DTU

Reinforcement Learning Control of Raman Amplifiers 18.12.2025

Simulation model validation

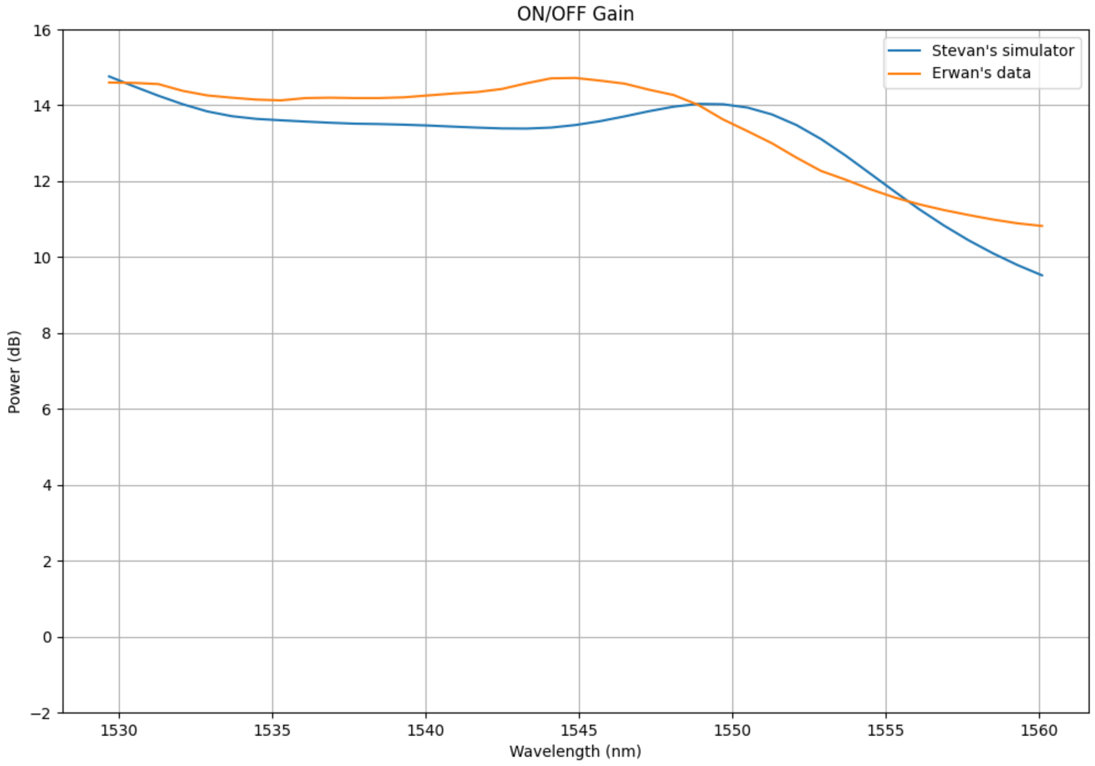
The experiment was performed on Erwan's and Stevan's simulators.

The results are showcasing ON/OFF gain of the Raman system.

The ON/OFF gain is measured by running the simulation with the pump powers set to their values, then set to 0W, which produces two power spectra. The gain spectrum is calculated by dividing the two power spectra.

- Fiber
  - Type - Standard Single Mode
  - Length - 100 km
  - Attenuation @ signal – 0.2 dB
  - Attenuation @ pump – 0.25 dB
  - Peak Raman efficiency – 0.42
- Raman Amplifier
  - Powers – 200 mW
  - Wavelengths – 1420, 1440, 1455 nm
  - Only forward pumping
- Input spectrum
  - 40 components, 1530 – 1560 nm
  - Component power - 250 uW
  - Total input power – 10 mW

Simulation model validation



The two gain profiles have a slightly different shape, due to Stevan's model simplifying interactions between pumps, but their magnitude is very similar.

Changes to the model

- Previously the contributions of each pump were treated as separate, and their resulting spectrums were simply summed together.
- This approach was used since it allowed for the simulator to have any number of pumps.
- Raman ODE system solved 3 differential equations for each pump-signal component pair, meaning that a single step of the simulation calculated 3 (pump) * 40 (signal components) sets of 3 differential equations.

- The error in previous approach was the assumption that the pump contributions could be simply summed.
- This approach was used since it allowed for the simulator to have any number of pumps.
- Now the ODEs are created in sets of 7 for each signal component, and the system is fixed to 3 pumps. For each signal component, the system of 7 ODEs is solved.

