

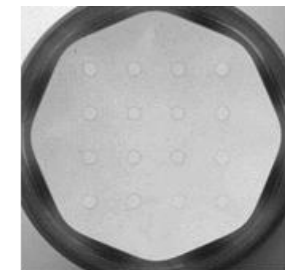
# Intercore–gain–crosstalk in multicore fiber amplifiers for telecommunication applications

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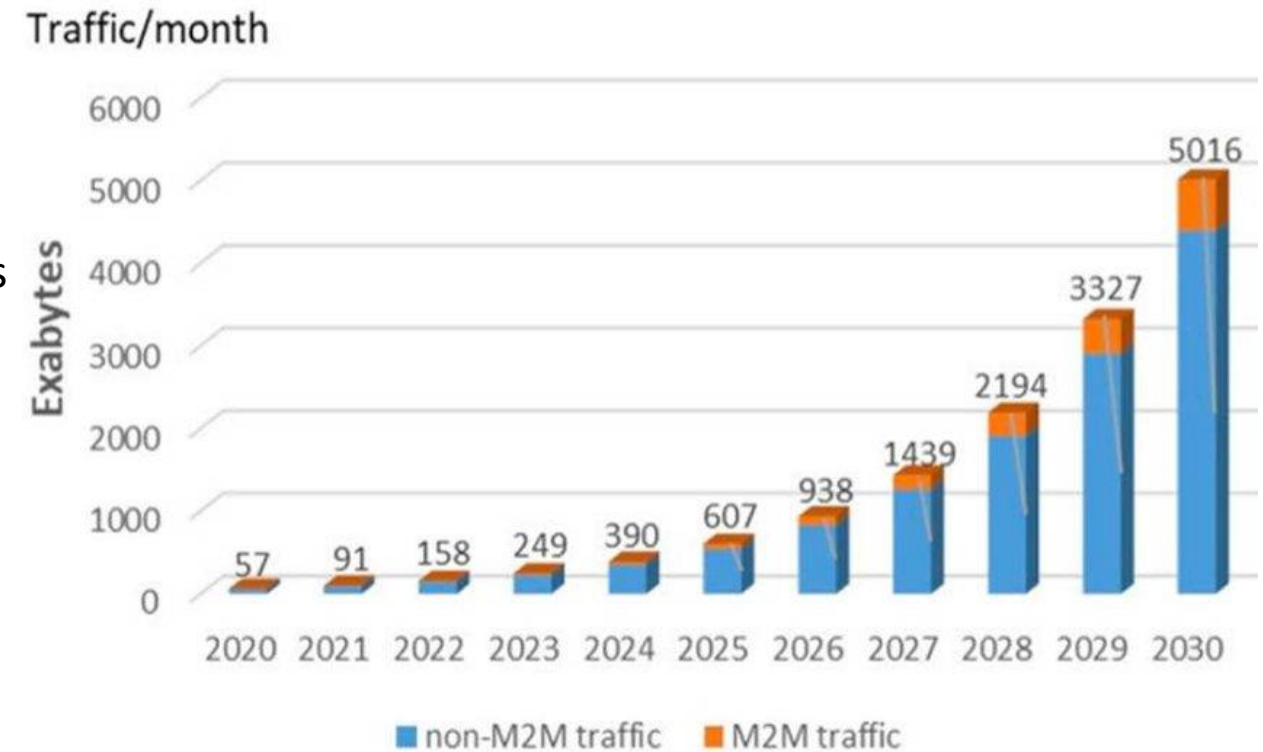


**Multi-Cap**

”Spatial division multiplexing in fiber optic networks” (16KIS1474K, 16KIS1477 and 16KIS1478)

## Multicore Amplifiers for Spatial Division Multiplexing (SDM)

- Demand for higher capacity in global networks  
→ SDM with multicore fiber (MCF)
- EDFA for MCF necessary  
→ typical core pumping with single mode pump diodes
- Capacity increase must not be coupled linearly to...
  - ... power consumption
  - ... investment cost

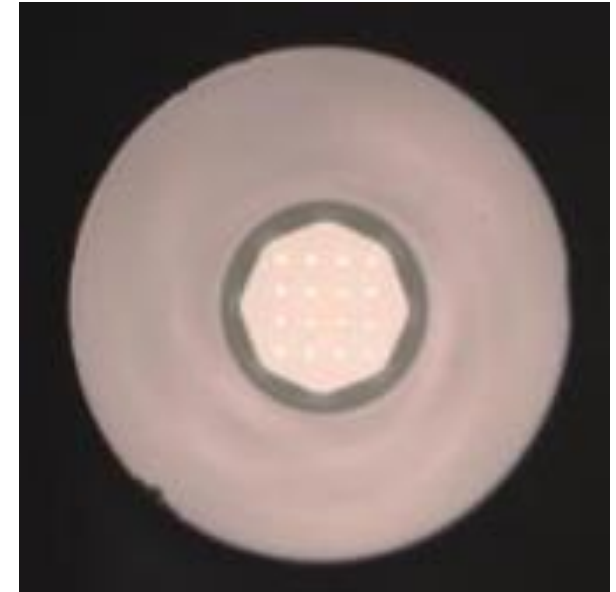


[1]

## Building MCF EDFA in Double Clad Design

### ■ Advantages:

- Sharing of pump power in MCF through shared cladding
- Usage of an uncooled multimode pump possible
  - cost efficiency + energy efficiency



[2]

