Constant SNR-Error Step-Size Selection Rule for Numerical Simulations of Optical Transmissions

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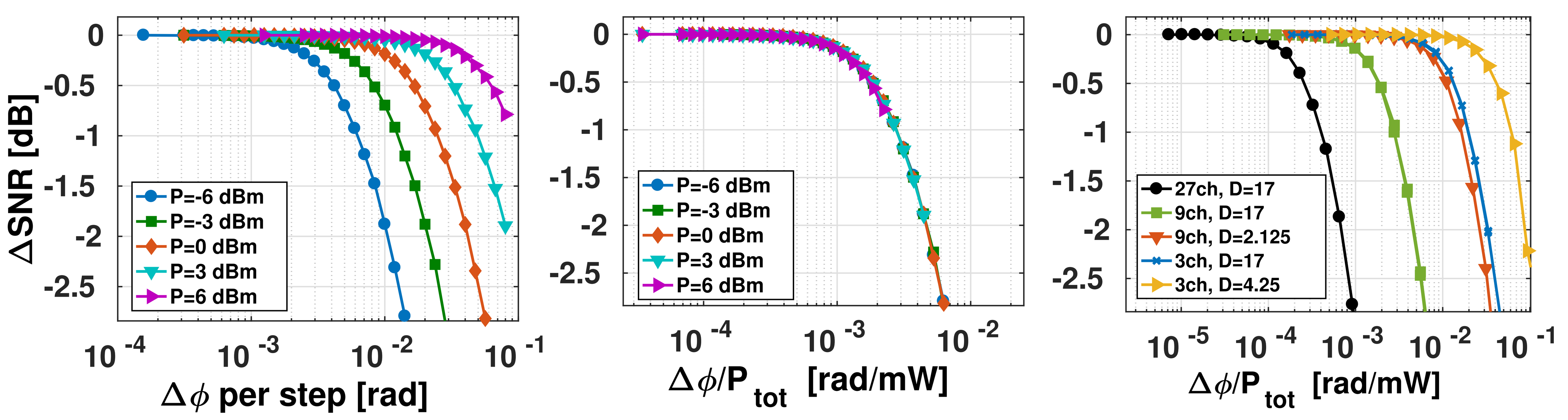
Abstract

- A **trustworthy Split Step Fourier Method (SSFM)** should simulate the NLSE with the desired accuracy whatever the optical link under investigation.
- Targeting a desired accuracy is crucial in nowadays time-consuming simulations of fully loaded wavelength division multiplexing systems, where a fine tuning is mandatory to save computational effort.
- A lot of effort has been put over the years in the optimization of the accuracy/run-time trade-off of numerical simulations [1–3].
- In this work we review the SSFM error in the general framework of the **Gaussian noise (GN) model** [4], which focuses on the signal to noise ratio (SNR), and propose a simple power-independent method to set up simulations granting a fixed relative numerical error on SNR.

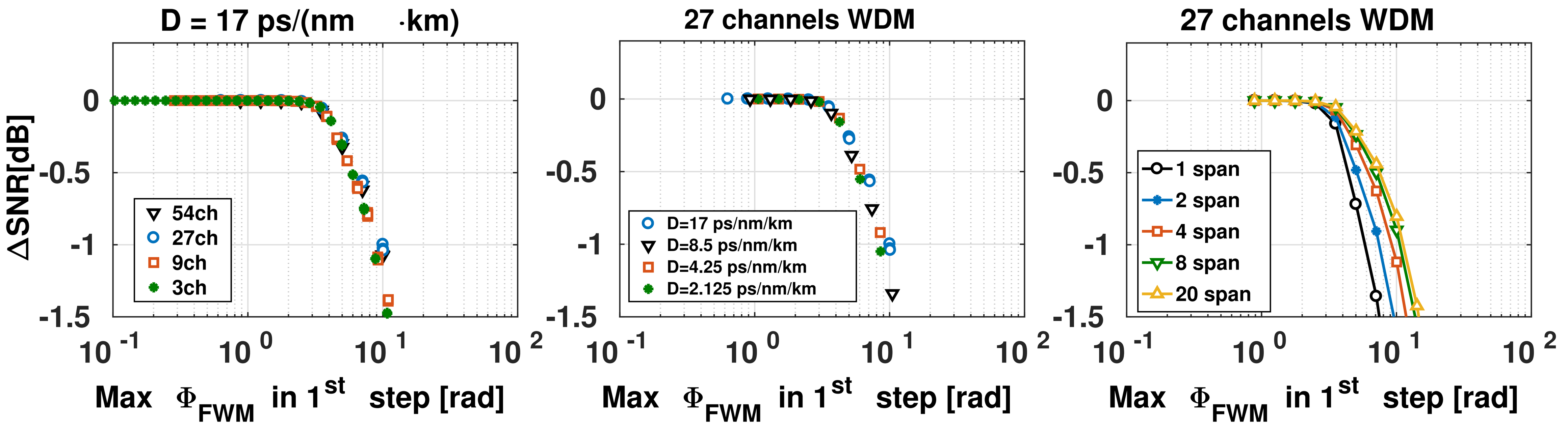
Data analysis and results

The popular Nolinear Phase criterion [2] is not good... *...while a power independent criterion is fine...* *...but still unreliable by varying dispersion/bandwidth!*



$$\text{SSFM error} \triangleq \Delta SNR \triangleq \frac{SNR}{SNR_{\text{true}}}, \qquad \Delta\phi = \gamma P_{\text{peak}} L_{\text{eff}}(h), \quad h = \text{step length}$$

Our Proposal



- We propose to scale the first step h_1 with the maximum tolerable Four Wave Mixing phase matching coefficient $\Phi_{\text{FWM}} \triangleq h_1|\beta_2|(2\pi B_{\text{WDM}})^2$, with B_{WDM} signal bandwidth.
- **Such criterion grants a constant SSFM error in [dB]** by varying fiber dispersion D or number of WDM channels.
- **single span transmission is a worse case** in accuracy due to a smaller growing rate with distance of SSFM error w.r.t. NLI.

