PHOTONICS RESEARCH GROUP

SILICON PHOTONICS
FOR RESERVOIR COMPUTING

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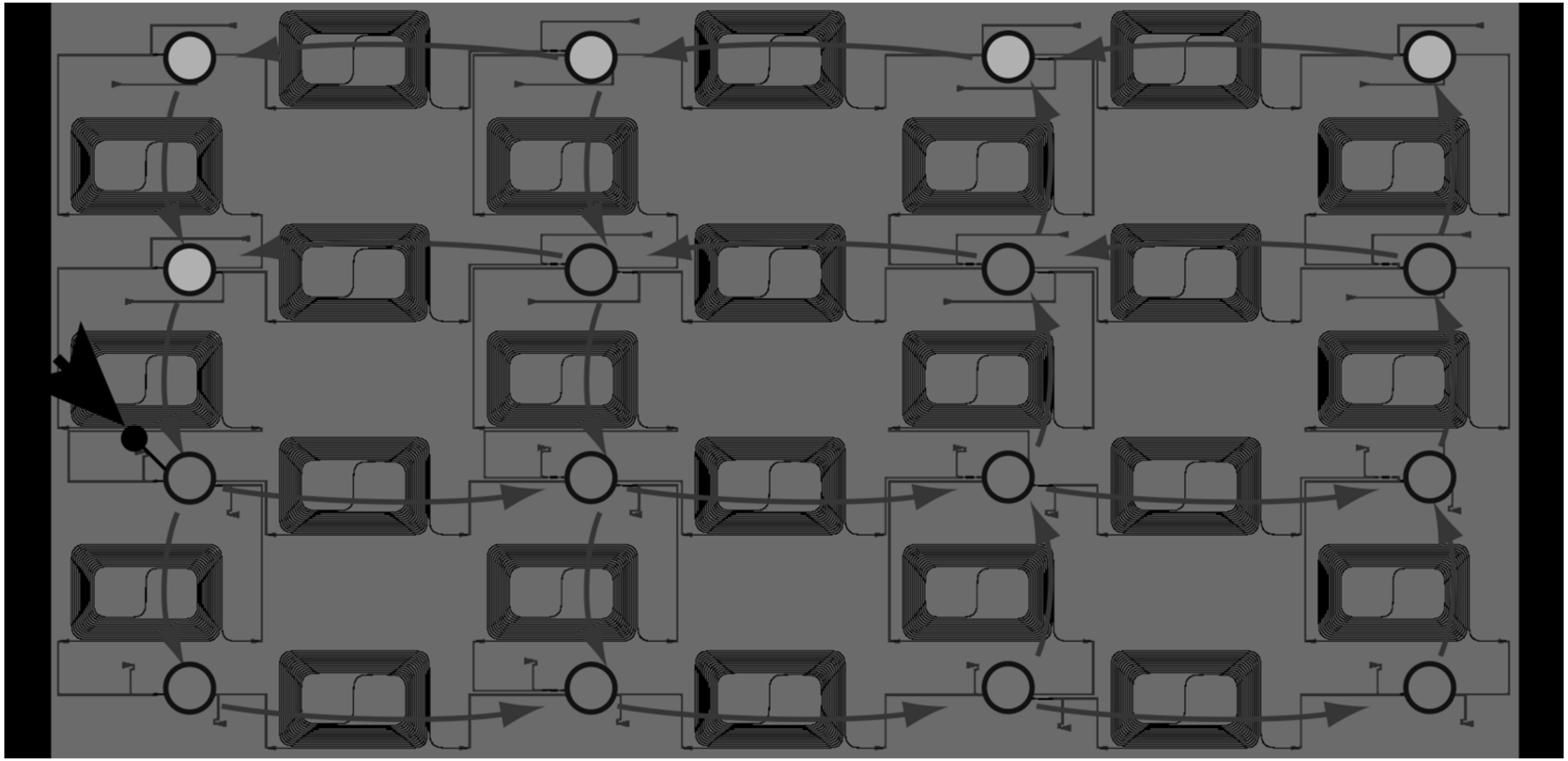
THE BLACK BOX

What can this chip do?



Several things!

- Do arbitrary boolean calculations with memory on a bitstream
- Recognise arbitrary 5-bit headers at 12.5 Gbps
- Perform speech recognition of isolated digits
- Does not consume any active power
- Easily upscalable to higher speeds

How does it do it?

Using “Reservoir Computing”, a brain-inspired technique to solve pattern recognition problems in a fast and power-efficient way

WHAT IS RESERVOIR COMPUTING?

WHAT IS RESERVOIR COMPUTING?

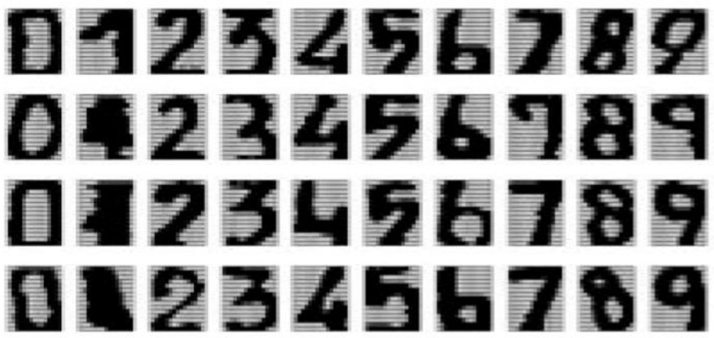
From field of machine learning (2002)

Addressing issues with recurrent neural networks

Originally mainly in software

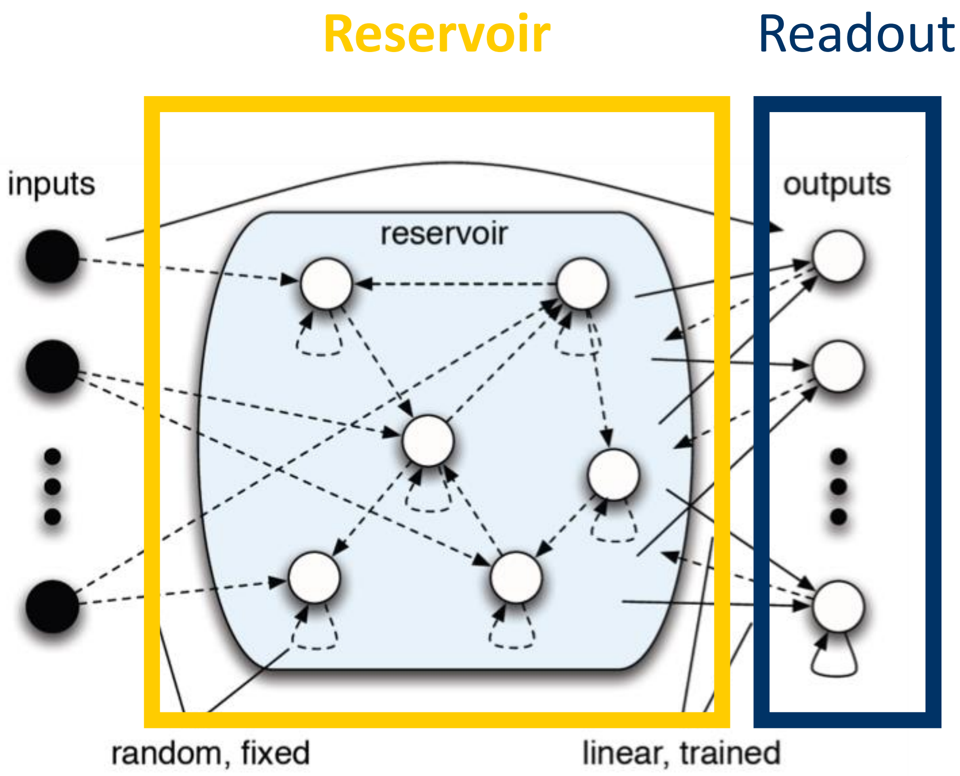
Quite successful:

- Digit recognition
- Speech recognition
- Robot control
- …

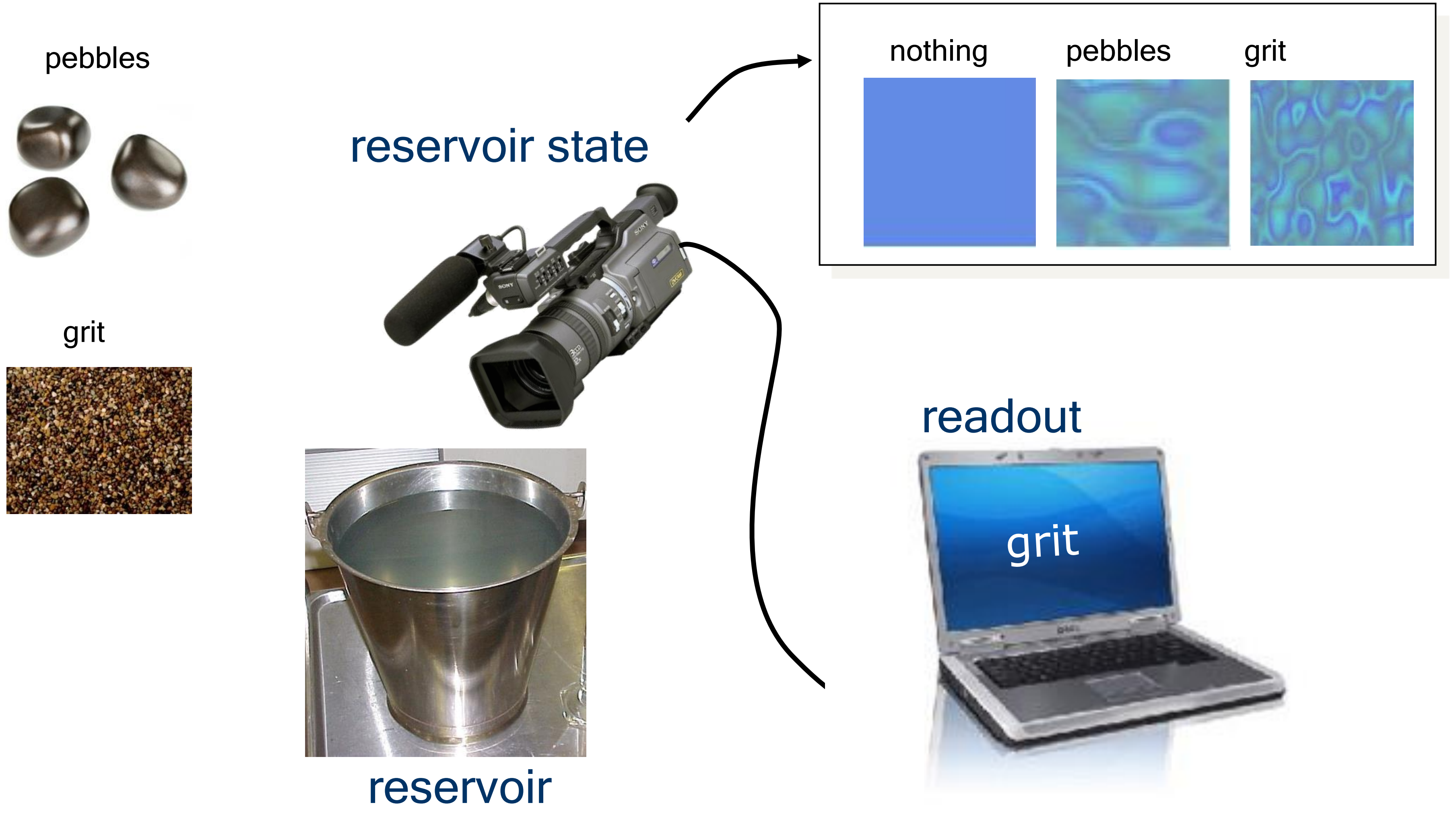


Reservoir computing

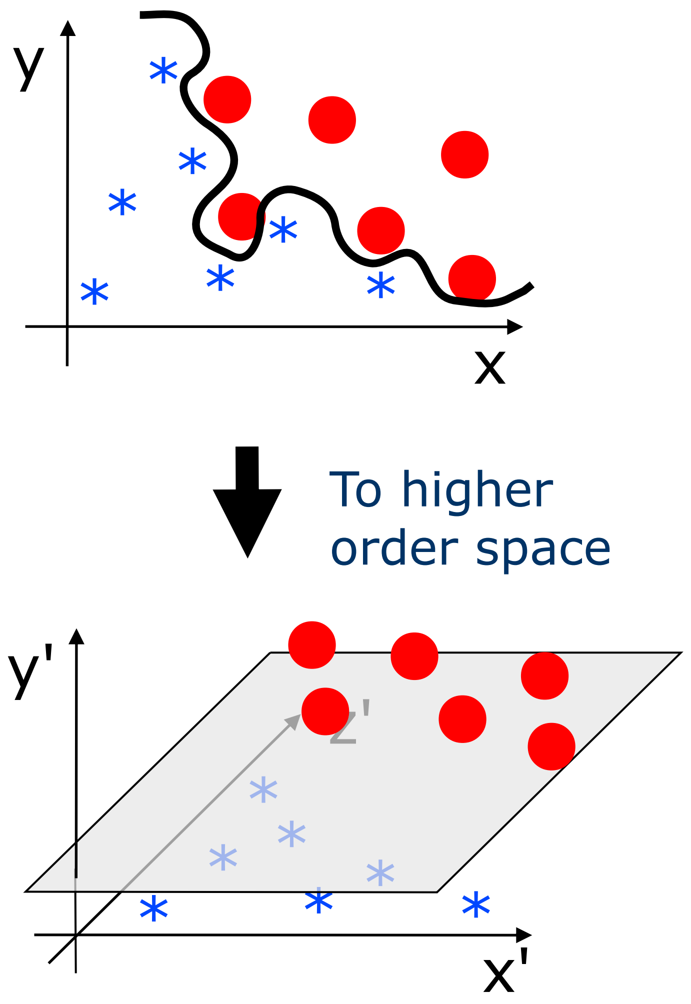
Don’t train the neural network, only train the linear readout



A HARDWARE IMPLEMENTATION…

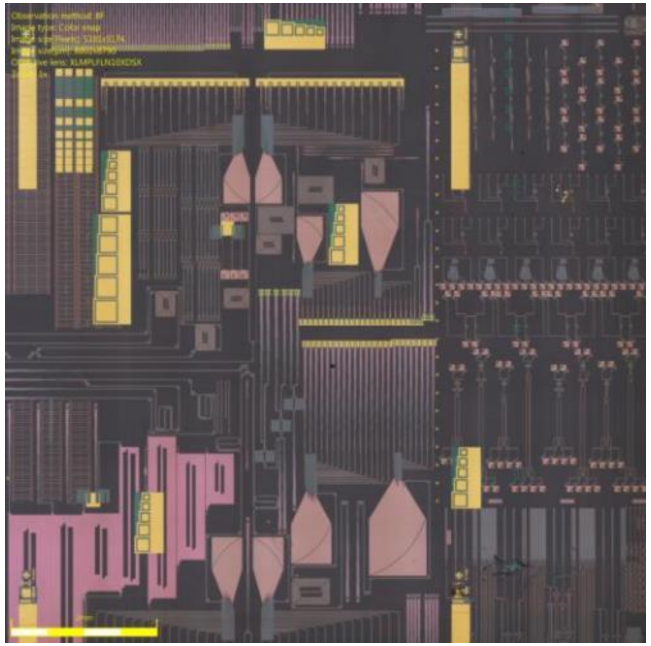


Why does it work?



What is silicon photonics?

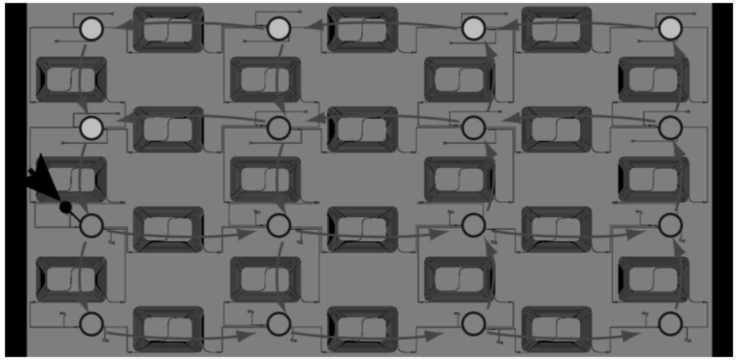
The implementation of high density photonic integrated circuits by means of CMOS process technology in a CMOS fab



Pictures courtesy of imec

Enabling complex optical functionality on a compact chip at low cost

Passive Silicon reservoir



- Silicon photonics: mature technology
- Giant multipath interferometer
- Nodes are simple splitters/combiners
- Non-linearity in readout suffices
- No active power consumption inside chip
- No longer limited by timescale of non-linearity

