UNIVERSITY OF ROCHESTER

Design Description Document

3D Atomic Vapor Display

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Customer: Curtis Broadbent
Engineers: Amy Entin, Alexander Rainville, Yucheng Wang, Lindsey Willstatter
Advisor committee: Curtis Broadbent

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E

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04/26/16

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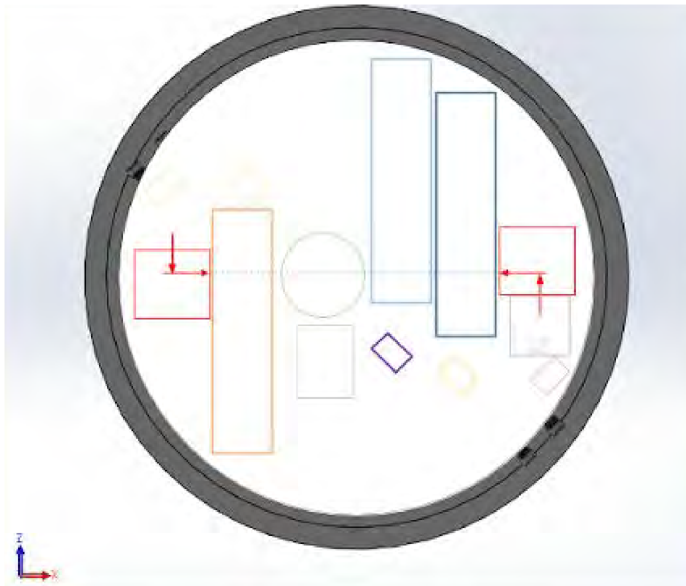
Authentication Block

Contents

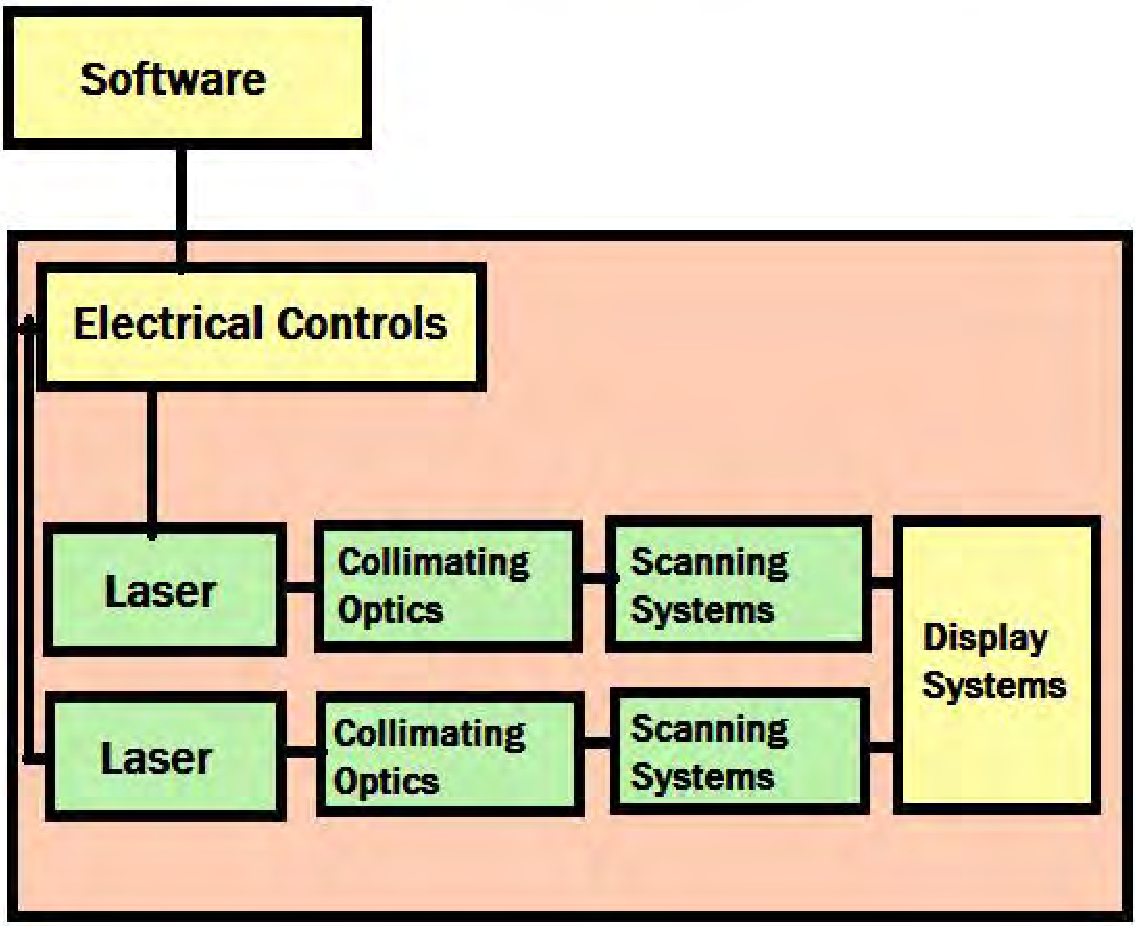
Project summary:

The system consists of a device to scan two laser beams to an intersection in a sphere. Each scanner system consists of a laser, collimation optics, two beam steering mirrors, 2-D galvo scanners and final mirrors. In addition, one of these scanners is joined by a second laser, and the system is illuminated from below using a fourth laser and a convex mirror. The system must fit on a 18” circular base.

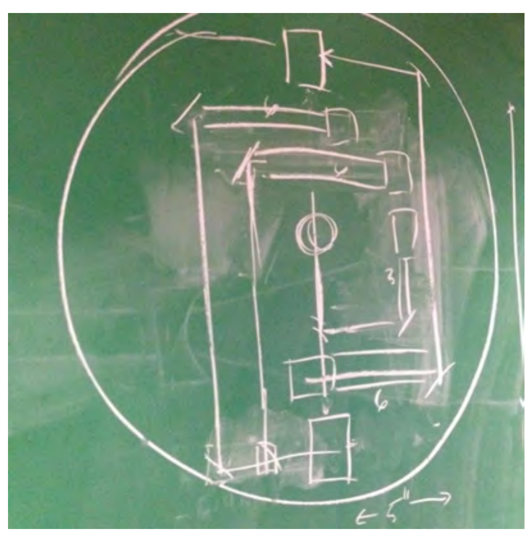


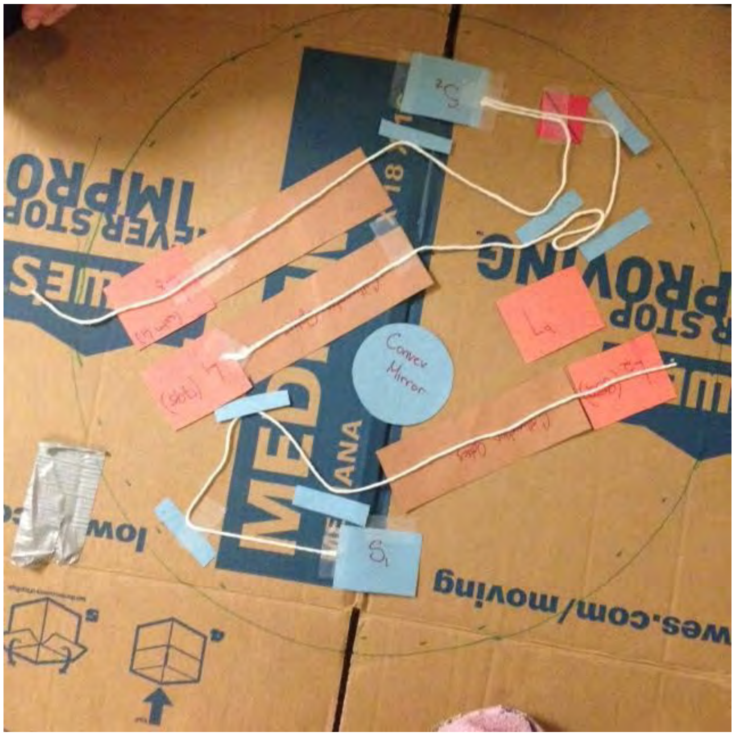
System Block Diagram

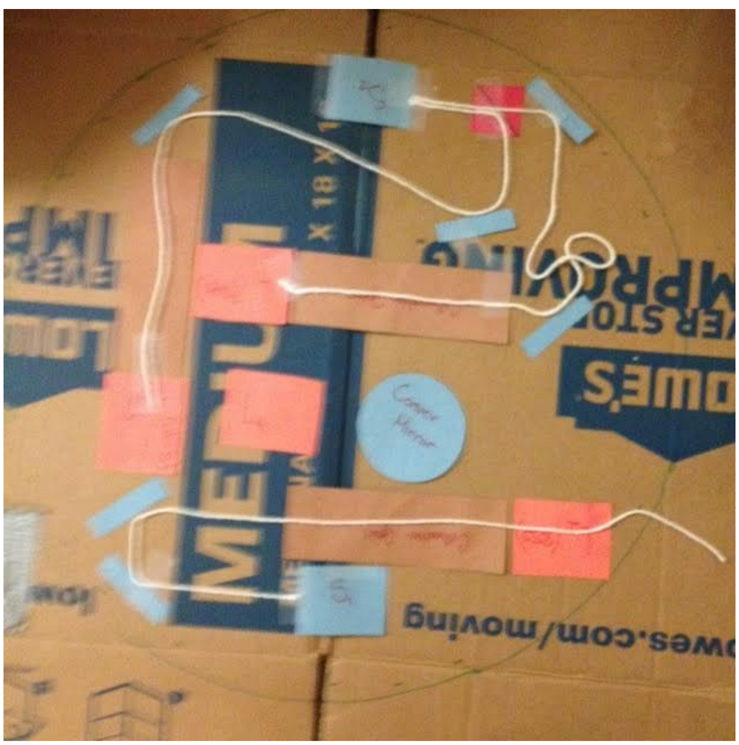
1. Two laser systems, as ordered by the customer.
2. Collimating optics.
3. 2D Galvo scanners for steering beams, with holders.
4. Display system, as ordered by customer, includes the sphere with cesium gas.

