Heriot-Watt University
Edinburgh

Optoelectronics and a Neural Network Packet Switch Controller

http://www.optical-computing.co.uk

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Introduction

- This presentation examines an optoelectronic neural network that can be used to solve a variety of problems.
- The design and motivation for the system will be discussed.
- Results will be presented from the first generation system.
- Performance and optical system scalability issues for current hardware will discussed.
- Design and engineering issues will be examined.

The Assignment Problem

This problem can be found in situations such as:

- Network service management.
- Distributed computer systems.
- Work management systems.
- General scheduling, control or resource allocation.

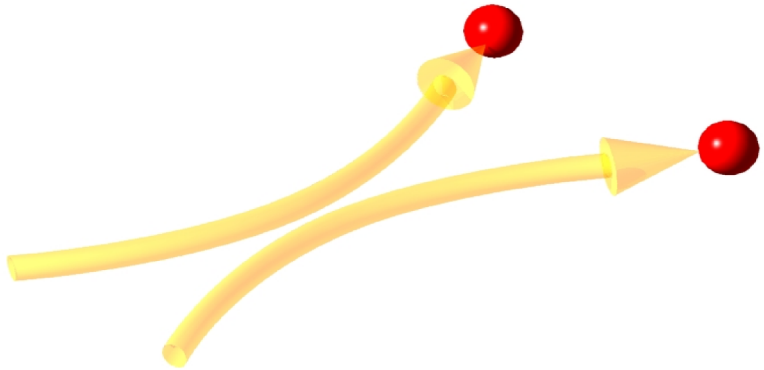
Solving the assignment problem is computationally intensive.

Neural networks are capable of solving the assignment problem.

Their inherent parallelism allows them to outperform any other known method at higher orders.

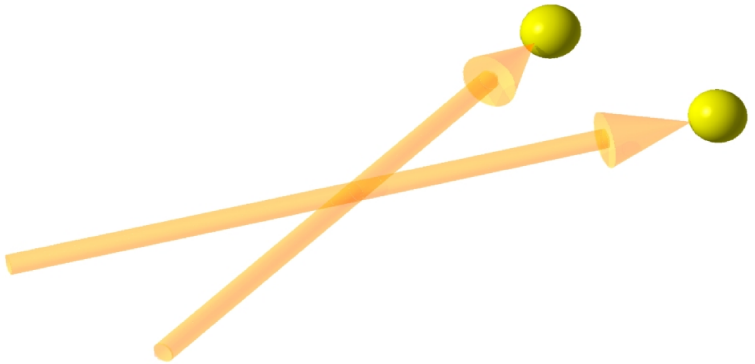
Optoelectronic Interconnects

Electrons



Since electrons carry mass and charge they interact strongly (Coulomb Interaction). Ideally suited for switching.

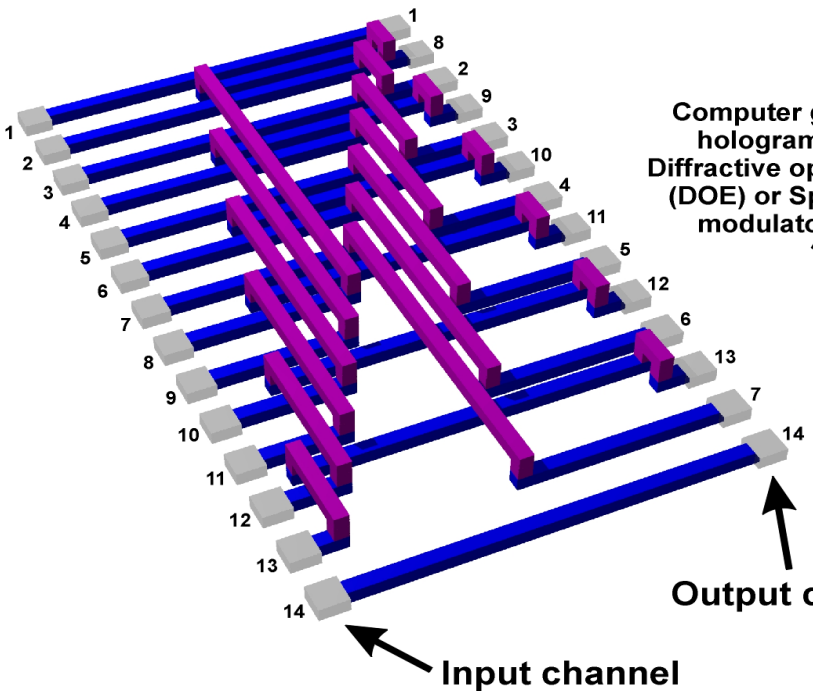
Photons



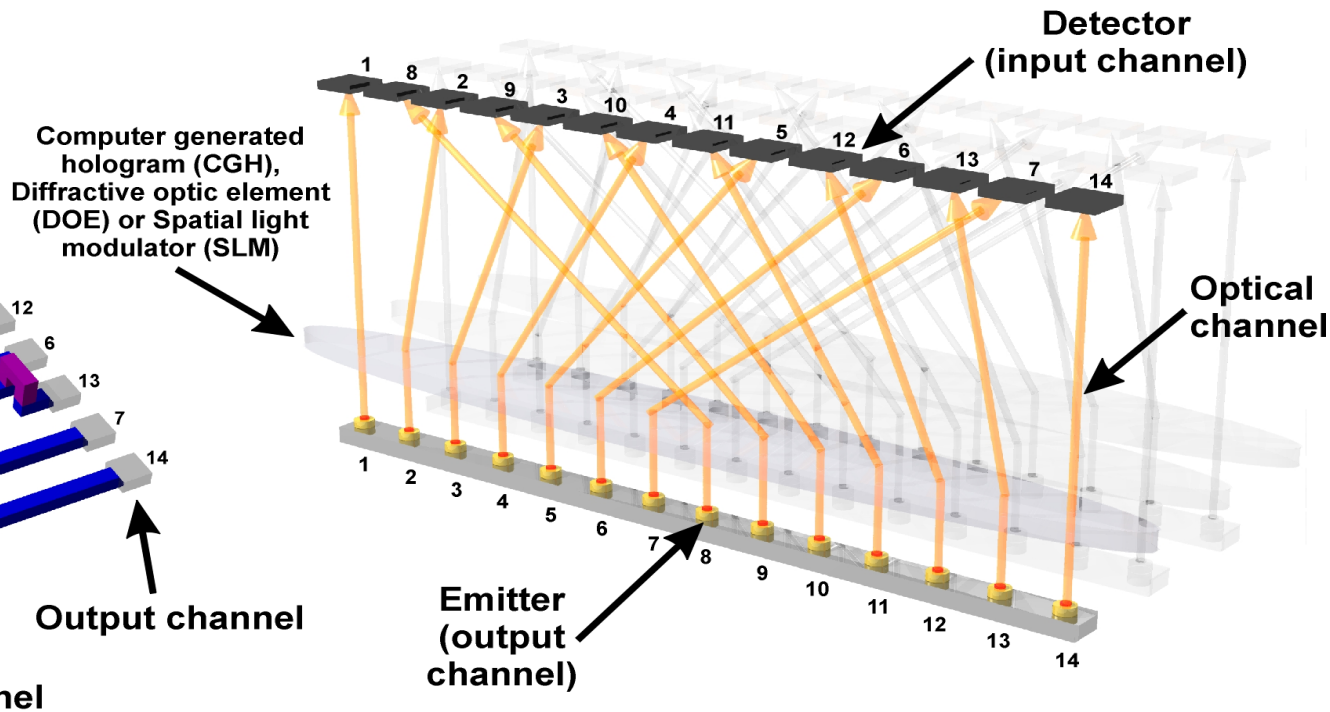
Photons do not carry mass or charge and are non-interacting in free space. They are ideally suited to interconnection.

