Pulse Optimization for Amplified Ultra-Short Lasers

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Abstract:

- To increase the intensity of the ultra-short wave pulses by controlling their dispersion using an Acousto-Optic Programmable Dispersive Filter (AOPDF) that decreases the duration of the pulse

Background:

- Laser Operation
  - A green laser pump excite atoms in gain medium to higher energy states
  - Gain medium
    - Ti:Sapphire capable of producing large range of frequencies in near infrared spectrum
  - A cavity consisting of two mirrors to reflect photons to create a beam
- Two ways to achieve femtosecond ultra-short laser pulses
  - Active mode-locking
  - Kerr-lens mode-locking
- Dispersion
  - Varying frequencies experience a phase change when passing through a material which effects the pulse shape
- The phase change can be measure with a Taylor series
  - The first two terms of the Taylor series have no effect on the shape of the pulse

$$E(\omega) = E_0 e^{\left(\frac{-(\omega-\omega_0)^2}{\Delta\omega^2}\right)} e^{(-i\omega_0 t - i\phi(\omega))}$$

$$I(\omega) = |E(\omega)|^2$$

$$\phi(\omega) = \phi_0 + \phi_1(\omega-\omega_0) + \frac{\phi_2(\omega-\omega_0)^2}{2} + \frac{\phi_3(\omega-\omega_0)^3}{6} + \frac{\phi_4(\omega-\omega_0)^4}{24} \ldots$$

Figure 1: The electric field (top) of the laser as a function of angular frequency ω, where ω_0, is the peak angular frequency, and Δω is the bandwidth. The intensity is the absolute value of the electric field squared and the phase Φ(ω) is a function of angular frequency and calculated using a Taylor series.

