Topic 12:

Spatial Light Modulators

and Modern Optical Systems

Aim: This lecture look the need and uses of Spatial Light Modulators and their applications in real-time optical processing

Contents:

- Types of SLMs
- Optical Addressed SLMs
- Real Time Optical Correlators
- Electrically Addressed SLM
- Optical system based on ESLMs

Real-Time Input

To utilise Fourier Properties of lenses we need **coherent** input of information.

Most imaging systems are **incoherent** so we have a problem.

Old Method: Use Photographic film. It work, but not really “real-time”

Spatial Light Modulator

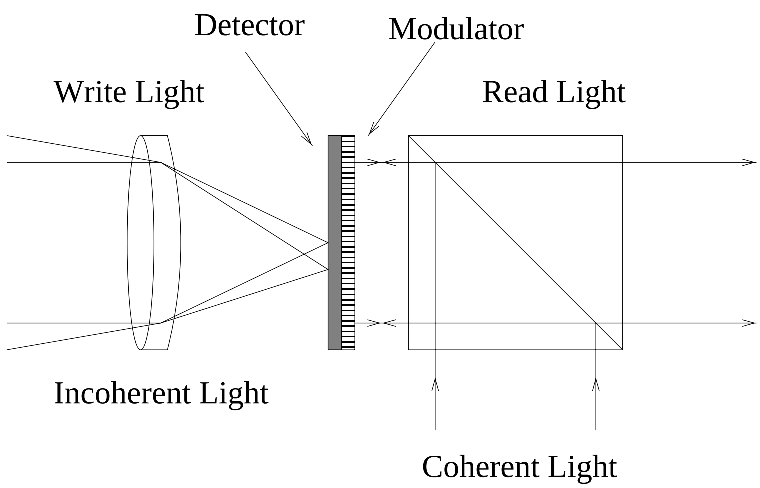
Device that “spatially modulates” a *coherent* beam of light.

There are **two** basic types

1. Optically Addressed: “Converts” incoherent light to spatial modulation.
2. Electrically Addressed: “Converts” electrical signals to spatial modulation.

Optically Addressed SLM

The basic system is:



The “incoherent” light is detected (as intensity), by a photo-detector (as an electrical change distribution).

This charge distribution affects the modulator, and so changes the *Amplitude* **or** *Phase* of the reflected coherent light.

Vast range of technologies for both photo-detector and modulator.

Most common (and only commercially available) are:

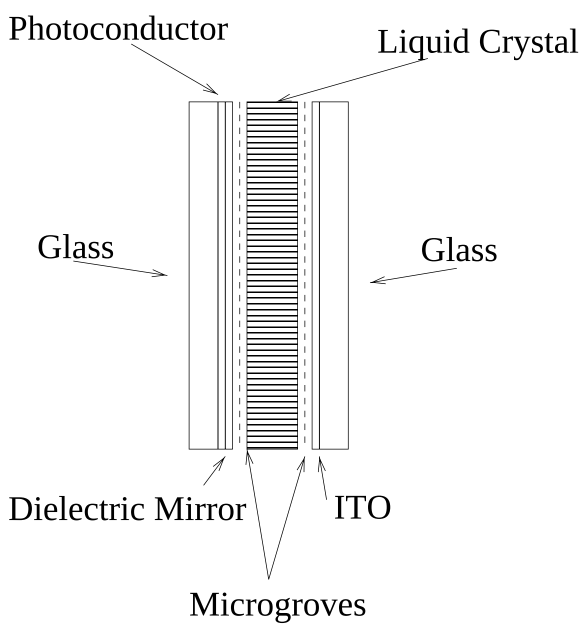
Photo-conductor: Amorphous Silicon, (low light levels) or thin film Photo-transistor (high light levels).

Modulator: Liquid Crystal.

Liquid Crystal: Partially aligned “crystal” that is optically active and changes the polarisation of reflected (or transmitted) light depending on electric field.

