# Frequency Encoded Optical CDMA

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# Introduction

Former FE-OCDMA publications showed either theoretical analyses, and/or limited experimental validation.

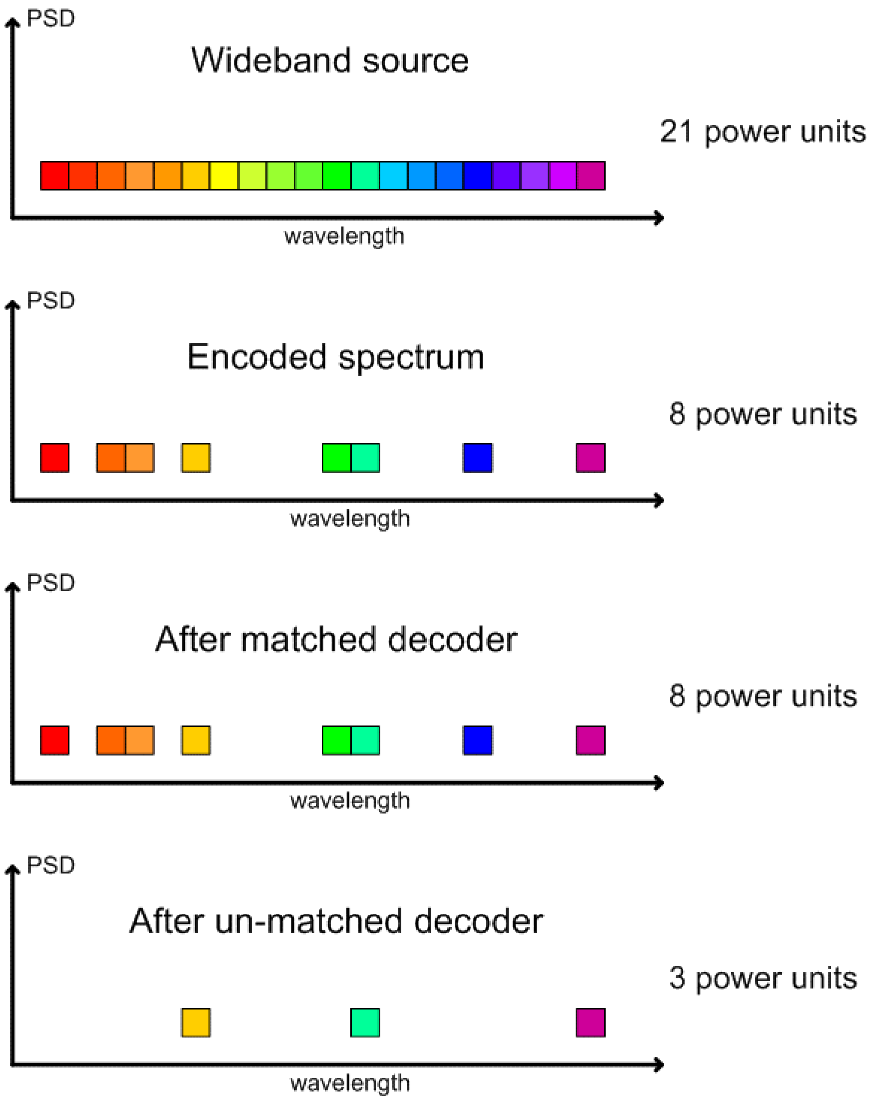
In our work we present:

- Bit error rate (BER) measurement at 155 Mb/s and 622 Mb/s.
- Excellent match between experiment and simulation for up to four users.
- Prediction of potential system capacity.