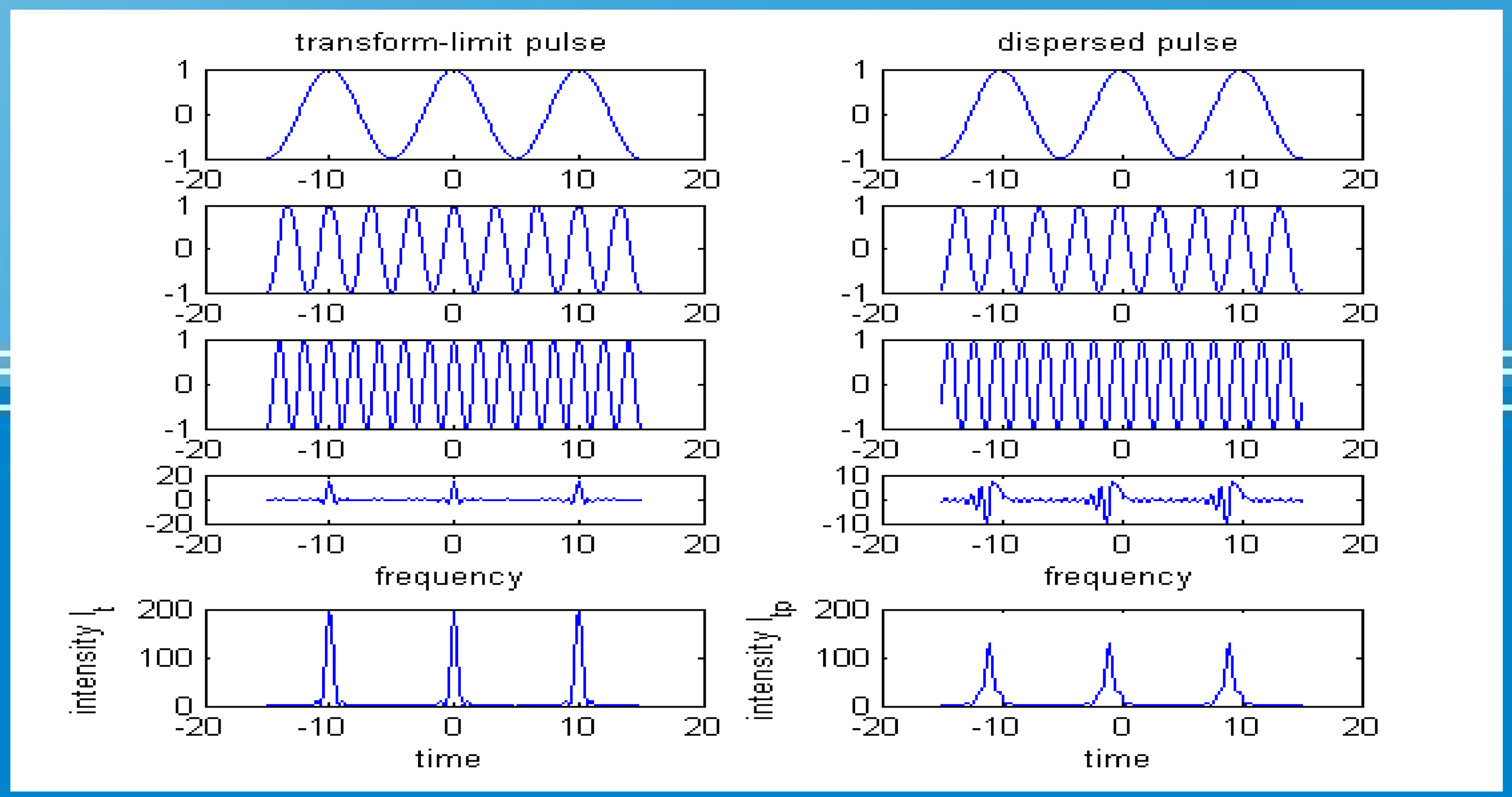

Figure 2: Above are three different frequencies combining into the fourth one down. The left shows a transform limited pulse with zero phase. The right shows when a phase shift is added. Their respective times are shown on the bottom from a Fast Fourier Transformation where the time increases and the intensity decreases with the phase shift.