Structure of OASLM

The basic structure of such a device is:

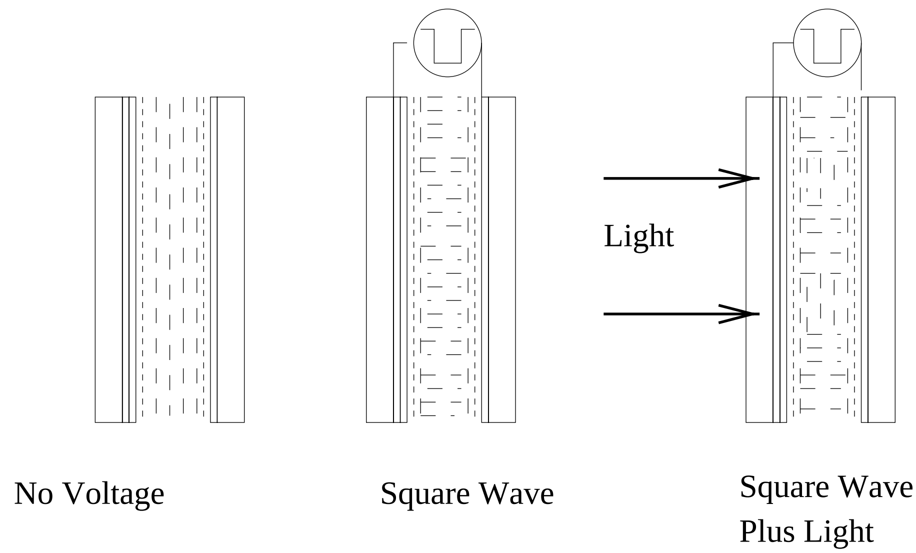


with the LC in a thin cell with surface groves that align the molecules.

Need a apply electric field, so need transparent conductor, (Indium-Tin Oxide).

Operation of SLM

The system basically operate are follows:



No applied voltage the molecules are “aligned” by the surface groves.

Square Wave applied, “induced” dipole on molecule that is then “twisted” by the electric field.

Square Wave *plus* light: photo-conductor is locally discharged by the light, so molecules in these regions not effected by electric field, so do not twist round.

LC has a different *refractive index* in “aligned” and “twisted” state, so changes phase of reflected light.

Crystal is also bi-refringent, so if illuminated with polarsied light it can be used to rotate axis of polarisation, and hence change Amplitude (with analyser)

Typical Specification

Contrast Ratio: 20:1 (film better than 1000:1)

Resolution: 100 lines/mm at best (comparable to film).

Response Time: Speed depends on type of Liquid Crystal:

Neumatic: 20msecs (analogue amplitude or phase)

Ferroelectric: 50μsec (binary amplitude or phase)

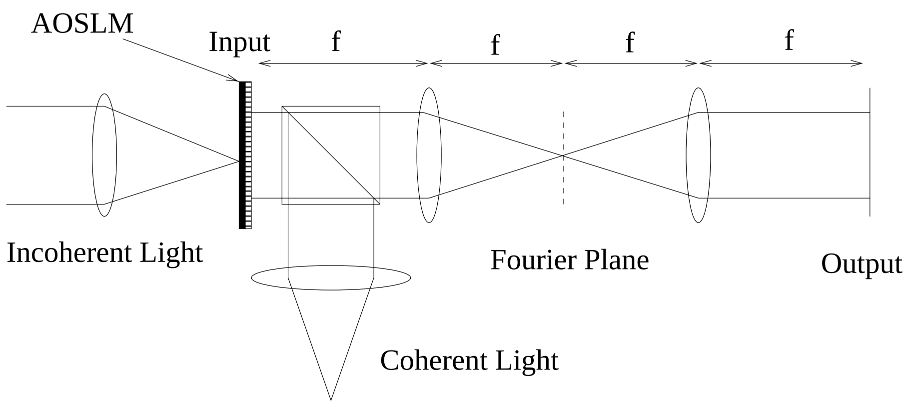
Still *experimental* devices but with some commercial sales. Effectively 1-off devices, so very expensive.