# What is FE-OCDMA?

## Frequency Encoded Optical Code Division Multiple Access

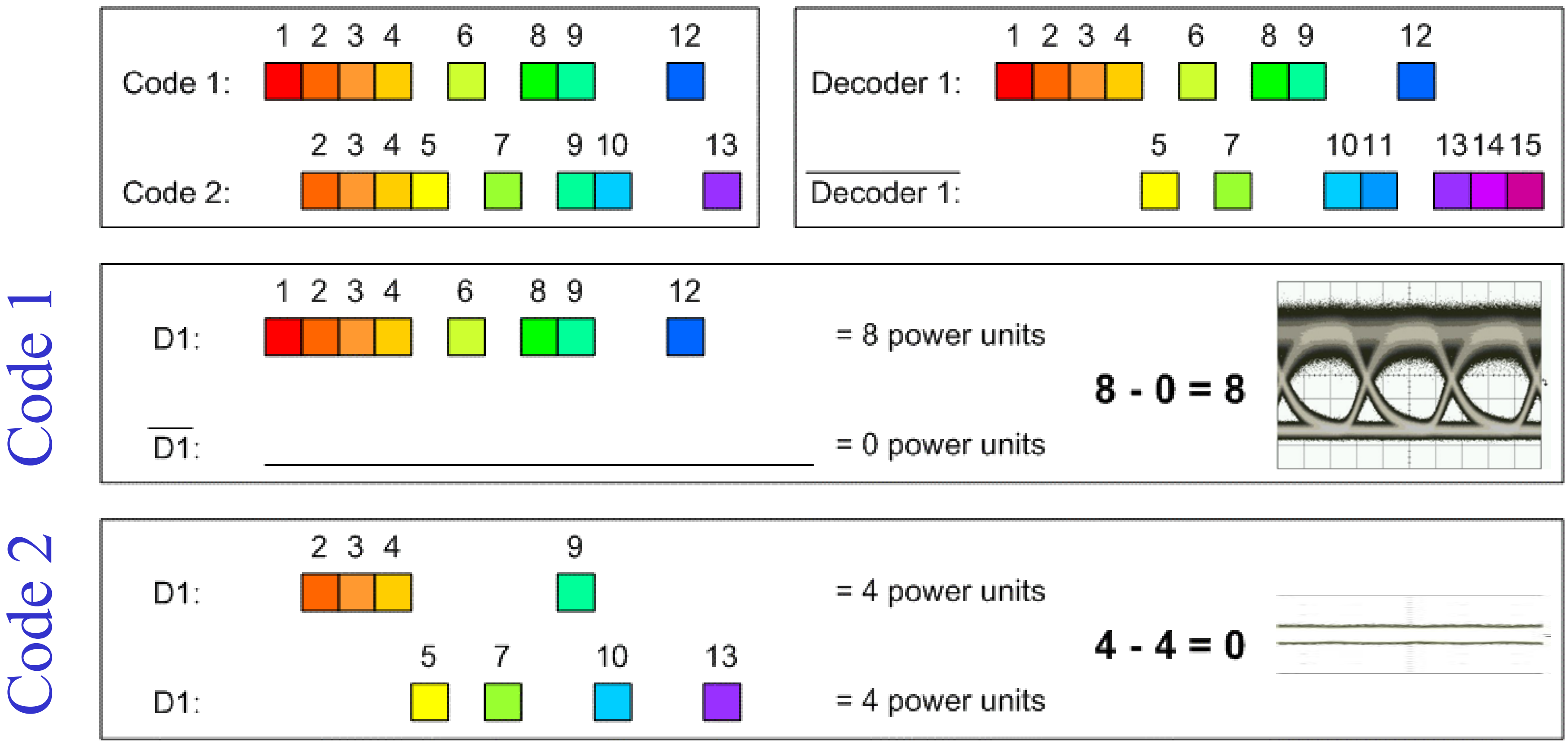
- Codes are composed of a combination of wavelength sub-bands.
- After matched decoder: High auto-correlation level.
- After un-matched decoder: Low cross-correlation level.



# Balanced Detection

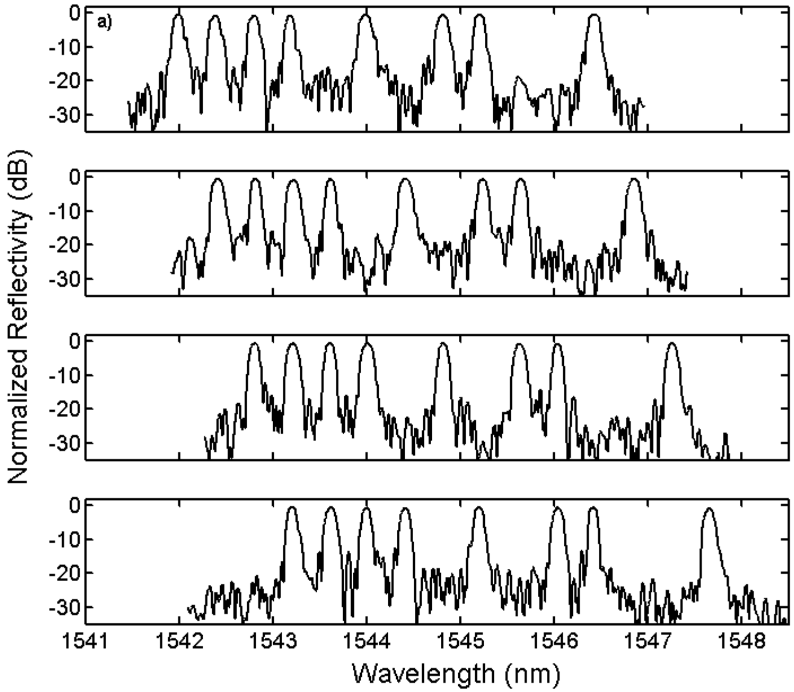
## The energy from un-matched codes is eliminated.