Vandoorne et al, Nature Comms, 5, 3541, 2014

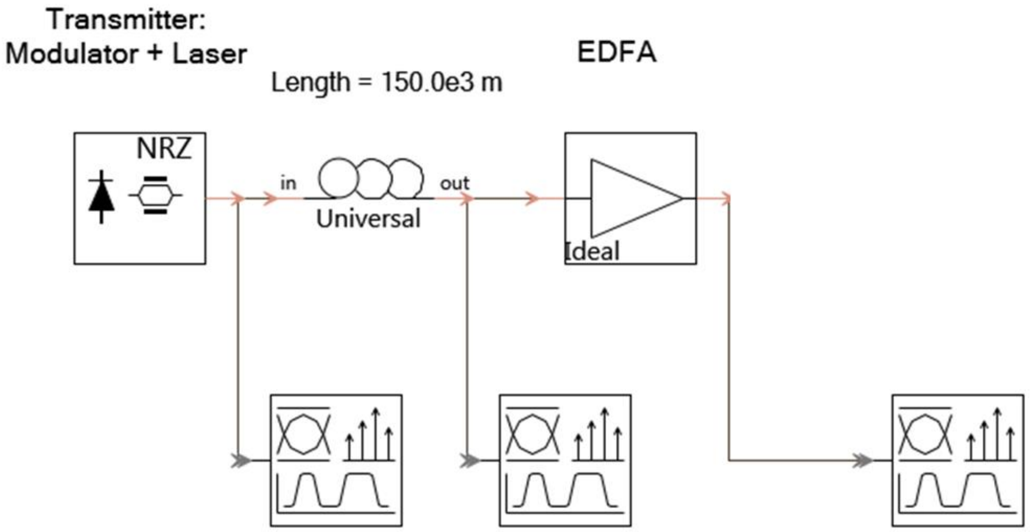
ADVANTAGES

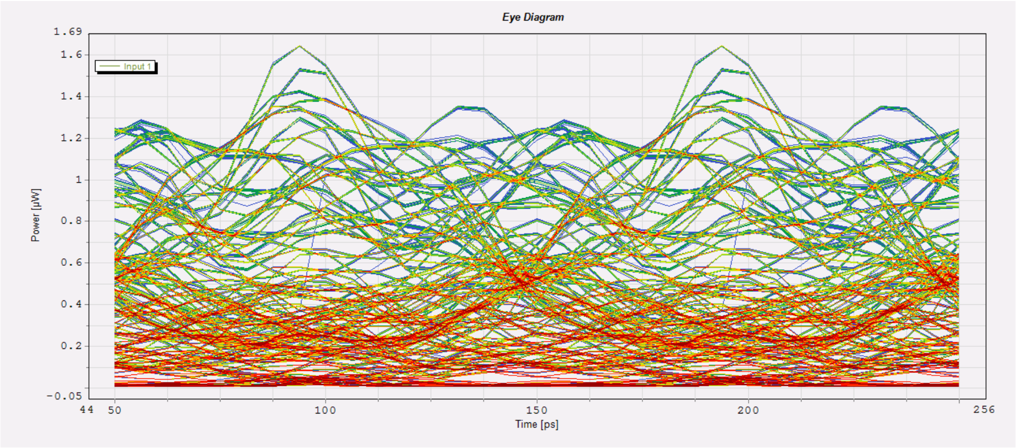
- Scalability:
  — we spent a lot of effort to slow down the signal!
  — easily scalable to higher speeds by shortening the delays
- No active power consumption on chip
- Same generic chip can be used for:
  — digital tasks
  — analog tasks

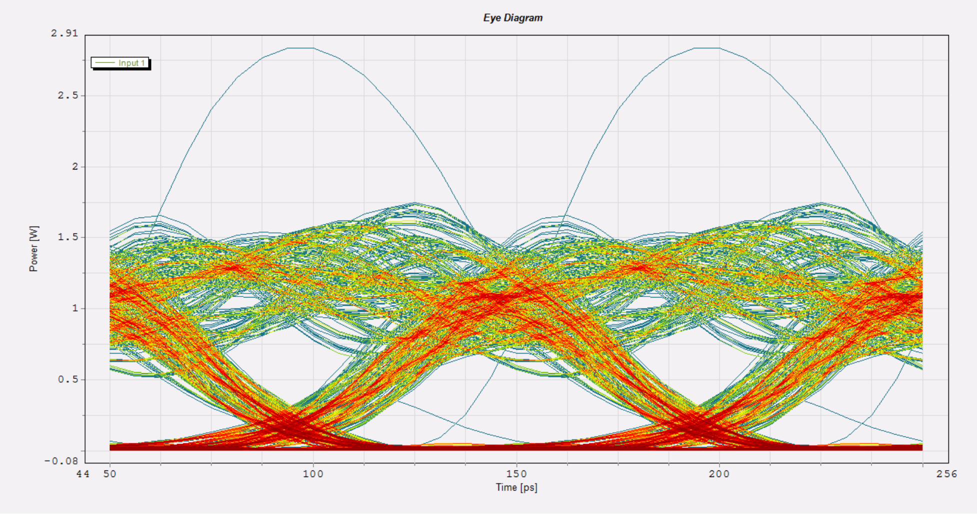
So, generalizes to different applications

NON-LINEAR DISPERSION COMPENSATION AT 32 GBPS

Sending signals through an optical link suffers from distortion







Fixing these problems requires expensive digital processing.

Can we do it in the optical domain at high speeds?

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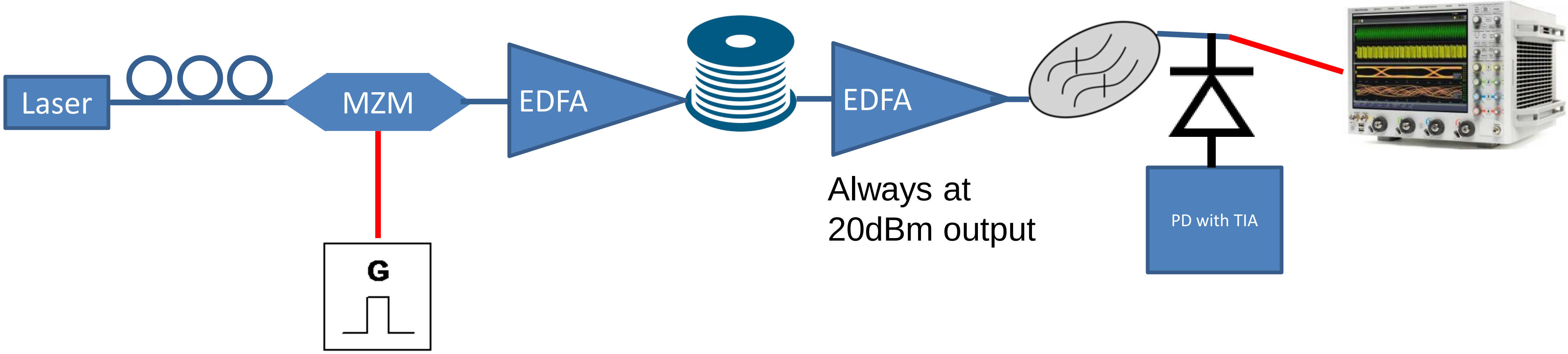
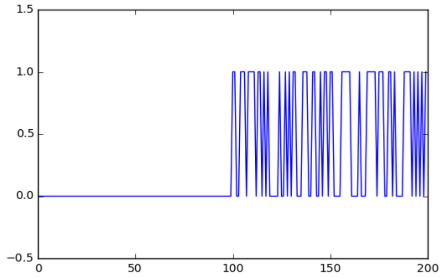
Reference measurement without reservoir