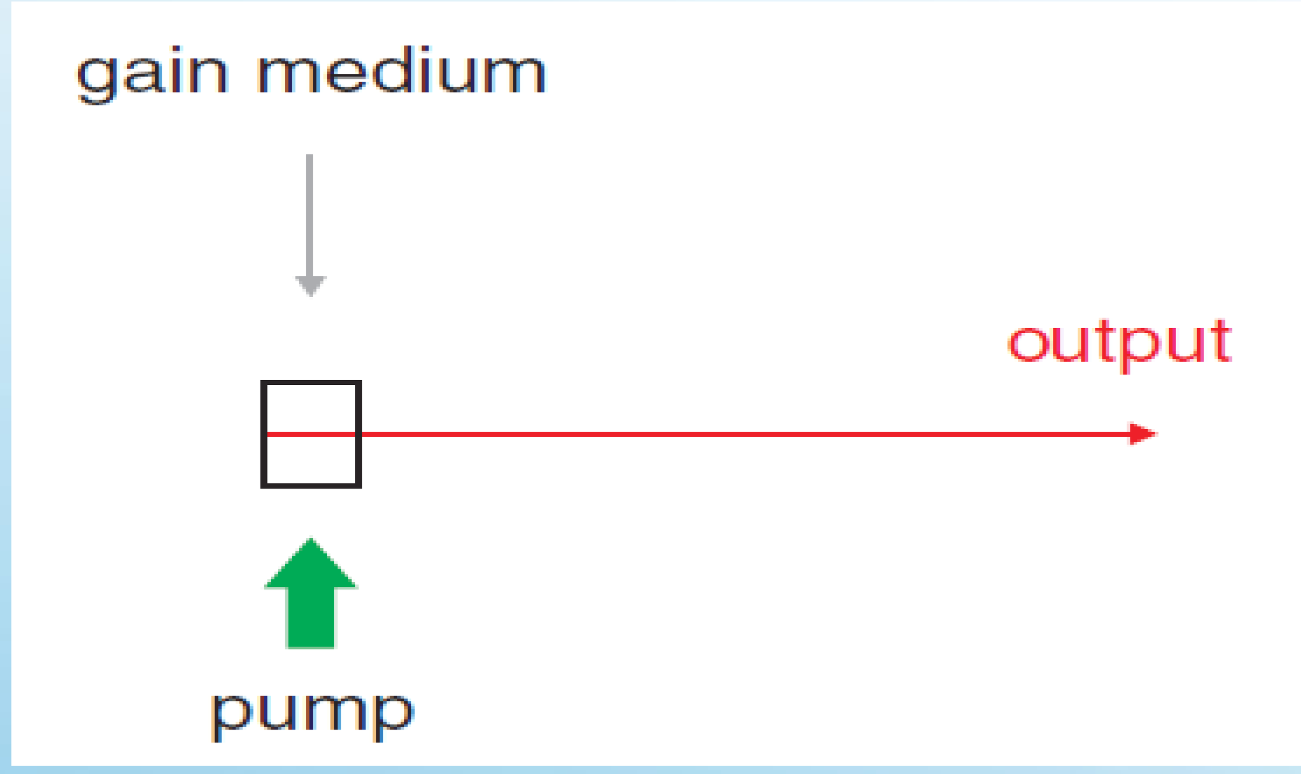

Figure 3: A simple set-up of the laser with the pump which is a green laser, the gain medium that is the Ti:Sapphire, and the output which is a near infrared laser.

