PHOTOELASTIC MODULATORS

LIGHT INTENSITY MODULATION USING A PEM

APPLICATION NOTE

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The photoelastic modulator (PEM) modulates light polarization.[1-3] The operating principle of a PEM manifests the photoelastic effect, in which a mechanically stressed sample exhibits optical birefringence.

The PEM functions as a resonant device.[1-3] Being driven at its fundamental vibrational frequency, the optical element of a PEM generates a modulation of birefringence. When the linearly polarized incident light passes through this optical element, the two orthogonal components of the incident light, one parallel and the other perpendicular to the PEM optical axis, experience a modulation of phase retardation. Therefore, the outcome beam is modulated between two different polarization states.

The phase retardation can be controlled by the PEM electronics, which determines the polarization states of modulation. Using a PEM, polarization can be modulated between right and left circularly polarized light ($\pi/2$ or a quarter-wave retardation), two orthogonal linearly polarized light (π or a half-wave retardation) or right and left elliptically polarized light (all other degrees of retardation).

When a PEM is used between two crossed polarizers, it can modulate the intensity of a light beam,[4] which is normally referred to as "chopping."

"Chopping" has long been used with electro-optical systems to enhance the signal-to-noise ration (S/N) of the detected signal. When used with lock-in amplifiers or synchronous devices, detection system with very narrow electronic bandwidths result.

There are numerous ways to modulate the intensity of a light beam. On the order of 100 Hz, a mechanical chopper may provide the simplest method for intensity modulation. For high frequencies on the orders of MHz and GHz, different types of electro-optic and acousto-optic modulators are available. The photoelastic modulator, with its wide wavelength range (UV to mid-IR), large acceptance angle and large aperture, offers the scientific and industry community and instrument for intensity modulation in the range of 20-200 kHz.

Two basic techniques for using a PEM as a light chopper are described below:

Method 1

As shown in Figure 1, this set-up consists of two polarizers that are oriented at +45° and -45° from the PEM optical axis, respectively. (Hinds PEM series I and II have their optical axes parallel and 45° from the horizontal directions, respectively.) In the optical bench, when the PEM optical element is at its neutral position (i.e. neither compressed or stretched), only a minimum amount of light (its amplitude depends on the quality of the two polarizers) will pass through the two crossed polarizers and will reach the detector. When the PEM optical element is compressed or stretched sufficiently that the retardation is +/-π, the light polarization after passing the PEM will be parallel to the second polarizer, and thus light reaching the detector will be at its maximum intensity. In this manner, light intensity modulation is obtained.

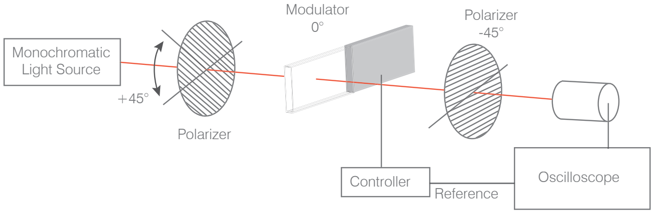

Figure 1: Optical set-up I for Light Intensity Modulation

This intensity modulation can also be analyzed theoretically. For the sake of simplicity, let us assume that the polarizers have an ideal extinction ratio and all optics used in the bench have perfect transmission. If the incident light has an initial intensity of I_0, the light intensity, I, at the detector will be:

$$
\begin{aligned}
I &= (I_0/2)\,[1 - \cos \delta_M\,] \\
&= (I_0/2)\,[1 - \cos (\delta_M^0 \sin (\omega_M t))\,] \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn. 1}
\end{aligned}
$$

where δ_M and δ_M^0 are the retardation and the maximum value of the retardation during the modulation, respectively; ω_M is the PEM fundamental frequency and t, the time.

Using Eqn. 1, the intensity modulation curves at different PEM maximum retardation can be calculated. Figure 2 shows the waveforms obtained at δ_M^0 being π ($\lambda/2$ or half-wave) and $\pi/2$ ($\lambda/4$ or quarter-wave), respectively.

In this figure, I/I_0 and the numbers of PEM modulation cycles are used for the Y-axis and X-axis, respectively.

The following features should be noted:

1) with perfect polarizers, the light intensity is completely cut off at the minimum points;
2) light intensity modulation is at twice the PEM frequency, or 2f;
3) the duty cycle of the function is not 50% for half-wave retardation, that is the light is on more than it is off. A 50%-50% duty cycle and sinusoidal modulation function can be obtained by use of a quarter-wave retardation. The drawback is that the maximum intensity has been reduced by a factor of 2.

By controlling the PEM driving voltage, desired values of δ_M^0 and thus certain modulation waveform can be obtained.

The modulation discussed above can also be obtained by setting the second polarizer parallel to the first one which only shifts the modulation curves as shown in Figure 2 by quarter a cycle.