**Example:** *M*-sequence code of length 15, weight 8 and fixed cross-correlation of 4.

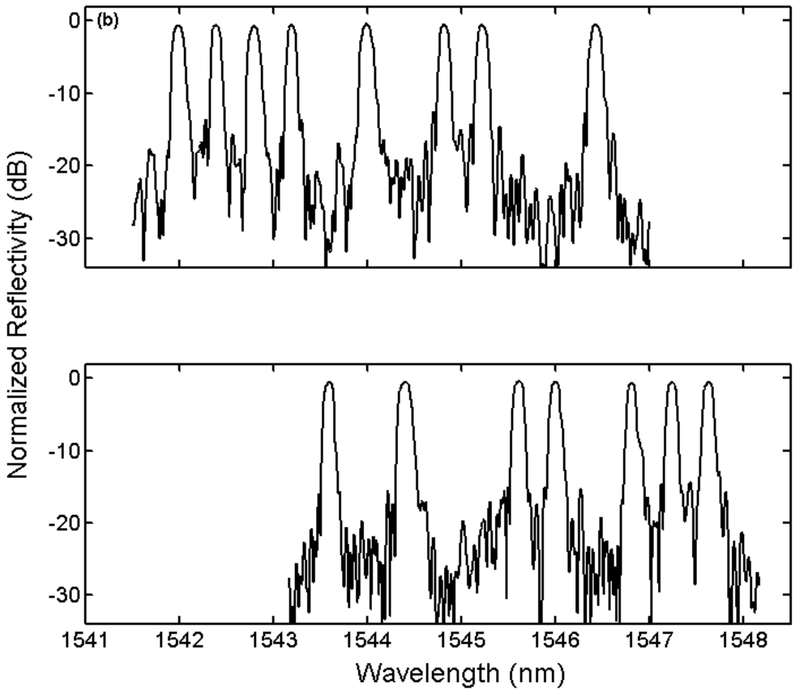


# Physical implementation of the codes

Encoders 1 to 4



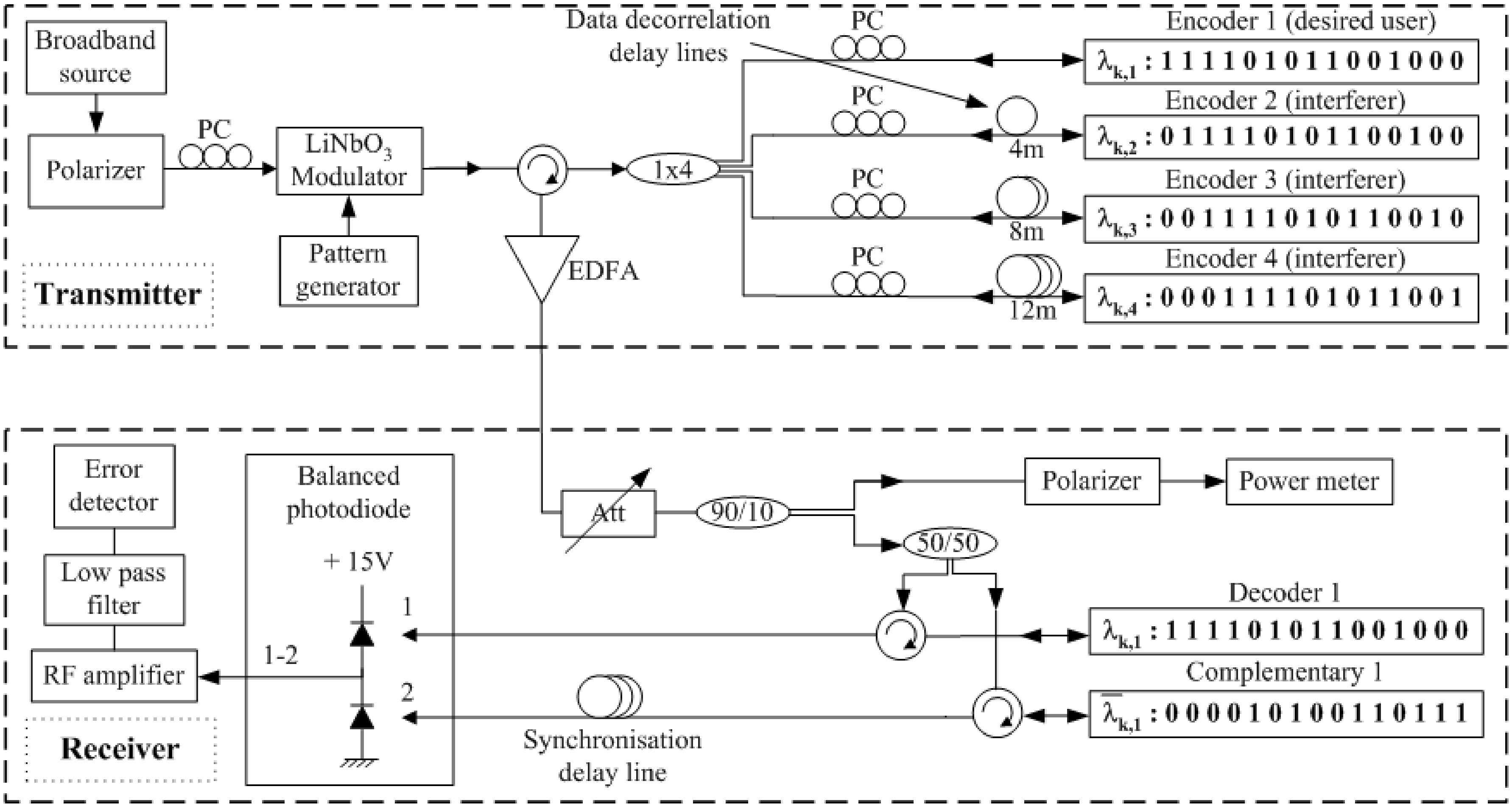

