# Use of a Fourier LOCKIN Continuous Wave (CW) Waveform for the ASCENDS Mission

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The need for a global greenhouse gas monitoring system throughout all times of the day and night led the 2007 NRC decadal survey to recommend the orbiting Active Sensing of $CO_2$ Emissions over Nights, Days, and Seasons (ASCENDS) mission. Since then work has focused on solving the challenges associated with carrying out this project using satellite based sounding LIDAR (Fig a), given the requirement to record column integrated values even in the presence of atmospheric reflectors such as clouds and aerosols. Standard space based pulse laser systems required to do this using straightforward altimetry methodologies still lack the needed power by an order of magnitude. Significant work has hence also concentrated on developing continuous wave or CW systems for ASCENDS which utilize cheaper, more reliable and lower power solid state laser systems widely used in the telecommunications industry. However the standard CW auto-correlation methodologies used to remove atmospheric scattering signals typically provide retrievals at a lower accuracy than theoretical future pulsed systems. A new 'Fourier Lockin' $S(t_k)$ waveform has recently been developed by Zedika Solutions LLC (Eqn 1 & Fig b), which in simulations has suggested CW $CO_2$measurements are possible at accuracies equal to or even surpassing that of a pulsed laser system (see Fig c).

$$\begin{aligned} S(t_k) &= \sum_{n=1}^{P} cos\left\{n\Delta\omega \times k\Delta t + \phi_n\right\} && (1) \\ ||S(\omega_k)|| &= ||\delta(\omega_k)|| && (2) \\ &= 1 \end{aligned}$$

The CW waveform achieves this with only 5% of a pulsed systems peak power by having a frequency amplitude content that is designed to be indistinguishable from that of a perfect Dirac delta time function $\delta(t)$ (i.e. as $P \rightarrow \infty$ and $\Delta\omega \rightarrow 0$, see Eqns 1 & 2). Deliberate choice of random phase values $\phi_n$ in Eqn 1 allows a flat spectrum waveform be to generated using a standard EDFA to take the time domain form of Fig b. Using the phase values measured in real-time by the reference detector in Fig a it is then possible to recover an atmospheric profile with a number P reflectors, a spatial resolution limited only by sampling frequency and hence an effective impulse response of a perfect Dirac delta time function $\delta(t)$ . An easily generated waveform as shown by Fig b can be tested in standard CW dial LIDAR systems already in use to demonstrate its capabilities. Fig c shows simulations of the recovery of a square wave atmospheric profile by the Fourier Lockin waveform (top) in addition to comparison with that obtained from existing Chirp and a pulse systems (bottom, where again it should ne noted the pulse device needs 2000% the power of the other two and is beyond current orbital technical capabilities). Given minimal investment and risk, this new waveform could enable the ASCENDS mission to go ahead in the near future as per the suggestion of the 2007 NRC decadal survey. The Fourier Lockin waveform is also applicable to other sounding fields such as seismic imaging, where for example it could remove the need for marine life damaging air-gun use in offshore oil exploration.