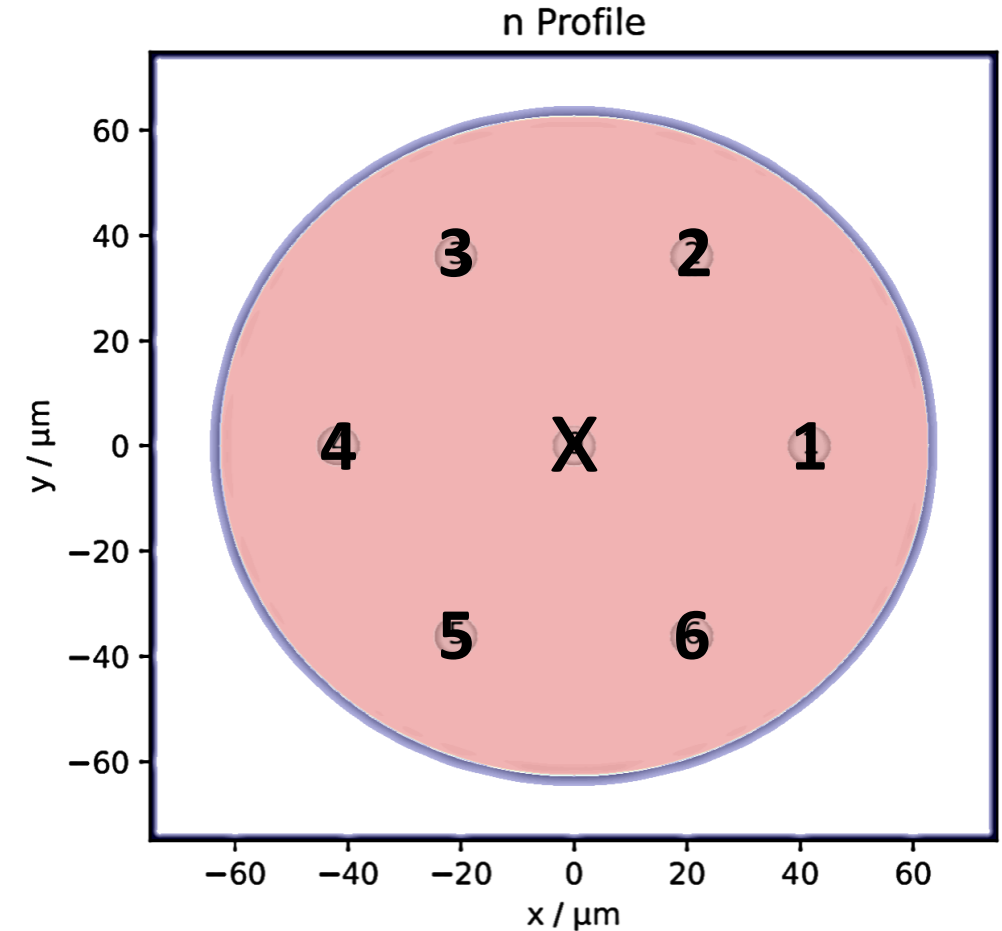
### ■ Challenges:

- Pump absorption in cores varies depending on the input signal (varying input signal typical for EDFA)
  - available pump power for other cores varies
- Pump power in cores not adjustable separately

Our scope:  
→ Cross gain influence between cores?

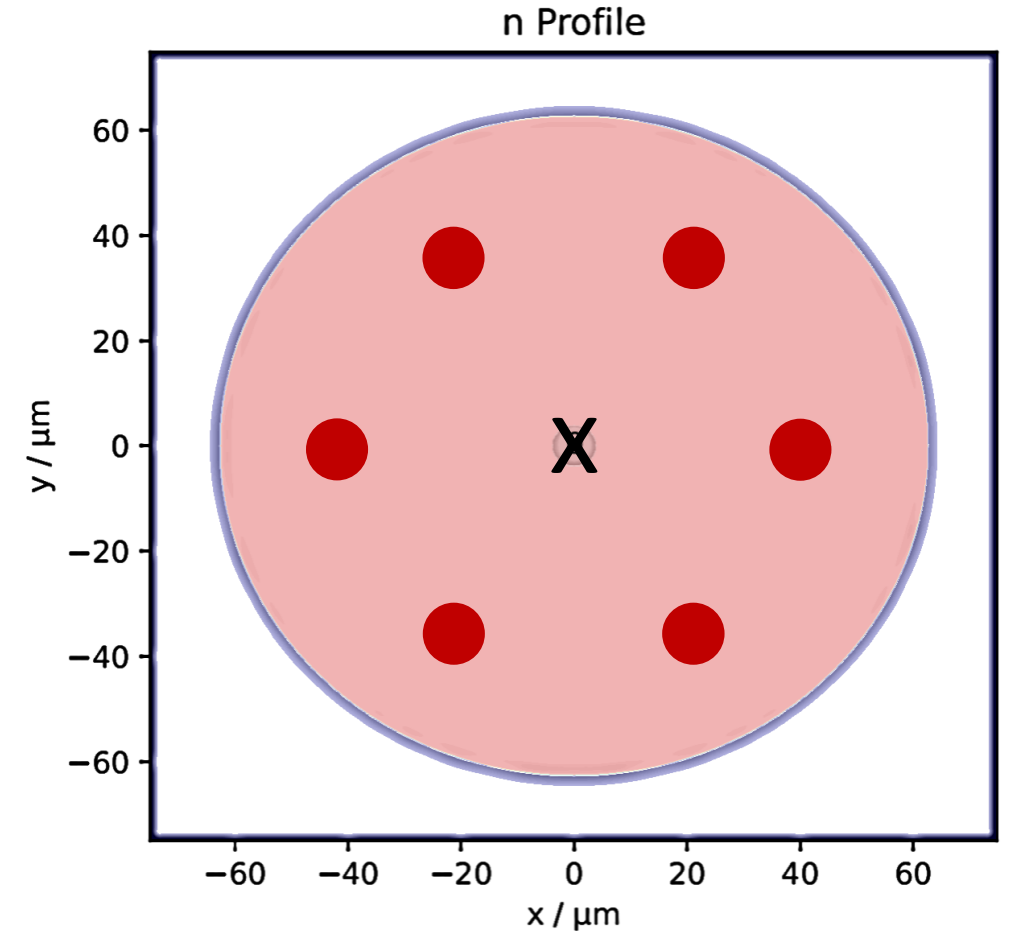
## Theoretical Work:

- Uncoupled 7 core MCF, compatible to SSMF , 20 m
- Spectral dependence of cross sections from standard erbium fiber
- 9 WDM channels, 2 cases:
  - High input signal power: -3 dBm
  - Low input signal power: -13 dBm
- 6 simulations:
  1. Starting with weak input signal power on 5 cores
  2. On every iteration: Full input signal power on one more core



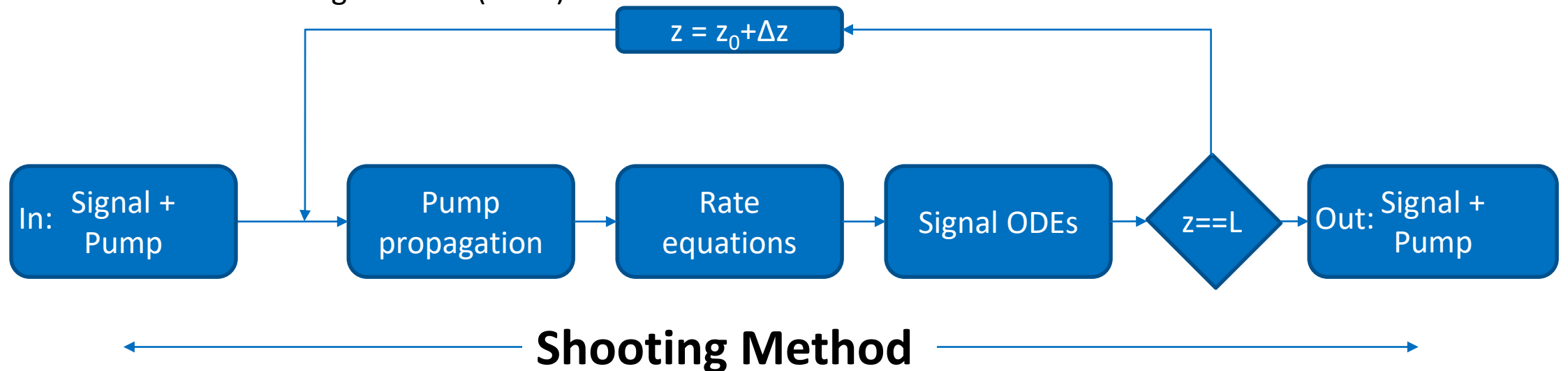
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## Module Based Model

- Two pump propagation models:
  - Beam propagation method (BPM)
  - **Geometric overlap**
- 2 level erbium rate equation model
- Numerical ODE solver for signal ODEs (RK45)



# Is the Geometric Overlap Simulation valid?

## Pump Power differences in cores?

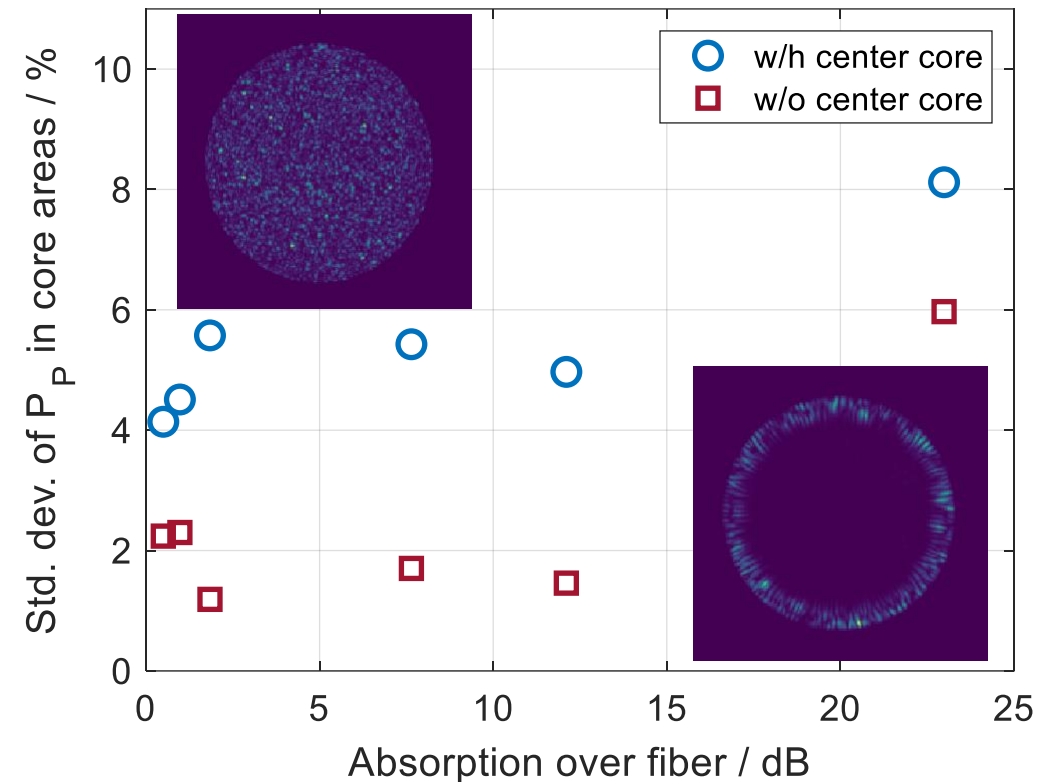
- Geometric overlap assumes equal pump power for equal geometries, but is much faster