Simulation Setup

WDM signal:
- $[3, 9, 27, 54]$ channels
- Symbol rate $R = 32$ Gbaud
- Channel spacing $\Delta f = 37.5$ GHz
- PDM quadrature phase shift keying
- NRZ Root Raised Cosine pulses, roll-off $r = 0.01$

Optical link:
- up to 20x100 km Single Mode Fibers
- Dispersion Uncompensated link
- Attenuation $\alpha = 0.2$ dB/km
- Nonlinear coefficient $\gamma = 1.3$ 1/mW/km
- Dispersion $D = [17, 8.5, 4.25, 2.125]$ ps/nm/km

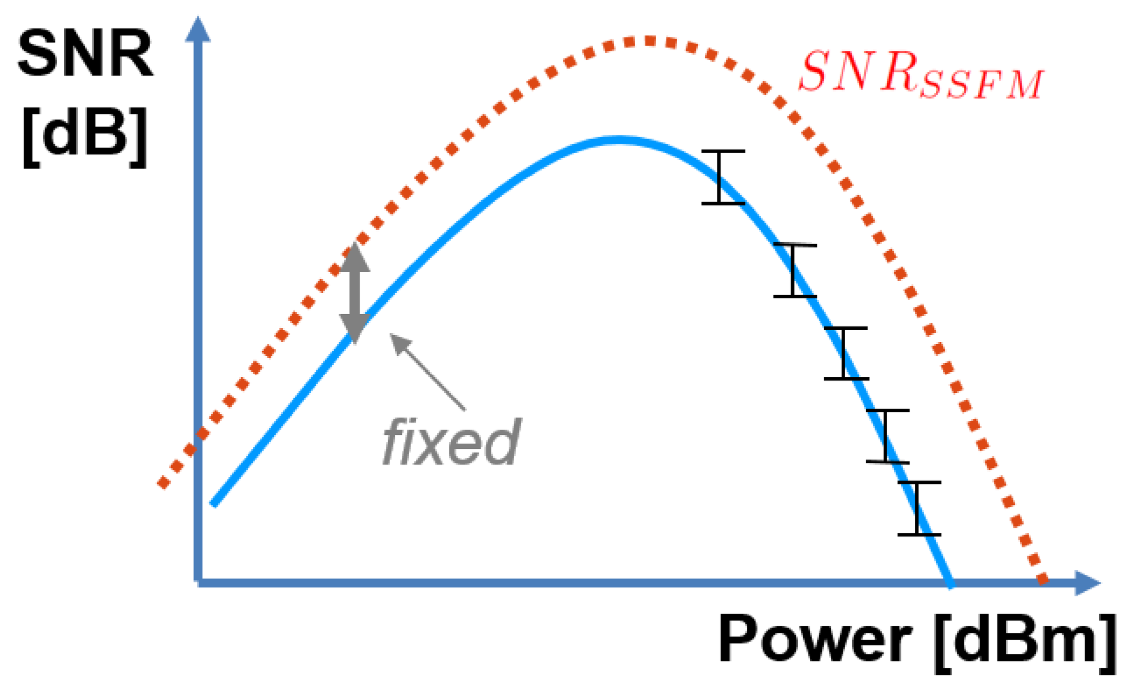
Rx: Matched filter + 1 tap Data-Aided Least Square Butterfly filter

SSFM accuracy

- Under GN model analysis, SSFM error can be seen as a perturbation similarly to nonlinear interference (NLI). The received SNR can thus be expressed as:

$$\frac{1}{SNR} = \frac{1}{SNR_{\text{ASE}}} + \frac{1}{SNR_{\text{NLI}}} + \frac{1}{SNR_{\text{SSFM}}}$$

where each right hand term refers to the SNR accounting for the corresponding effect only. The only term affected by the numerical implementation is SNR_{SSFM}.



- A trustworthy simulation should give a **constant error in [dB]**, i.e., a constant relative error, as sketched above.
- From GN model [4], the variance of SSFM error is expected to scale as P^3, P being power, similarly to NLI $\rightarrow$ **for increasing power we can tolerate more absolute SSFM error**.
- This criterion differs from popular SSFM criteria [1–3], where the step size is decreased for increasing power.

The degrees of freedom to set up a SSFM simulation are:

- **First step**: setup to have an almost GVD-independent SSFM error.
- **Step updating rule**: setup to keep constant local error along propagation.

Conclusions

- SSFM error scales with the cube of power as much as NLI, thus the relative error on SNR is independent of the transmitted signal power.
- A good way to set up SSFM numerical simulations at constant SNR error is by fixing the maximum FWM phase shift in the first step and to scale it along distance as in [3].
- SSFM error grows along distance at a smaller rate than NLI, hence sizing SSFM in the single span case is a conservative choice.

References

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