Decoder and Complement



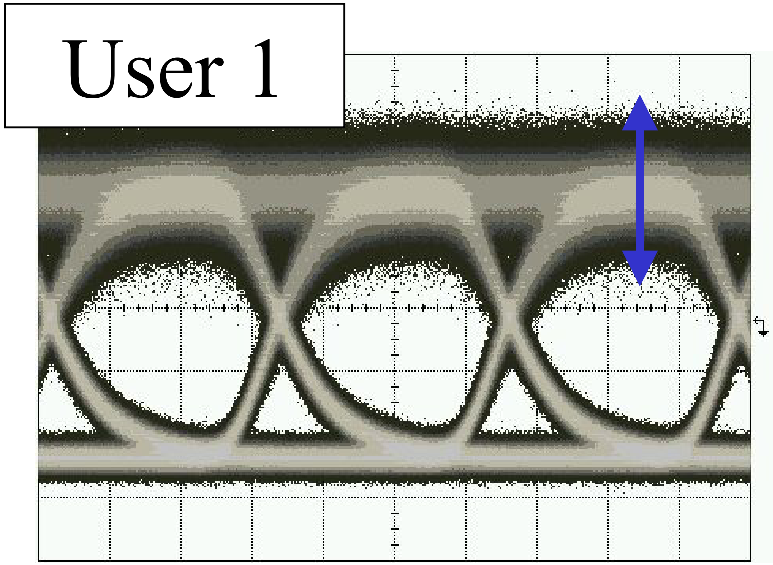

## Superimposed Fiber Bragg Gratings

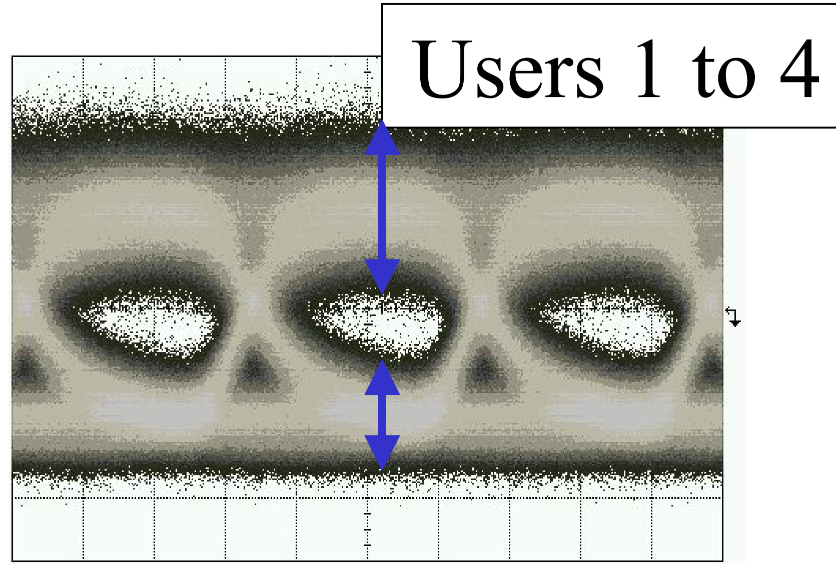
- From 1542.0 nm to 1548.0 nm
- 50 GHz separation
- 12.5 GHz bandwidth
- 85% reflectivity

