European leader in advanced technology solutions

Introduction to laser beam modulation

A laser beam modulation system can be required or significantly improve performance in many electro-optic applications, each having specific needs. There are plenty of reasons why you should select a laser beam module, some of which are listed below.

- Laser material processing or microscopy requires controlling the position of the laser beam and, in most instances, the laser power (either continuously or on/off).
- Laser light shows and projection systems require control of the angle and on/off operation.
- CD mastering requires highly stabilised lasers and active noise reduction.
- Pulsed Solid-State Laser manufacturers require active loss control inside the cavity (Q-Switching).
- A number of laser based measurement techniques (Ellipsometry, birefringence measurement) require modulation of the laser beam polarisation to improve signal to noise ratio and sensitivity in these and other polarisation-based measurements.
- Many particle size or flow cytometry devices need a "light sheet" and require laser scanning devices.
- Many low power level measurement required lock-in amplifiers techniques which involve on/off laser modulators (choppers or AC modulation).
- All high power/energy applications need to consider carefully laser safety and shutters / beam dumps are widely used.
- Medical laser and regenerative laser amplifier applications require laser pulse pickers or pulse gating systems to select one or more laser pulses from a pulse train. Single pulse selection is important in laser spectroscopy.

consult. design. integrate.

Controllable laser parameters

Laser beam modulation allow to control a set of parameters including: angle, power, phase, polarisation and many more, whilst there are several technologies available in the market place which allow for laser beam control, there is a lack of awareness of technical solutions available and their respective benefit and drawbacks. Acal BFi has an expert team of engineers who can help you find the best solution that meets your specific needs.

Our broad range of technologies gives us the opportunity to provide customers good and fair advice. The following chart is a brief overview of the most commonly considered parameters but many others such as: damage threshold, wavelength range, beam diameter and driving requirements have to be taken into account before selecting a technology.

Technology	Intensity	Polarisation	Phase	Frequency (optical)	Angular Deviation	Spectral Filtering	Q-Switch
Acousto-optic	Yes	No	No	Yes	Yes	Yes (AOTF)	Yes
Electro-optic (Pockels cell)	Yes	Yes	Yes	Yes (Unusual)	Yes (Unusual)	No	Yes
Galvanometers (Scanners)	No	No	No	No	Yes	No	No
Mechanical shutters, choppers	Yes	No	No	No	No	No	No
Photo-Elastic Modulators	Yes	Yes	Yes	No	No	No	No

Achievable levels of performance

The below chart has been designed as a guide to help you make a quick pre-selection. The numerical information is in order of magnitude of best possible values which cannot all be achieved simultaneously.

You can download more detailed specification sheets from our website or contact your local Acal BFi office to discuss your specific application with one of our engineers to obtain a more targeted recommendation. Our team will be more than happy to assist you.

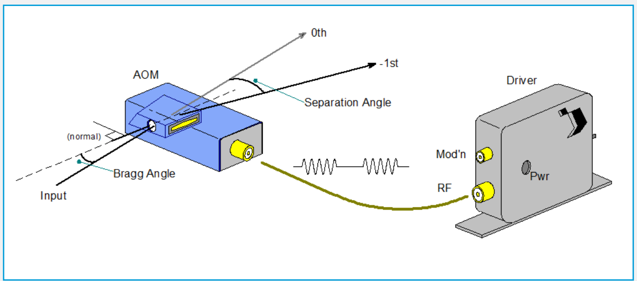
Technology	Wavelength range	Modulation bandwidth	Active Aperture (max)	Scan Angle	Rise Time
Acousto-optic	257nm-12 µm	DC-100 MHz 300 MHz for shifters	9mm (visible) 12mm (infrared)	0 - 4.4 °	9 ns
Electro-optic (Pockels cell)	200nm-5 µm	DC-1 GHz 10GHz (resonant)	50mm 2mm (resonant)	NA	40 ps
Galvanometers (Scanners)	all	1.3 kHz	50 mm	80 °	0.15ms small step response time
Mechanical shutters, choppers	all	0 - 500 Hz (Choppers: 120kHz)	57 mm	NA	0.2 ms
Photo-Elastic Modulators	170nm-19 µm	20 - 84 kHz (fixed)	13 - 56 mm	NA	NA

consult. design. integrate.