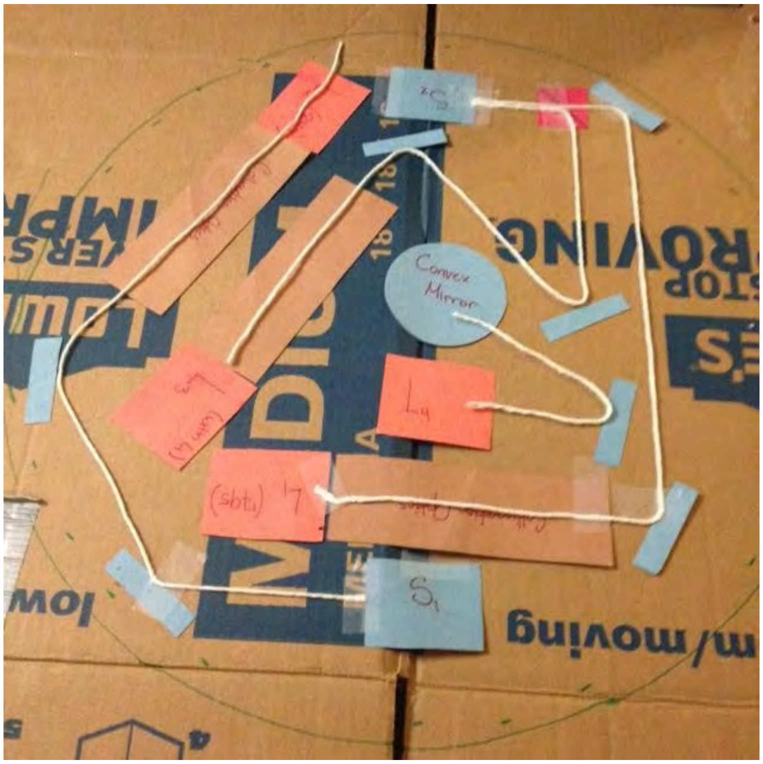


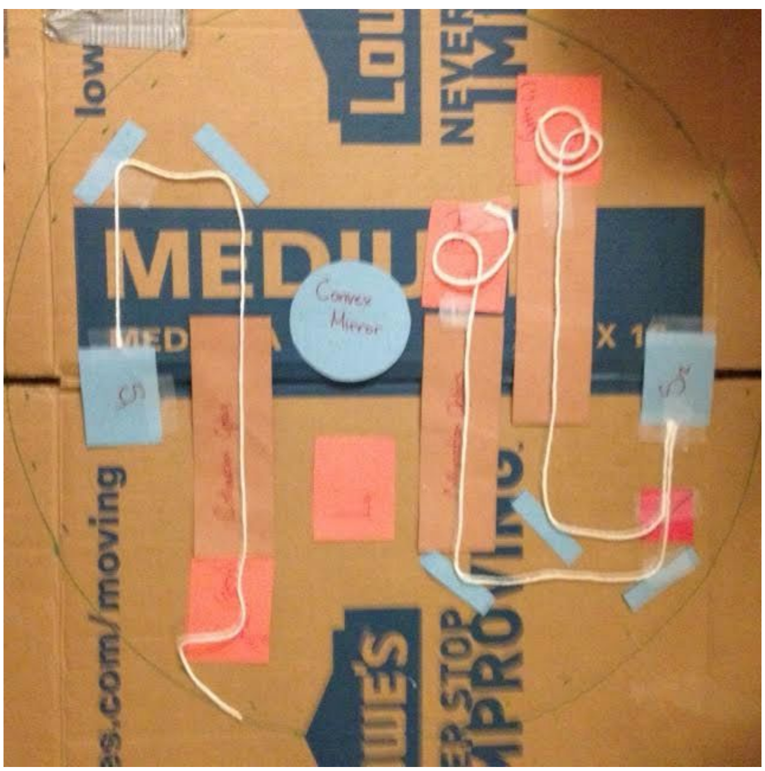
Base Layout Preliminary Designs



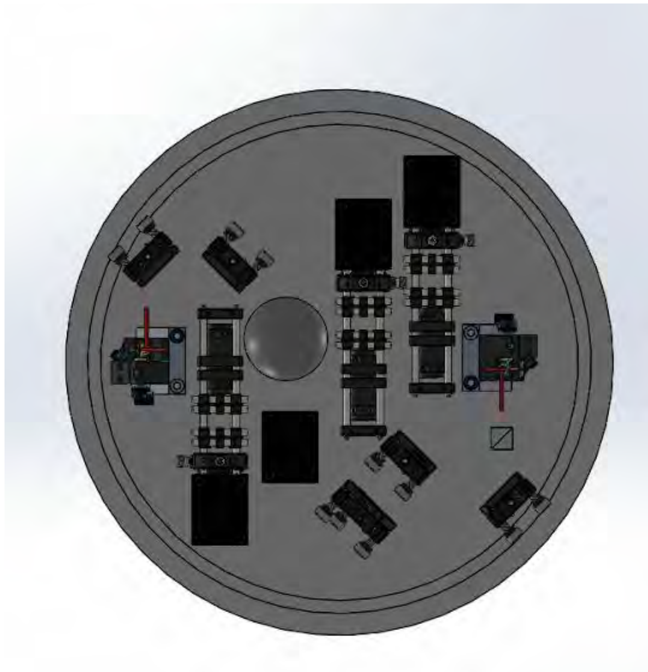

Convex Mirror

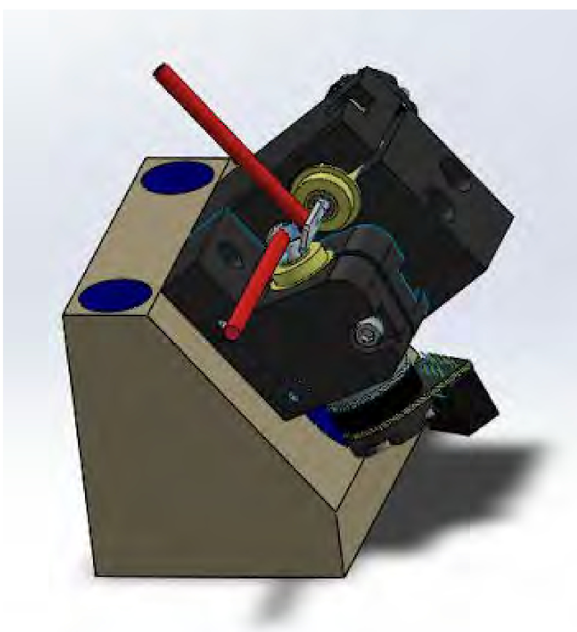

Convex Mirror

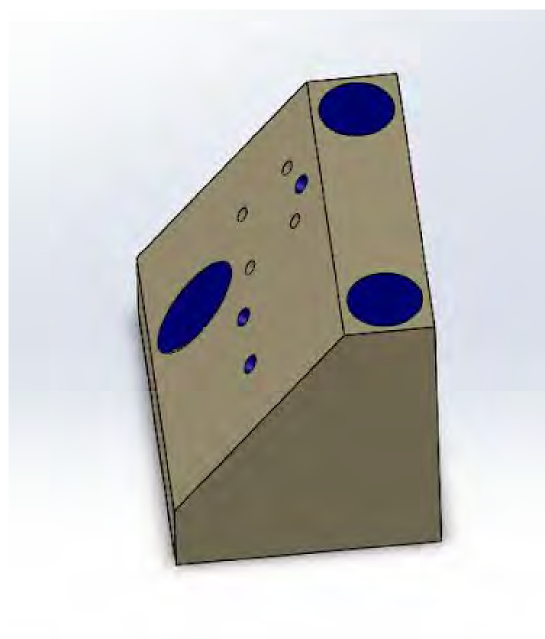

Convex Mirror
S1
L4

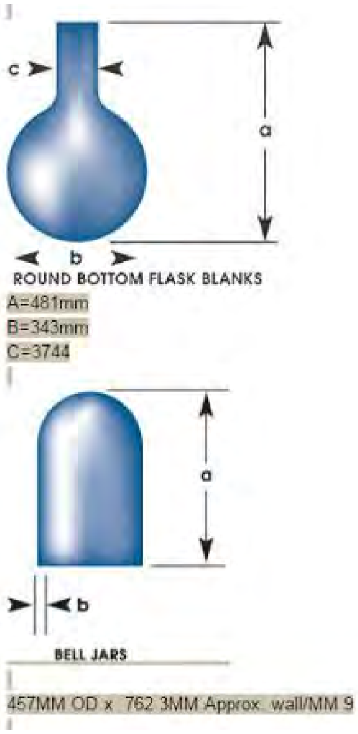

Convex Mirror

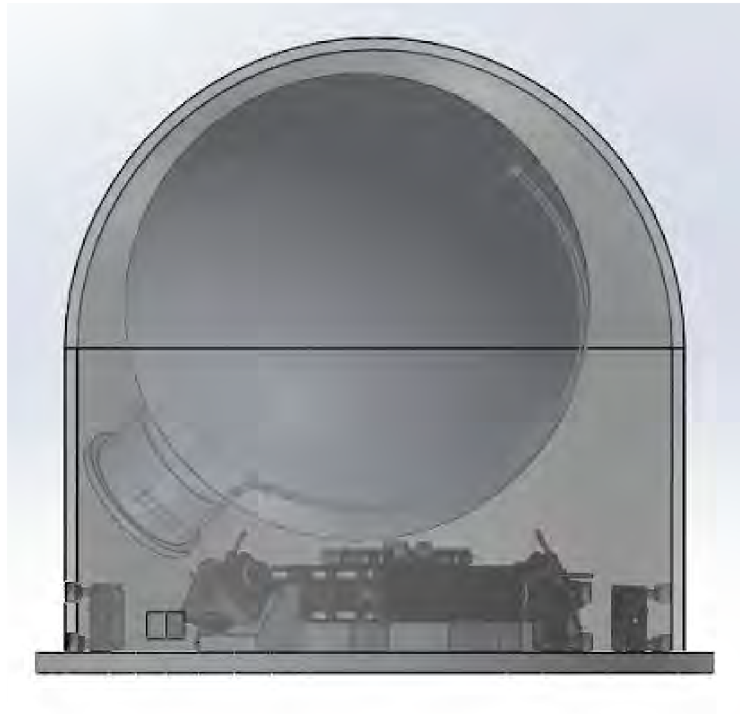
3D Drawings