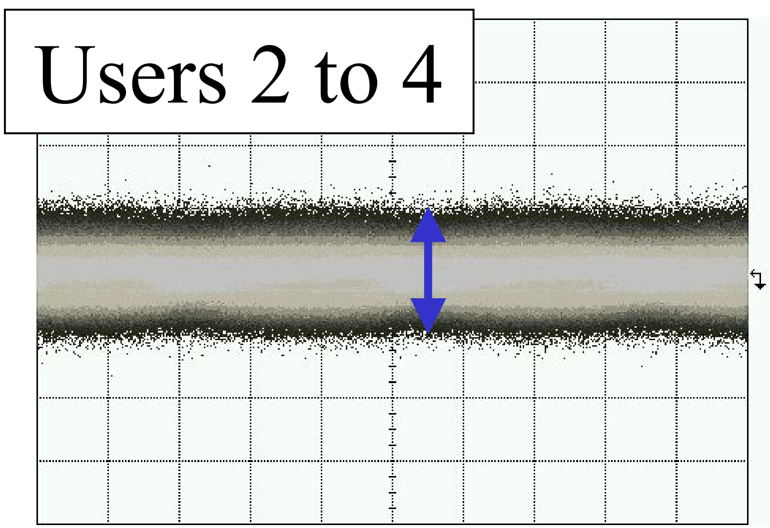
# Experimental Setup



# Eye Diagrams



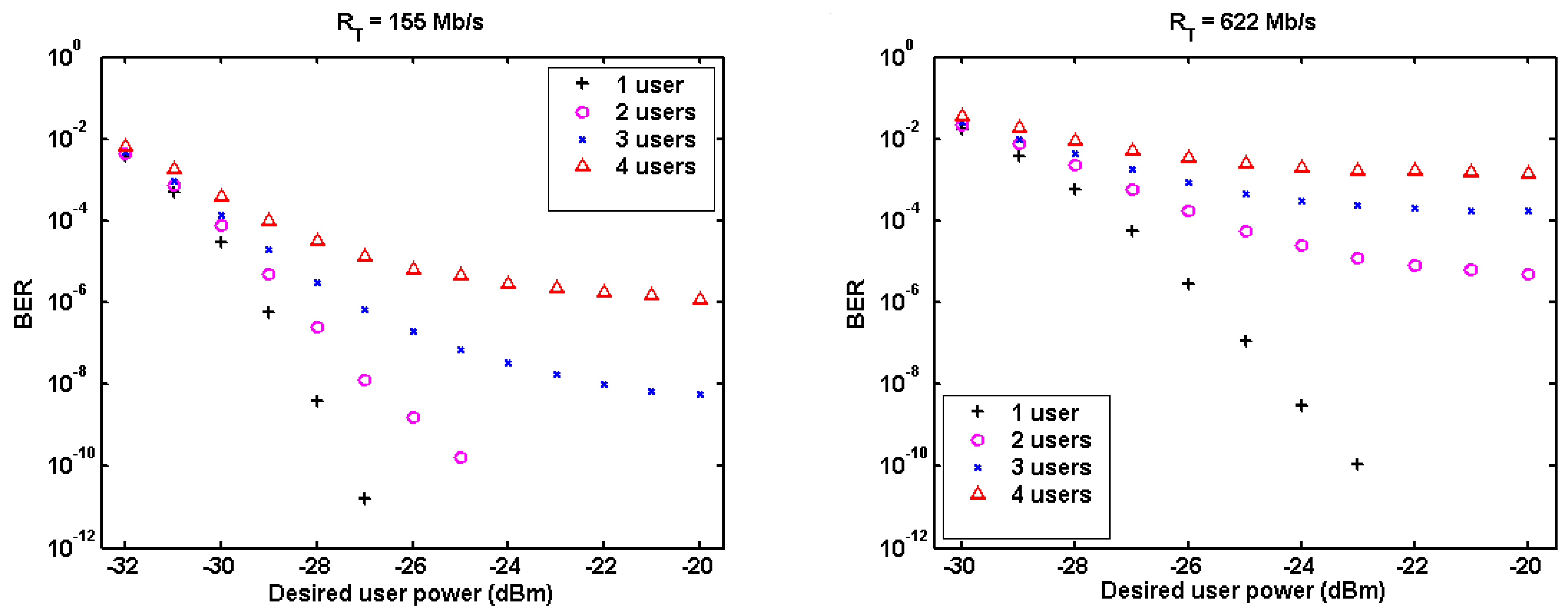




Multiple access interference (MAI) is cancelled out.

Only intensity noise remains.

# Bit Error Rate Measurements




BER floor due to intensity noise intrinsic to incoherent broadband sources.

# Intensity noise: theoretical model

- SNR of incoherent sources with rectangular electrical filter ($B_e$) and spectral shape ($B_o$):[1]

$$SNR = \frac{N_{pola} B_o}{2B_e}, \quad (B_o >> B_e)$$