Non-Local Interconnection

Two layer metallisation



Optical implementation

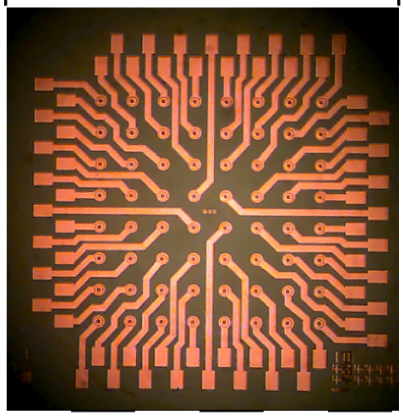


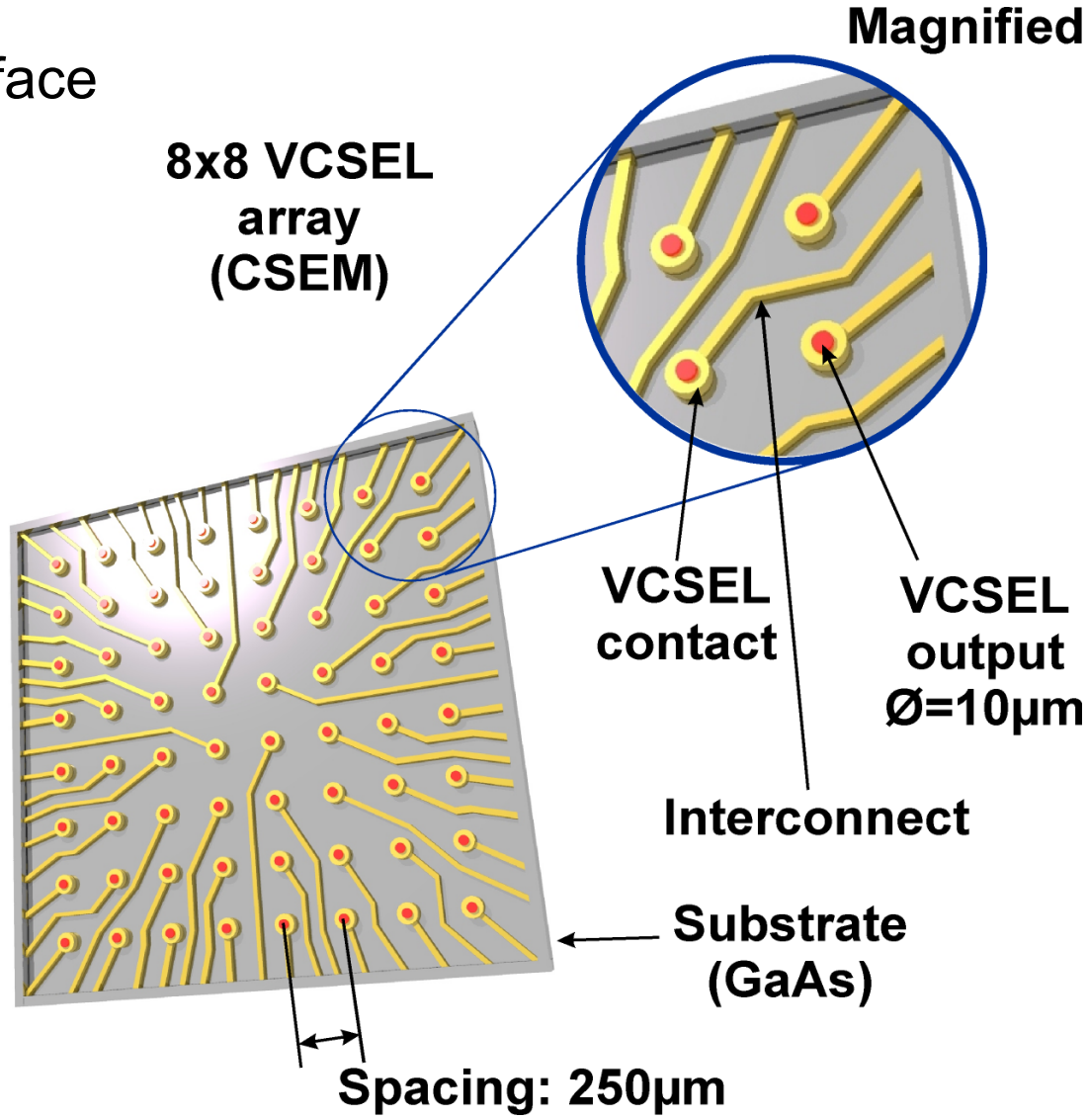
The VCSEL Array

The VCSEL (Vertical Cavity Surface Emitting Laser) is a laser diode that emits from the surface of the substrate.

Typical speeds are >1GHz.

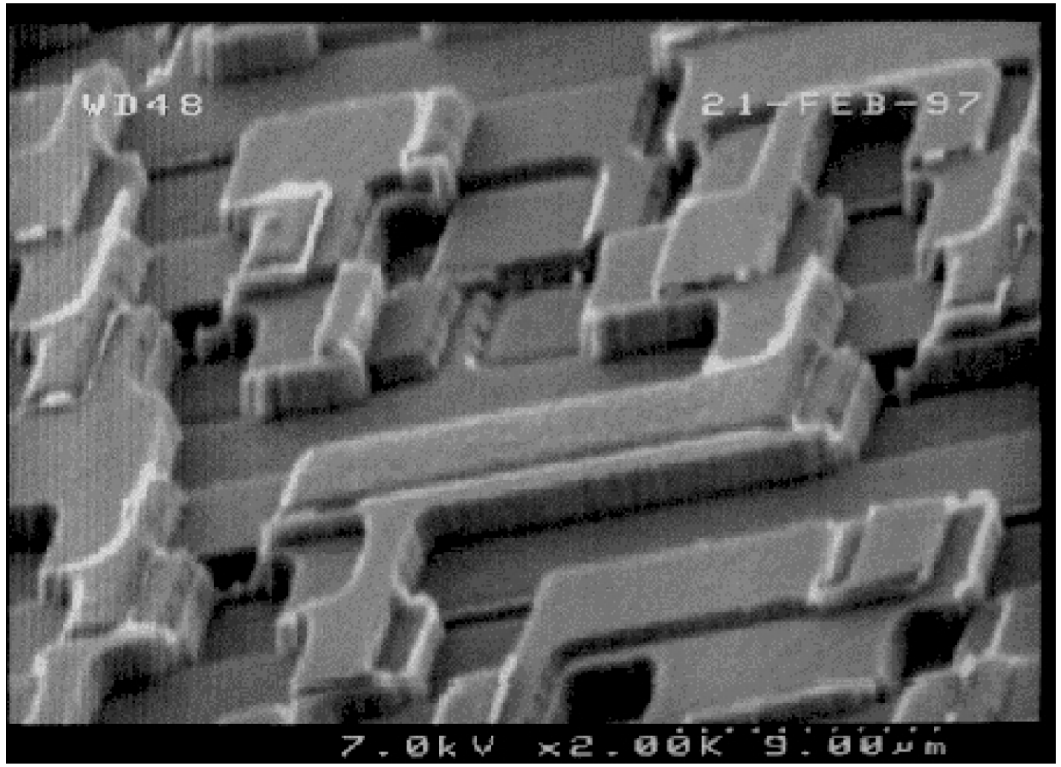
VCSEL array photograph
2.8mm



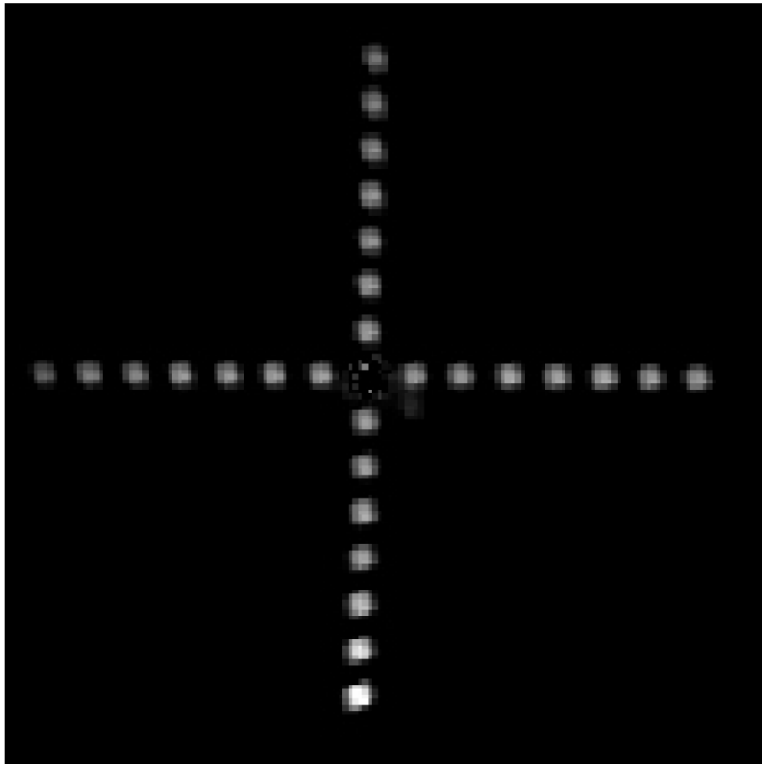


Diffractive Optic Elements (DOEs)

Sample DOE



DOE Output (Single beam input)