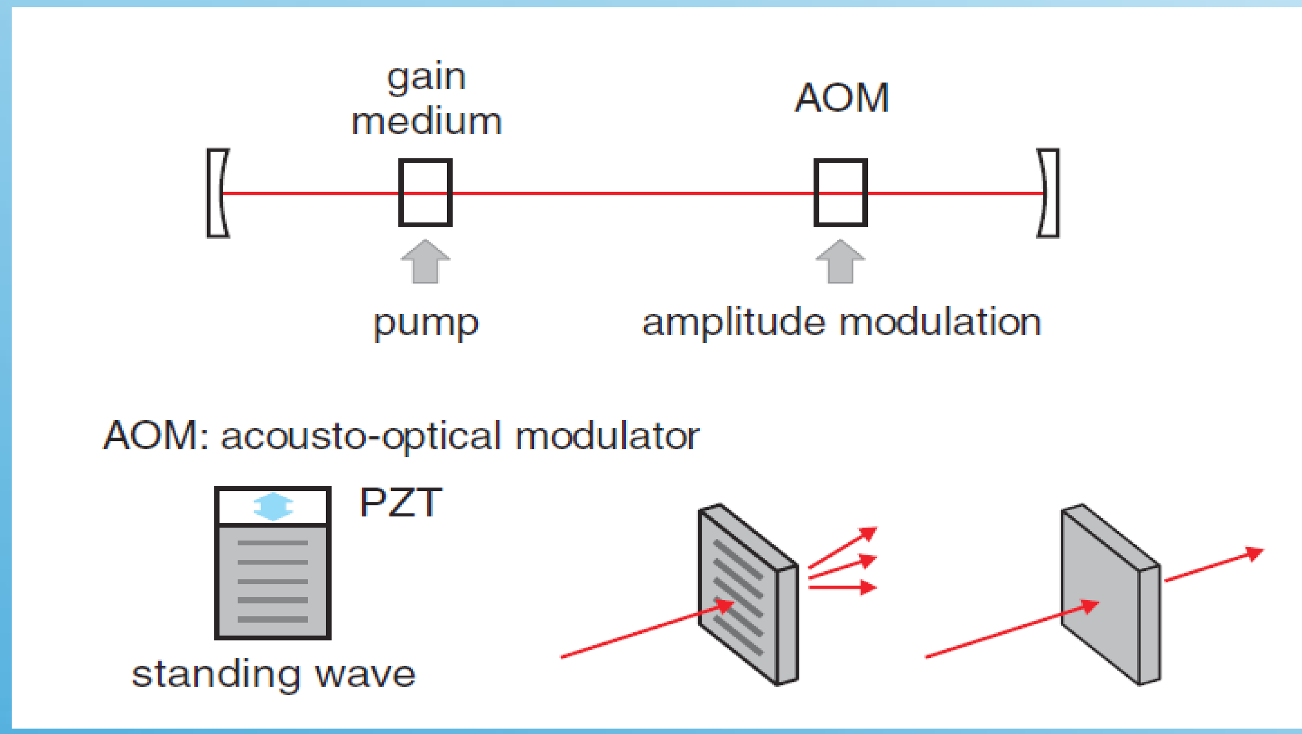

Figure 4: Active mode-locking uses a Piezo-electric absorber transducer that produces a standing sound wave in the material to create different densities allowing for ultra-short lasers to be produced.

