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Abstract. The ability to coherently spectrally manipulate quantum information has the potential to improve qubit rates across quantum channels and find applications in optical quantum computing. Here we present experiments that use a multi-element solenoid combined with the three-level gradient echo memory scheme to perform precision spectral manipulation of optical pulses. If applied in a quantum information network, these operations would enable frequency-based multiplexing of qubits.

Keywords: Gradient Echo Memory, quantum memory, quantum information; coherent manipulation; quantum repeater
PACS: 42.50.Gy, 42.50.Md

INTRODUCTION

An ideal optical quantum memory allows coherent, noiseless and efficient storage and recall of optical quantum states. They are an essential building block for quantum repeaters [1], which will extend the range of quantum communication. They could also find applications as a synchronization tool for optical quantum computers, and in a deterministic single-photon sources [2].

In addition to memories, a method for conditioning qubits in terms of their timing, frequency and bandwidth would be another useful component of a quantum communication system. Given that a memory will already be a part of a quantum information network, an enticing possibility is that qubit conditioning could be built into the memory functionality. If this is possible, it would not only save the addition of extra components (and the extra loss and complexity this entails) but would also allow dynamic programming of the manipulation and timing - as the information would not simply be passing through the system, but trapped. It could also allow for controllable multiplexing within the memories - a powerful tool where multiple signals are bundled into one over a communication channel to increase bit rates by orders of magnitude.

Here we will investigate the coherent spectral manipulation abilities of the three-level gradient echo memory (Λ-GEM) scheme [3], based on the theoretical work presented in Ref. [4]. GEM is a photon-echo based quantum memory that has been shown to have high efficiencies in both its two-level [5] and three-level [6] forms, which are based on rare-earth ions and atomic gases, respectively. Both forms have been shown to not add noise to the quantum state [5, 6], therefore performing above the no-cloning limit, making GEM a promising candidate as an optical quantum memory.

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EXPERIMENTAL SET-UP

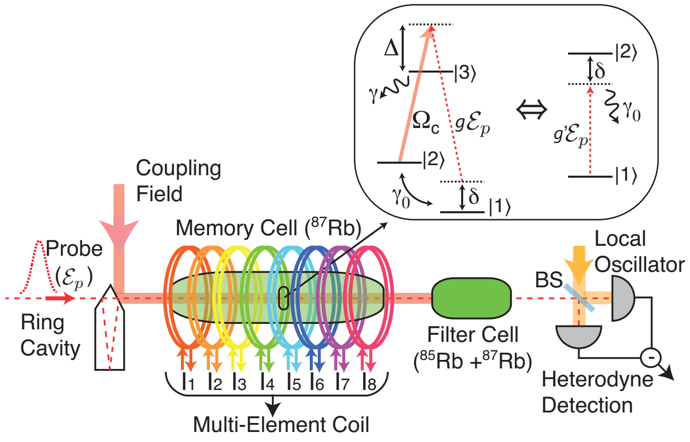

FIGURE 1. **Experimental set-up**

An overview of the set-up used for the following spectral manipulation experiments is shown in Fig. 1. We use the Λ-GEM scheme and warm rubidium-87 vapor for our experiments. For more information on the set-up, see Ref. [6]. The main difference from previous experiments is that the variable-pitch solenoids used to create a reversible linear gradient were removed. Instead, eight separate solenoid coils, with four turns each, are placed along the length of the memory. This multi-element coil (MEC) is used to create the complex gradients for the experiments by placing a different current in each coil, and using the superposition principle for magnetic fields.

RESULTS

With the MEC we were able to perform a number of different pulse manipulation experiments. These included controllably altering the centre frequency of a pulse by recalling with an offset on the recall magnetic field gradient. We could also control the bandwidth of the output pulse by recalling with a steeper or shallower output gradient. Spectral filtering was possible due to the frequency-encoding nature of GEM and, using this, we could store a pulse with multiple frequency components and then choose to recall them one after the other, or only recall one. Finally we showed that we could take two initially time-separated pulses of the same, or different, frequencies and combine them at the output of the memory.

Some of these results are shown in Fig. 2, others are presented in Ref. [7].

ACKNOWLEDGEMENTS

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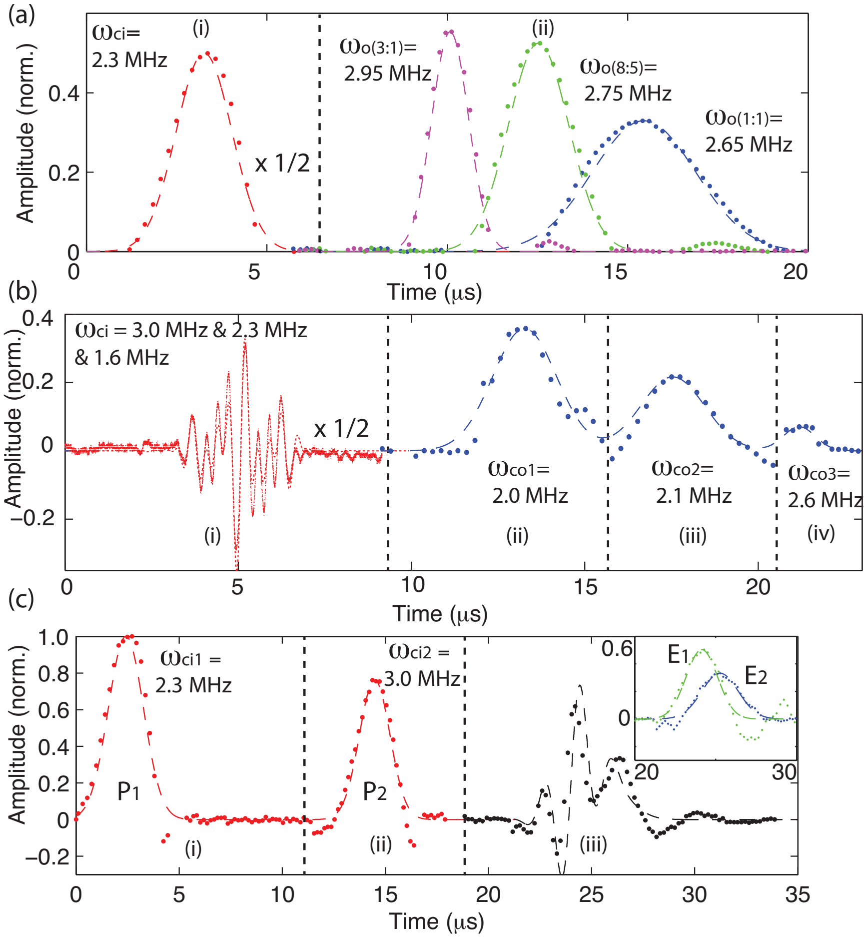

FIGURE 2. (a) Bandwidth Manipulation - (i) demodulated input pulse, (ii) demodulated output pulses achieved by varying output to input gradient ratios (bracketed terms). (b) Spectral Processing - (i) non-demodulated input pulse containing three frequency components, (ii)-(iv) demodulated retrieval of these three components sequentially. (c) Pulse Intereference - (i), (ii) demodulated input pulses entering the memory, (iii) retrieval of interfered pulses. Insert: retrieval of single pulses P1 (E1) or P2 (E2). ω_c, ω_o values are centre frequencies of pulses, demodulated pulses are averaged over 100 heterodyne data traces.

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