Introduction to and example of use for various modulation technics

Acousto-optic (courtesy of Isomet)

In an acousto-optic device (or Bragg cell), a crystal subjected to an ultrasonic wave (generated by a piezo transducer driven by an RF signal) behaves like an electronically controlled grating, deflecting a laser beam passing through the device. Both the deflection efficiency and the separation angle can be actively controlled by the RF signal power and frequency respectively.



Acousto-optics devices are a key element in many research programs. Acousto-optic devices were for instance used in the pioneering experiments on Bose-Einstein condensates that led to Dr Ketterle's 2001 Nobel Prize in Physics.

Another popular application is CO2 lasers modulation for Differential Absorption LIDAR (DIAL). This is a laser-based technique used to measure the concentration of trace gases. The trace gas to be detected determines the required laser wavelength. Since the CO2 laser can be tuned over a relatively large range (9.2-10.8 microns), it can be used to measure a variety of trace gases. A rapidly tunable CO2 laser that utilizes intra-cavity acousto-optic deflectors for wavelength selection has been demonstrated.

But the largest volume for acousto-optic devices today is for use as a Q-Switch. Solid state laser systems utilise intra-cavity acousto-optic Q-switching to generate high-repetition-rate pulse trains, for both industrial lasers and military applications. Depending on the exact requirements, Q-switches can be made from all commonly used acousto-optic materials (e.g. Fused Silica, Quartz, TeO2, etc.).

Electro-optic Modulators

(courtesy of Conoptics)

An Electro-Optic modulator utilises a transparent crystal having an index of refraction that can be controlled electrically, this index change results in a rotation of the polarisation of the beam going through the device. The phenomenon, in crystal materials, is known as the Pockels effect (or in certain liquids and solids as the Kerr effect). Thus those Electro Optic modulators are also often called Pockels cells. The electric field can be applied either transversely or longitudinally. The description below is about transverse-filed electro-optic modulators. The electroded crystal may be considered to be a voltage-variable waveplate. When a voltage is applied, the polarisation of the light propagating through the crystal changes. This variation in polarisation results in intensity modulation downstream from the output polariser.

The ideal electro-optic material possesses all of the following properties:

- large change in refractive index per volt
- high optical quality and transmission
- low dielectric constant (low capacitance)
- low dielectric loss tangent (no dielectric heating due to a high-frequency electric field), and
- no distortions in modulators output from piezoelectric resonances.

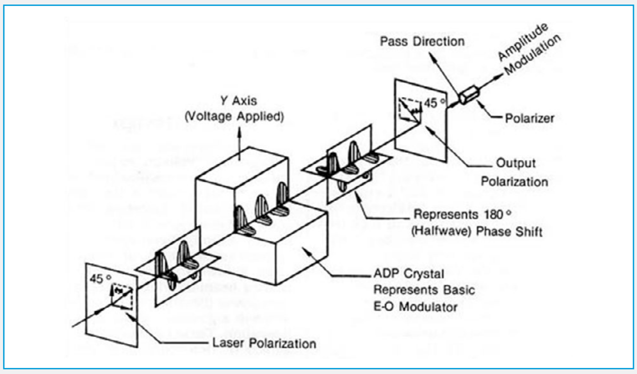


Figure 1. Retardation of laser polarisation while a laser beam passes through an ADP crystal. The output polariser converts the phase shift into an amplitude modulation. (Image courtesy of Conoptics)

consult. design. integrate.

Modulation design

The aperture size and halfwave voltage (the voltage required to change the transmission from minimum to maximum) of the modulator are fixed by laser beam dimensions and realisable levels of driver output. A 3-millimeter aperture will accommodate nearly all commercially available lasers without requiring beam-forming optics. Available power transistors will handle a 100-volt signal in a push-pull configuration. These two requirements generally determine the crystal dimensions.

The 45° Y-cut ADP crystal exhibits double refraction as well as birefringence. The first pair of crystals (Figure 2) are aligned to cancel out the double refraction. The second aligned pair is rotated 90° with respect to the first pair to cancel out the natural birefringence.

The operational stability of the modulator depends upon the four crystals being exactly aligned and of exactly the same dimensions. To insure that these requirements are satisfied, all the crystals used in the modulator are cut from the same crystal boule and are polished together to keep the lengths the same.

