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Optimisation of a Laser Field Synthesiser

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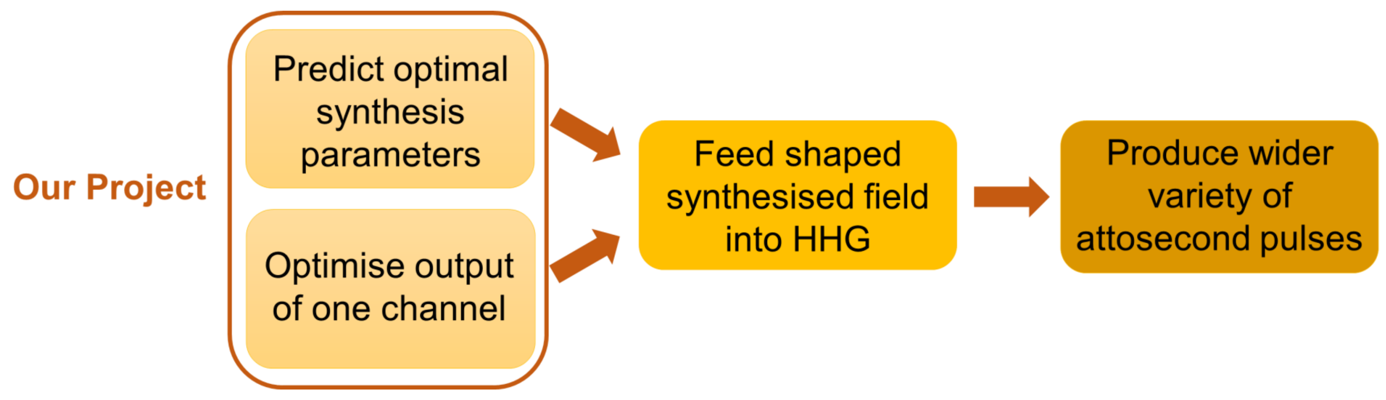
Femtosecond Laser
30fs, 790nm

Motivation

Attosecond (10^{-18}s) light pulses allow us to observe charge motion on incredibly short timescales in phenomena such as electron tunnelling and photoionisations [1].

They can be made from femtosecond (10^{-15}s) laser pulses using High Harmonic Generation (HHG). We seek to improve the attosecond output by shaping the input pulse.



Background

Laser Field Synthesis: Split a pulse into channels, individually manipulate them using nonlinear optical effects, and recombine into a shaped pulse.

The optimal channel parameters are challenging to predict so we use **Bayesian Optimisation (BO):** A machine learning method for expensive to evaluate black-box functions.

Self-Phase Modulation (SPM) is a nonlinear effect in which the high intensity of an ultrashort pulse changes the refractive index of the gas it is propagating through. This induces a phase shift and broadens the pulse's frequency spectrum.

Optical Parametric Amplifier
45fs, 1100-2100nm

Field Synthesiser Simulation

1) Define each synthesiser **channel** with its initial parameters.
2) Combine the channels into **one laser pulse**.
3) Define the **figure of merit**, for example:
   - ideal pulse shape
   - maximum intensity
   - … or any combination!
4) Define the pulse parameters to vary during the optimisation.
5) Run **Bayesian Optimisation** of the synthesised pulse for a given number of iterations.

- ➢ Enables prediction of optimal synthesiser parameters.
- ➢ With as few as 6 iterations, our maximum output intensity increased by a factor of 9.

Result: BO Tool for Field Synthesisers.
Example: RMS error minimisation with a ramp:

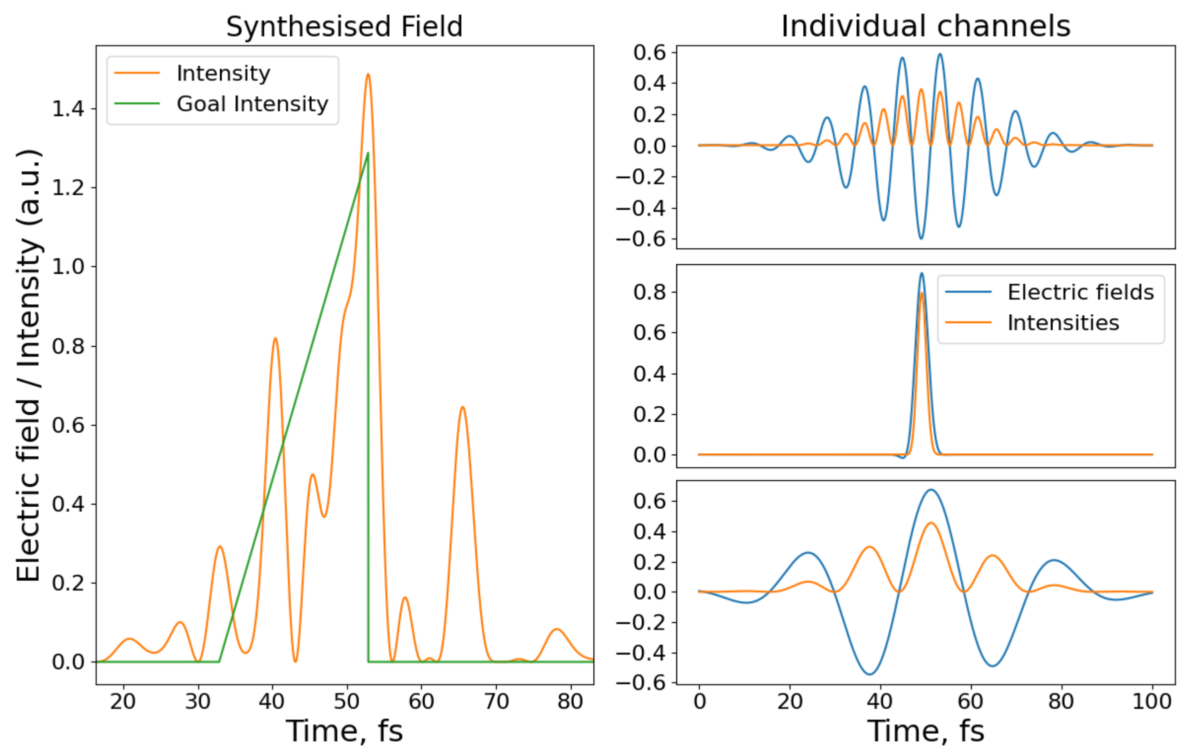
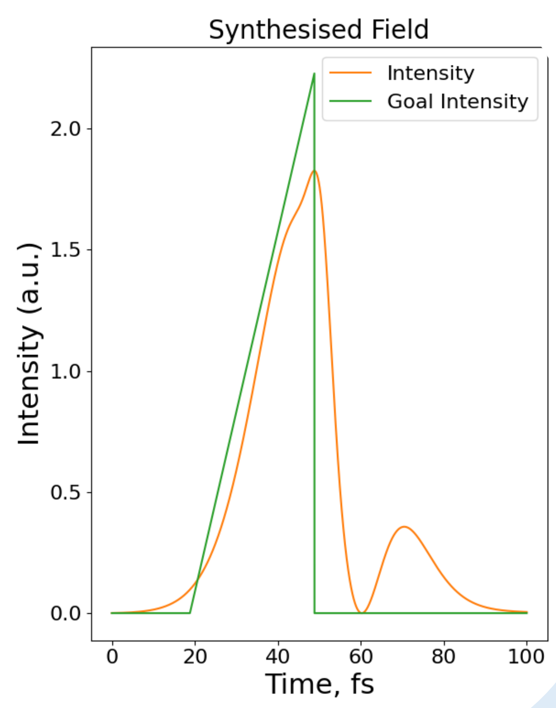


Fig.1 (above): Output after 100 BO iterations. Used 3 channels and 9 variable parameters analogous to our physical synthesiser.

Fig.2 (below): Output after 500 BO iterations. Used 15 channels and 60 variable parameters.



Hollow Core Fibre
4s, 775nm

Hollow Core Fibre (HCF) Simulation

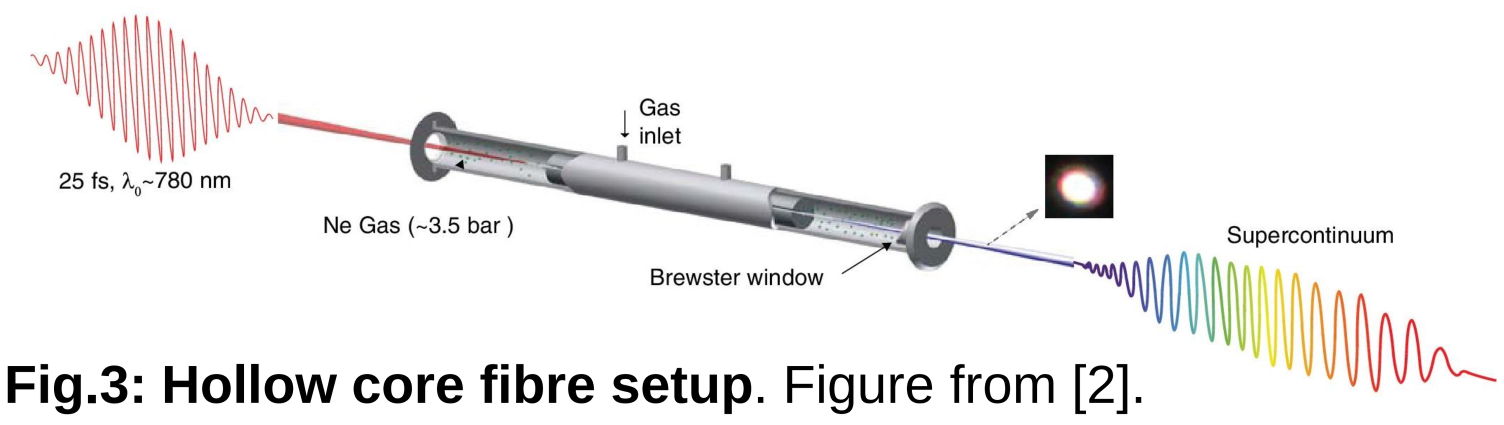


Fig.3: Hollow core fibre setup. Figure from [2].

