It is theoretically possible to produce any linear superposition of quantum states with a well-defined phase and this possibility is widely used in matter wave interferometry. However, the superposition of motional states of free propagating particles with different kinetic energies has rarely been produced and detected, because there is no widely applicable technique to produce such a superposition. We have used the matter-wave analogue of the Kerr effect for light to modulate the phase of the waves propagating in the two arms of an atom interferometer: time-dependent electric fields produce these phase modulations thanks to the polarizability energy shift of the atom ground state. These phase modulations are detected on the interferometer output signal as shown in Figure 1. A sinusoidal electric field with a frequency of 21 Hz is applied and we can observe the first and second harmonics (see Figures 1 and 2)

When we apply two modulations at the same frequency ν, we detect a modulation involving up to many harmonics of this frequency when the modulation phase amplitude is large. When we apply modulations at two different frequencies ν_1 and ν_2, the interferometer output signal present beats at the frequency $\nu_1 - \nu_2$ and at its harmonics, even if ν_1 and ν_2 are large with respect to the detector bandwidth and the dispersion of the atom time-of-flight from the modulation region to the detector. All the experimental results are in excellent agreement with theoretical expectations; in particular, the delay between modulation and detection is well explained by the fact that the signal propagates with the atom group velocity. Finally, we have used this technique to transmit signals, either digital or analogic.

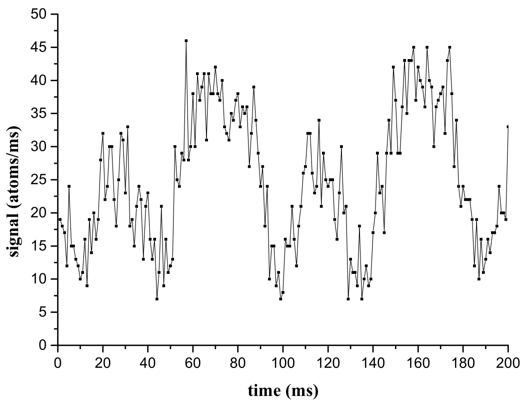

Figure 1: *Signal of the atom interferometer as a function of time. The count period is 1 ms. We apply a sinusoidal electric field on one interferometer arm, which induces a periodic phase shift. We can clearly distinguish the first and second harmonics.*

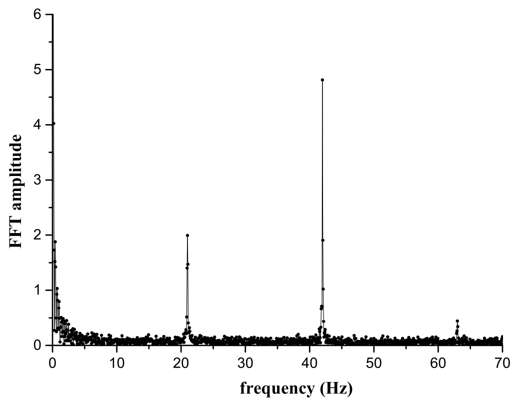

Figure 2: *FFT amplitude of the interferometric signal. The first and second harmonics are well resolved and a small contribution of the third order can be recognized.*