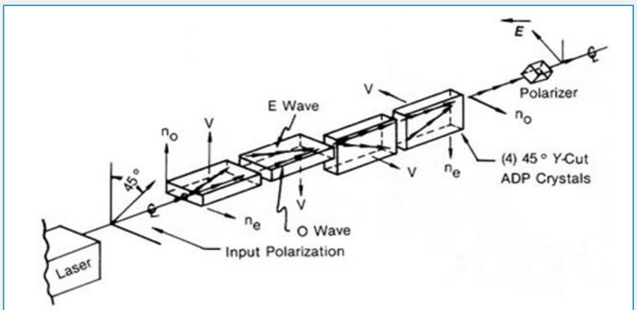


Figure 2. Typical transverse-field elctro-optic moodulator. The first two crystals cancel double refraction and the second pair cancel the natural birefringence. (Image courtesy of Conoptics)

Applications

Electro-optic modulators and modulation systems have been available for many years. They have found use in many applications requiring amplitude or phase modulation of cw or pulsed lasers. They offer speed and optical efficiency without the need for beam-forming optics.

Some of the more common applications include the following:

.

Imaging and Data Recorders - High-speed recording of analog imagery or digital data on photographic film has both military and commercial applications. As the state of the art in laser beam recorders advances, the need for broader modulation bandwidth and higher laser throughputs increases. Electro-optic modulators can deliver this performance without compromising overall beam geometry.

Disk Recorders - Videodisk mastering has been entirely dominated by electro-optic systems. the "mother" disk is typically written with a 7-MHz FM-encoded format by a largeframe argon laser and a 50-MHz electro-optic modulation system. This combination delivers high power density and 7-ns rise and falltimes. The high frequency response of this system allows the resultant recorded pit geometry too be shaped correctly by bandlimiting the input signal.

Digital Recording - The extremely large storage density capability, rapid access time, and archival storage properties of optical media make it attractive over traditional magnetic formats. Real- time single-track data recording of over 100 MHz is attainable with the laser-based system.

Other applications include:

- seismic recording for oil well exploration
- color separation and halftone screen generation for reprographics, and
- recorders for the entertainment industry that convert either real-time television camera or videotape recorder output to 35- or 70-mm film.

This allows electronic "special effects" and editing to be done before the picture is recorded. Electro-optic modulators also lend themselves to many research and development applications such as: polarisation rotators in high-speed ellipsometry, broadband optical feedback loops for plasma noise reduction of argon and dye lasers used in Raman spectroscopy, and high-speed pulse from a modelocked train.

Electro-optic modulation systems offer the system designer very broad modulation bandwidth along with high optical efficiency. No dedicated beam-forming optics are required, and the interface requirements placed on the host system are minimal.

Multi Photon Microscopy (MPM)

Multiphoton fluorescence microscopy is a powerful research tool that combines the advanced optical techniques of laser scanning microscopy with long wavelength multiphoton fluorescence excitation to capture high-resolution, three-dimensional images of specimens tagged with highly specific fluorophores.

Image courtesy of Conoptics

Conoptics has developed a resonance-dampened) KD*P Electro-Optic modulator. When configured with the right amplifier, it offers the ability to control laser intensity as well as high-speed shuttering. In addition, this solution can control beam attenuation and fly-back blanking with minimal dispersion and full modulation over the lasers bandwidth. The system operates center in/out with no spatial dispersion and rise/fall times of 1 micro-second. The solution is also available for UV MPM (down to 350 nm).

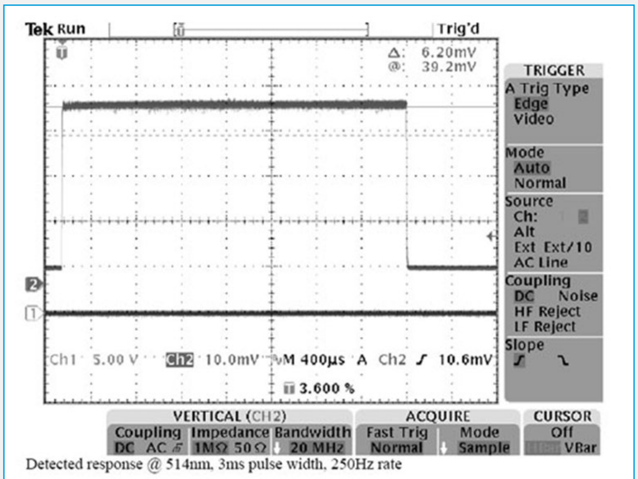


Image courtesy of Conoptics

Electro-Optic Q-Switches

(courtesy of FastPulse)

Electro-Optic devices or Q Switches are commonly used to control a laser cavity through the loss and ‘block’ the cavity where stored energy flares up and “quickly re-opens”, allowing to extract the energy at a maximum level and create short pulses - usually of the nansecond range. It usually requires a large aperture and high damage threshold.