## Method:

- 7 Core elements with equal absorption coefficients
- Full field BPM simulations with absorbing core elements
- Analysis of standard deviation in pump power over fiber

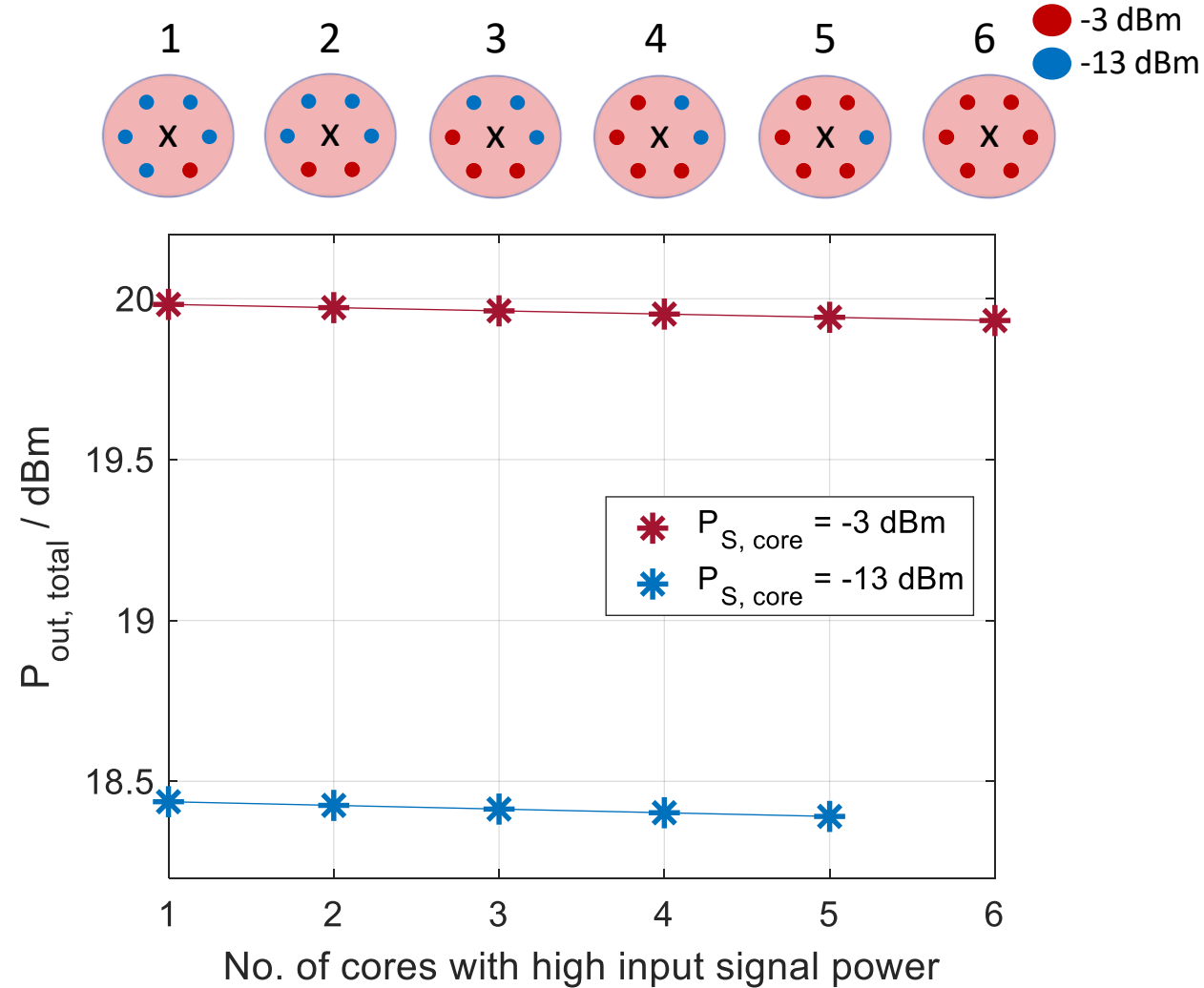
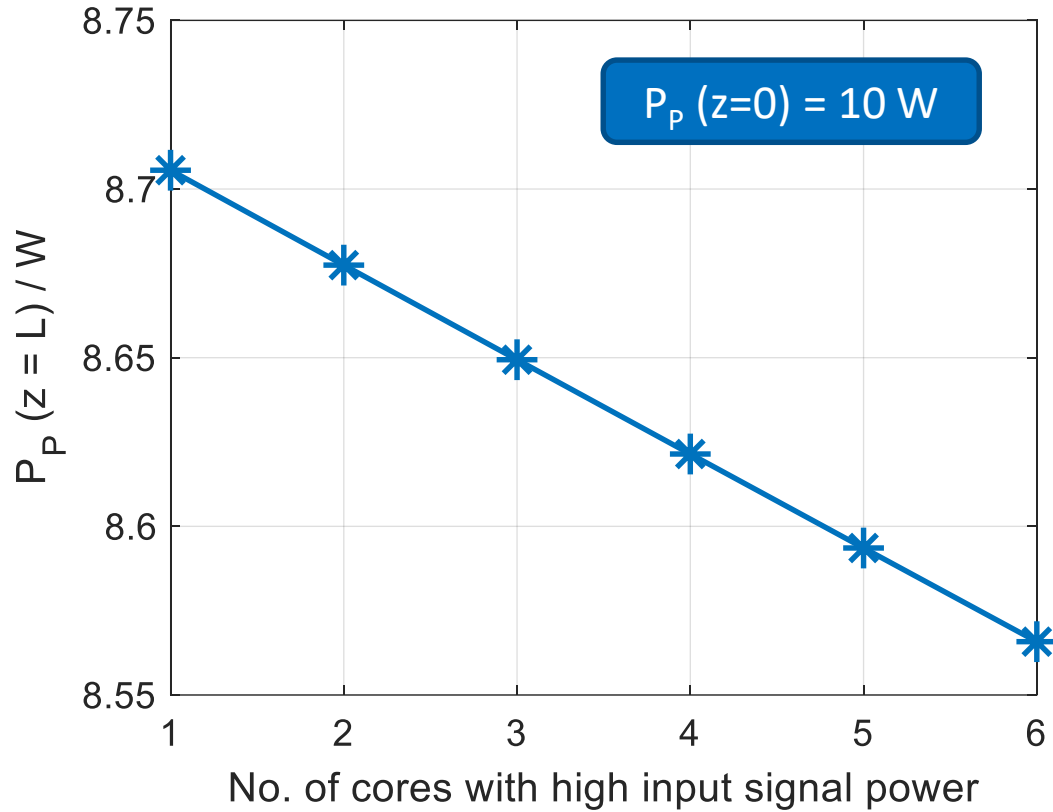
## Results:

- Annular core arrangement with center core shows std. dev. >4%
  - Annular core arrangement with low absorption: <2,5% std. dev.
- **Geometric Overlap Pump Propagation valid in our case**



# Residual Pump Power and Total Output Power

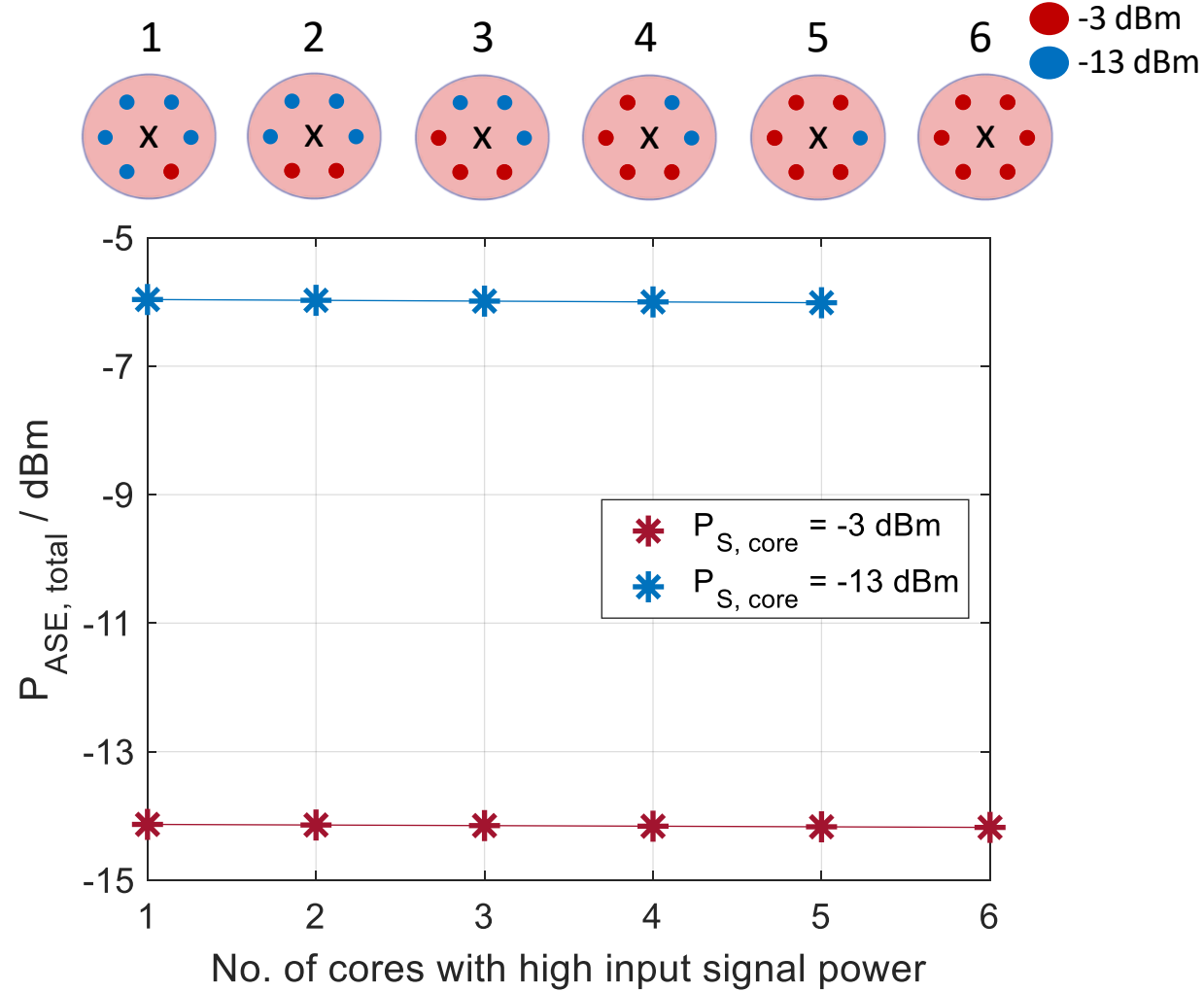
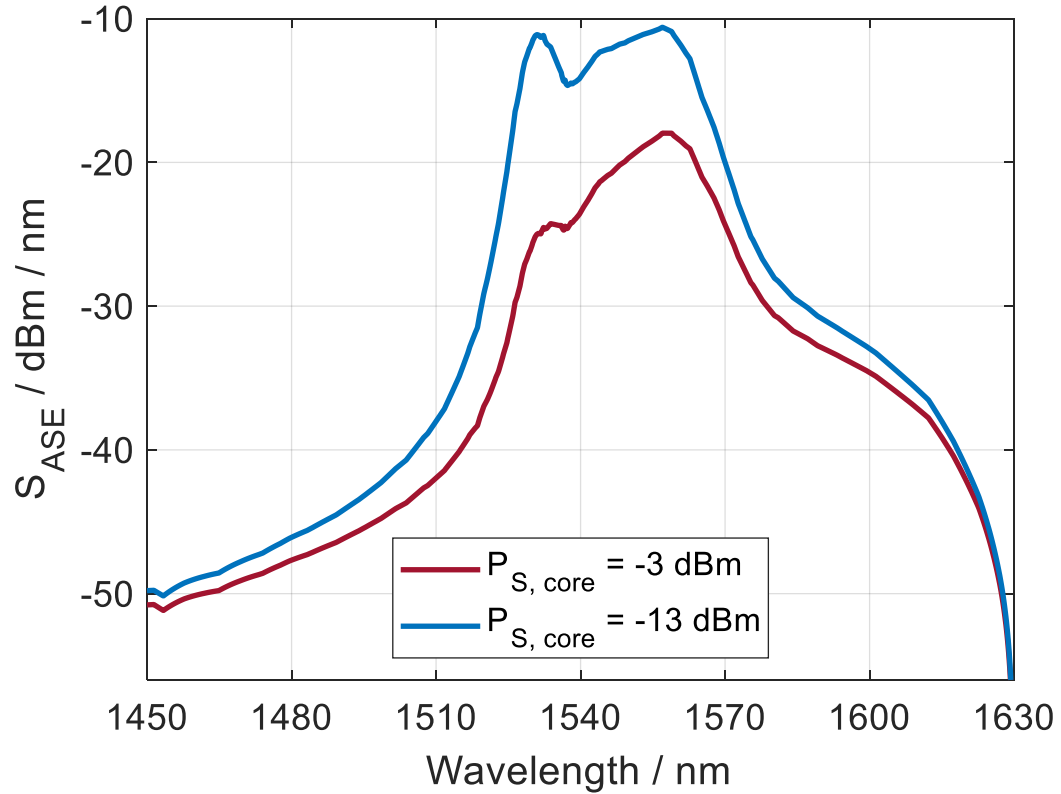
## Negligible Cross-Influence on Total Output Power