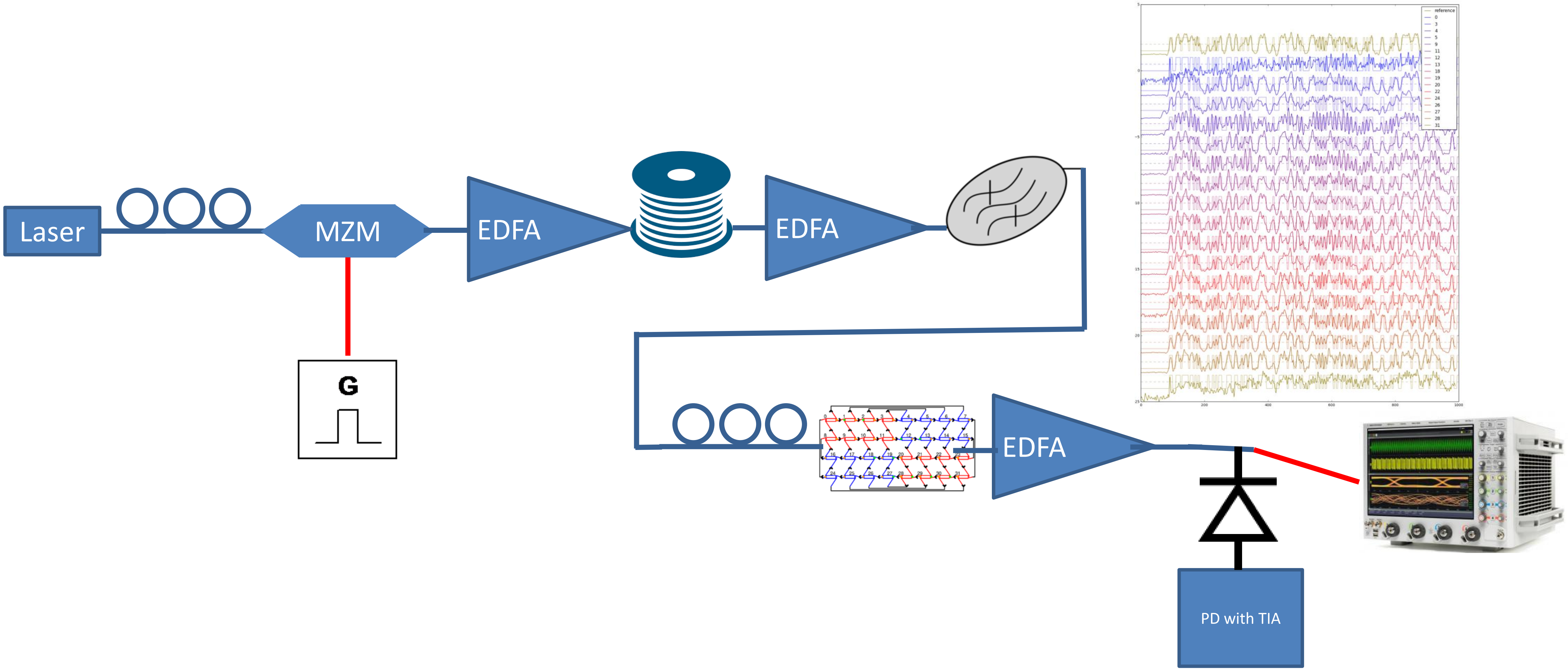
25km - 13.2dBm and 20.5dBm to fiber





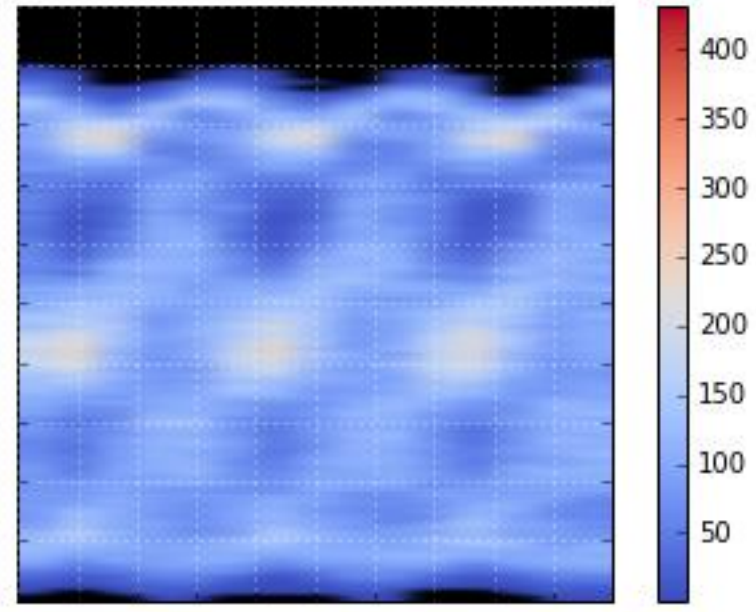
Stream length = 131072

Measurement with reservoir chip

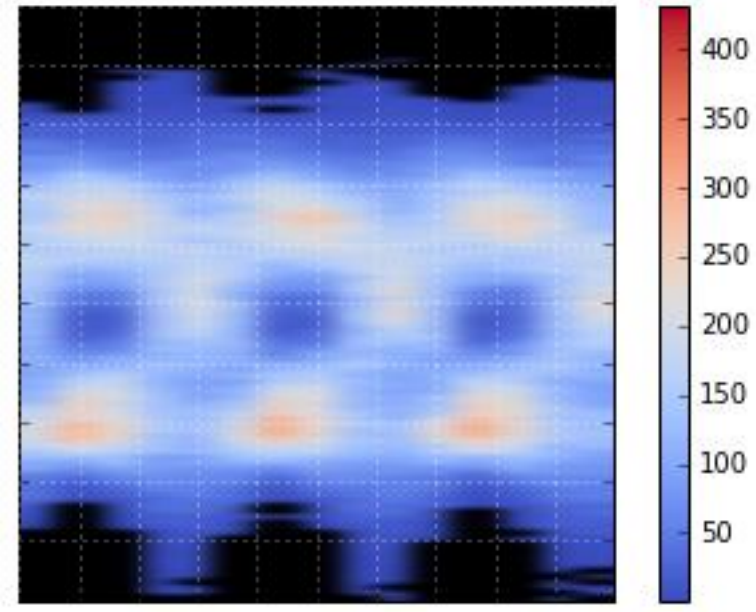


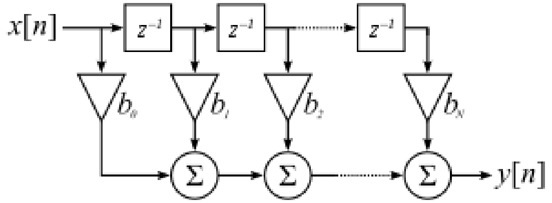
EXPERIMENTS: RC IS BETTER AT EQUALISING THIS NL DISTORTED SIGNAL

Distorted signal



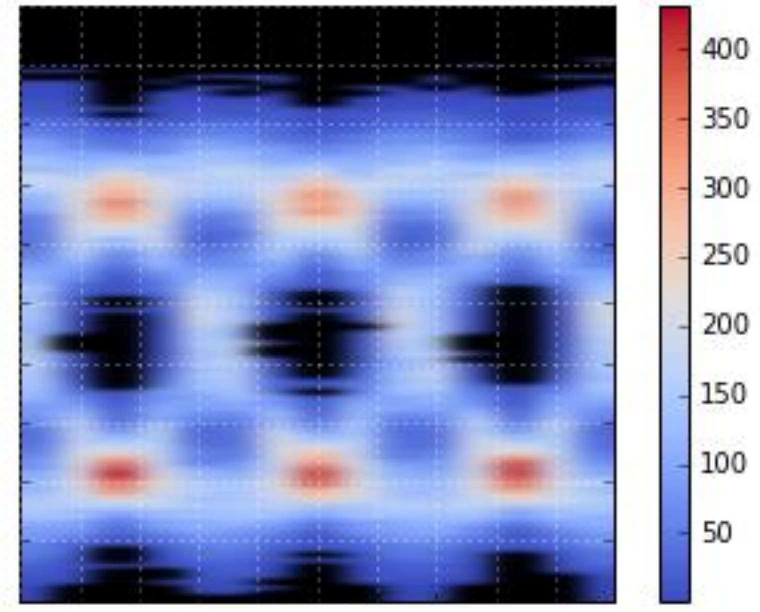
Linear equalizer
BER: 2.25 x 10^{-3}

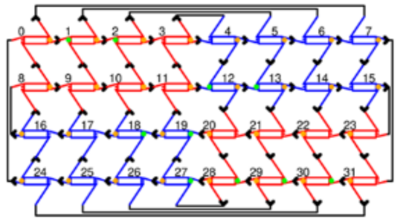




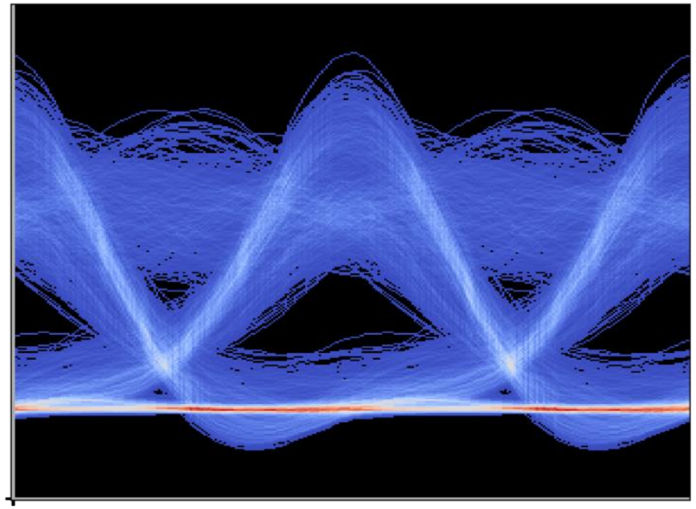
Same number of copies as the reservoir has nodes