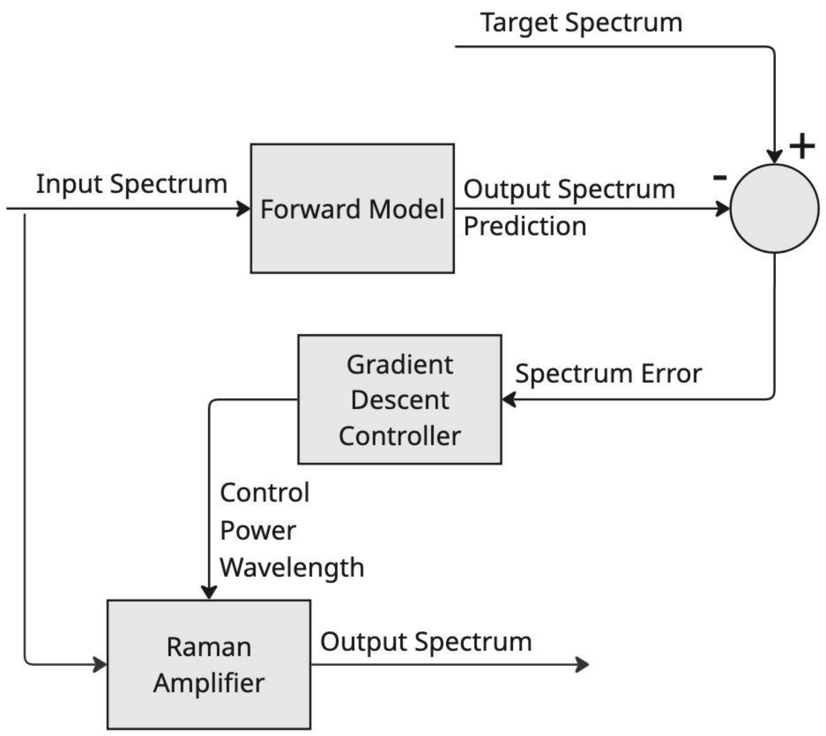
Gradient Descent Controller

The gradient descent controller computes the gradient of the loss function using the forward model as an approximation.

The forward model is based on the sampled pairs of Raman input powers and wavelengths, and the corresponding power spectrum at the output.

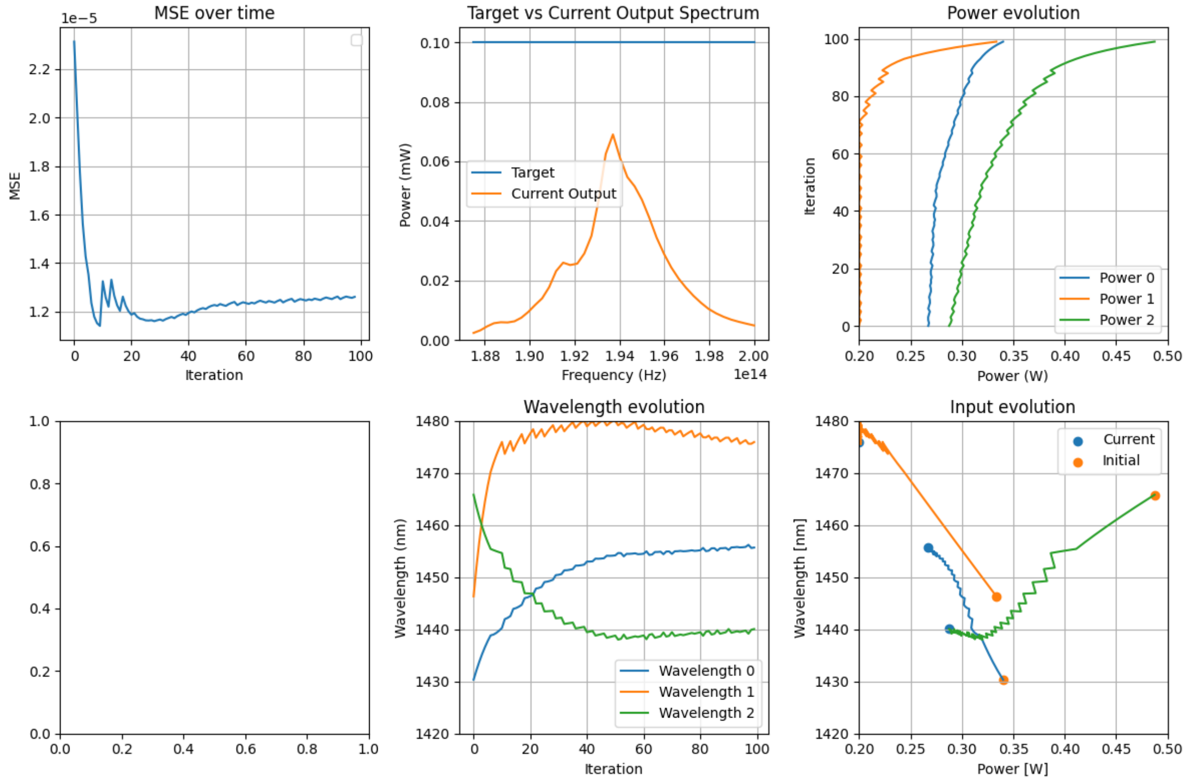
The dataset for training the forward model will be acquired once the model is validated.

