Novel resonance technique with sub-coherence-lifetime limited linewidth and (possible) relation to weak measurement

Pengxiong Li¹, Lei Feng¹, Jian Sun¹, Mengzhen Zhang¹, Tun Wang², Jianming Wen³, Liang Jiang³ and Yanhong Xiao¹
¹Fudan University, Shanghai 200433, China
²Institute of Care-life, Chengdu 610041, China
³Yale University, New Haven, Connecticut 06511, USA

We demonstrate a novel approach to obtain a resonance linewidth far below the coherence lifetime limit. The second-order cross-correlation between the induced intensity fluctuations of two lasers forming an Electromagnetically Induced Transparency (EIT) resonance has a transition from 1 to -1, as the EIT resonance conditioned is removed [1]. We found that such a transition has a linewidth much smaller than the zero-power EIT linewidth [2]. In a proof-of-principle experiment where the EIT linewidth was limited by transit broadening and where intensity fluctuations in the two EIT fields were converted from laser frequency modulations, we achieved 1/30 of the transit-limited width [2] (Fig.1). In a paraffin-coated vapor cell system where the EIT linewidth was limited by residual magnetic field inhomogeneity induced broadening, we achieved a linewidth of 0.8 kHz, about 1/30 of the zero-power EIT width. We also compared the frequency resolving power of this method to that of EIT, and found an improvement factor of about four. An enlarged advantage of this method over traditional ones on resolving power is expected with further reduction of the residual amplitude modulation in the laser and other technical noises. The fundamental limit of the linewidth of this method is laser shot noise. Linewidth below the coherence-lifetime-limit can also be obtained using lasers that only have intrinsic random phase noises [3]. Furthermore, we investigated the multi-peak resolving capability of our technique and found better contrast than traditional resonance method. All the above experimental results qualitatively agree with our intuitive analytical model and numerical calculations. Our recent study on higher-order intensity correlations has shown even narrower linewidth, which exhibits a strong analogue to the high-order ghost imaging experiment [4]. Finally, we suggest that our approach might be viewed as a generalized form of weak measurement.

![Graph of transmitted signals](image)

This technique can be easily implemented and should be applicable to many atomic, molecular, and solid state spin systems for spectroscopy, metrology, and resonance-based sensing and imaging.