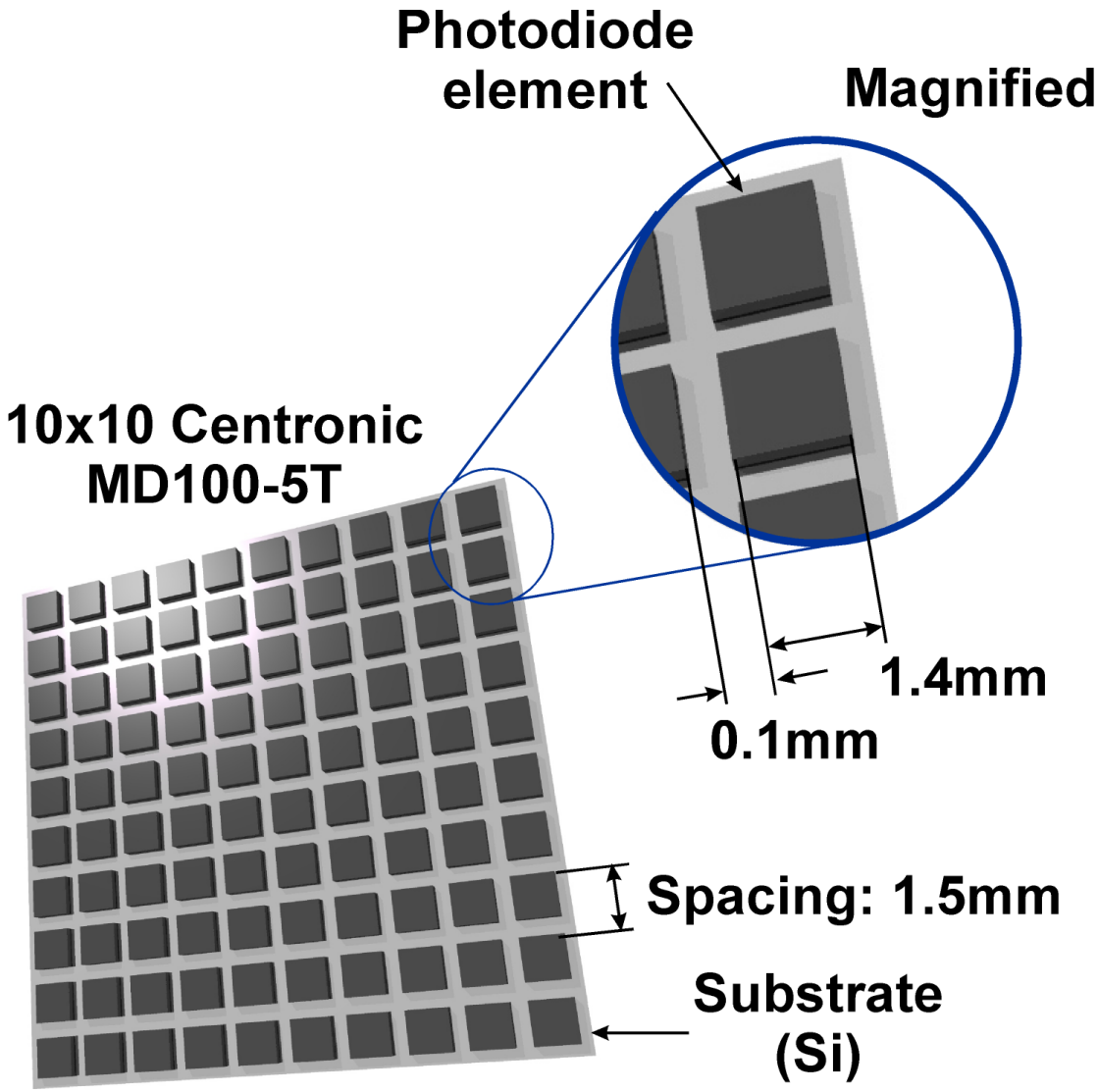


These elements are used as array generators and interconnection elements

Detector Arrays

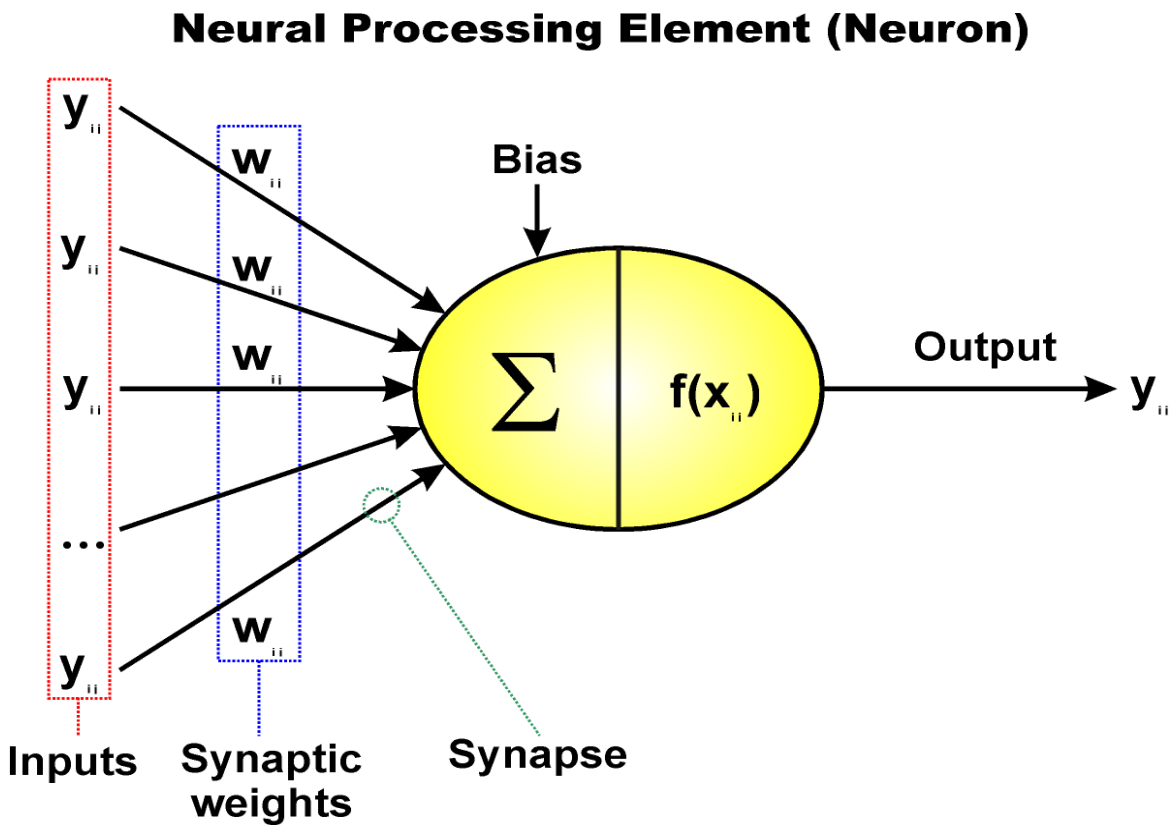
Photodetectors act as input devices and are currently available in a wide range off-the-shelf.

They are already responsive enough to handle input from any emitter (speed >1GHz): however the faster they are driven the more power they require.

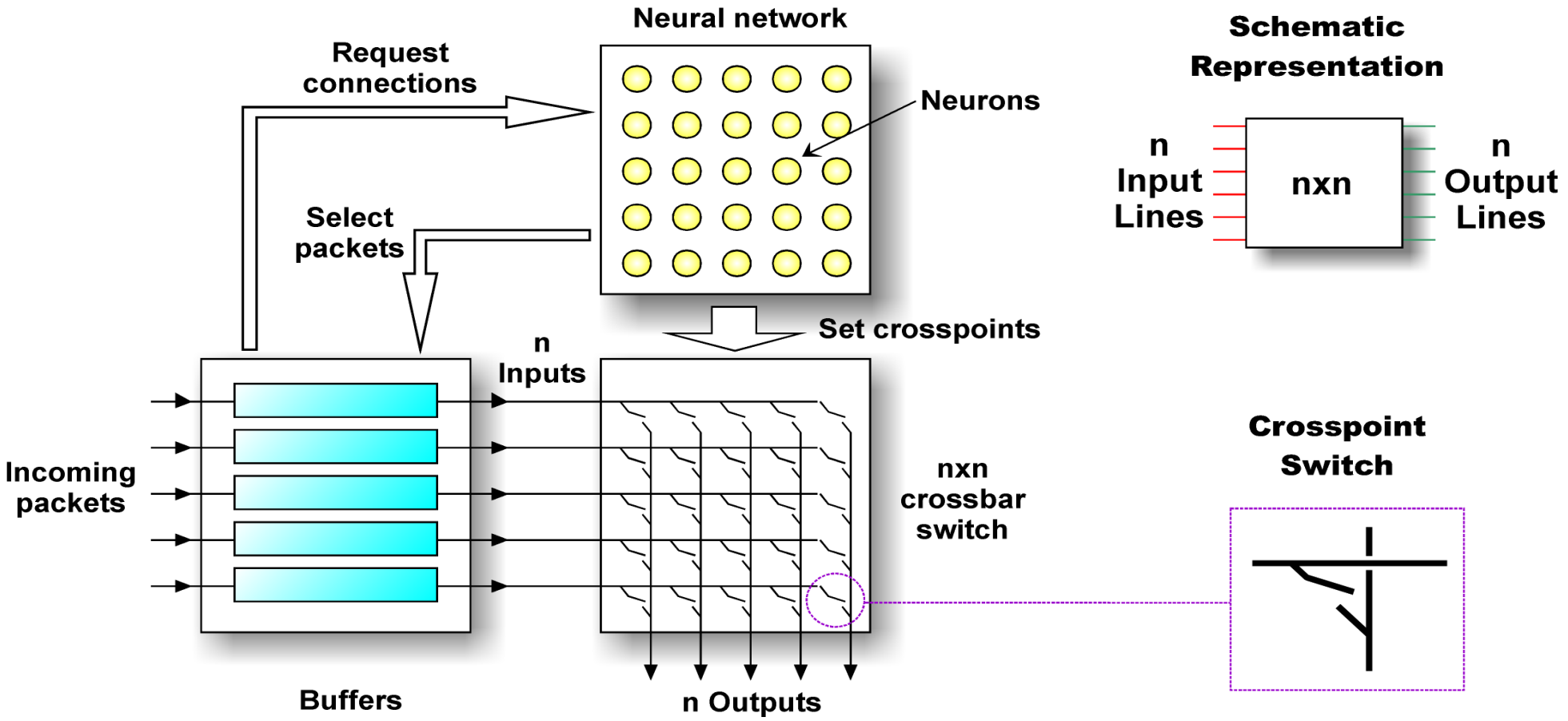


Optoelectronic Neural Networks

- Neural networks are intractable to build to any extent on silicon.
- Free-space optics can be used to perform interconnection.
- Optoelectronics allows scaleable networks.
- Input summation is also done in an inherently analogue manner.
- Noise added naturally.



Crossbar Switching



Algorithm

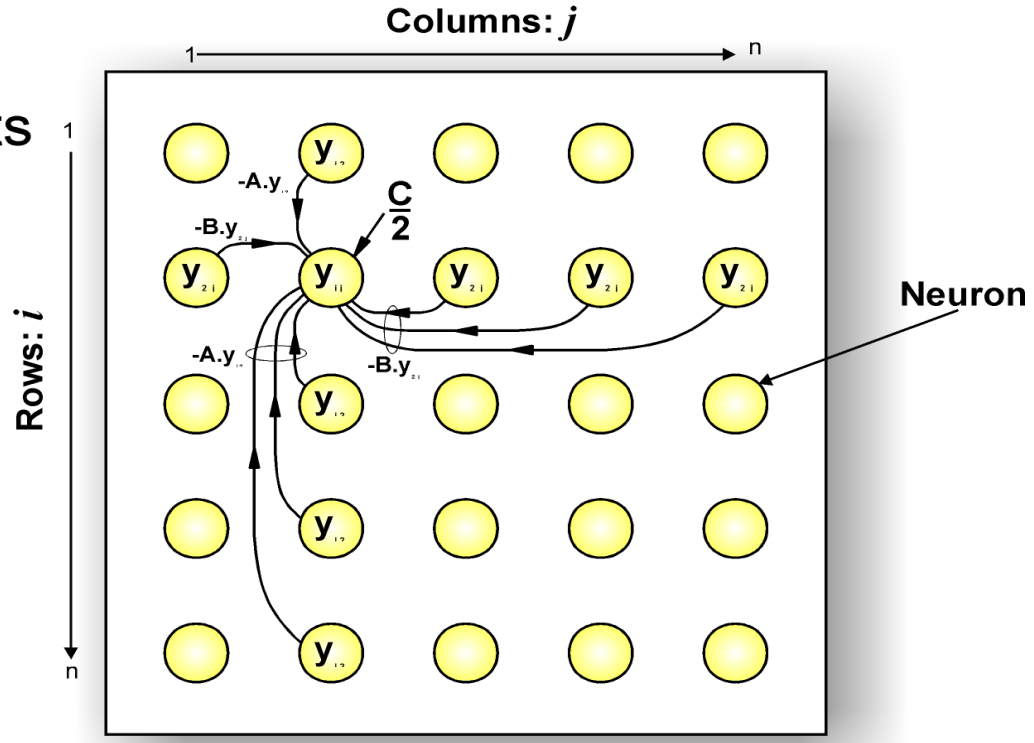
$$x_{ij}(t) = x_{ij}(t-1) + \Delta t\left(-\alpha x_{ij} - A\sum_{k\neq j}^{n} y_{ik} - B\sum_{k\neq i}^{n} y_{kj} + \frac{C}{2}\right)$$

where:

x_{ij} : Summation of all the inputs to the neuron referenced by ij: including the bias.