Reservoir: BER < 10^{-5}
0 errors in 131072 bits

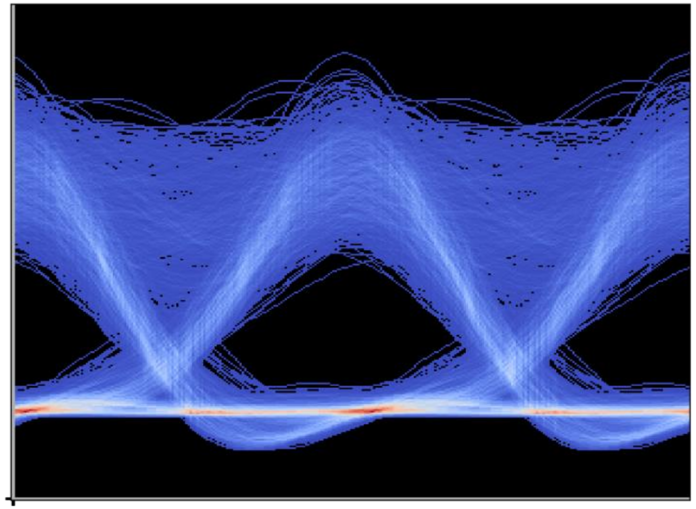




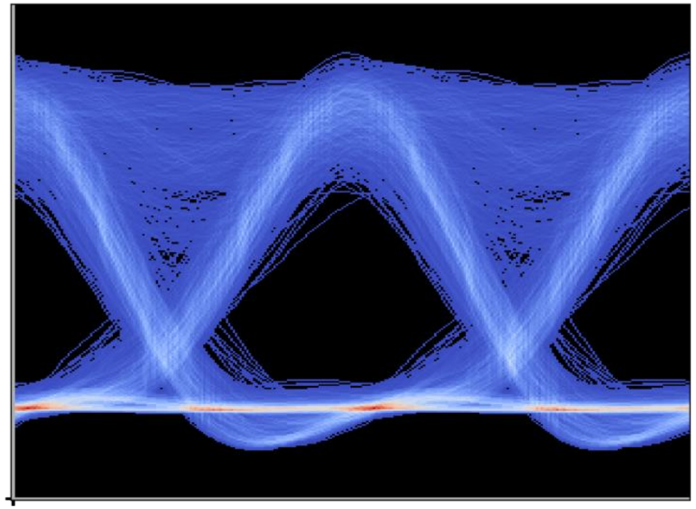
SIMULATIONS: "BAD" NON-LINEAR DETECTOR EVEN BETTER



Distorted stream



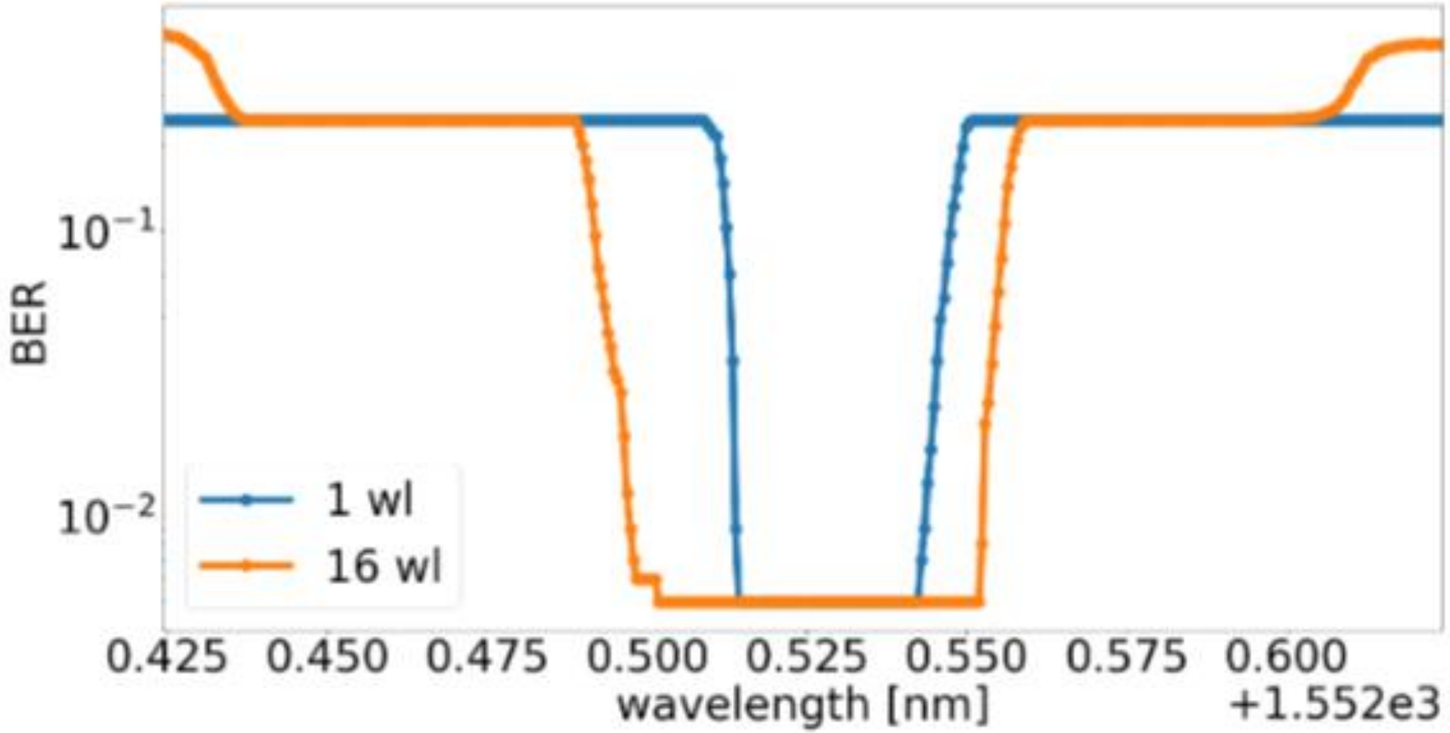
Compensated stream using RC
BER: 3 orders of magnitude better



compensated stream with extra Non-linearity from TIA
BER: 7 orders of magnitude better

OTHER TELECOM TASKS

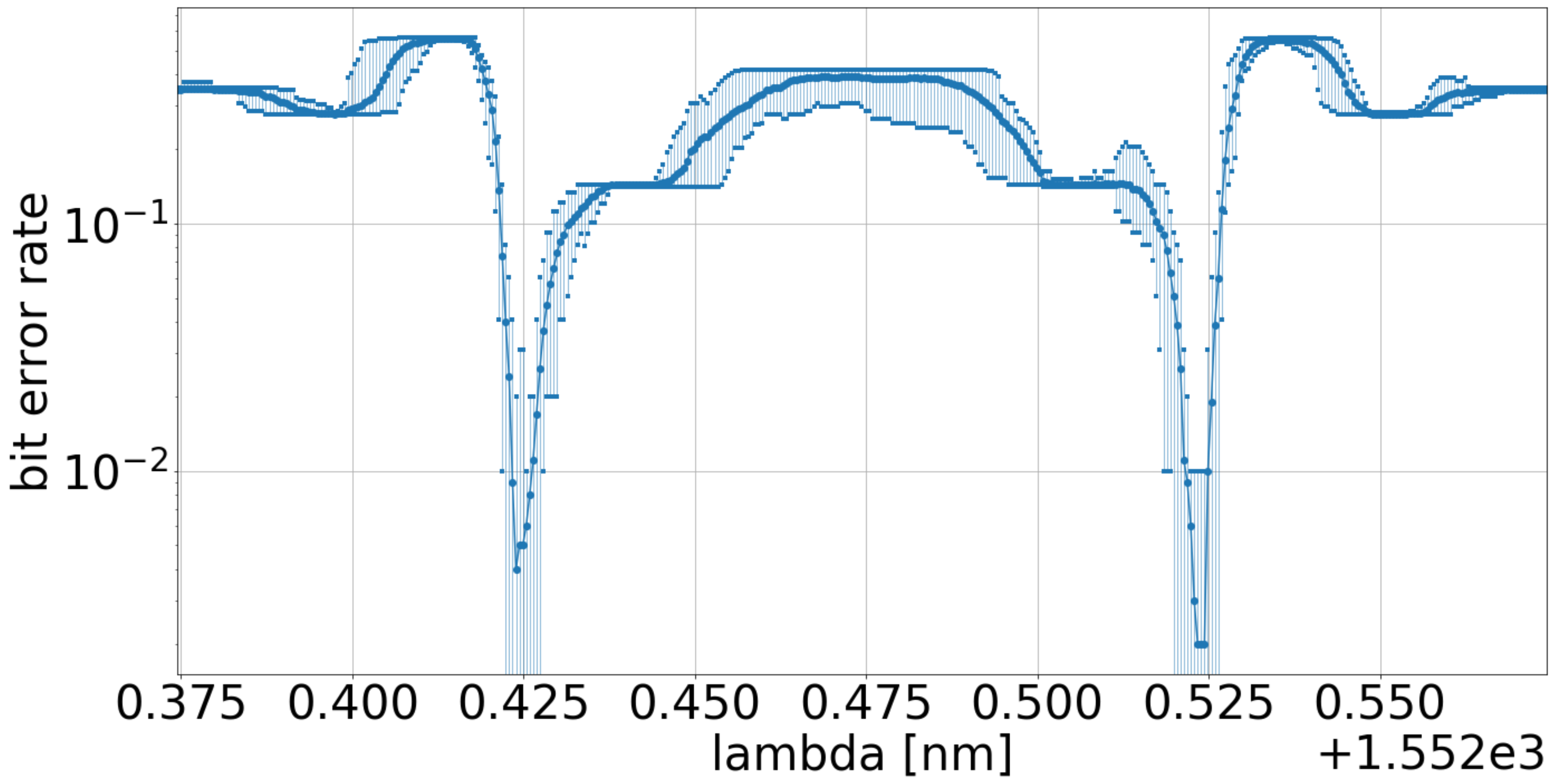
MAKING THE SYSTEM MORE ROBUST AGAINST DRIFT