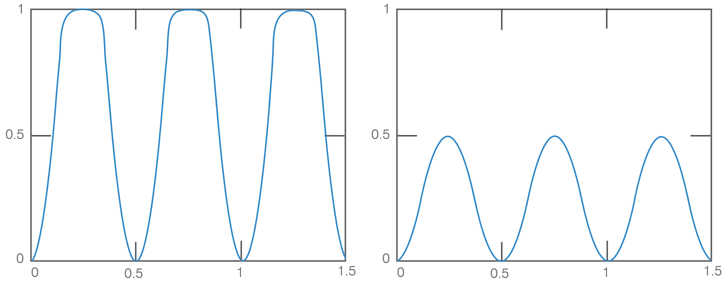

Figure 2: Waveforms at PEM retardation of half-wave and quarter-wave

Method 2

The set-up for the second method of "chopping" employs an extra quarter-wave plate that is placed between the PEM and the second polarizer with its optical axis parallel to the PEM optical axis. Figure 3 shows the central part of this optical bench.

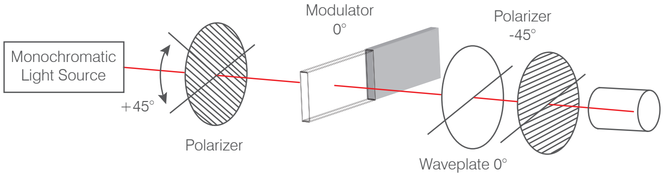

Figure 3: Optical set-up II for Light Intensity Modulation

In this set-up, the mathematical description for the light intensity at the detector becomes:

$$
\begin{aligned}
I &= (I_0/2)\,[1 - \cos (\delta_B + \delta_M\,)\,] \\
&= (I_0/2)\,[1 - \cos (\delta_B + \delta_M^0 \sin (\omega_M t))\,] \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eqn.2}
\end{aligned}
$$

where $\delta_B = \lambda/4$ is the static retardation of the wave-plate, and all other variables are the same as in Eqn. 1.The modulation curve obtained using Eqn. 2 for $\delta_M^4 = \pi/2$ is shown in figure 4.

As we can see, using an extra quarter-wave plate, this optical set-up results the 1f (the PEM frequency) intensity modulation, a 50-50% duty cycle and a 100%

ideal maximum light intensity. For many "chopping" experiments, this may be the optimal set-up.

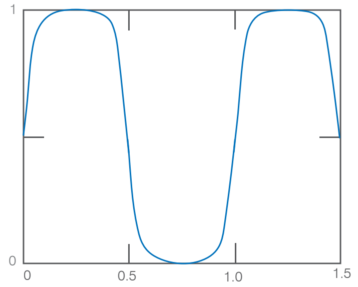

Figure 4: waveforms obtained at $\delta_M^0 = \pi/2$ (quarter-wave retardation)

By controlling the PEM peak-to-peak retardation around $\delta_M^0 = \pi/2$, similar modulation patterns to that in Figure 4, can be obtained (Figure 5).

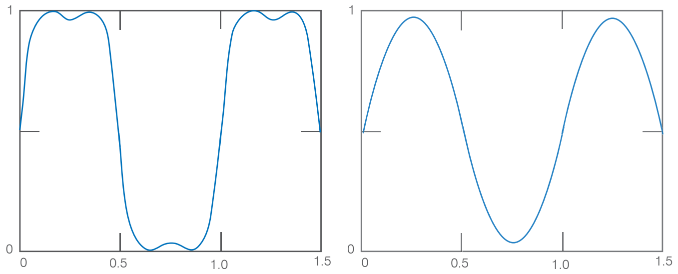

Figure 5. Waveforms obtained at $\delta_M^0 = 5\pi/8$ (left) and $3\pi/8$ (right)

However, at half-wave peak retardation, this optical bench produces a wave-form shown in Figure 6, which may not be desirable for normal "chopping" purpose.

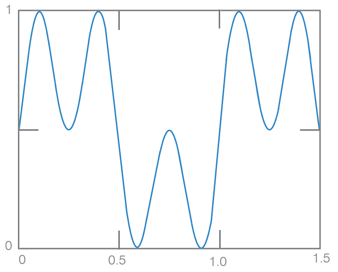

Figure 6. Waveforms obtained at $\delta_M^0 = \pi$

Summary

The standard PEMs available at Hinds Instruments have a resonant frequency in the range of 20-100 kHz. These PEMs offer intensity modulation in the unique region from 20 kHz to 200 kHz. The PEM is designed as a resonance device for modulation purpose at a fixed frequency. Different PEMs may have different working frequencies, but none of them is tunable. In exchange for the fixed frequency characteristic, PEMs afford unique features of high transmission, large aperture, wide acceptance angle, availability over wide wavelength range (UV to mid-IR), high sensitivity (10^{-6}) and high efficiency of modulation.[5]

Finally, Hinds PEMs are specifically designed to generate light polarization or intensity modulation. They are not static wave-plates or isolators.

References

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3. Hinds Instruments, Inc., PEM-90 Photoelastic Modulators.
4. T. Oakberg, PEM-90 Application Note—Calibration.
5. Hinds Instruments, Inc., PEM-90 technical note—Unique Features of Hinds PEM.