A typical basic laser cavity is shown below:

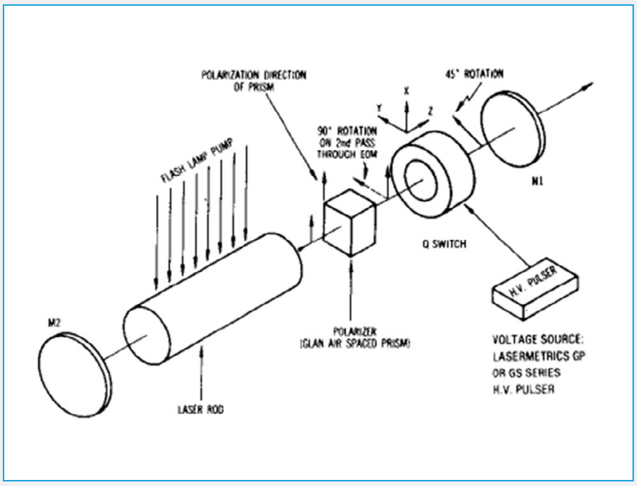


Image courtesy of FastPulse

consult. design. integrate.

Use of Electro-Optics technology as deflectors

(courtesy of Conoptics)

An Electro-Optic device is an efficient mechanism to use when changing the angle of a laser beam with great accuracy. Although the device is not commonly used for this purpose, E-O systems offer control of deflection over a small angle with rapid and extremely precise random access. Unlike acousto-optic deflectors, the intrinsic random access response of an electro-optic deflector is the optical rather than acoustic transit time. In practice, however, E-O Deflectors appear as capacitive loads and the response is driver limited. The precision with which a laser beam can be located, for all intents and purposes, is equivalent to the precision with which a voltage level can be applied to the device.

Since operation is based on an index gradient, variations due to ambient temperature changes are reduced to second order effects. Similarly, unlike acousto-optic deflectors in which the deflection angle is proportional to the optical wavelength, the deflection angle of an electro-optic deflector is a function of the index dispersion and is relatively constant over the wavelength range of operation. Other advantages of an E-O Deflector include the fact that the entire beam is deflected. The transmission efficiency is limited only by the Fresnel reflections, absorption, and scattering losses in the cell and is not a function of the deflection mechanism.

Furthermore, E-O Deflectors are "straight through" devices, that is, the beam is deflected about the un-deflected zero applied signal position. This is in contrast to acousto-optic devices which have a large angular offset to the center of the deflection range and require that RF be maintained on the cell when the beam is in the quiescent position.

The deflection angle **θ** of an E-O Deflector is given by:

$$\theta = K \frac{LV}{a^2}$$

Where K is a constant determined by the electro-optic material used, V is the applied voltage, L is the active length of the device, and a is the laser beam diameter. Translating deflection angle to the number of resolvable spots:

$$N = \frac{\pi}{4} \frac{KL}{\lambda} \frac{V}{a}$$

Where a diffraction limited Gaussian beam of diameter 'a' and wavelength λ is assumed and beam clipping losses are ignored. Since V/a is limited by the internal breakdown voltage (approx.1000v/mm for fluid filled units), once an electro-optic material and operating wavelength have been chosen, the active length is the only parameter remaining to increase the number of resolvable spots. Note that the equation given above is highly idealized and that "V" and "a" deserve considerable consideration because they determine the difficulty of electronics design and crystal fabrication.

Construction of X-Y systems by coupling two deflectors with an intermediate polarisation rotator is also common. Addition of a sensor and feedback loop driver allows the construction of a beam pointing stabilizer.

consult. design. integrate.

Galvanometers

Optical scanners / galvanometers consist of a mirror mounted on an actuator which rotates according to an electrical signal, usually using a magnet to drive the rotation. When a laser light source hit the mirror it is reflected and its direction vary with the mirror angular position, allowing the user to control the laser direction electrically. While the principle of operation is simple, there are a number of challenges in manufacturing reliable high speed, high accuracy devices.

Mechanical design, position detector, electrical design and heat load management are essential to provide both high performance and long lifetime within a compact package at an affordable cost.

Galvanometers can be provided as "single axis" components, packaged within 2D devices (marking heads) or even 3D where a third axis is used to correct the focusing distance of the laser beam: this is becoming more and more popular and is a required capability for marking on large fields and/or curved surfaces.