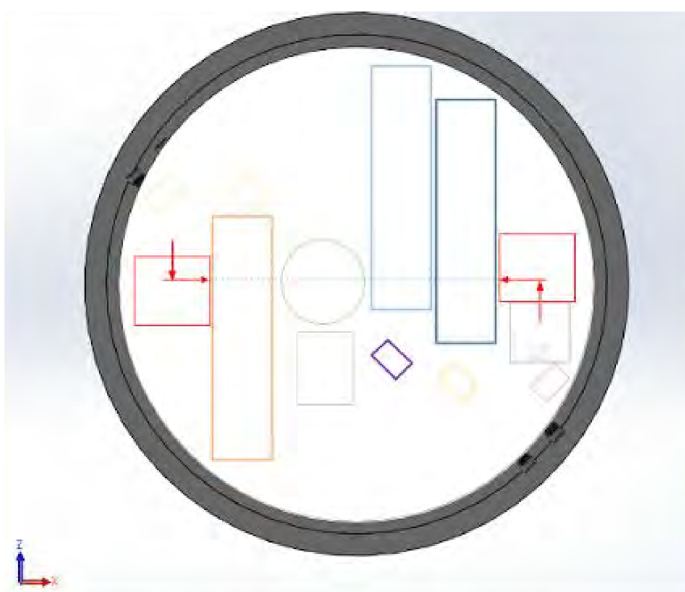






Optical Design

Overview: The system consists of a device to scan two laser beams to an intersection in a sphere. One of these beams consists of an overlap of two separate lasers of different wavelengths. All three of the laser beams required for this must have two-mirror alignment. The sphere must also be illuminated from underneath with a fourth laser.



Lens System

The laser system needs to take a highly divergent laser diode output, keep the beam diameter small enough to pass through mirrors and isolators, and then partially focus the beam into the gas sphere. Inside the sphere the beam radius should be 300-500µm and at the edge of the sphere the beam radius should be 600-1000µm (twice the center radius). This corresponds to a beam divergence of < 0.17^{o}.

As an estimate, we set the rayleigh range ($Z_R = \frac{\pi\omega_0^2}{\lambda}$) to be the radius of the sphere. Calculating this through we find that a 200µm beam waist gives a rayleigh range of the sphere radius; a beam waist any larger than this provides a rayleigh range larger than the radius of the sphere, which satisfies our requirements.

Our customer desires the use of as few lenses as possible, using only catalog lenses.