Problems:

- Variable contrast and sensitivity across device.
- Relatively insensitive to light.
- Tends to retain image.
- Liquid crystal degrades
- Very low yield during manufacture.

Practical Uses of AOSLMs

Real-time input to Optical Correlator
Simplest applications is for real-time input to “4-f” optical processor



where the “outside-world” is imaged onto the OASLM, this image is then processor by the “4-f” system. (Laboratory project).

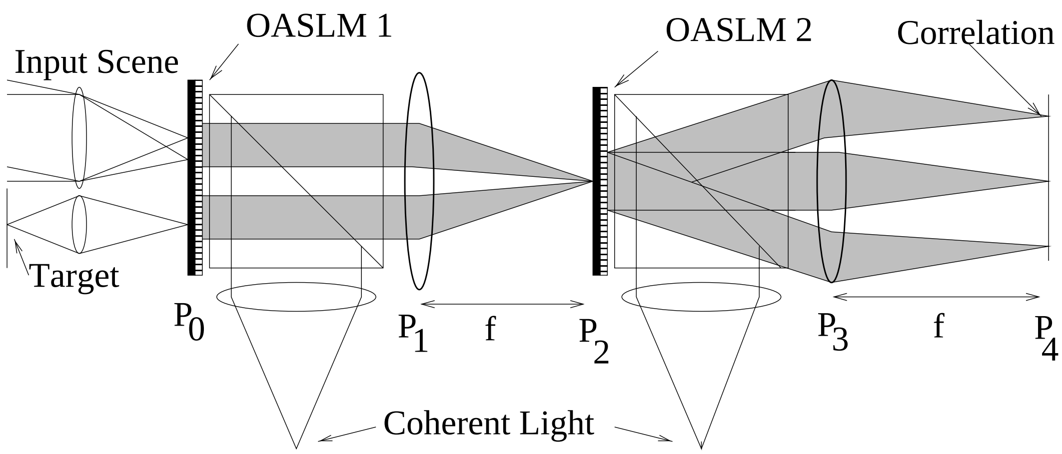
Replace Fourier filter with a *Fourier Hologram*, you get a real-time correlation system. (Look for one object).

Practical system:

- “Portable” vehicle recognition system by BAe (1986), 30 cm by 30 cm base. Able to “make hologram” on same optical system. Stable enough to be driven about in army Land-rover.
- “Hand-held” system by Leib (Lockheed), (1988). About the size of old style video camera.
- Range of simple industrial inspection systems

Practical system, but a bit limited due to the need to physically change the filters (or holograms) in the Fourier plane.

Joint Transform Correlator:
More complicated system at end of last lecture, but with 2 AOSLMs can be full “real-time” system.



Operation of system:

1. Project input scene and target (incoherent), onto OASLM 1. Plane P_0.
2. Coherently read from OASLM 1 and Fourier Transformed onto OASLM 2 in plane P_2.
3. OASLM 2 detects *intensity*, so form real-time Fourier Hologram.
4. Coherently real from OASLM 2 and Fourier transformed to produce correlation plane in plane P_4.

Working practical system for real-time object recognition.

Electrically Addressed SLM (ESLM)

Electrical signals to coherent (or incoherent) modulation.

Fundamental optical “input device” so link between imaging optics and electronics.

Typical Uses:

- Optical Processing (input and/or Fourier filter).
- Optical Switching.
- Optical neural systems.
- Real-time optical beam steering.
- Image projection, (projection TV, computer projection, VR projection).

Far more use that OASLM, also much more development since they are useful outside field of “coherent optical processing”.

Note: all ESLMs are pixelated. Leads to some diffraction problems when used in coherent optical systems.

ESLM Technologies

Range of technologies, the most promising are:

Liquid Crystal: LC modulators switched by either thin-film transistors (transmissive displays), or silicon backplanes (reflective devices). Usable in all applications, but rather “slow”.