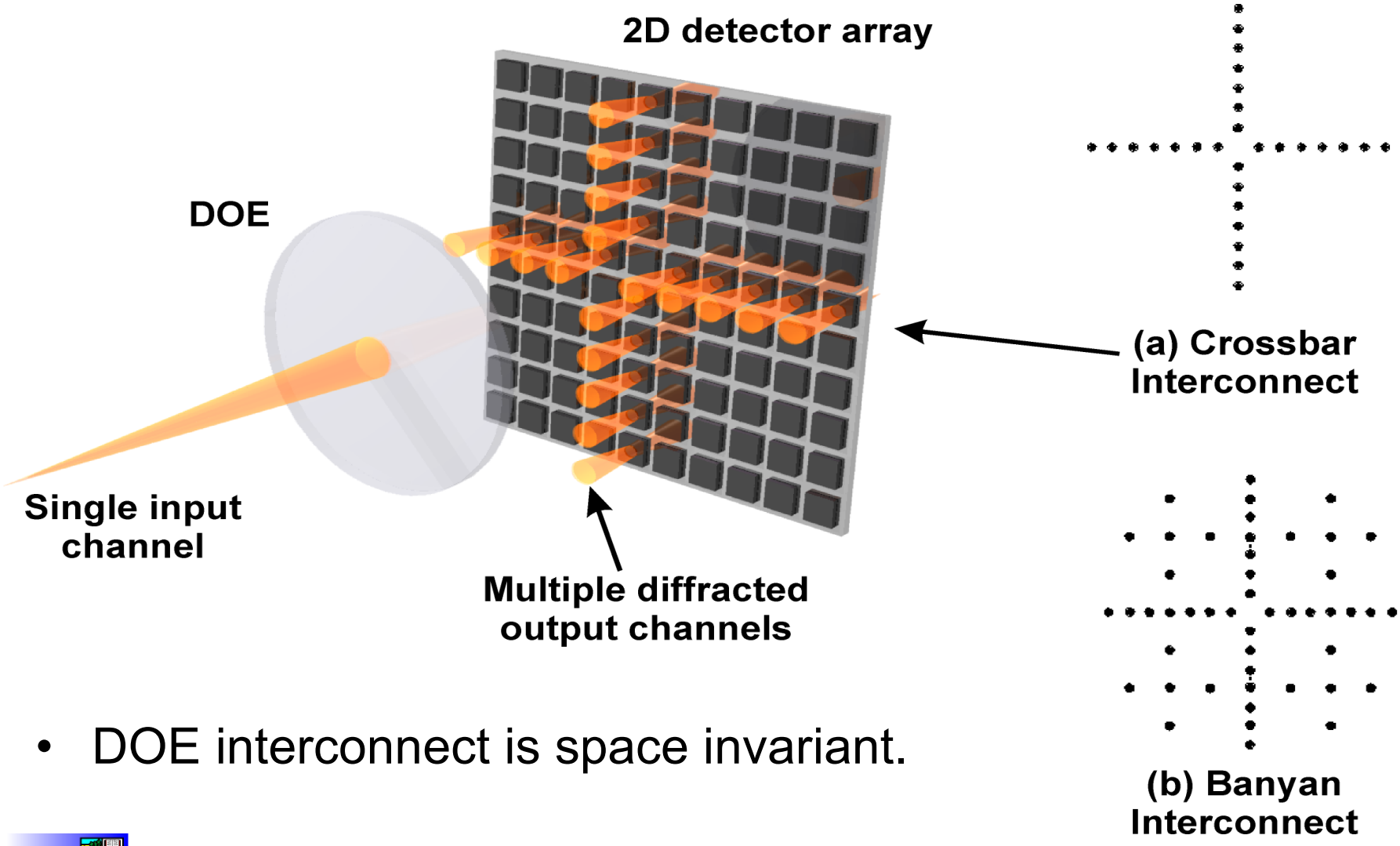
y_{ij} : the output of neuron ij.

A, B and C: Optimisation parameters.



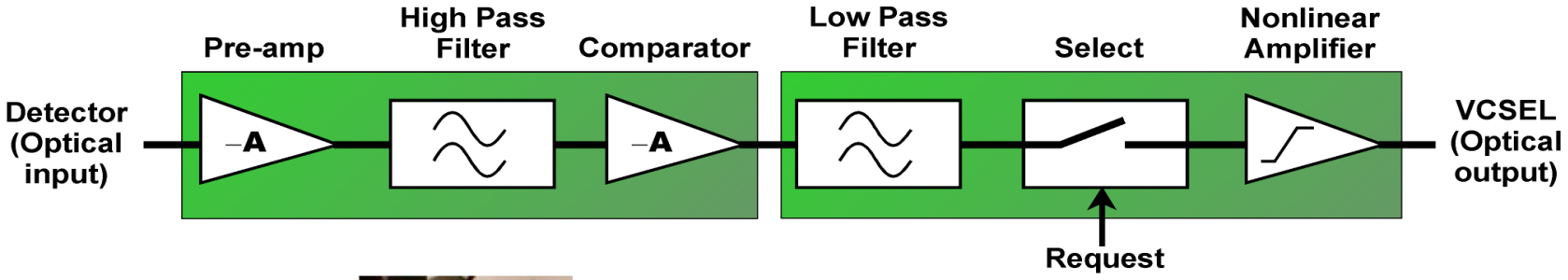
Modified Hopfield Neural Network Interconnection

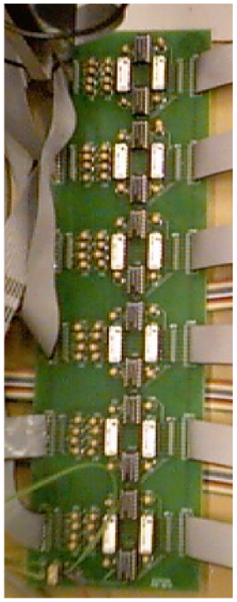
Optical Interconnect

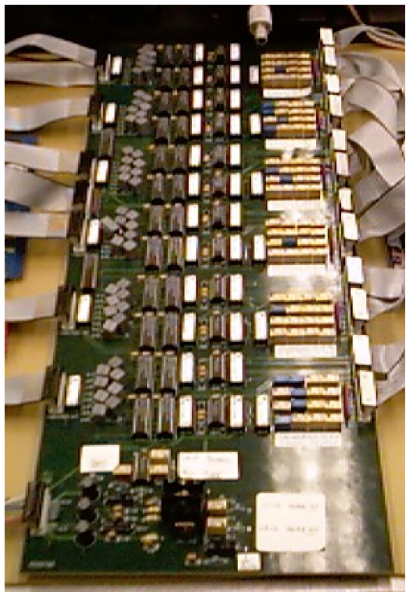


- DOE interconnect is space invariant.