- SNR for any electrical filter ($H(f)$) or spectral shape ($S(\upsilon)$):[2]

$$SNR = \frac{N_{pola} \cdot \left|H(0)\right|^2 \left( \int_{-\infty}^{\infty} S(\upsilon) d\upsilon \right)^2}{\int_{-\infty}^{\infty} \left( \int_{-\infty}^{\infty} S(\upsilon) S(\upsilon + f) d\upsilon \right) \left|H(f)\right|^2 df}$$

- Probability density function follows a Gamma distribution:[3]

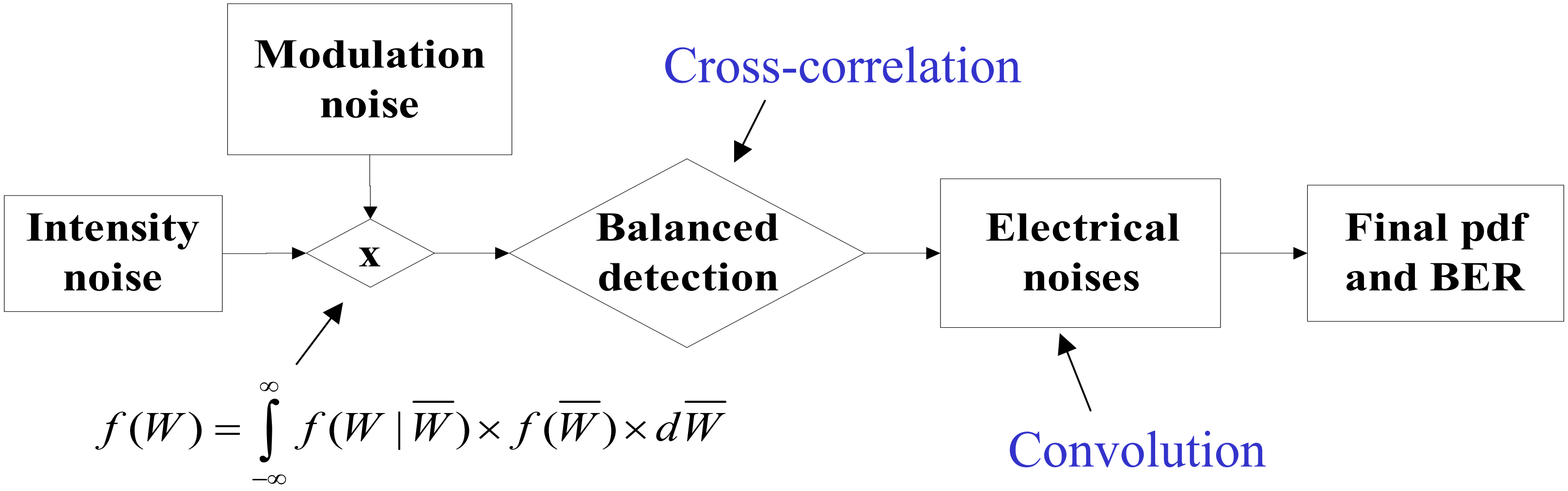
$$f\left(W \mid \overline{W}\right) = \left(SNR/\overline{W}\right)^{SNR} \frac{W^{SNR-1} \exp\left(-W \cdot SNR/\overline{W}\right)}{\Gamma(SNR)}$$