For the laser diodes we are using (Photodigm Mercury series laser diodes), the typical beam divergence is $\theta_{||}$ x $\theta_{\perp}$ = 6° x 28° (FWHM). The laser mounts have a Thorlabs 30mm cage mount system on the front; this is very helpful for mounting lenses, however the available cylindrical lens mounts cannot get the cylindrical lenses close enough to the diode facet. In order to get around this we need to first use a collimating asphere. Photodigm recommends a 2-4mm EFL lens with an NA > 0.6. This leaves us with an elliptical beam with a divergence of < 0.1 degree (based on modeling).

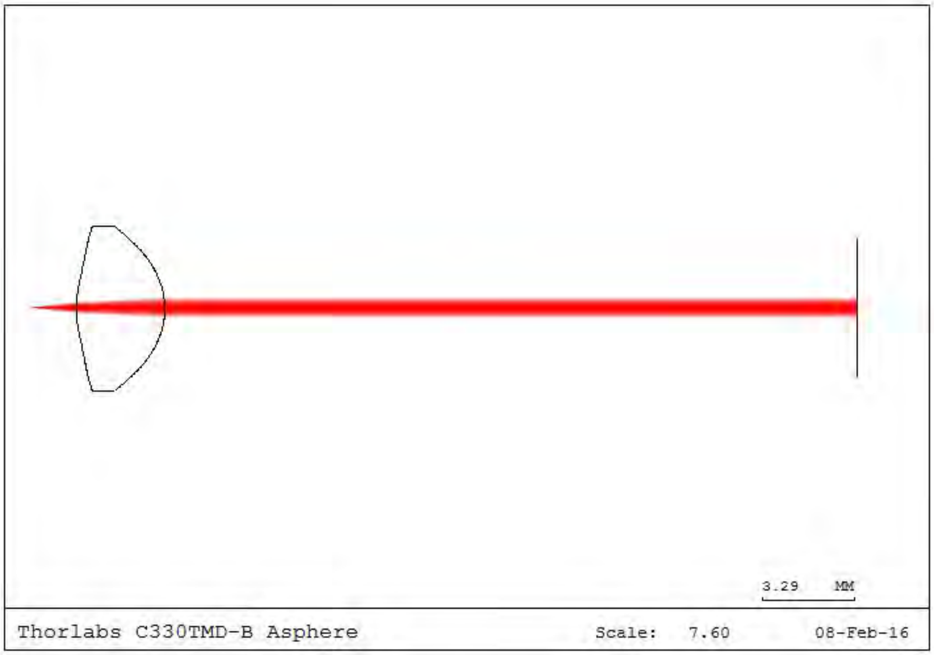
First order modeling is done with thin lens equations, and more advanced modeling is done with FFT based BEA & beamlet-diffraction based BSP in Code V.

Photodigm has provided us with the facet size of the diodes:

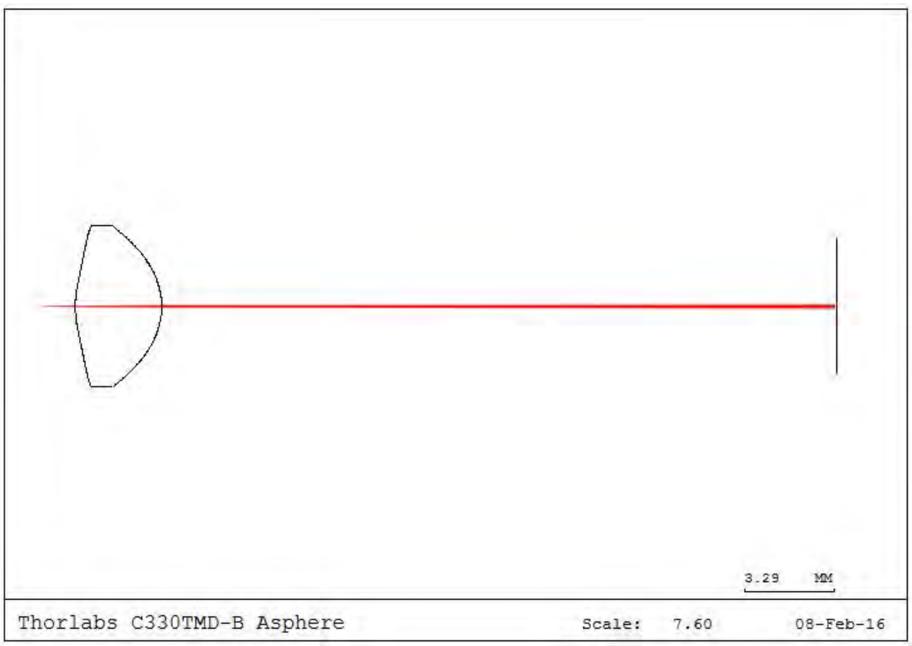
780G4TX: 6.6 um * 1.4 um (780nm laser)

