Texas Instruments Phase Light Modulator for Holography

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Abstract: The Texas Instruments Phase Light Modulator (TI PLM) is a new type of MEMS that modulates the phase of the incoming light by moving micro-mirrors up and down. We characterized this device for beam steering and for the projection of holographic images. © 2021 The Author(s)

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1. Phase Light Modulator

Liquid crystal on silicon (LCoS) spatial light modulators (SLM) technology has dominated the market and research fields for optical phase array beam steering and for generating holographic images. To their advantage, LCoS have to capability of large phase modulation (few μm of optical path difference), small pixel size (10μm), and a refreshing speed high enough for display applications (few hundreds hertz). However, when a smaller pixel size is needed, fringe field starts to be problematic with that technology; and the photoelasticity of the molecules prevents higher refreshing speed that would be useful for temporal multiplexing. [1]

Micro-electro mechanical system (MEMS) on the other hand are a promising alternative to LCoS technology since the pixel size can be reduced to only a few μm, enlarging the diffraction angle, and the refreshing speed can be up to hundreds of kHz, which increases the spatial bandwidth product. [2] One such a device is the well known Texas Instruments Digital Light Processor (DLP) that was initially manufactured for image display but has been used in holography and phase modulation applications. [3, 4] The problem that the DLP was facing is that its mode of action, which is tilting the micro-mirror in one direction or another, only allows to display binary amplitude holograms that have a maximum diffraction efficiency of 10%, even though its overall reflectivity is in the 90%. [5] To reach much higher efficiency, a multilevel phase diffraction pattern is needed. That is exactly what the new TI PLM is offering.

Instead of titling the micro mirrors, the TI PLM is moving the micro-mirrors up and down in a piston motion to modulate the optical path length and so the phase. By adjusting the voltage on the electrode, the PLM offers 16 levels, and a maximum of 2π phase shift at 532 nm. [6]

2. Characterization

We measured the diffraction efficiency of the TI PLM using blazed grating structures at different wavelength and angle of incidence. The efficiency (η) of such a structure given a number $N$of phase level is given by the following analytical expression:

$$\eta_{+1} = \mathrm{sinc}^2\left(\frac{1}{N}\right) \qquad (1)$$

Which for 16 levels give a first order efficiency of 98.7%.

Unfortunately, the phase levels of the TI DLP are not perfectly equidistant, and have been measured using an interferometric setup to be as presented in figure 2(b). Because of this non-linearity ($R^2 = 0.93$), the efficiency is reduced to 70%. However, we realized that it is possible to achieve a better linearity ($R^2 = 0.99$) by skipping some levels and duplicating some other as presented in figure 2(c).

Figure 2(a) presents the calculated and the measured efficiency of the different blazed structures from figure 2 according to the number of phase levels. It can be seen that the nonlinearity of the TI PLM phase levels is penalizing its efficiency by a 30% drop compared to the ideal case. However, it is possible to recover half of that loss by linearizing the levels as proposed in figure 2(c), and achieve an efficiceny of 85%.

The interpolation lines are numerical simulations using Rigorous Coupled Wave Analysis (RCWA) from the DiffractMOD package in Rsoft by Synopsys. They are in very good agreement with the measurements.

We also measured an calculated the effect of the wavelength as well as the angle of incidence on the blazed structure. Figure 2(b) shows that by reducing the wavelength from 532 nm to 450 nm, the maximum efficiency is

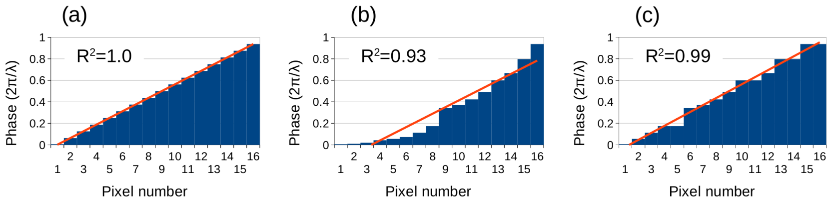

Fig. 1. Blaze profile for: a linear ideal case, (b) measured TI PLM, (c) corrected TI PLM. Lines are linear interpolations.

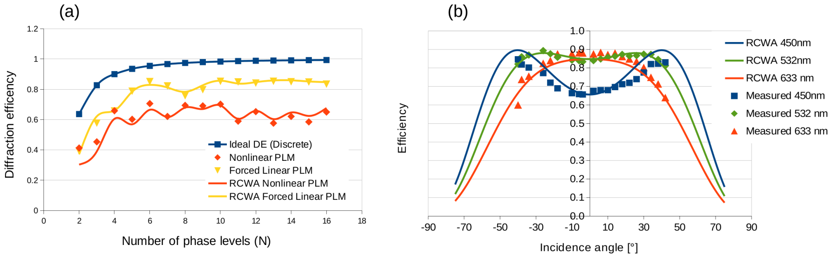

Fig. 2. Diffraction efficiency of Blaze gratings according to the number of levels and their non-linearity.

achieved by increasing the incidence angle to 45°. On the other hand, when illuminated at 633 nm, the maximum efficiency is only reached at 0°. These values have been obtained with the linearized phase levels ($R^2 = 0.99$). Nevertheless, the same trends, although with reduced amplitude, are observed for the non-linear phase levels ($R^2 = 0.93$). Once again, the RCWA simulations are in very good agreement with the measurement.

The diffraction efficiency numbers presented in figure 2 have been measured and calculated respective to the zero order reflection (i.e.: the reflection with all micro-mirrors at the same level). To obtain the total efficiency respective to the incident beam power, some additional losses should be added. These losses are coming from the fresnel reflection from the cover window that is anti-reflection coated with a transmission of 95%, the reflectivity of the micro-mirror aluminum coating (90%), the pixel array fill factor (94%), the diffraction from the micro-mirror edges, and finally the scattering due to the non-perfect planeity of the micro-mirror surface. This total additional loss was measured for this particular DLP unit to be 37%. However, it should be kept in mind that this number can easily be reduced by coating the faces of the front window with better anti-reflection coating, and use a higher reflective coating on the top of the micro-mirrors.

In addition, we used the TI PLM to display holographic images generated with different algorithms, and we will also present these results during the conference.

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