In a gas-filled HCF, the pulse undergoes SPM which broadens the frequency spectrum, allowing it to be compressed in time.
Using Luna (a simulation developed at Heriot-Watt) we seek to maximise this output frequency bandwidth to achieve the shortest pulse duration. By experimentally characterising our HCF output and input pulses, we verified the credibility of Luna.

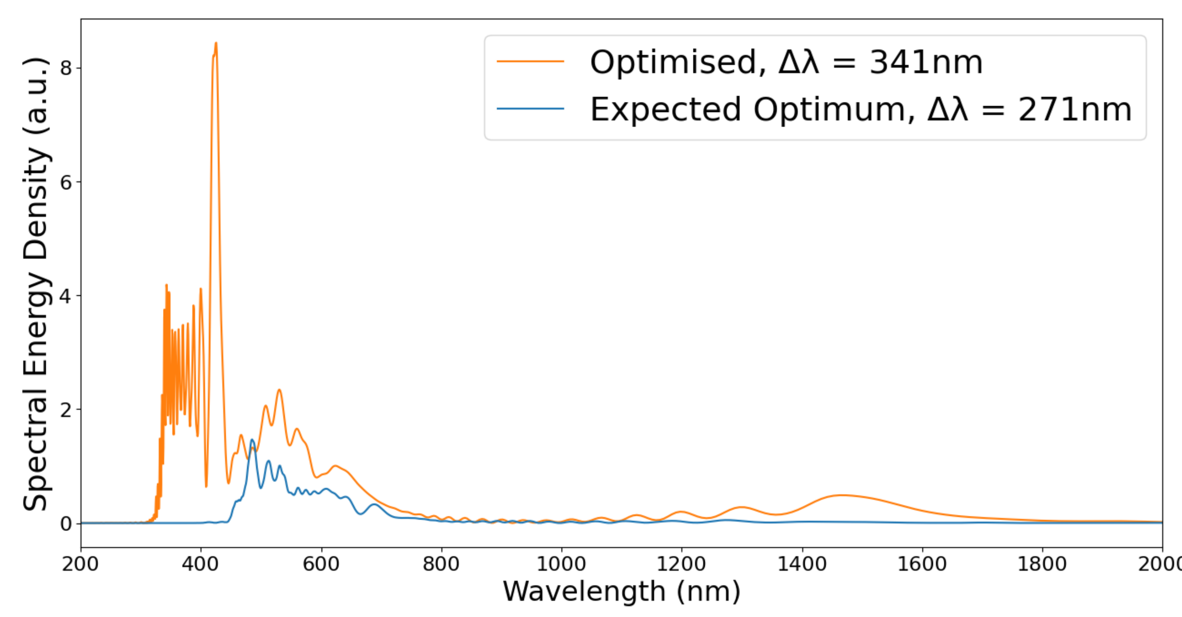


Fig.4: BO Outcome from the HCF simulation for maximum bandwidth comparing theoretical optimal parameters and 100 BO iterations. The input energy, and the pressure, radius, and fibre length were varied. The width was determined with a 7% threshold.

Second Harmonic Generation
33fs, 395nm

Conclusion

BO can improve the output of the field synthesiser in under ten iterations.

Optimising the parameters of the HCF allows us to form shorter pulses in time, establishing more flexibility in the synthesiser. Current simulations suggest a bandwidth increase of 26% after BO.

Further Research

- Our BO predictions can be implemented experimentally to produce a greater variety of attosecond pulses with higher photon fluxes and energies. Alternatively, the experimental HHG output values could be fed into each BO iteration to optimise in real time.
- Our flexible and general BO software can optimise present or future synthesisers with any number of channels.
- Our 'HCF Simulation - BO' software is being used by a group at Heriot-Watt to improve their production of solitons from HCFs.

High Harmonic Generation

OUT

References

[1] M. Chini, K. Zhao, Z. Chang., "The generation, characterization and applications of broadband isolated attosecond pulses", *Nature Photonics*, vol. 8, no. 3, p. 178-86, 2014.
[2] M. Hassan et al., "Invited Article: Attosecond photonics: Synthesis and control of light transients", *Review of Scientific Instruments*, vol. 83, no. 11, p. 111301, 2012. Available: 10.1063/1.4758310.