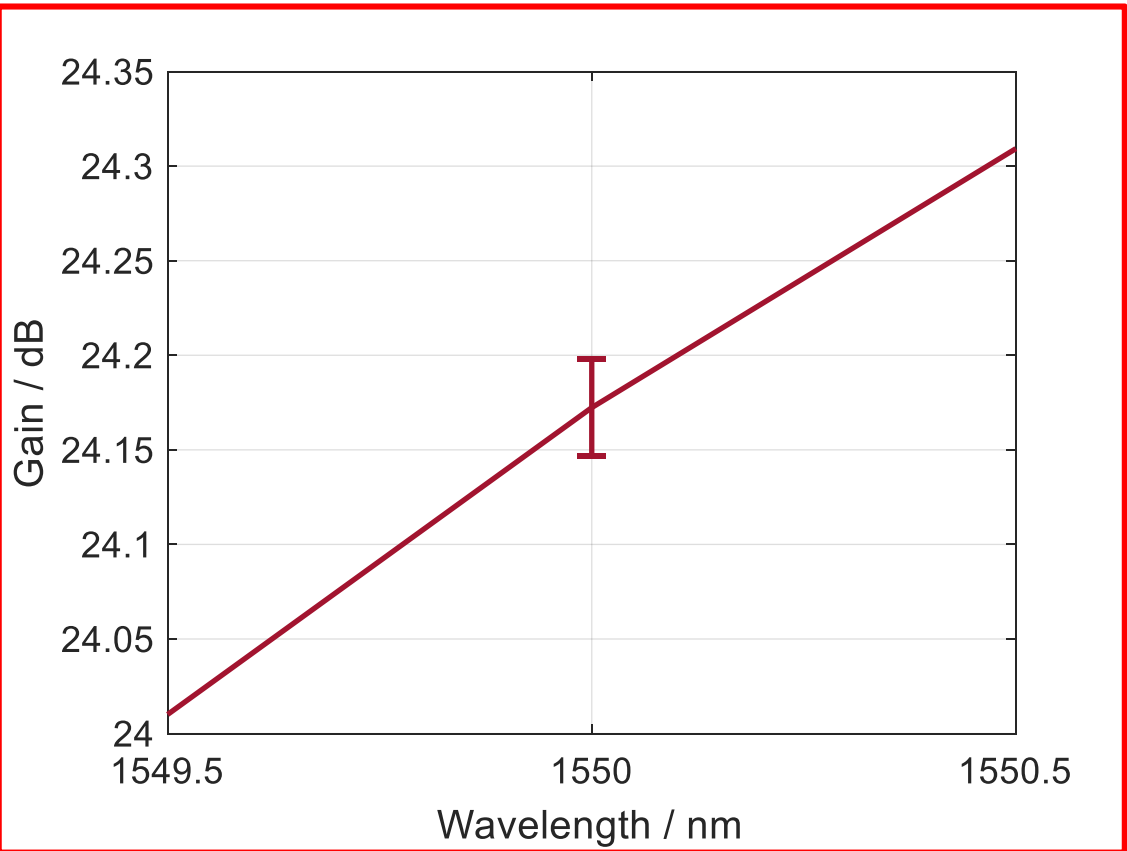
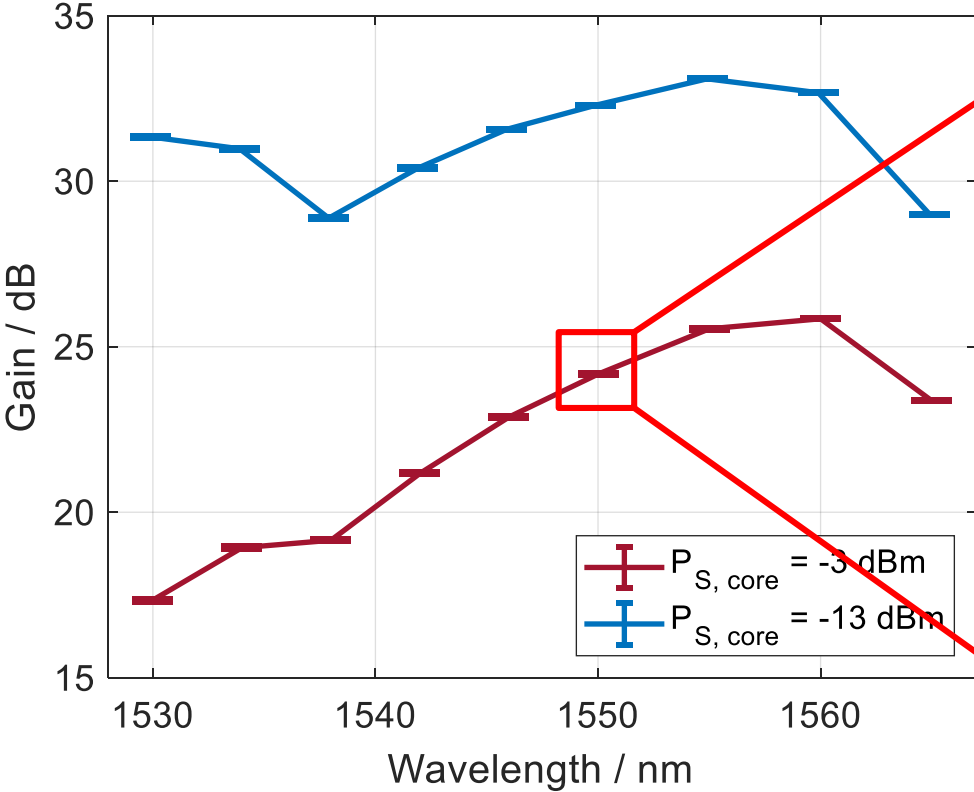
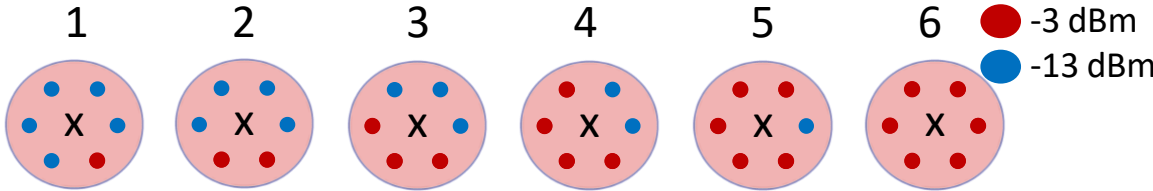
# Noise Characteristics