Applications of galvanometers and marking heads (either 2D or 3D) are covering a wide variety of markets, some of which are listed below:

- laser material processing including: marking, engraving, welding, cutting, drilling, trimming, rapid prototyping, marking on the fly.
- laser display
- laser therapy
- image scanning, and
- R&D

Laser "beam dump" shutters

(courtesy of NM Laser Products)

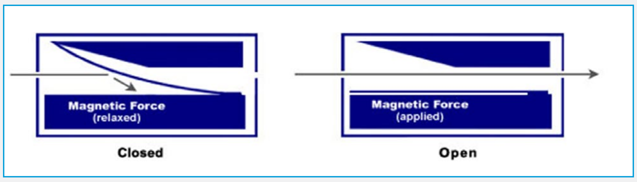
While there are many mechanical shutters on the market that can be used for "on/off" modulation purposes, NMLP patented electro-mechanical laser shutters provide features not found in other types of mechanical shutters, combining unique modulation features with a true laser safety tool from low to high irradiance laser sources.

Shutter Basics

Laser shutters pass the laser beam undisturbed in the open position, and dump laser energy safely into the shutter body when in the closed position. This requires well designed thermal properties of the moving optical element as well as the stationary absorbing element. By using a lightweight, reflective optical element to steer the energy to a stationary absorber, little heat is generated in the moving reflector. This allows higher optical power handling and faster switching speeds. The use of a stationary absorber allows a solid heat conduction path to the shutter mounting plane.

The heart of our NMLP (patented) shutter technology is a cantilever flexure beam that is magnetic, has good thermal conductivity, provides excellent spring properties, and is optically coated. This optical beam is magnetically pulled to the open position by a closely coupled cylindrical toroid electromagnet with pole curvature that matches the catenary curve of the flexure beam. This provides high pulling forces and resultant rapid switching speeds.

With loss of electrical power, the stored mechanical energy in the flexed beam returns it to the closed position, yielding failsafe closure safety.



Basic Principle - Image courtesy of NM Laser Products

We offer two families of shutters:

Modulation/Exposure/Gating - series provide fast switching speeds and high repetition rates, with higher electrical power dissipation use.

Safety Interlock and Process - series are designed for moderate switching speed applications, at low repetition rates, typically in safety interlocking or industrial processing. Optically, the two shutter families are very similar; power handling and damage threshold ratings vary a little. The key differences being flexure beam stiffness and electromagnet power.

consult. design. integrate.

Mechanical choppers

(courtesy of Stanford Research Systems)

Mechanical choppers can handle most of your optical chopping requirements, either laser based or not — from simple measurements to dual-beam and inter-modulation experiments.

Standard configuration is based on two anodized aluminum blades: a 5/6 slot blade for frequencies up to 400 Hz, and a 25/30 slot blade for frequencies up to 3.7 kHz. It is usually used in combination with a Lock In Amplifier for detection of the signal.

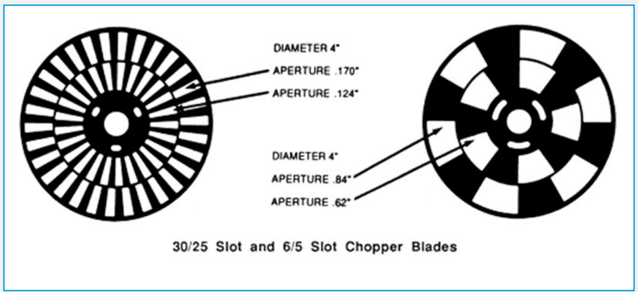


Image courtesy of Stanford Research Systems

Typical single-Beam Experiment

In this application, a single optical beam is chopped by the outer row of slots, and the reference output from the right BNC is used to lock the lock-in amplifier to the chop frequency. The inner row of slots could also be used, in which case the left BNC would be the reference output. In either case, the REFERENCE MODE switch is in the "up" position.