Train the system for a range of wavelengths

Works for temperature too

Solve a task simultaneously on 2 WDM channels

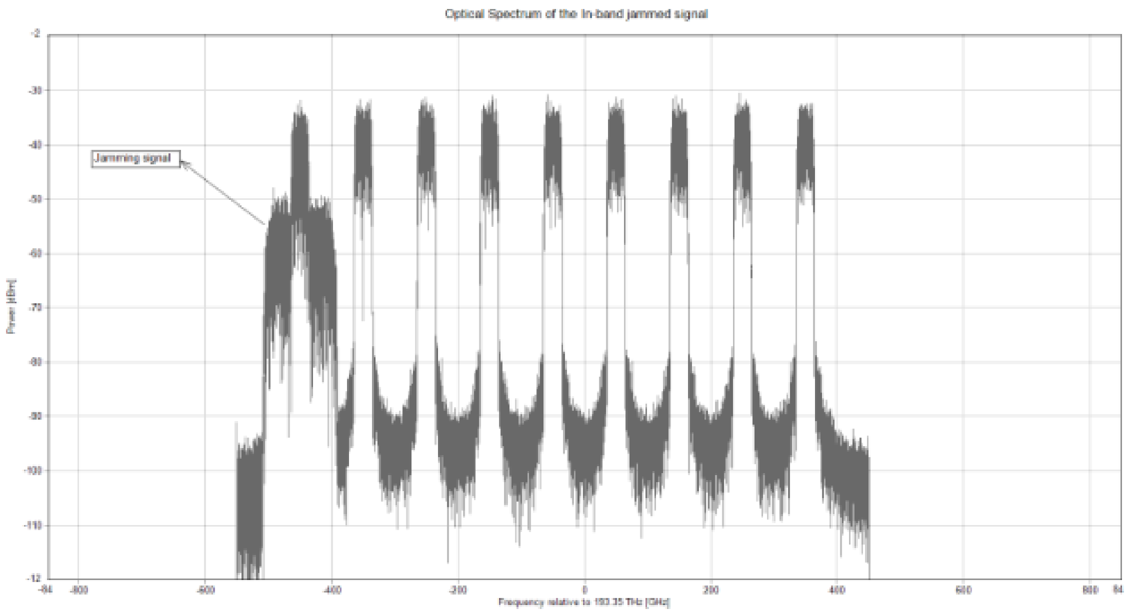


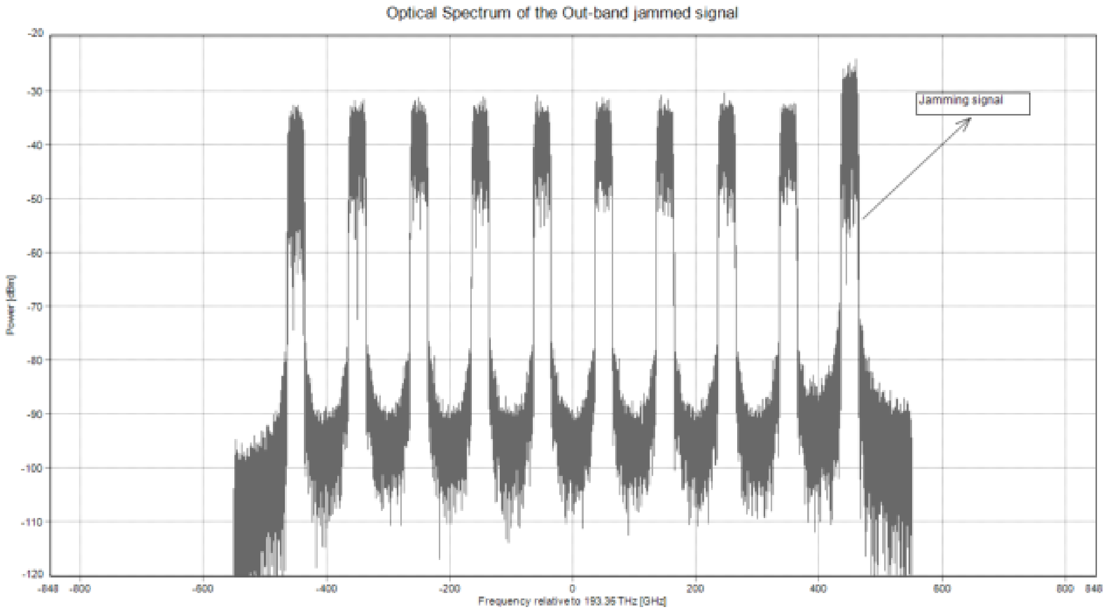
XOR task

Same readout for both channels!

JAMMING DETECTION

Successful identification in real time of in-band and out-of-band jamming





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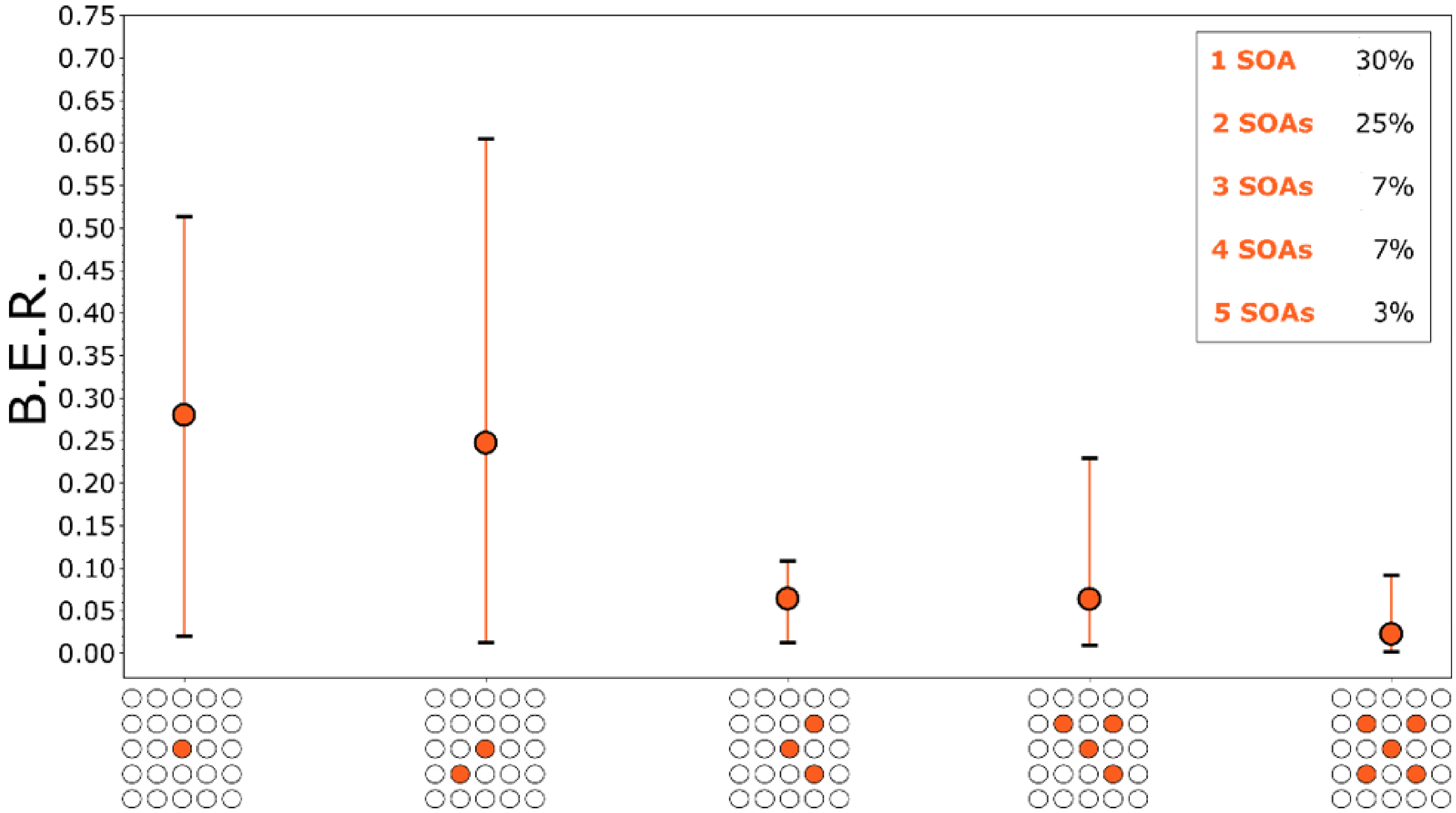
Modulation format identification: BPSK vs QPSK