First Generation System

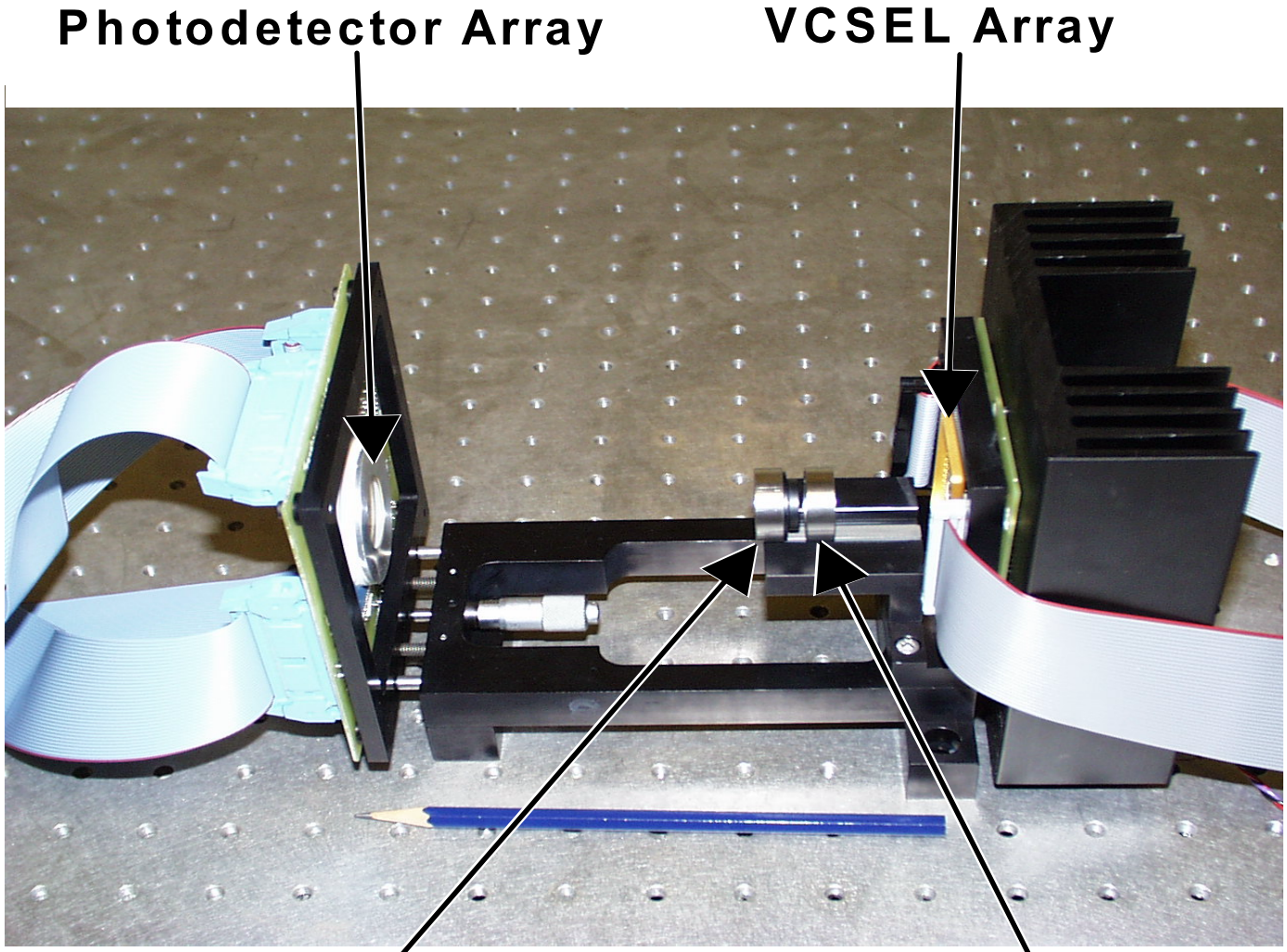






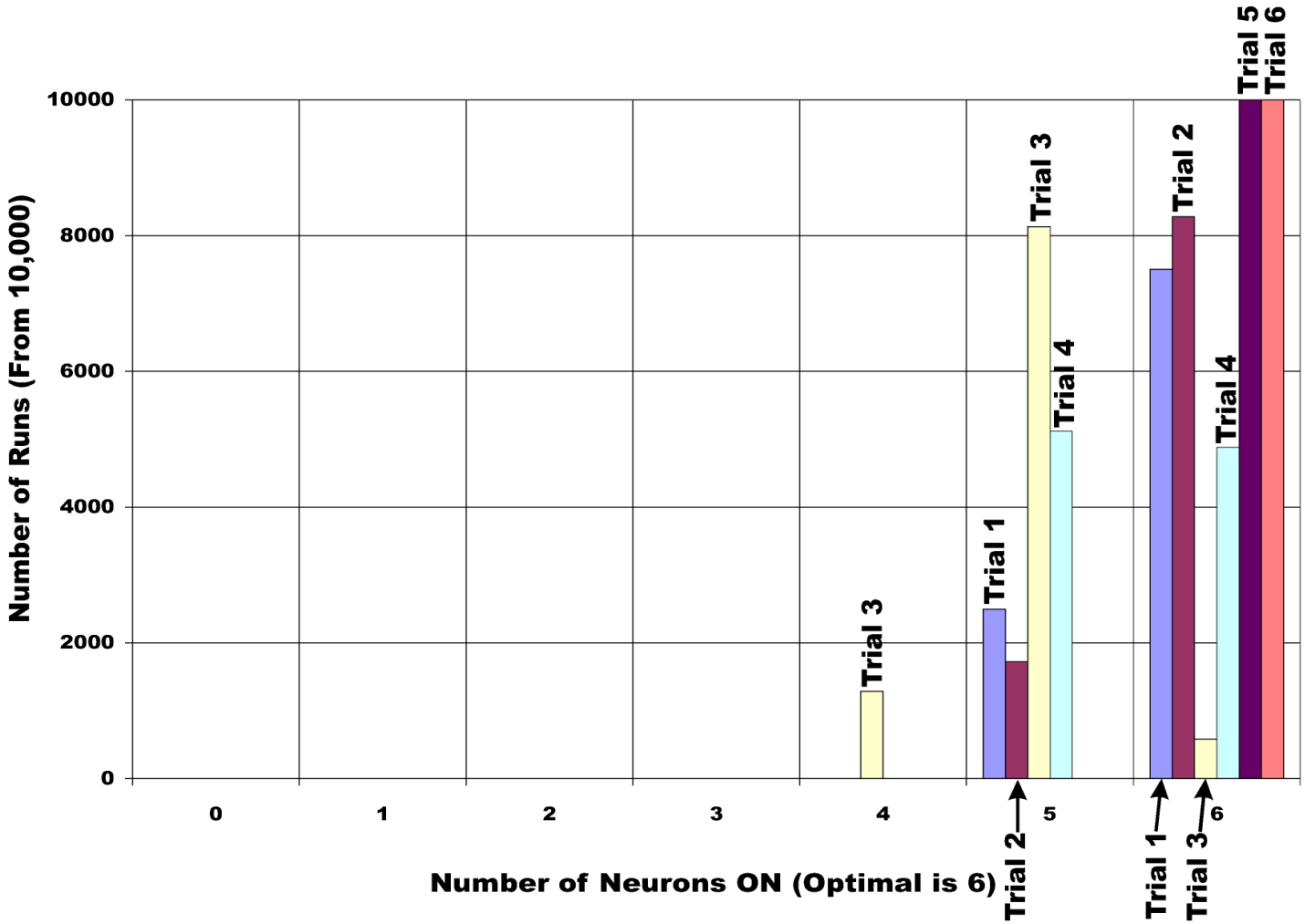
- Constructed using discrete components.
- Lacked the ability to prioritise input packets.

Optical System



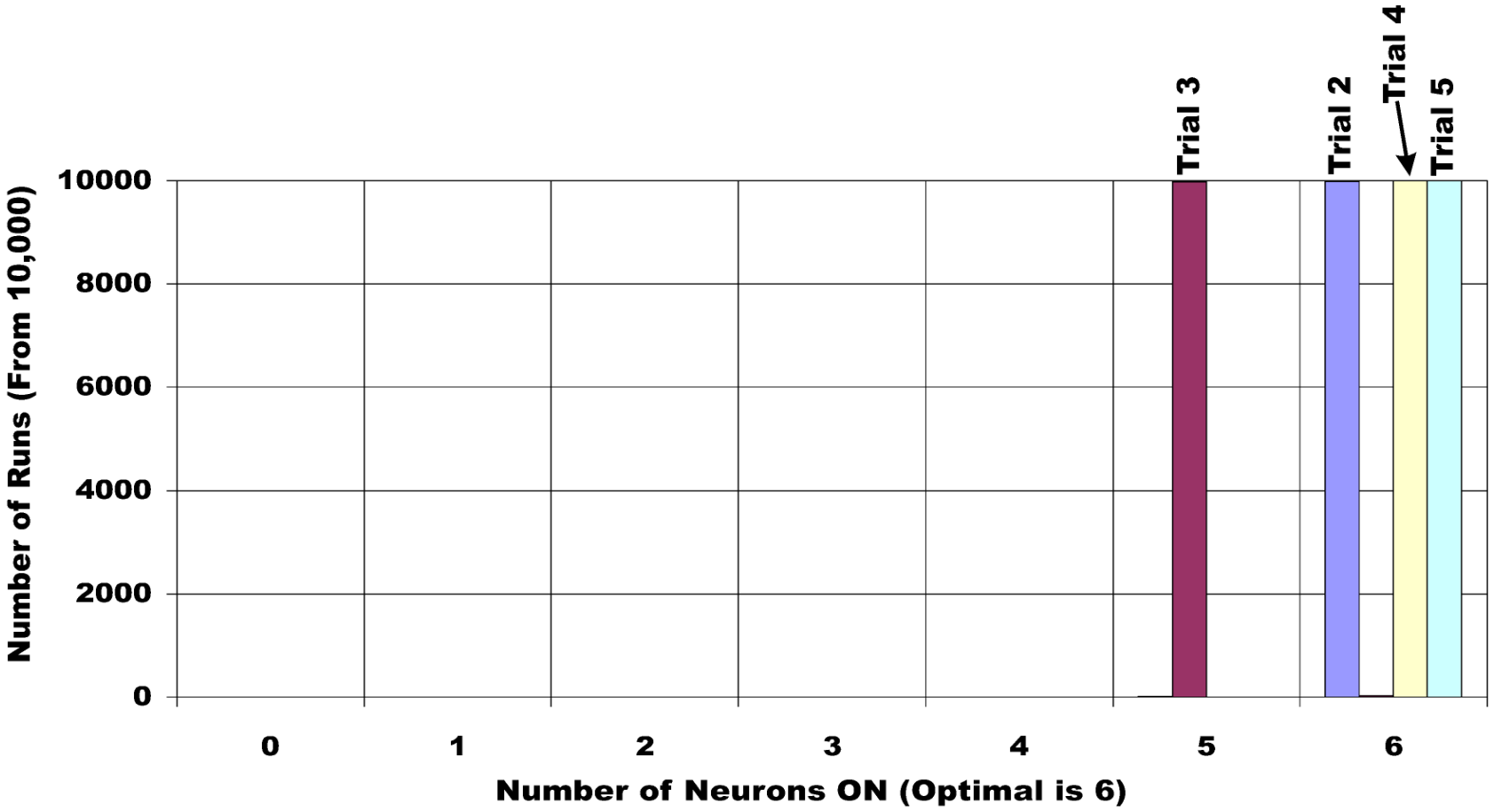
Crossbar Switch Results

- Histogram of packets routed successfully in a crossbar switch.