Magneto-Optic: Pixelated crystal of Aluminum Garnet switched by array of magnetic coils using magneto-optic effect. High powered drive circuits, and low efficiency, but are commercially available.

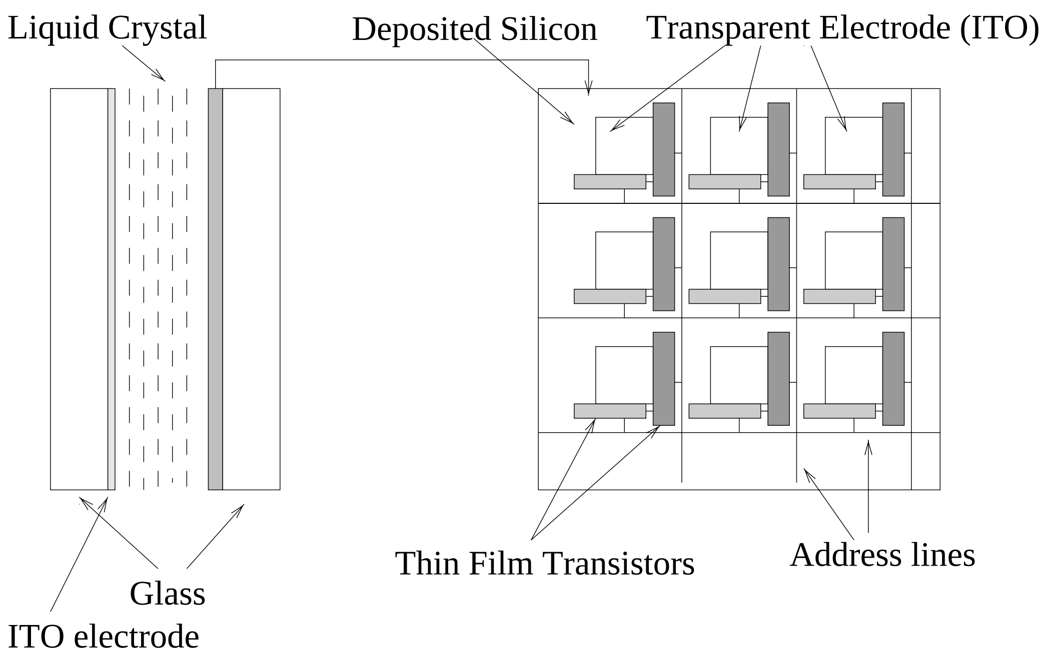
Deformable Mirror: Array of “sprung” mirrors make by nano-technology techniques. Very expensive to make, rather slow, and not flat. (Excellent for incoherent light).

Multiple Quantum Well: non-linear optical effect, Quantum Stark Effect in stack of very thin layer ($\approx 100\mathbf{r}A$). Extremely fast (quantum limited), but poor contrast, difficult to make in large arrays, and difficult to drive. Future of fast optical switching.

Look at two of these technologies, LC and Deformable Mirror.

Liquid Crystal ESLMs

Transmissive LC panels: Liquid crystal between two glass sheets, with control circuitry added with thin film transistors.



Address the "pixels" to change the local electric field across the liquid layer and hence switch pixels on or off. Add "grey-level" by altering the time each pixel is on for and colour by placing an array of colour filters on top of the display to group pixels in threes.

Typical displays are very large (up to 30 cm) for laptop computers, but also small displays for projection TVs and head-up displays.

Best "optics" device is 320×320 pixels, in 4×4 cm display.

Problems:

- Large pixels (TFT are always big)
- Small “fill-factor” (large dead areas due to TFTs)
- Not very flat, problem in coherent optics.