## Negligible Cross-Influence on Noise Characteristics



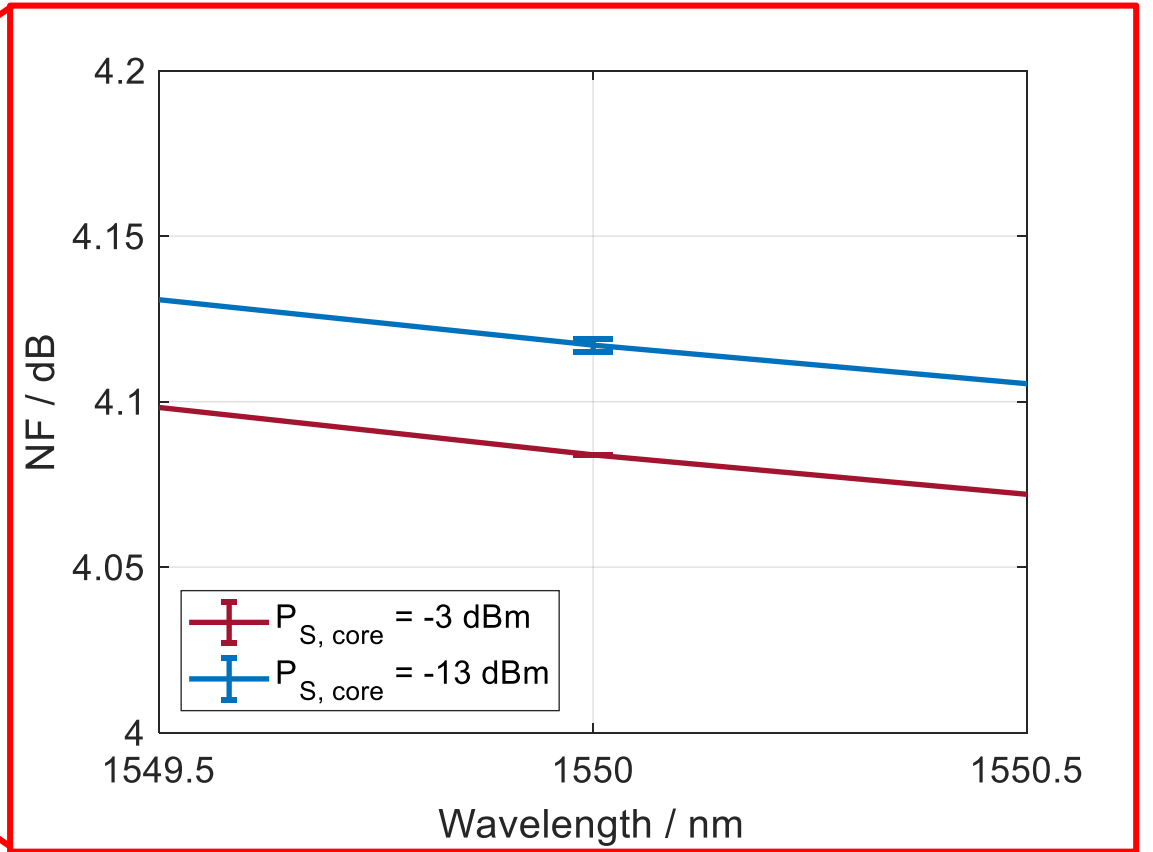
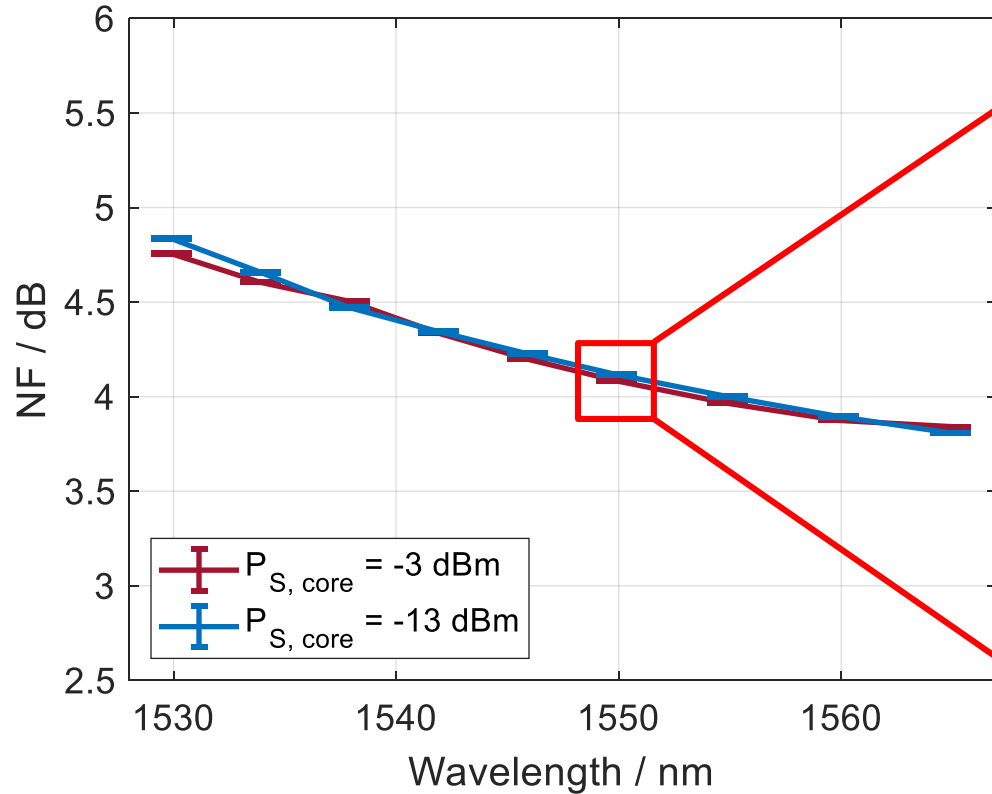
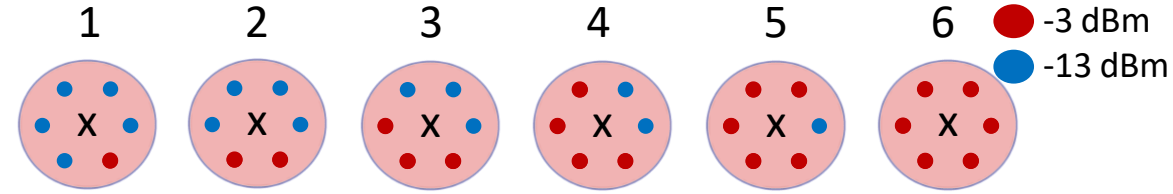
# Gain Characteristics

## Negligible Cross-Influence on Gain Characteristics



# Noise Figure Characteristics

## Negligible Cross-Influence on Noise Figure



## Validity of much faster Geometric Pump Propagation?

- Sufficient for annular core arrangements in low absorption scenarios

## Intercore-Gain-Crosstalk?

- Negligible cross-effects (gain and noise) from other core's input power
  - very stable behavior at constant input power
- Remaining challenges:
  - Pump power and gain not adjustable for every core individually
  - Low pump efficiency

- [1] E. A. Kadir, R. Shubair, S. K. Abdul Rahim, M. Himdi, M. R. Kamarudin and S. L. Rosa, "B5G and 6G: Next Generation Wireless Communications Technologies, Demand and Challenges," *2021 International Congress of Advanced Technology and Engineering (ICOTEN)*, Taiz, Yemen, 2021, pp. 1-6, doi: 10.1109/ICOTEN52080.2021.9493470.  
<https://doi.org/10.1109/ICOTEN52080.2021.9493470>
- [2] Arno Klenke, Albrecht Steinkopff, Christopher Aleshire, Cesar Jauregui, Stefan Kuhn, Johannes Nold, Christian Hupel, Sigrun Hein, Steffen Schulze, Nicoletta Haarlammert, Thomas Schreiber, Andreas Tünnermann, and Jens Limpert, "500 W rod-type 4 × 4 multicore ultrafast fiber laser," *Opt. Lett.* **47**, 345-348 (2022).  
<https://doi.org/10.1364/OL.445302>