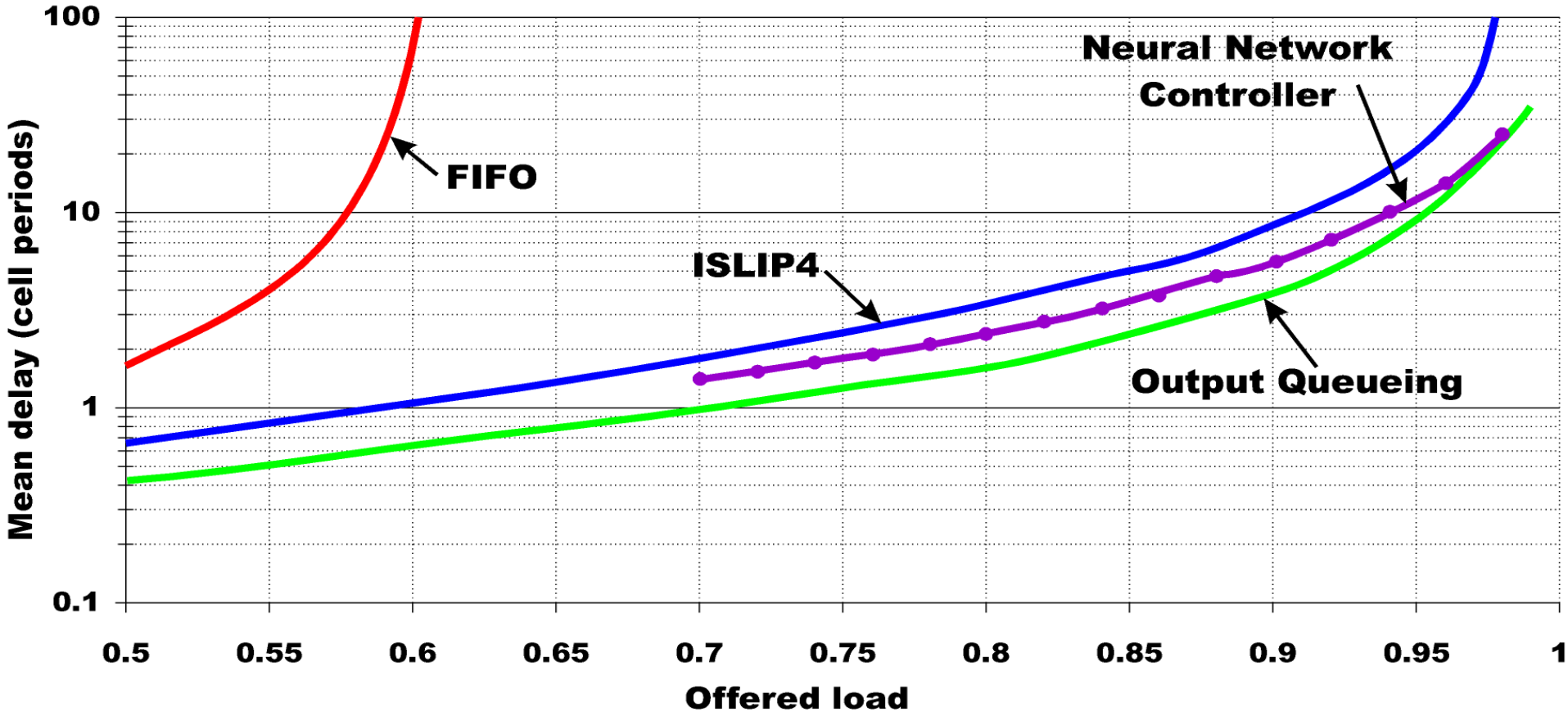


Banyan Switch Results

- Histogram of packets routed successfully in a banyan switch.