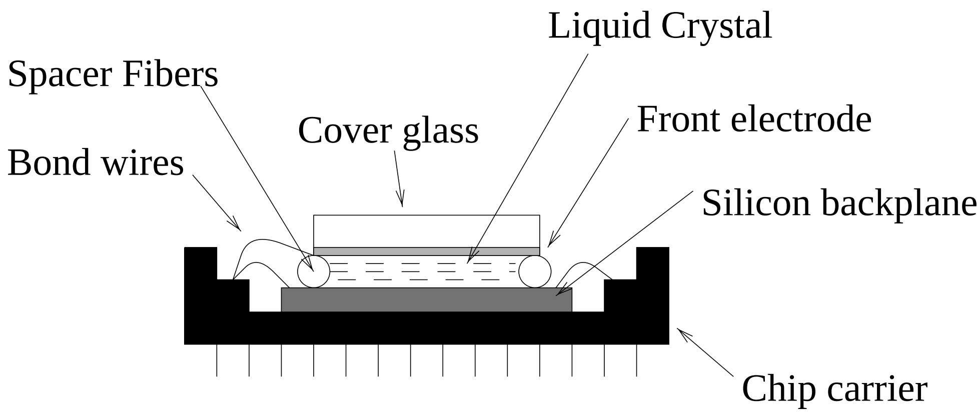
Excellent for image display and projection system, but rather large and not usually flat enough for coherent optics.

Many commercial system from Thorn-EMI, Philips, Sony, Casio, Sharp.

Big commercial growth area, cost still rather high, mainly due to yield problems.

This technology is set to take over from CRT monitors for computer displays and televisions, (replacement for 17” colour monitor available from now).

Liquid Crystal over Silicon: same basic idea as LC panels, but operate in reflection with control voltages supplied by mirrors on a silicon chip.



the silicon backplane is then essentially a “memory chip” with reflective mirrors.

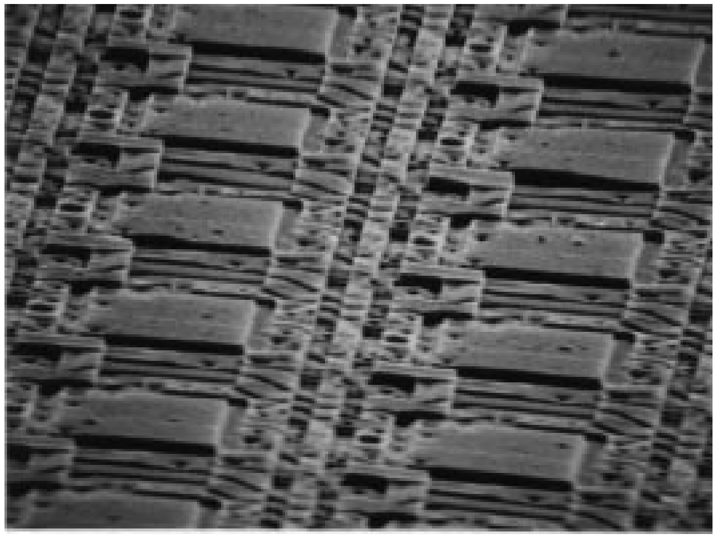
Address the mirrors (set them on/off), and so switch the LC above each mirror.

Devices are small (typically less than 14 mm), and very high resolution 1024×768 produced last year.

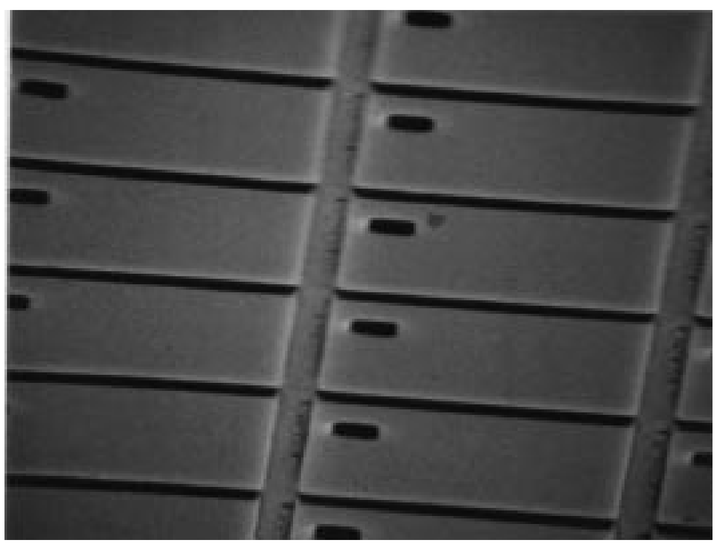
Compatible with standard TTL electronics, (easy to interface), small, light and robust.

