

Application Note: Electro-Optic Modulators for Laser Frequency Stabilization

Electro-optic modulators (EOMs) can be used to modulate the amplitude, frequency or phase of a beam of light. These devices exploit the electro-optic effect whereby the application of an external electric field to a medium, which does not possess inversion symmetry, may induce a change in the ordinary and extraordinary refractive indices [1]. Here we consider the use of a resonant phase modulator to generate frequency sidebands. When a single frequency beam of light passes through an EOM driven by an oscillator at frequency ω_m , the transmitted phase-modulated light can be represented in terms of a carrier frequency ω_c and sidebands separated by the modulation frequency.

The frequency modulated light from an EOM can be used to obtain a signal which can be used to regulate the frequency of the laser (the error signal) via various techniques provided a phase sensitive detection scheme is used. Two pump probe schemes used to interrogate an atomic vapour are modulation transfer spectroscopy and frequency modulation (FM) spectroscopy. Both of these techniques achieve sub-Doppler resolution and as a result display large signal gradients and enhanced frequency discrimination, though at the expense of a more limited capture range (typically below one hundred MHz), compared to some other techniques such as the dichroic atomic vapour laser lock.

Modulation transfer spectroscopy uses approximately equal pump and probe beam powers with the pump beam being frequency modulated [2]. This modulation is transferred to the probe beam via a four-wave mixing process in the atomic medium. The biggest signal peak to peak amplitudes are observed for closed transitions where the four-wave mixing process is very efficient as atoms cannot relax into other ground states. As a result modulation transfer spectroscopy can only generate useful error signals when locking to closed transitions. This can be advantageous when there are many closely spaced hyperfine transitions, such as the $^{85}\text{Rb } F = 2 \rightarrow F'$ transitions. Away from sub-Doppler resonances there is no modulation transfer. This leads to a flat, zero background signal and is one of the major advantages of modulation transfer spectroscopy. FM spectroscopy involves a weak frequency modulated probe beam and a strong unmodulated pump beam [3]. The Doppler-free signal is observed on a sloping background approximating to the derivative of the Doppler-broadened absorption profile which can be removed using a second stage of demodulation, although at the expense of extra complexity (and cost). Unlike modulation transfer spectroscopy this process works equally well for both open and closed transitions meaning that FM spectroscopy can be used to lock to all hyperfine transitions. This can be an advantage in applications where one wants to lock away from the closed transition.

Here we demonstrate both techniques using a Photonics Technologies EOM with a resonant frequency of 10.24(2) MHz (see figure 1). Both the FM and modulation transfer signals can be conveniently observed using the same setup shown in figure 2. Note that the pump-probe power ratio differs for optimum FM and modulation transfer signals. See figure 3 for typical signals.

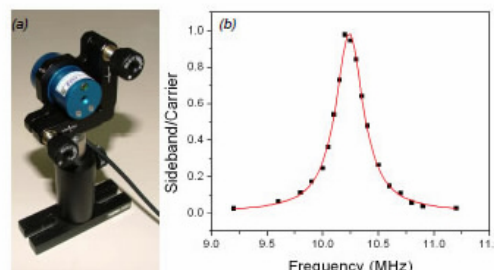


Figure 1: (a) A photograph of the Photonics Technologies EOM (b) The resonance curve for this EOM was mapped out by measuring the sideband/carrier ratio as a function of frequency. The resonant frequency was found to be 10.24(2) MHz. The peak to peak voltage applied to the EOM was 8.4 V, giving a sideband/carrier ratio of approximately unity on resonance.

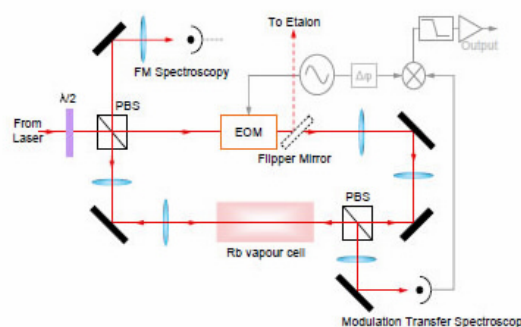


Figure 2: Schematic diagram of the experimental setup used to perform both modulation transfer and FM spectroscopy (PBS = polarizing beamsplitter, EOM = electro-optic modulator). To monitor the sidebands applied to the modulated beam a flipper mirror is used to send the light to an etalon.

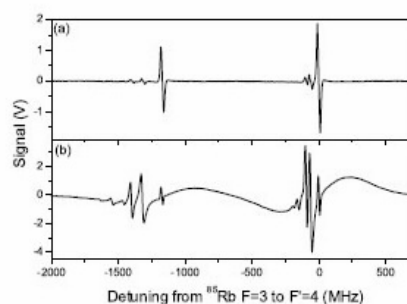


Figure 3: A comparison between (a) modulation transfer spectroscopy and (b) FM spectroscopy for the $^{87}\text{Rb } F = 2 \rightarrow F'$ and $^{85}\text{Rb } F = 3 \rightarrow F'$ transitions.

References

- [1] A. Yariv *Quantum Electronics*. Wiley, 3rd edition, 1989.
- [2] J. H. Shirley. *Opt. Lett.*, 7:537, 1982.; F. Bertinetto *et al.*, *IEEE Trans. Instrum. Meas.* 50:490, 2003.
- [3] G. C. Bjorklund. *Opt. Lett.*, 5:15, 1980.