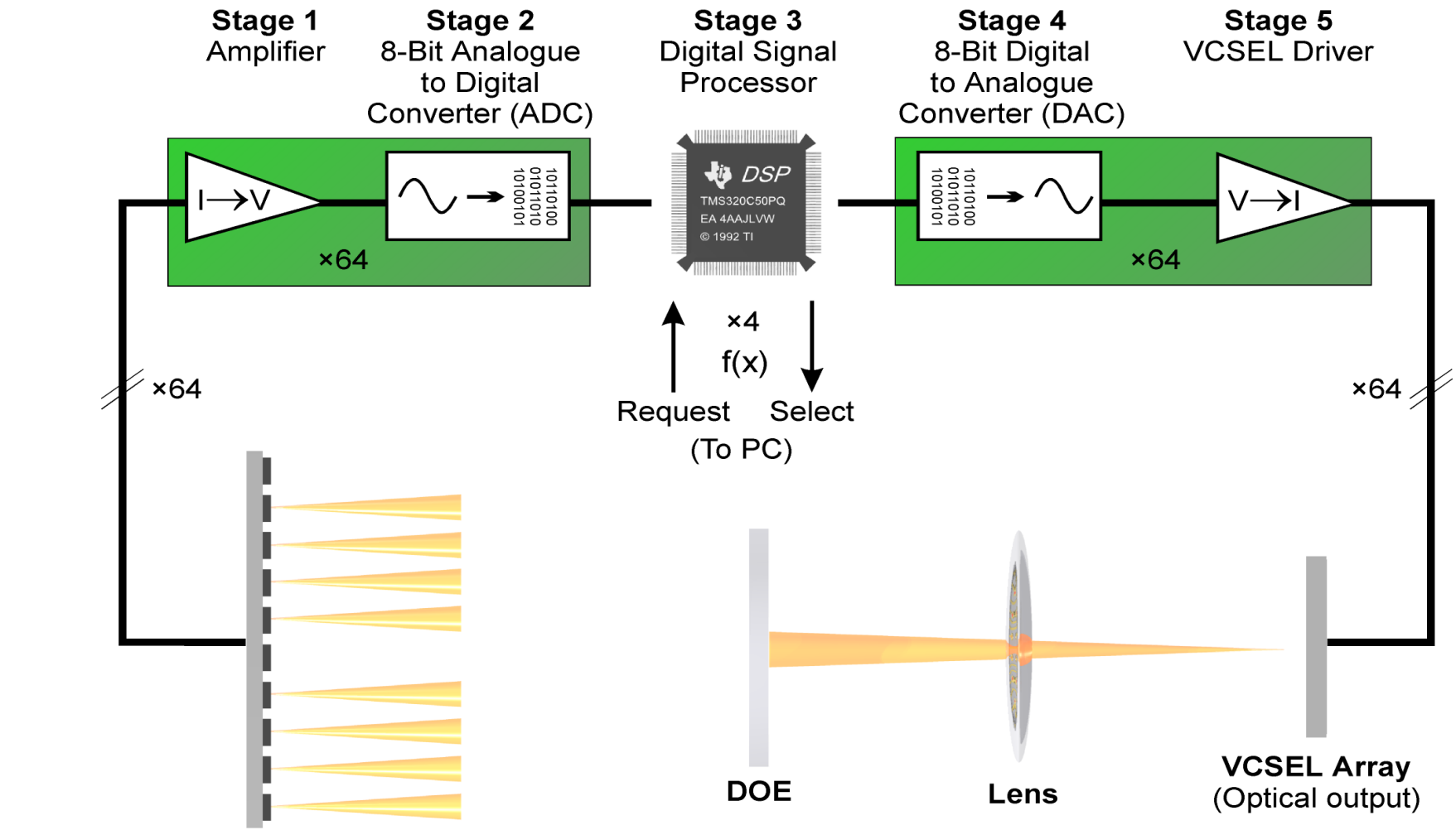


Performance



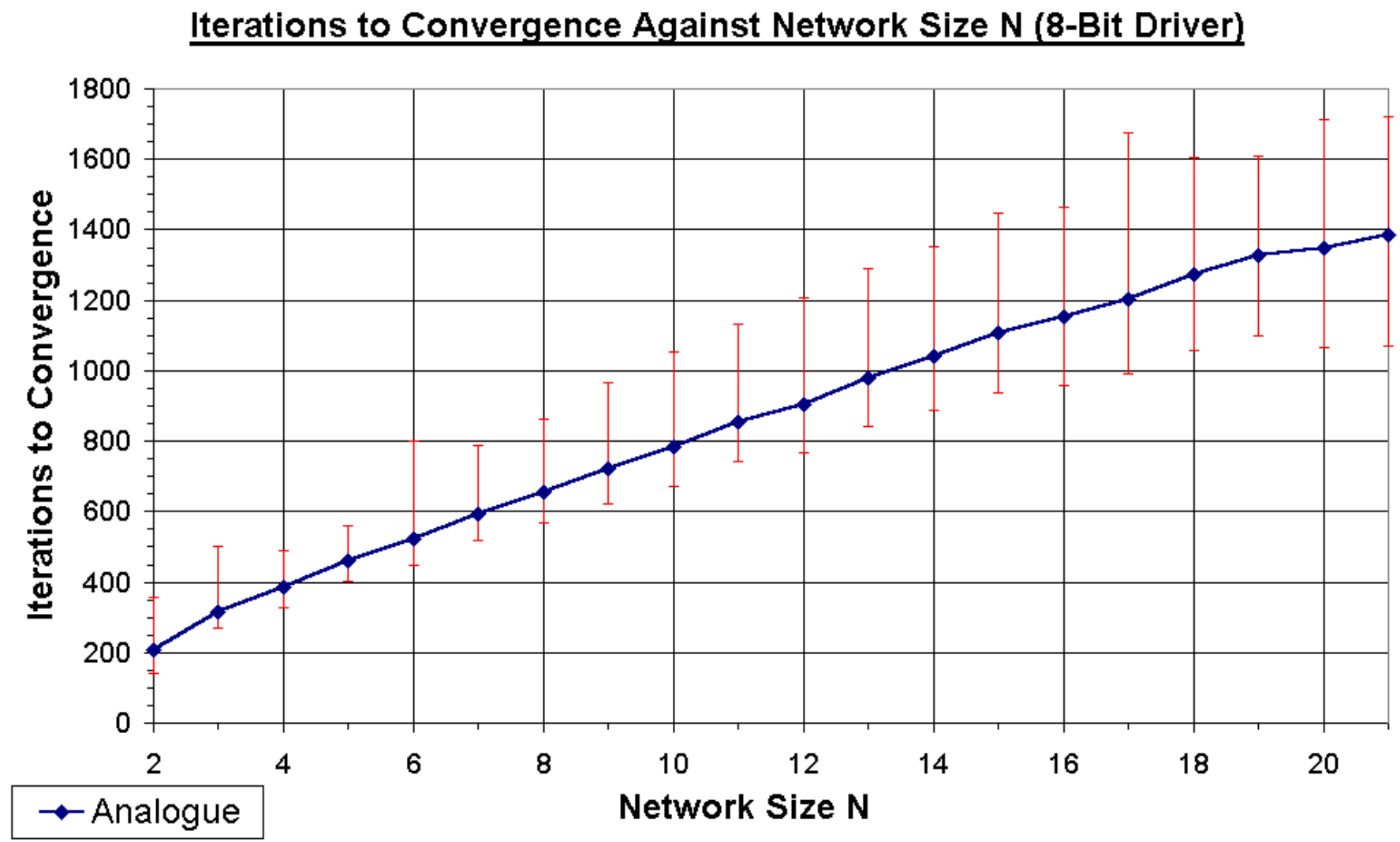
Current System

Electronic System

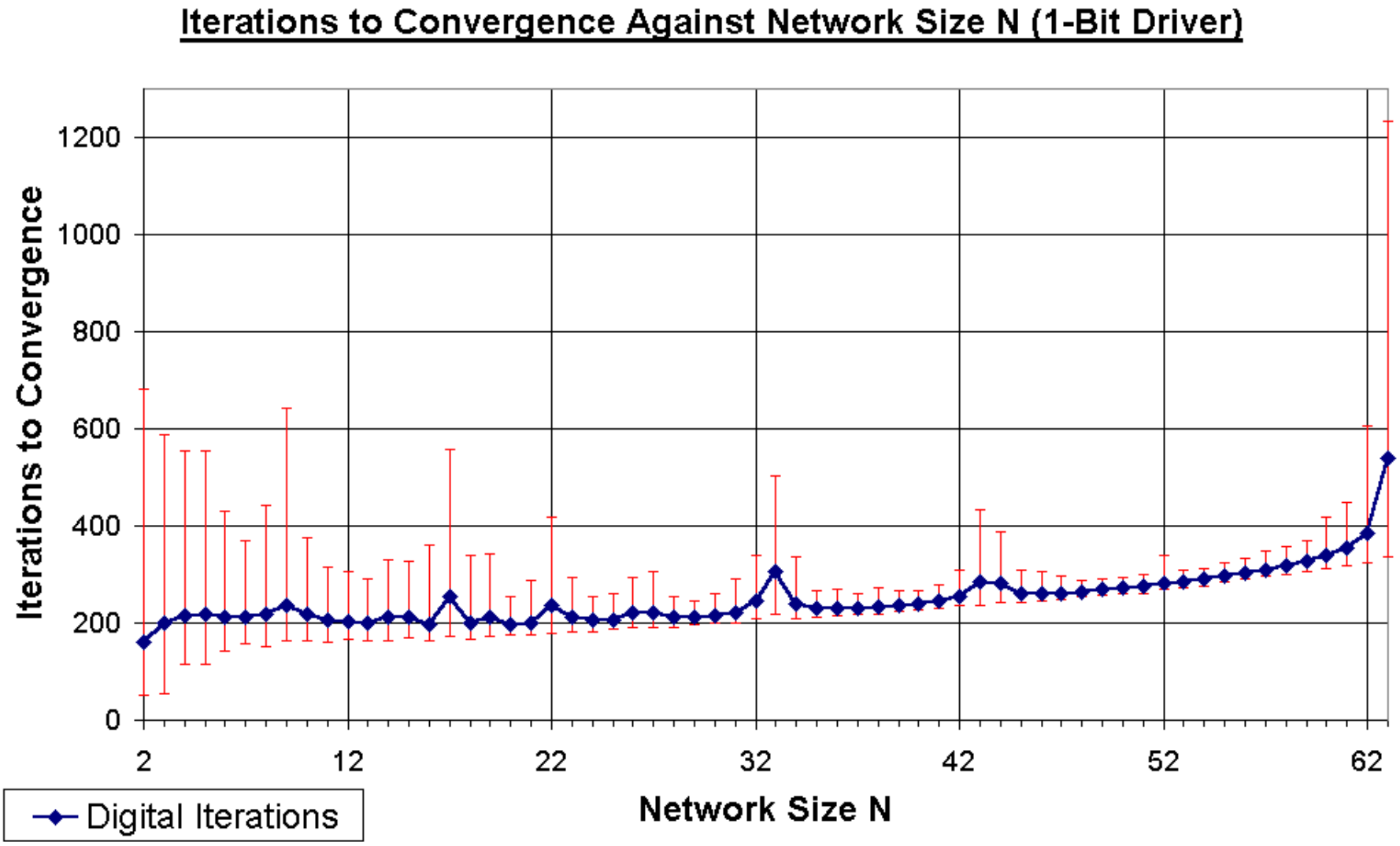


Optical System

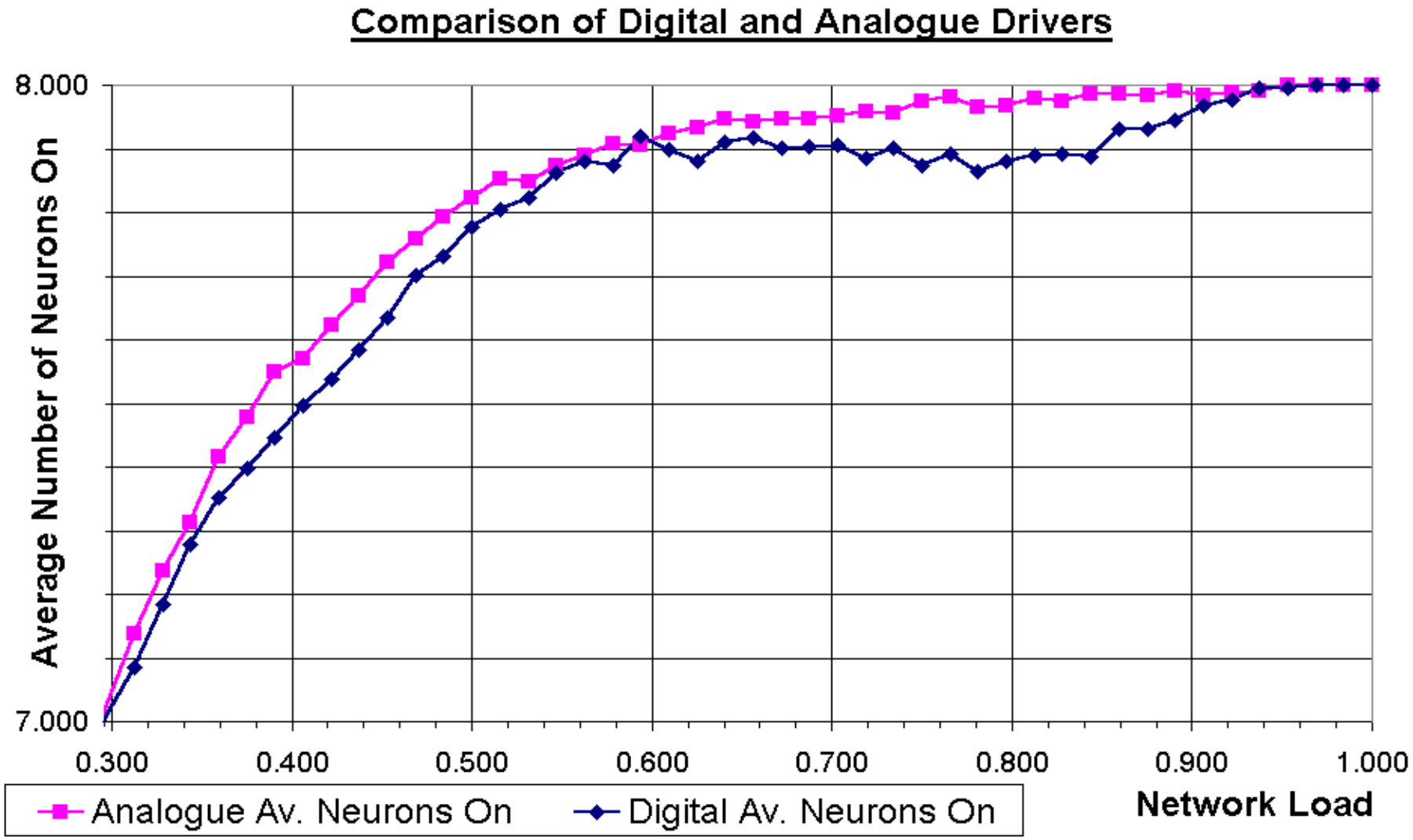
Analogue Scalability



Digital Scalability



Digital vs. Analogue



Analogue: Optimal ~97%. Digital: Optimal ~91%.

Engineering Issues

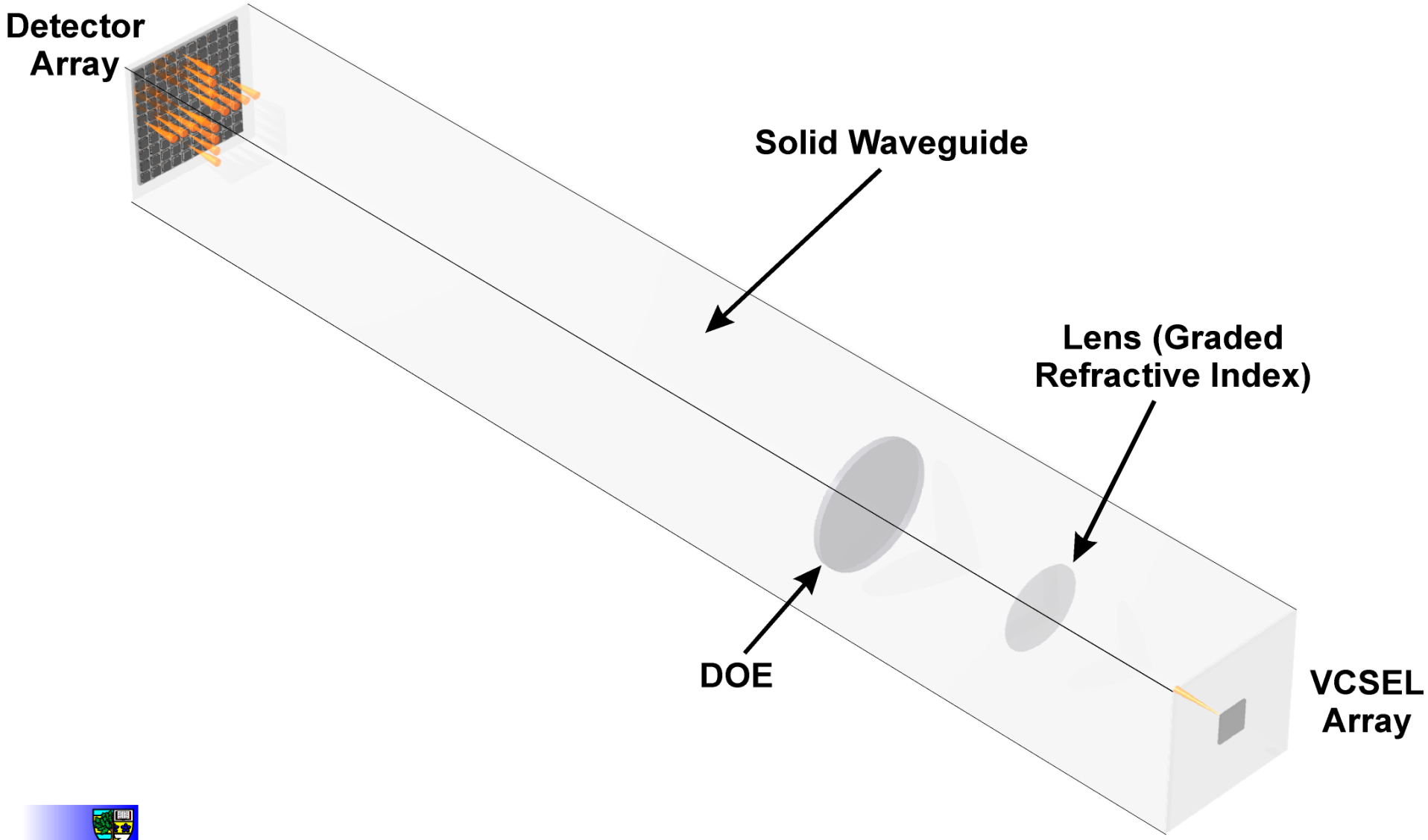
When using optics in any practical system, various factors must be considered.