The training of the forward model will be conducted on normalized input and output values.



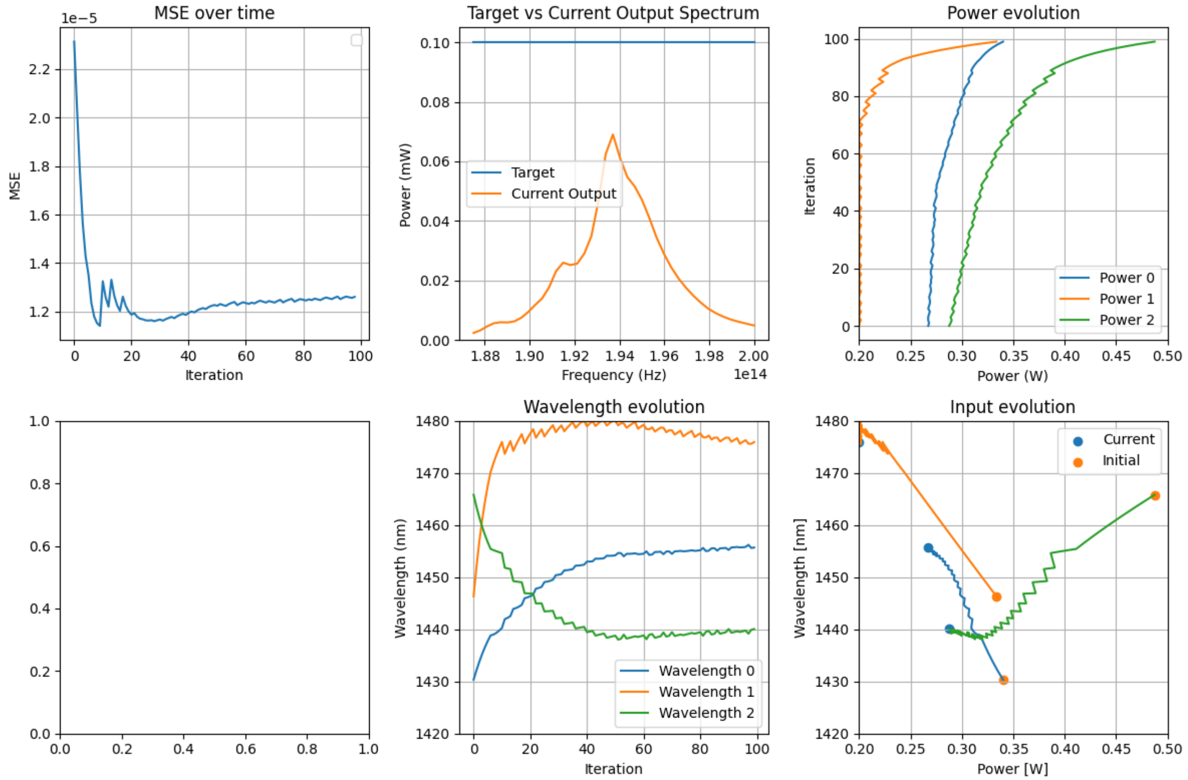
Gradient Descent Controller

- Analyzing the results given by the GD controller, we can see that the MSE goes down initially quite quickly but starts to stagnate after ~30 steps.
- All three pump powers are gravitating towards the lower side of their domains, due to the shape of the loss function which is tilted towards low power side of the domain.
- The final spectrum is quite far from the target spectrum both in shape and in value. This means that the GD controller doesn't capture the nature of the Raman model.



Gradient Descent Controller - Improvements

- Currently the dataset for training the forward model contains only ~600 data points. The model is therefore simplified, and its training shortened. A more detailed model could result in better controller behavior.
- Different definition of loss could help prevent convergence to local minima, which would prevent the drift to low power ranges.



Bernoulli Controller

- Looking at the results given by the Bernoulli controller, we can still see that one of the three pumps ended up in a local minimum on the low pump power edge of the domain.
- Despite this, the Bernoulli controller managed to move the two, initially low, powers into their upper ranges.
- The final output spectrum is not flat in shape, but it is at least centered around the correct mean value. For it to be flatter, the target spectrum could be lowered, so that target pump powers are lower in the domain.