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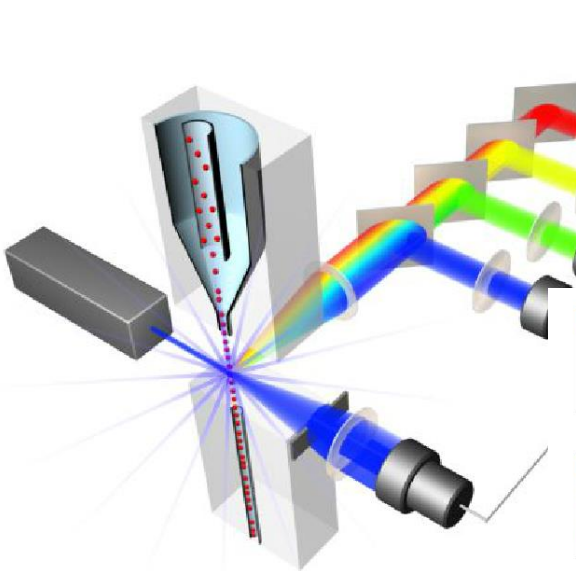
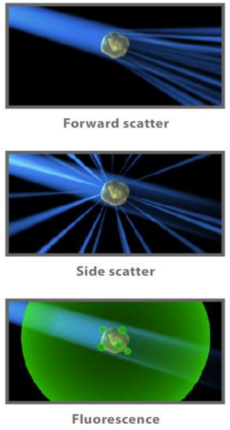
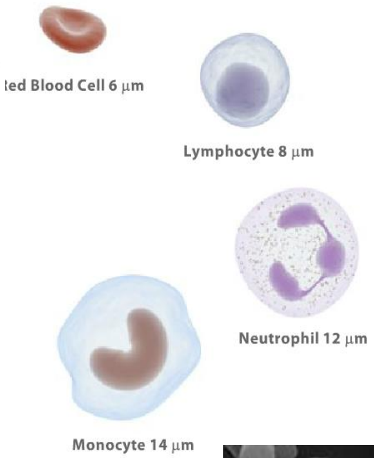
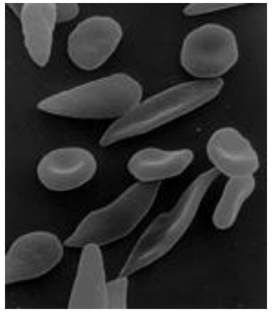
BIOLOGICAL CELL SORTING