- **Active effects:** <1Hz thermal changes and component creep.
- **Static effects:** Tolerances in fabricated components could lead to misalignment in final system.
- **Adaptive effects:** Vibrational effects >1Hz - e.g. 10kHz.

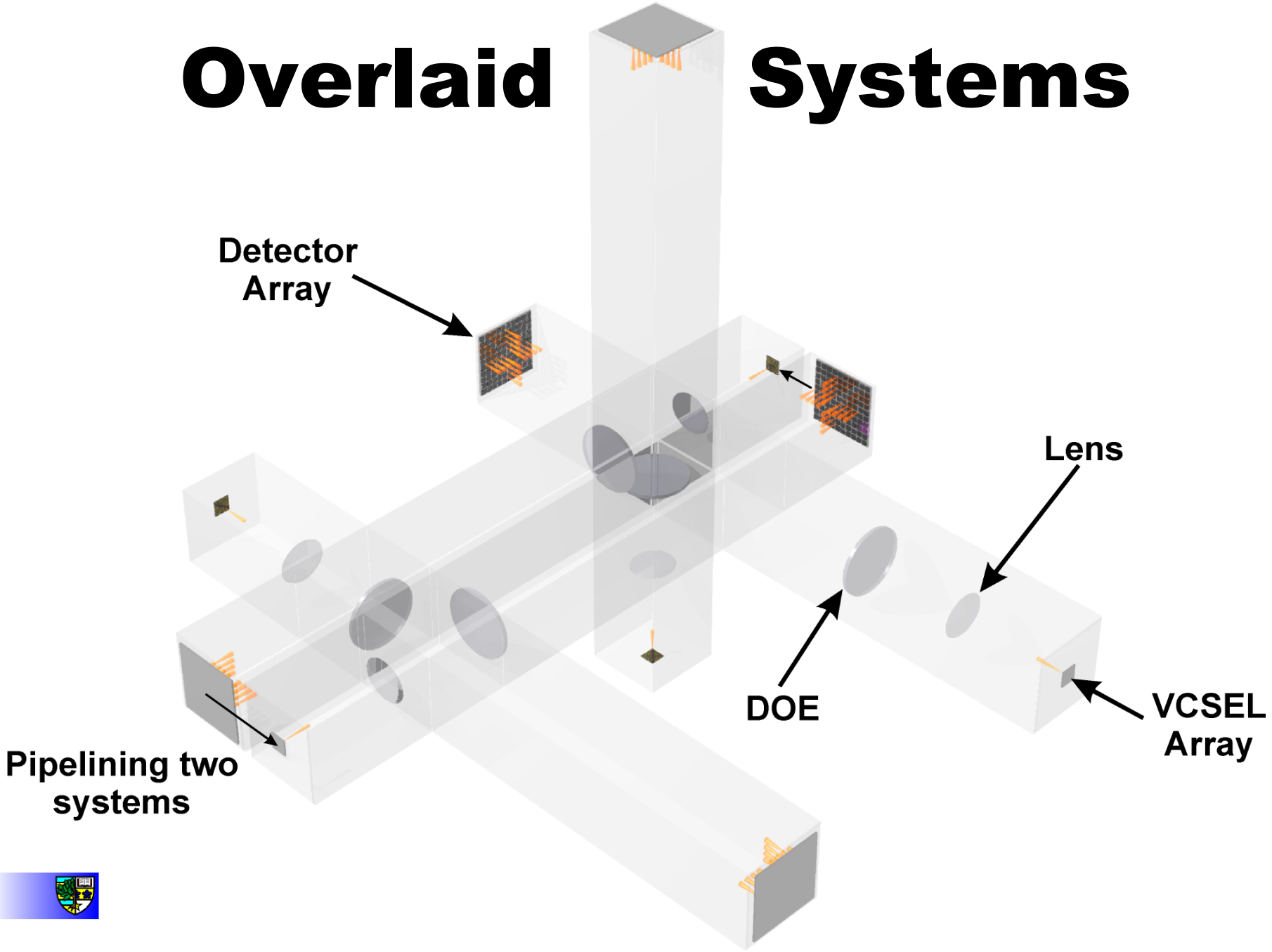
One way around these problems is to use active optic alignment or adaptive optics (AO) which perform measurement and correction of focusing and positional error in real time.

The commercial viability of such techniques is easily seen by looking at a CD player, now generally regarded as a disposable piece of machinery, which maintains focus and position of a light spot in real time on a rapidly rotating optical disk.

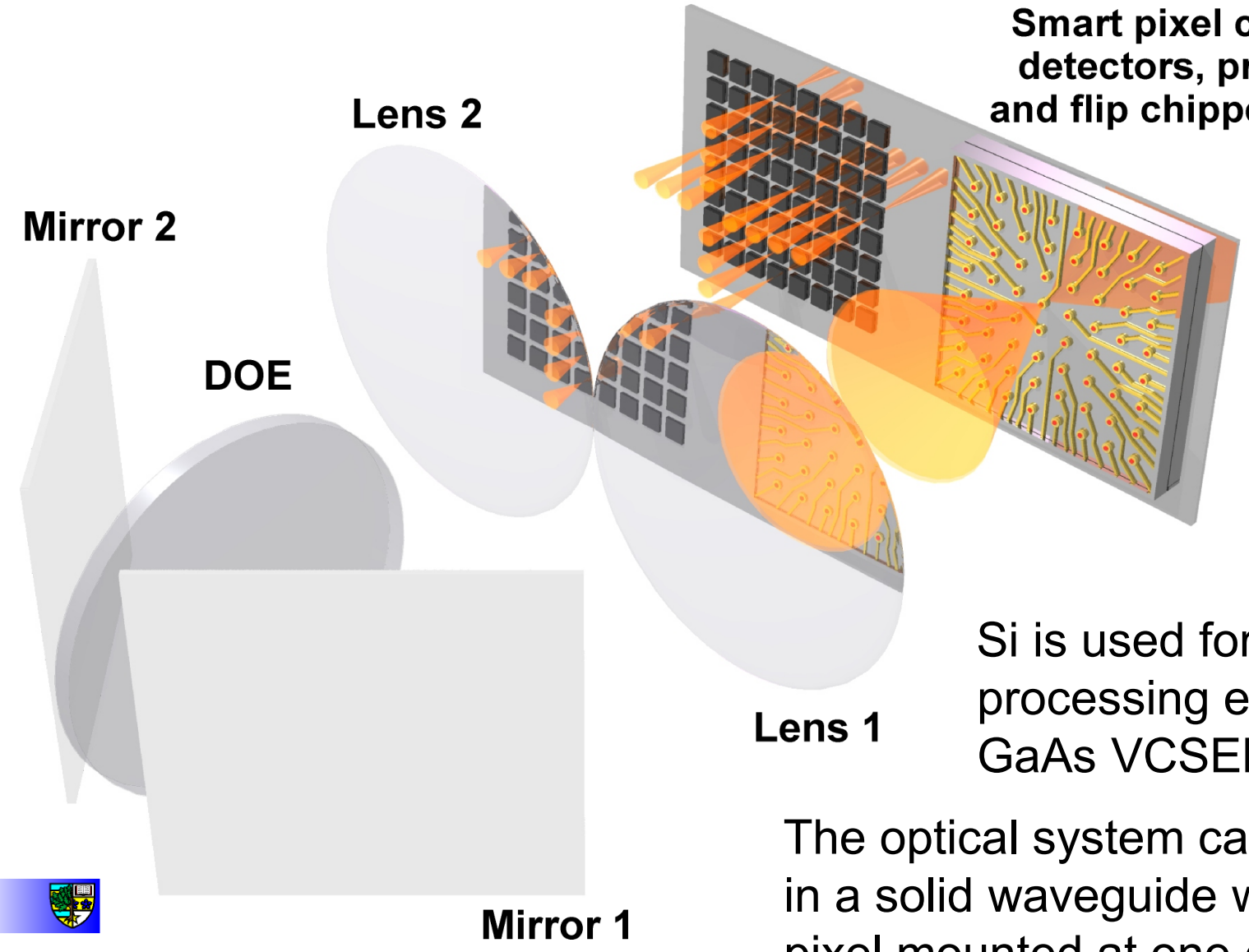
Encapsulated System



Overlaid Systems



Folded System



Si is used for detector and processing elements with a GaAs VCSEL unit.

The optical system can be encased in a solid waveguide with the smart pixel mounted at one end.

Conclusions

- Second generation builds on first in that it supports prioritisation.
- Generalisation of interconnect scheme simply by replacing DOE element.
- Reconfigurability of neuron functionality by simply reprogramming DSP.
- Further work:
  - Smart pixel implementation and packaging.
  - FPGA or custom ASIC implementation using optical interconnects.
  - Novel neural algorithms and learning.