Modelling an Acousto-Optic Beam Shaping Device for a DIRCM Laser Laboratory Setup

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***Abstract*—Directed Infrared Counter Measure (DIRCM) laser laboratory setups are used to mimic the real life DIRCM system and IR heat-seeking missile engagement scenarios in isolated laboratory environments. Typically, the output beam of a mid-infrared (Mid-IR) laser source is modulated in time using an acousto-optic (AO) modulator (AOM). Following the AOM in the optical path, within a distance of few meters, the laser beam is expanded and collimated, using traditional methods to have almost a uniform intensity profile at the target aperture [1, 2]. The whole process results in the simulation of the engagement of a countermeasure laser with an IR heat-seeking missile on an optical table. AO devices, besides their common usage of modulation, can also be used to transform a given laser beam profile into various other beam profiles [3]. By applying an RF signal consisting of multiple frequency components to an AO device, diffraction occurs into multiple orders. By this way, various beam profiles can be obtained along the optical path. In this study, we analyze the usage of an AO device in order to have an expanded beam profile with a uniform intensity distribution at few meters away from the laser source that is enough to cover an IR seeker's aperture. With the use of an AO device for beam shaping, we aim to alleviate the need of costly and complex optical setups. The analysis is made in two dimensions using a numerical simulation software, which employs the finite element method with appropriate boundary conditions.**

Keywords—DIRCM laser, acousto-optic devices, beam shaping.

I. Introduction

Directed Infrared Counter Measure (DIRCM) systems are utilized on air and other platforms for countermeasuring infrared (IR) heat-seeking missiles. DIRCM laser laboratory setups are used to mimic the DIRCM system and IR seeker engagement scenarios in isolated laboratory environments [1, 2]. Typically, in these setups, the output beam of a high-power mid-infrared (Mid-IR) laser source is modulated in time using an acousto-optic modulator (AOM), which usually does not change the initial Gaussian-like intensity beam profile. Following the AOM in the optical path, a blackbody radiator is used for creating the target platform signature and it is combined with the laser beam using various optical components. Within a distance of few meters, the beam is expanded and collimated creating an almost uniform intensity profile over the IR seeker's whole aperture. This entire process results in the simulation of the engagement of a countermeasure laser with an IR seeker on an optical table. In order to expand and collimate the output laser beam, large aperture parabolic mirrors, aspheric or diffractive optical systems are conventionally employed.

AO devices, together with their common usage of modulation in time, can also be used to transform a given laser beam profile into various other beam profiles along the optical path [3]. Normally, a single frequency RF signal exciting the AO medium creates a sinusoidal grating causing the first order diffraction of the laser beam. However, when the RF signal consists of multiple frequency components, the diffraction occurs into multiple orders and various beam profiles can be obtained along the optical path. In this study, while creating an AO device model, we analyze the utilization of an AO device for creating a beam profile of uniform intensity distribution at few meters away from the laser source. With the use of an AO device for beam shaping, we aim to alleviate the need of costly and complex optical setups.

II. AO Interaction & Simulations

AO devices make use of the AO interaction, which is based on the photo-elastic effect where the refractive index changes due to acoustic oscillations. AO devices are used for purposes of modulation, deflection, Q-switching, frequency shifting, tunable filtering of light and more [4]. A sample AO device consists of an RF signal source, piezo-electric transducer and AO crystal where the interaction happens. The simulation results given in Fig. 2 presents the refractive index change in two dimensions with an AO interaction region of 4x12mm and a piezoelectric crystal length of 10 mm.

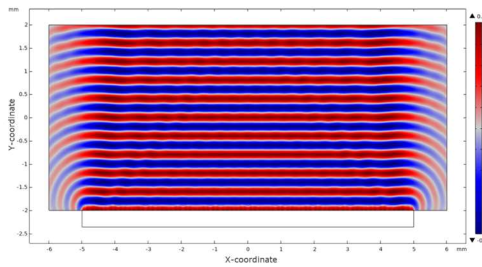

Fig. 2. Formed sinusoidal-like gratings by the piezo-electric interaction

The obtained results from the model assumes interaction of the piezoelectric $LiNbO_3$ crystal with an AO TeO_2 crystal. The interaction creates the sinusiodal-like gratings due to the RF excitation. With this type of grating one can diffract the laser beam into a direction different than propagation direction while usually preserving the initial beam profile. Fig. 3 shows the results that we generated from our 2D AO device model showing the interaction in two dimensions. As it is observed, the light is diffracted at a particular angle which is called the "Bragg angle" [4].

III. AO Beam Shaping Studies

When acoustic waves consisting of multiple frequency components diffracts a laser beam, multiple diffracted beams are generated, and a number of nonlinear effects occur [5]. This phenomenon leads to cross modulation and generates intermodulation beams. In fact, the outcome of multiple frequency diffraction paves the way for shaping the beam profile by the combination of these diffracted beams. Hence, by manipulating the amplitude and phase of each frequency component in an RF signal, one can control the resultant shape of the diffracted beam at a certain place in the optical path. Fig. 4 shows the intensity distribution at the cross-section of the transversal exit plane for two sample outputs. In these results, the RF signal forming the gratings has 3 and 9 frequency components where each component is 2MHz apart from each other and centered around the 40MHz.