FLOW CYTOMETRY



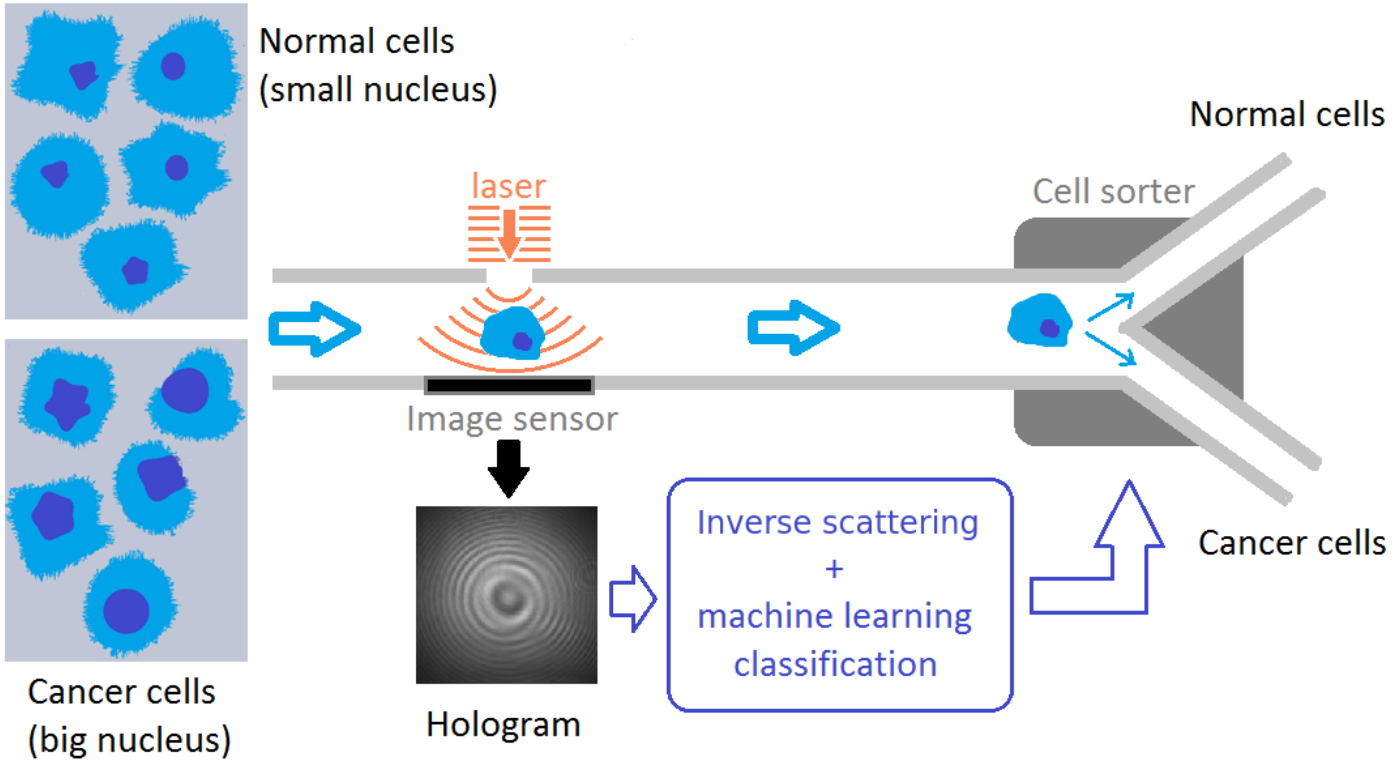






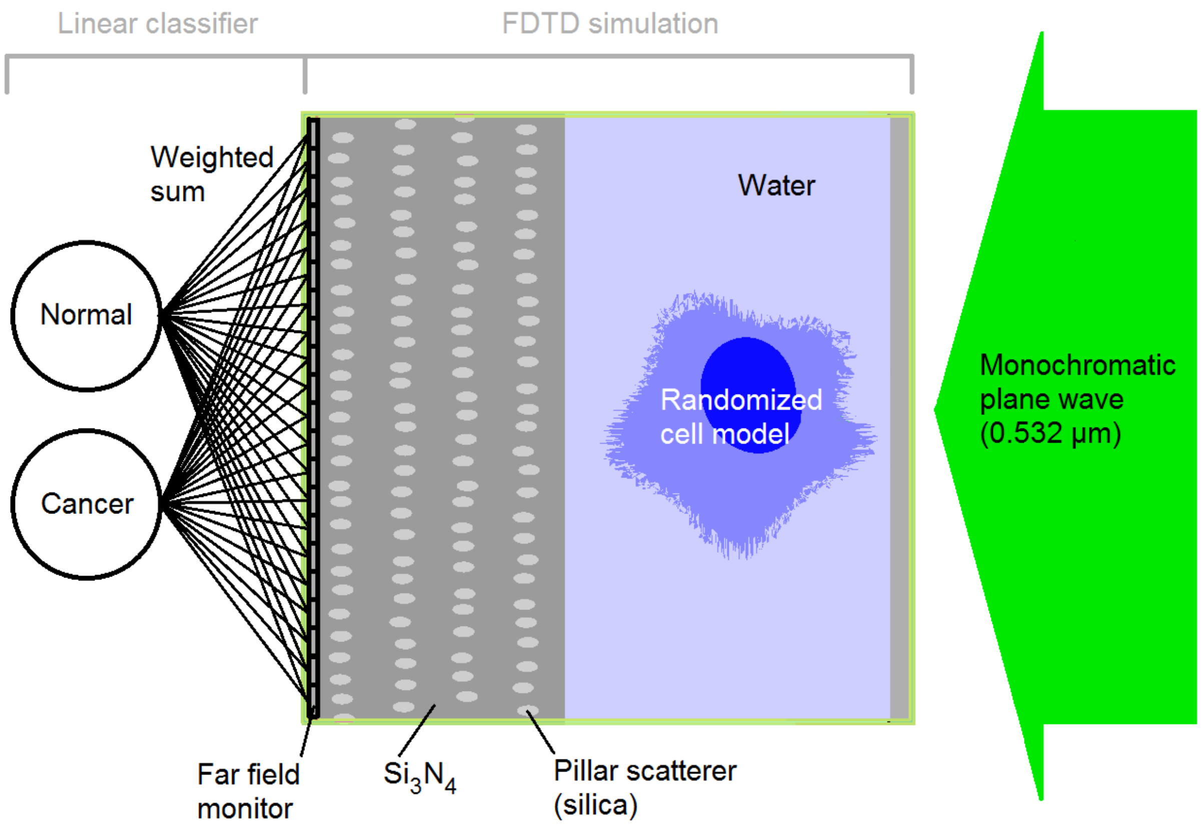
http://www.lifetechnologies.com

DIGITAL HOLOGRAPHY



Goal: 1000 microfluidic channels in parallel → ~ 1000 classifications each ms

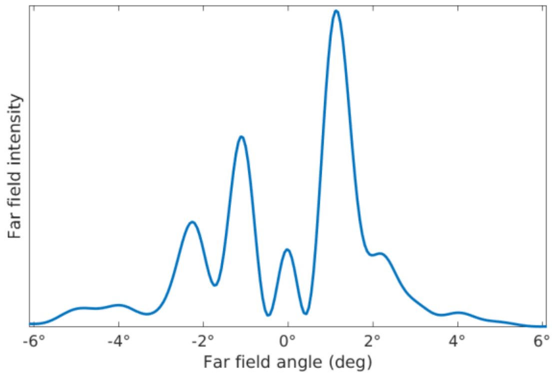
A SPATIAL ANALOG OF RESERVOIR COMPUTING



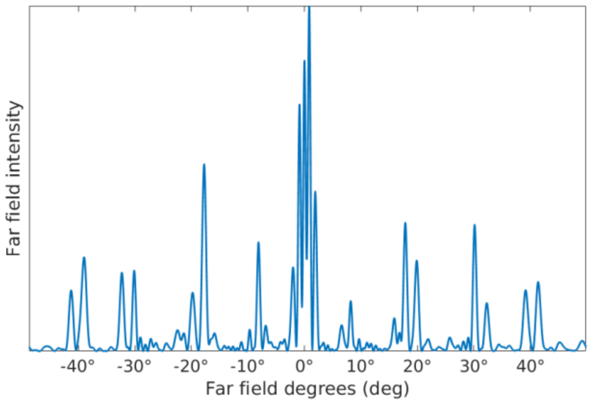
Phase-to-intensity transfer function is sinusoidal → Power-independent nonlinearity available for computation

SCATTERERS INCREASE HOLOGRAM COMPLEXITY

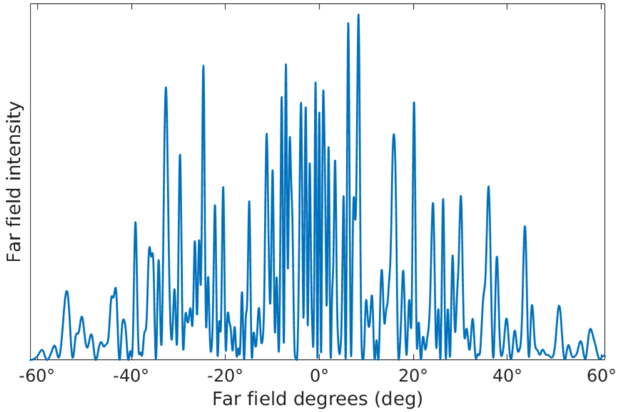
No scatterers



4 ordered scatterer layers



4 scatterer layers with 150 nm maximum random displacements



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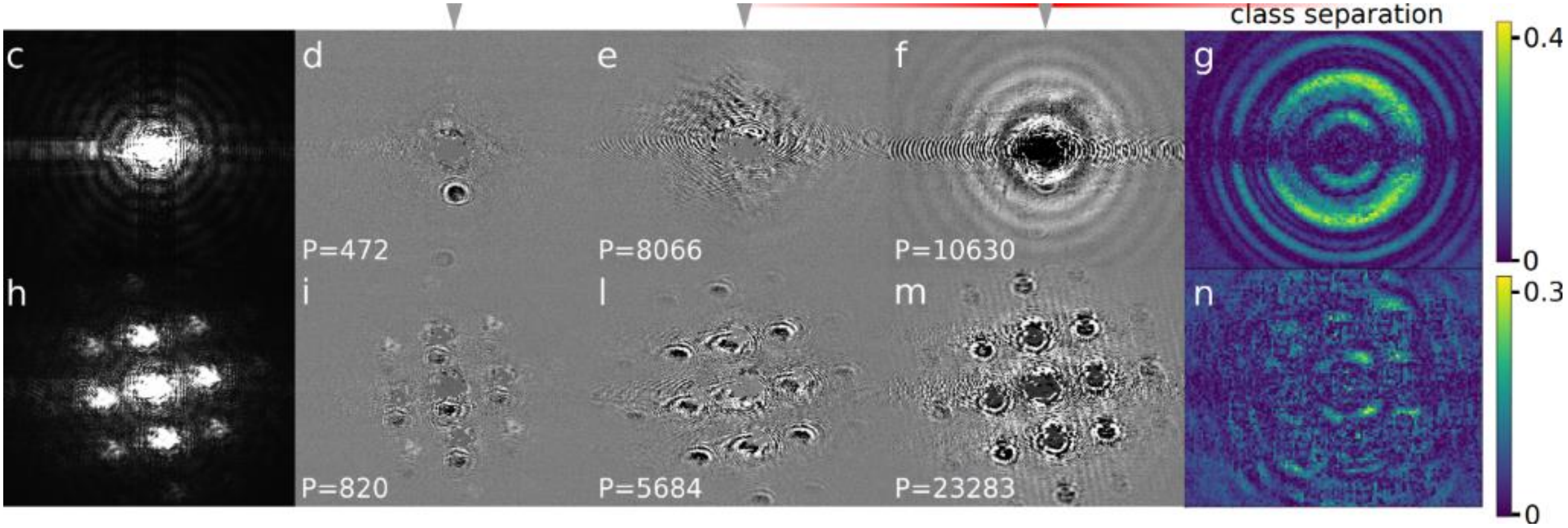
Experiments on beads with different sizes



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Much faster than other works in literature

Classification task	Classifier	Image resolution	Imaging method	Image FoV	Classification performance	Accelerator	execution time / particle	Meas. bias control
Beads with diameters of 7, 10 and 15 µm[15]	CNN	21×21	Microscope	Centered and cropped	93.3% mAP	GPU	< 1 ms	Unreported
3 white blood cell (WBC) types[16]	Rand. forest on extracted features	31×31	Lens-free - raw hologram	Unreported	96.8% accuracy	GPU	0.2 ms	Unreported
1 WBC type and an epithelial cancer cell[20]	Deep CNN	Unreported	Time-stretch microscope	25 µm along channel	95.74% accuracy	GPU	3.6 ms	Unreported
Beads with diameters of 15.2 and 18.6 µm (our work)	Linear (log. regression)	32×26	Lens-free - raw hologram	~ 300 µm along channel	> 90% accuracy	None	0.013 ms	Yes

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CONCLUSIONS

Reservoir computing

is interesting new paradigm

for all-optical information processing