1: P. C. Becker, N. A. Olsson and J. R. Simpson, *Erbium-doped fiber amplifiers fundamentals and technology*. Academic Press, San Diego, 1999.

2: G-H Duan and E. Georgiev, “Non-white photodetection noise at the output of an optical amplifier: theory and experiment”, *IEEE J Quantum. Electron.*, vol. 37, 2001.

3: J. W. Goodman, *Statistical optics*. Wiley, New-York, 2000.

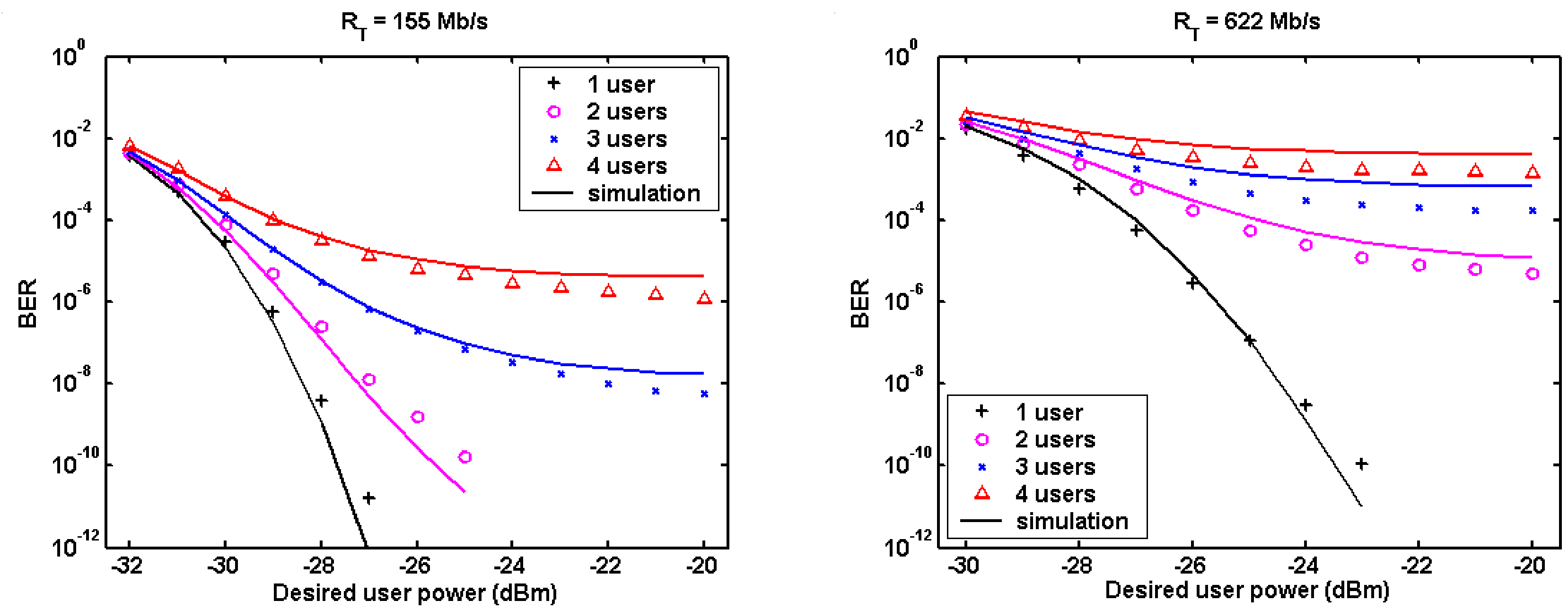
# Diagram representation of the simulation




$$f(W)=\int_{-\infty}^{\infty} f(W\,|\,\overline{W})\times f(\overline{W})\times d\overline{W}$$