Can be made optically flat, and with large area mirrors, built above circuitry.

Typical electron mircoscope picture before planarisation



and then after planarisation



where is these images the pixel spacing is $40\mu\mathrm{m}$.

Typical devices: (University of Edinburgh)

176×176 pixels 1 khz operation, binary, 5.25×5.25 mm

256×256 pixels. 5 khz operation, binary, 6.5×6.5 mm

1024×768 pixels, 3 khz operation, binary 14×14 mm

Devices can be optically flat, and small. (matches small optics), so ideal for coherent applications.

Ideal for small displays, (VR systems).

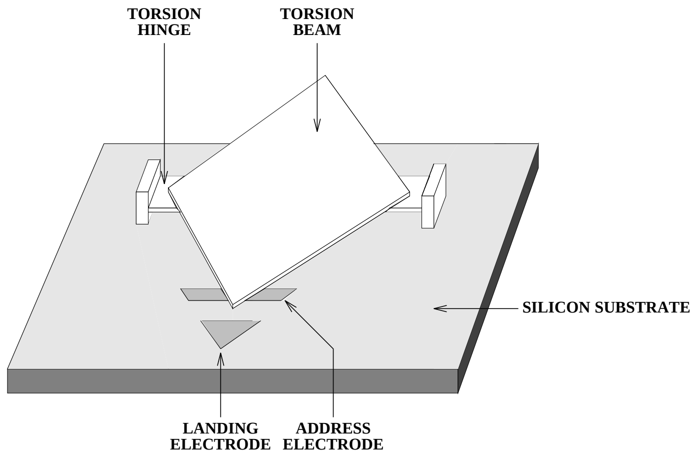
Problems:

- Silicon easy, but planarisation and LC cell difficult to make.
- Difficult to get completely flat.

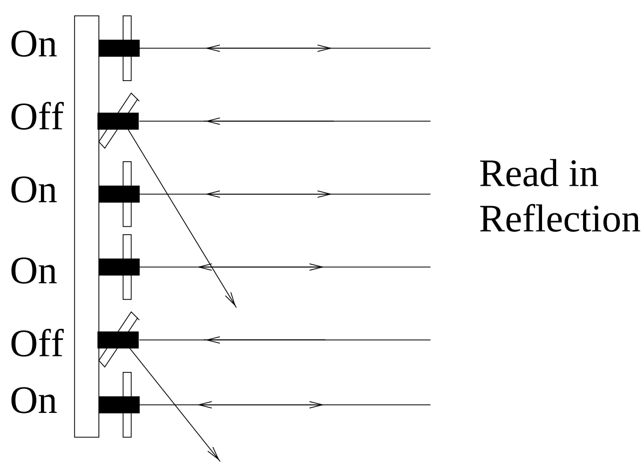
This technology developed here for over last 10 years. Becoming commercial both in UK and independantly in USA.

Deformable Mirror

Spatial Light Modulator formed by two-dimensional array of “movable” mirrors of the type:



where each mirror is controlled by electrostatic force. So when a mirror is “tilted” it deflects the light “out of the system”.



Mirror arrays up to 1024×1024 have been made with $30\mu\mathrm{m}$ mirrors. Made by controlled etching of silicon.