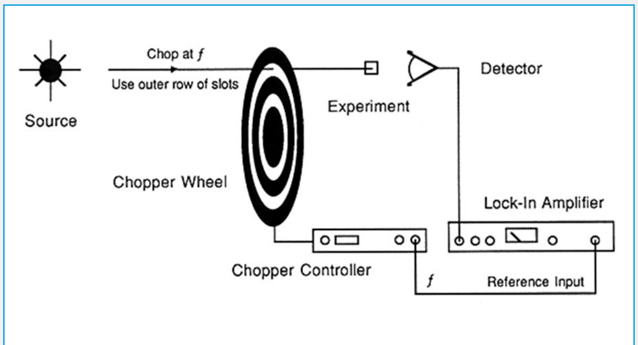


Image courtesy of Stanford Research Systems

Typical Dual-Beam Experiment

In this arrangement, the output from a single source is split and chopped at two different frequencies by the two rows of chopper slots. One beam passes through the experiment while the other is used as a reference beam. The beams are recombined and sent to the same detector. Two lock-ins are used to detect the signals at $f$inner, corresponding to the experimental signal, and $f$outer, corresponding to the reference beam. If the detected signal in the experimental arm is ratio to the detected signal in the control arm, then effects due to changing source intensity and detector efficiency are removed.

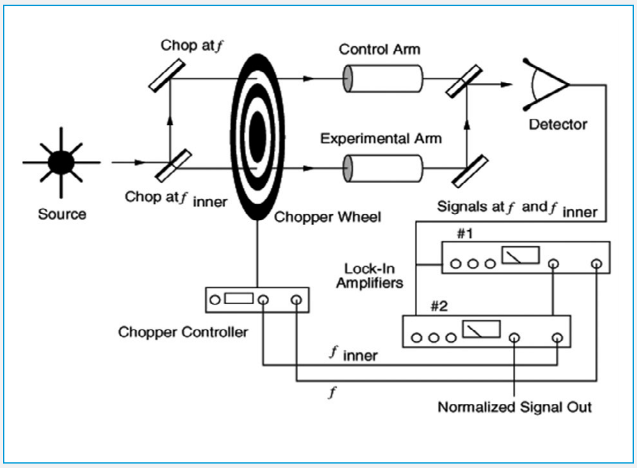


Image courtesy of Stanford Research Systems

consult. design. integrate.

Photoelastic modulators

(courtesy of Hinds Instruments)

For over 40 years, PhotoElastic Modulators (PEMs) have been the foundation of measurement solutions in applications ranging from astronomy to magneto-optics to glass and crystal characterisation. The following lists include applications where PEM components and systems are widely used to solve complex and demanding optical polarisation measurement challenges:

Polarisation Measurement - Astronomical Polarisation, Birefringence, Dichroism, Diattenuation, Ellipsometry, Extinction Ratio, Faraday Rotation, Fluorescence, Optical Chopping, Kerr Constant, Magneto Optic Kerr Effect, and PM IRRAS, Polarisation Extinction Ratio, Polarisation Scrambling, Reflection Difference / Anisotropy Spectroscopy, Rheology, Scattering Media, Stress Measurement

Polarimetry (Mueller Polarimetry, Stokes Polarimetry, Optical Rotation, State of Polarisation, Degree of Polarisation)

Optical Lithography (DUV Birefringence)

Lens Measurement (Discrete Optic Curved Surfaces)

Thin Films (Birefringence Measurement, MOKE, PM-IRRAS)

Fiber / Laser Crystals / Optical Metrology (Extinction Ratio, Polarisation Extinction Ratio, S. Polarimetry, Waveplate Measurement, SOP / DOP)

Hinds Exicor Mueller Polarimeter using PEM technology

Example of Mueller Polarimetry

The Mueller polarimeter is one of the two major types of polarimeters used in measuring polarisation properties. While the Stokes polarimeter is usually referred to as a light-measuring instrument, the Mueller polarimeter can be viewed as a sample-measuring instrument.

In a light polarisation model, a sample can be represented by a 4x4 Mueller matrix. When all 16 elements of the Mueller matrix of a sample are determined, the polarimeter can be called a general Mueller polarimeter or a complete Mueller polarimeter. Otherwise, if all 16 elements are not addressed, it is called an incomplete Mueller polarimeter.

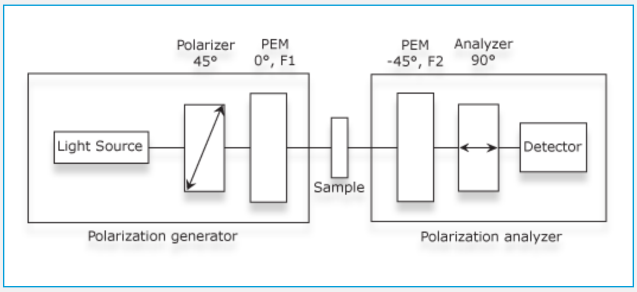


Image courtesy of Hinds Instruments

consult. design. integrate.