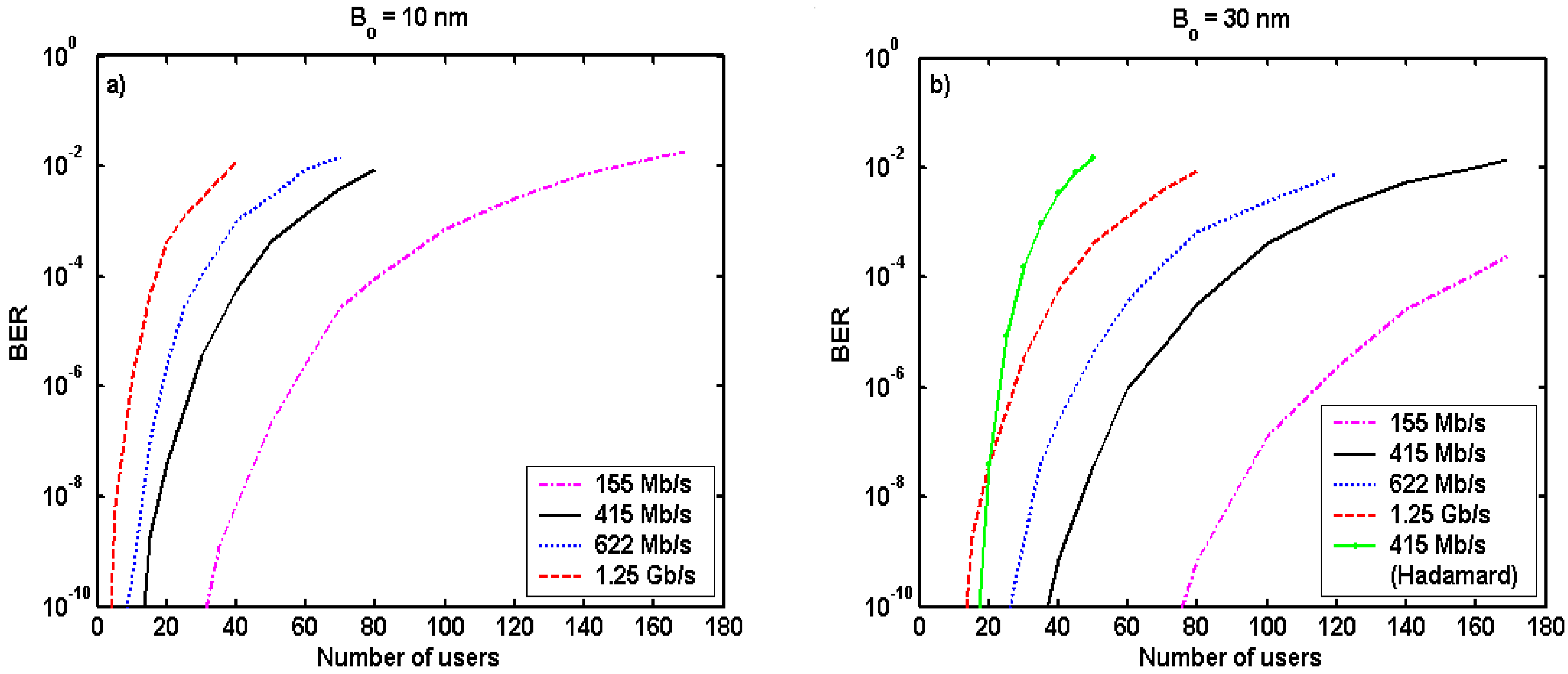
- The modulation noise and intensity noise are dependent.
- We take into account the optical spectrum at each photodetector for each possible set of data to calculate the intensity noise.

# Experimental validation




The good fit between simulation and experiment allows us to construct a general simulator that predicts the performance of an FE-OCDMA system with various code types: (*m*-sequence, Hadamard, MQC, BIBD, etc.).

# Other code structures




- No guard bands
- MQC codes outperform *m*-sequence or Hadamard codes

# Conclusions

- Good match between experiment and theory!
- Optimized FE-OCDMA system using incoherent sources:
  - Low cross-correlation codes (MQC)
  - FBGs in transmission (more flexibility in writing the gratings)
  - All available optical bandwidth used (no guard bands).
- To improve performance:
  - Investigate semi-conductor optical amplifiers
  - Investigate coherent sources