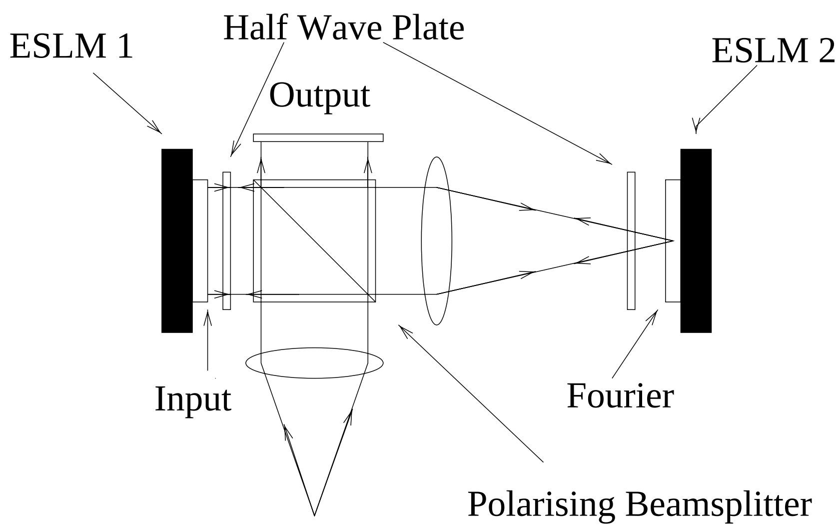
Binary device with response time of $10\mu\mathrm{sec}$.

Made mainly for projection TV using incoherent light. Flatness and scatter a problem when used in coherent light.

Manufactured by Texas Instruments (very expensive at the moment).

Optical Applications of ESLMs

Coherent Optical Processing: able to put ESLM in input and Fourier plane, and also "fold-up" the system.



Small SLMs, then you have short focal lengths.

Project in Boulder to put a correlator "inside a beer-can".

Input to JTC system, (discussed previously). EEC funded project just finished at Edinburgh to built a JTC for road sign recognition. (Whole system in a "shoe-box").

Realtime beam steering: Use in phase mode to steer and fan-out optical beams for optical computing. (See display boards in Applied Optics corridor).

Vector Matrix Multiplier

Many mathematical operations can be formulated at a Vector$\times$Matrix multiply of the form

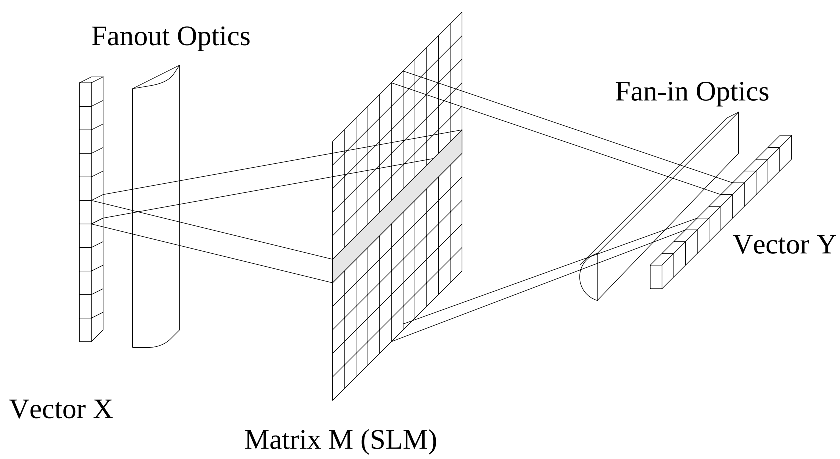
$$\mathbf{Y} = \mathbf{X}.\underline{\mathbf{M}}$$

where **X** and **Y** are vectors of length N and $\underline{\mathbf{M}}$ is an $N \times N$ matrix.

Applications include

- Optical computing
- Neural networks
- Cross-bar switching (telephone exchange)

There is a great deal of research work on this basic system of



where the SLM acts as a series of *Windows*

Practical systems: Use of cylinderical lenses not really practical, so "fold" system up by use of hologarphic fan-out elements.

OCPM: 64×64 all optical cross-bar switch using a custom designed 64×64 SLM nearing completion. System to be used to optically couple 64 Workstations into an reconmfigurable network.

Holographic System: Use of SLM as holographic elements allows for redundance in system. More likely to be practical.