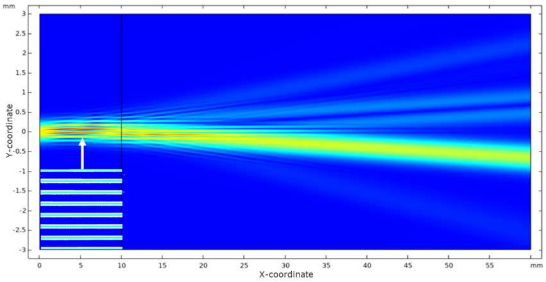

Fig. 3. Result of the AO device model

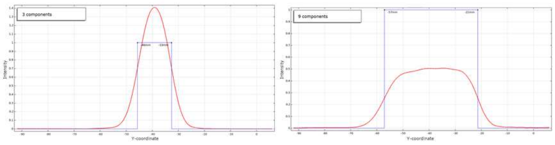

Fig. 4. Intensity distribution at the transversal cross-section of the exit plane for cases of RF signal consisting of 3 (left) and 9 (right) components

The results demonstrate that as the number of frequency component increases the beam tends to get uniform due to increasing number of diffracted orders at different locations along the propagation direction. Another deduction is that the real factor determining the beam shape is dependent on the frequency bandwidth of the signal, and with increasing number of frequency components, the beam can be shaped more easily.

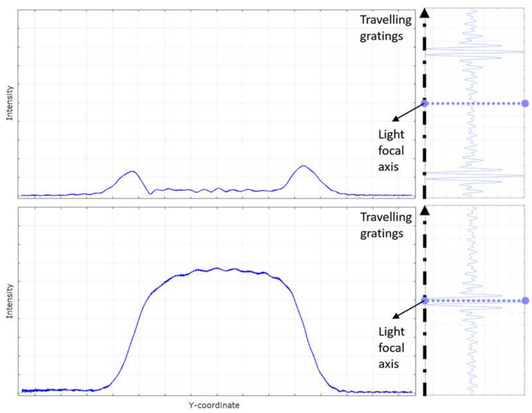

Fig. 5. Travelling gratings' effect to the beam shape for two different cases

There are few challenges for keeping the beam profile uniform at the seeker aperture. Firstly, having multiple frequency components results in non-periodic grating structure and since this gratings are travelling, the beam shape changes dynamically in time. Fig. 5 shows a sample result where the effect of travelling gratings can be seen. So as the multiple diffraction to be valid, the grating's effective region must be kept at the light's focal axis. For pulsed lasers, this can be achieved by synchronizing the rising edge of pulses with the RF excitation [6]. Another point to mention is that the change in beam shape due to travelling of gratings repeats atmost in few microseconds. Therefore, in some cases it is not necessary to keep the effective grating region at light focal axis. For instance, in DIRCM laser laboratory setups where the IR seekers working frequency is at most few kHz and seeker would perceive the beam as intended. Another challenge we observed is that since the shaped beam consists of many diffracted beams, each of which having vectors pointing at consecutive different directions, beam moving forward along the optical path results in beams getting split from each other. This splitting due to the beam moving forward results in the beamshape to break down. In order to preserve the shape one should collimate the beam using optics. Fig. 6 given below presents a sample output using a plano-convex lens which results in collimation of the beam for further use. For this example RF signal excitation was phase and amplitude optimized for each frequency component.

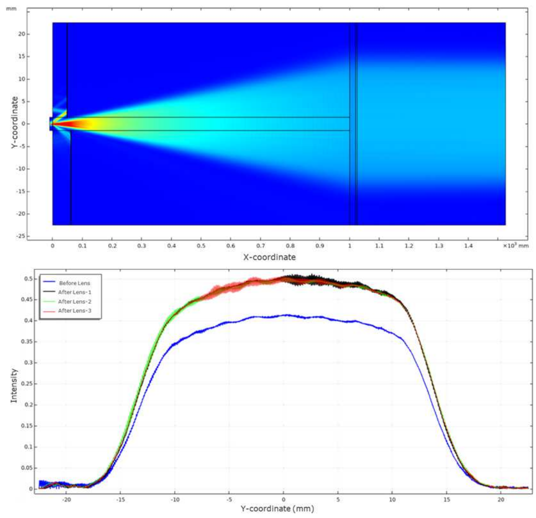

Fig. 6. Example of collimation and beam shaping (above), intensity distribution before lens, and at three planes after lens (below)

IV. CONCLUSION

DIRCM laser laboratory setups are used for imitation of the real-life engagement of DIRCM system and IR seeker engagement scenarios in isolated laboratory environments. These laboratory setups which use traditional beam shaping methods usually employ bulk optics such as off-axis parabolic mirrors, aspheric or diffractive optics. The utilization of AO devices for having uniform intensity distributions with expanded beam width at a few meters away from the exit aperture of the laser - while preserving modulation capability of the device - shows to be promising according to our modelling results presented in this paper.

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