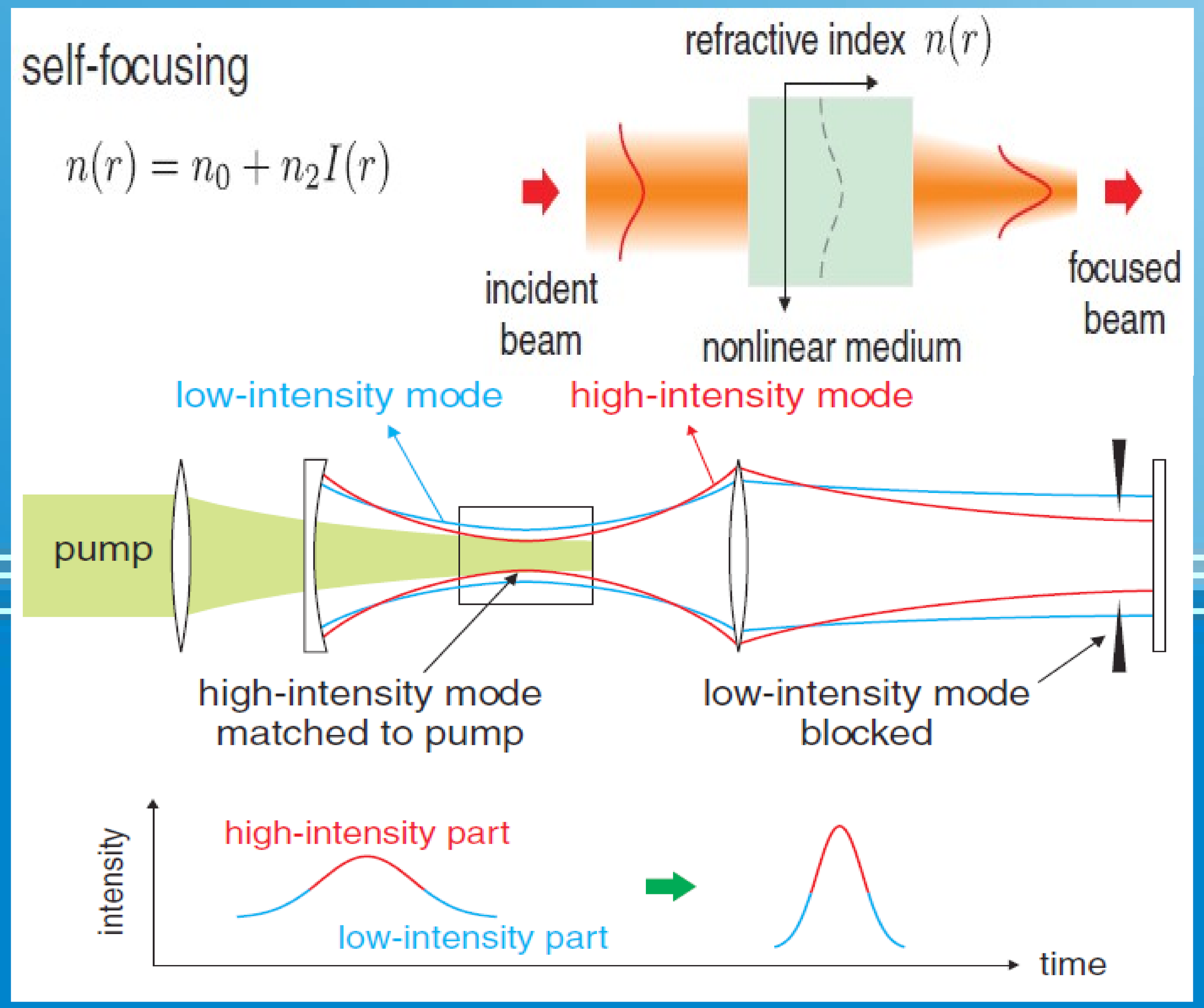

Figure 5: The Kerr-lens mode-locking takes advantage of the non-uniform intensity beam and causes a self focusing effect where I(r) is the intensity as a function of the beam's radius.

Project:

- Used MATLAB to optimize the duration of ultra-short laser pulses by manipulating the 2nd (chirp), 3rd, and 4th of the AOPDF using Fast Fourier Transformations

$$E(t) \rightarrow \left\{ E(\omega) \rightarrow \boxed{T(\omega)} \rightarrow E'(\omega) = E(\omega)\cdot T(\omega) \right\} \rightarrow E'(t)$$

$$E(t) = E_0 e^{\left(\frac{-t^2}{\tau^2}\right)} e^{(-i\omega_0 t - i\phi(t))} \qquad T(\omega) = e^{\left(\frac{-(\omega-\omega_0)}{2\omega_g}\right)} e^{(-i\theta(\omega))}$$

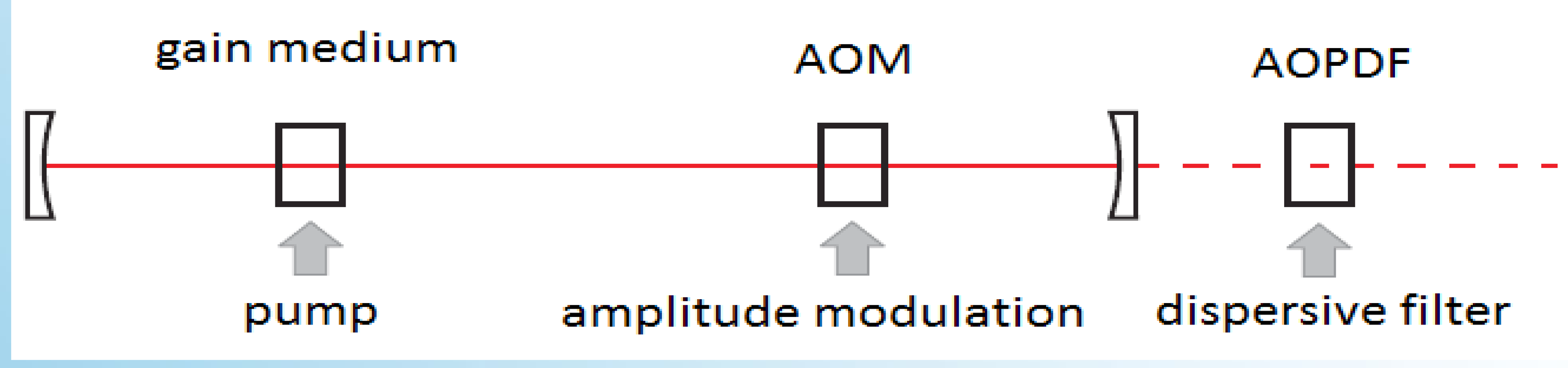

Figure 6: The AOPDF manipulates the higher order phase terms of T(ω) to add another phase shift to counteract the original phase shift from the gain medium where ω_g is the bandwidth of the AOPDF. This is multiplied by the original electric field and results in a new electric field.

