FF.SS.: THE FAST FIBER SIMULATOR SOFTWARE

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To design/manage a network, it is crucial to predict the performance of a single optical link

What about the GN-model?
The GN-model have some limitations:

- Large bandwidths (Raman)
- Short links
- Subcarrier multiplexing
- Low-dispersion fiber
- Constellation shaping
- ...

More sophisticated models (EGN) fixes some of these limitations, but not all of them

- Complexity also increases

Moreover, these models do not take into account some effects

- E.g. non-linear phase noise, PMD, ...
- *Crucial* for transceiver design

Accurate time-domain simulation tools are still very important!
Non-linear Schrödinger equation

\[ \frac{\partial \mathbf{E}(z, \omega)}{\partial z} = -j \beta(\omega) \mathbf{E}(z, \omega) - \alpha(\omega) \mathbf{E}(z, \omega) \]

\[ -j \frac{\gamma}{3} \mathcal{F} \left\{ \left[ 3|E_X(z, t)|^2 + 2|E_Y(z, t)|^2 \right. \right. \]
\[ \left. \left. \frac{E^*_X(z, t) E_Y(z, t)}{E^*_Y(z, t) E_X(z, t)} \right] \right. \]
\[ \left. + \left[ 3|E_Y(z, t)|^2 + 2|E_X(z, t)|^2 \right] \right\} \mathbf{E}(z, t) \]

- Dispersion and PMD (2x2 tensor)
- Linear random frequency-domain operator
- Attenuation linear frequency-domain operator
- Kerr effect non-linear time-domain operator

- Non-linear vectorial (2x2) equation
- Operators both in time-domain and frequency-domain
- PMD is a random effect
\[ \frac{\partial E(z, \Omega)}{\partial z} = -j \beta_2(\Omega) E(z, \Omega) - \alpha(\Omega) E(z, \Omega) - j \frac{8}{9} \gamma \mathcal{F} \left\{ |E(z, t)|^2 E(z, t) \right\} \]

- Assumes an *average* PMD over a small optical bandwidth around \( \omega_0 = \omega - \Omega \)
- Equation becomes *scalar* and *deterministic*
Assumption: in a small $\Delta z$ linear and non-linear operators act independently

For every step, a DFT and IDFT are necessary to apply the steps:
- Linear in frequency-domain
- Non-linear in time-domain

Complexity can still be high for small steps and/or large signals
Speed of FFTs can be increased using general-purpose GPU computing (GPGPU)

We called our GPU-powered implementation of the split-step Fourier method **FF.SS. – Fast Fiber Simulator Software**

Entirely written in MATLAB with the aid of the Parallel Computing Toolbox

Solves both the PMD-Manakov equation and the Dual-Polarization NLSE integrating the waveplate PMD model
TESTED HARDWARE

Low-cost desktop-class machine
4-core 3.4 GHz
(Core i7-6700)

High-performance server
2x 6-core 3.4 GHz
(Xeon E5-2643 v3)
TESTED GPUS

Low-cost “gaming” GPU
NVIDIA GeForce GTX 1070
Pascal architecture (2016) ~$400

High performance GPU
NVIDIA Tesla K40c
Kepler architecture (2012) ~$4,000

Bonus!
NVIDIA Tesla P100
Pascal architecture (2016)
TEST SCENARIO

- 32 GBd PM-QPSK channels (100 Gbit/s)
- 100km SMF spans
- Gaussian interfereres to compare results with GN-model
BASELINE (CPU) RESULTS

- Time to simulate a single 100-km span
- Executed on the server CPU
- Exponential increase with $\log_2(L_{fft})$
- Time increase with total transmit power (smaller steps)
GPU SPEEDUP

![Graph showing GPU speedup vs log2(Lfft)](image)
GPU SPEEDUP

+30%
GPU SPEEDUP

+4.5%
+30%
GPU SPEEDUP (BONUS)

208 times faster than CPU!
ACCURACY OF SINGLE-PRECISION

- Accuracy up to 1 THz of WDM bandwidth, then overestimation of non-linear interference noise
- Double precision is accurate even at 4 THz

$P_{ch} = -6$ dBm, 30x100km SMF
• Accuracy up up 4 THz of WDM bandwidth (81 WDM channels on 50 GHz grid)
• For this scenario, PMD has negligible effect on NLIN generation
Even though GN-model is good enough for most of use cases, there are cases where it is not sufficient
  ▪ For these cases, full time-domain simulations with SSFM are necessary

Use of GPUs can **significantly reduce** simulation time

A low-cost system (desktop + gaming-class GPU) can still provide enormous reductions in simulation time
  ▪ For “heavy” simulations, a server-class GPU is still needed
THANK YOU

We acknowledge NVIDIA Corporation for the donation of the Tesla K40 GPU

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STEP SIZE

- Depends on total optical power:

\[ \gamma \Delta z \left( \max_{t,z} |E(z, t)|^2 \right) \leq \xi \]

- A too large step size will overestimate the impact of Kerr effect

Maximum non-linear phase shift
DIFFERENCES BETWEEN GTX1070 AND K40

![Graph showing differences in speedup between GTX1070 and K40](image)

- **Single-pr.**
- **Double-pr.**

![Logarithmic graph with speedup values](image)