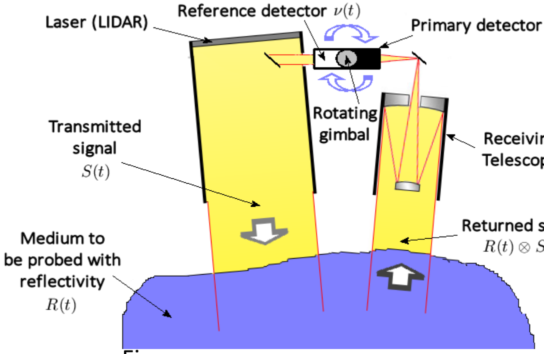


Fig a

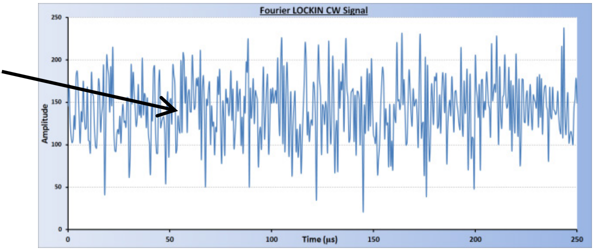


Fig b

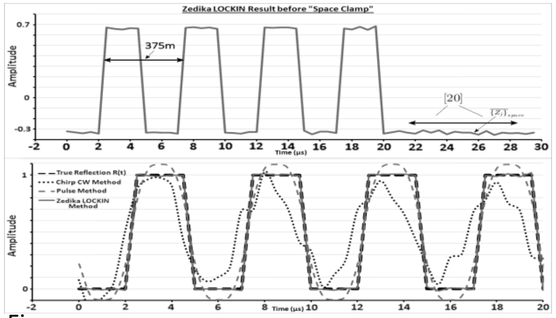
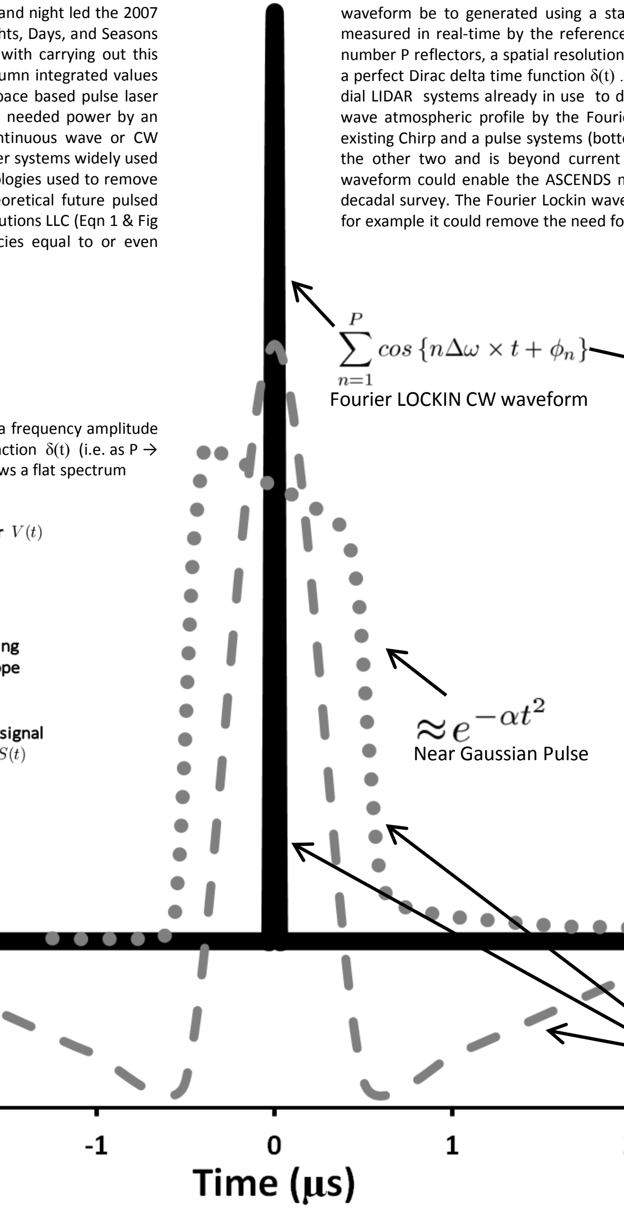


Fig c



$$\sum_{n=1}^{P} cos\left\{n\Delta\omega \times t + \phi_n\right\}$$

Fourier LOCKIN CW waveform

$$\approx e^{-\alpha t^2}$$

Near Gaussian Pulse

$$cos\left\{[\mu t + \kappa] \times t\right\}$$

Linear swept chirp CW waveform

Waveform Impulse Responses