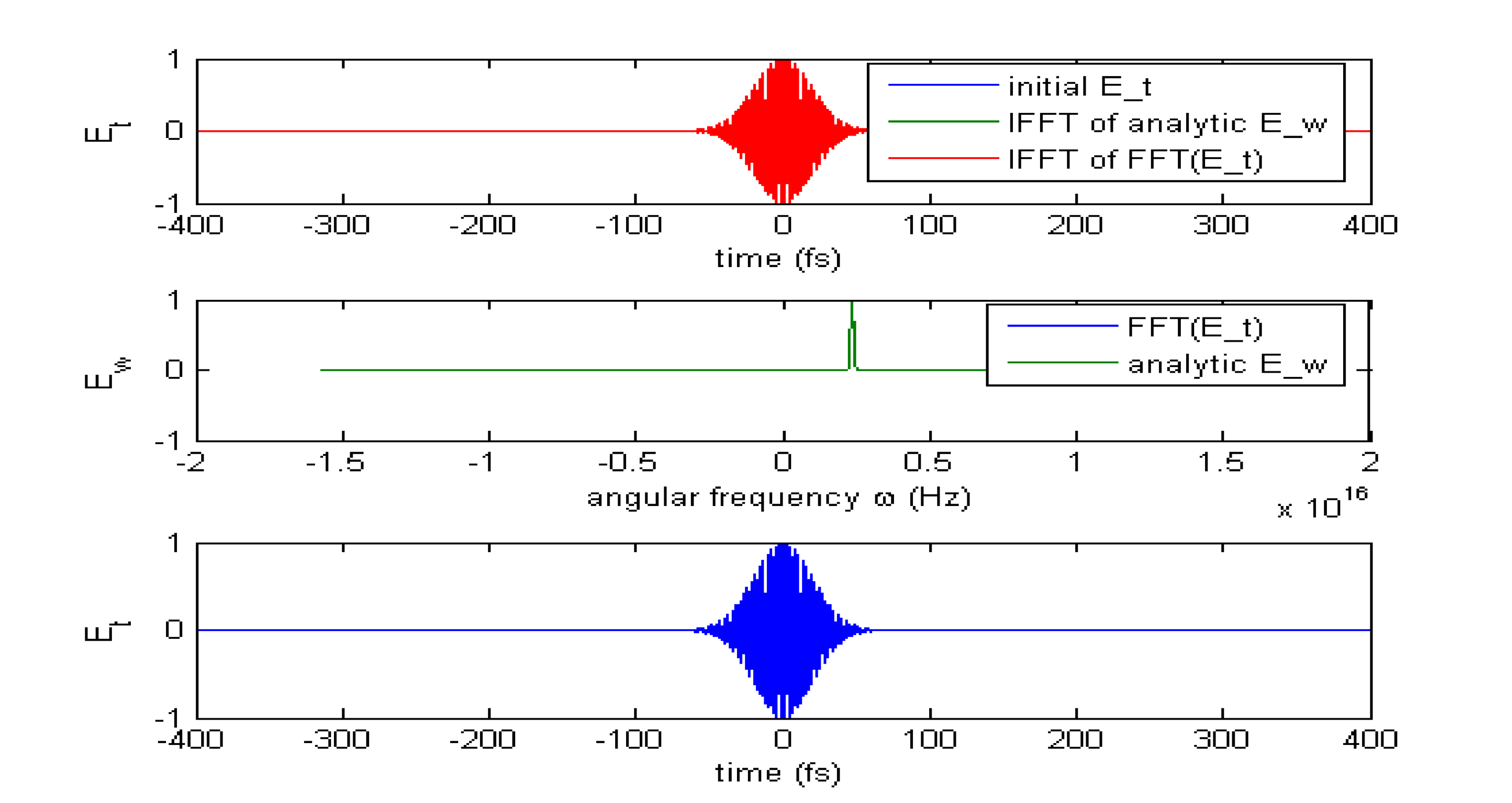

Figure 8: The MATLAB code that was made and compared to the analytical values ensure the accuracy the Fast Fourier Transformation algorithm

Conclusion:

- The Fourier Transformation algorithm worked along with the manipulations of the higher order phase terms for the AOPDF, but it still needs to be tested in an experimental setting

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