795G4TX: 6.7 um * 1.4 um (795nm laser)

895G4TX: 7.6 um * 1.6 um (895nm laser)

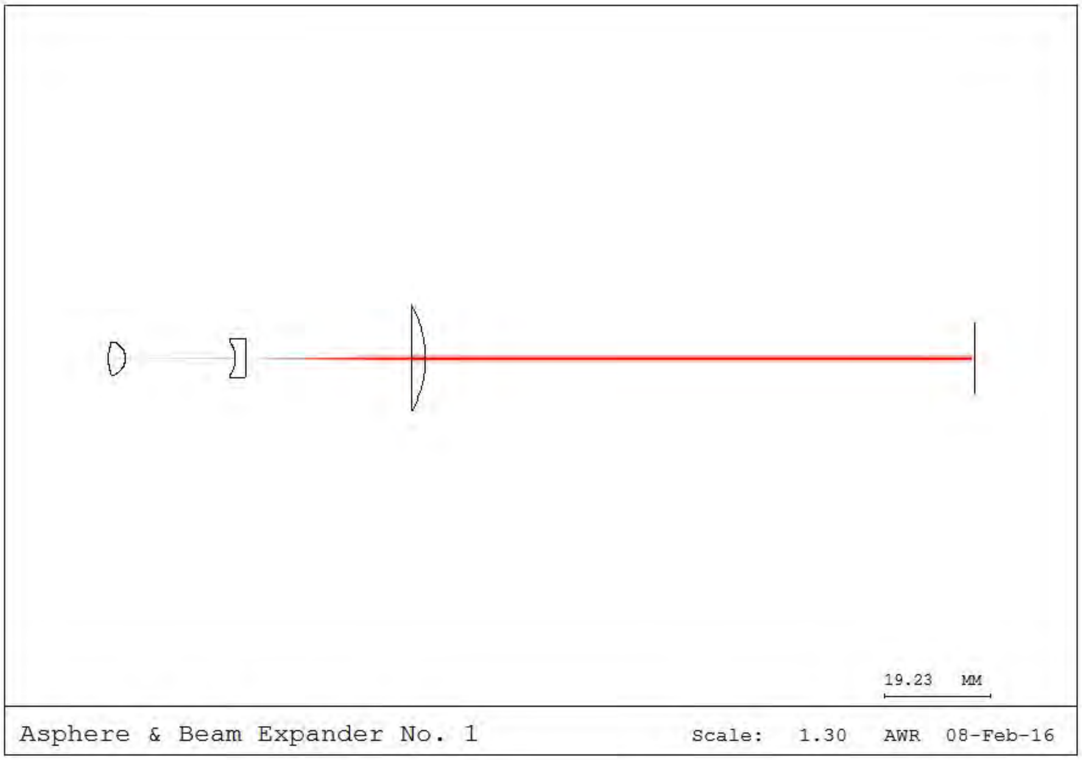


Example of BEA gaussian propagation in Code V. ω = 2µm beam waist is placed at the focus of the lens.

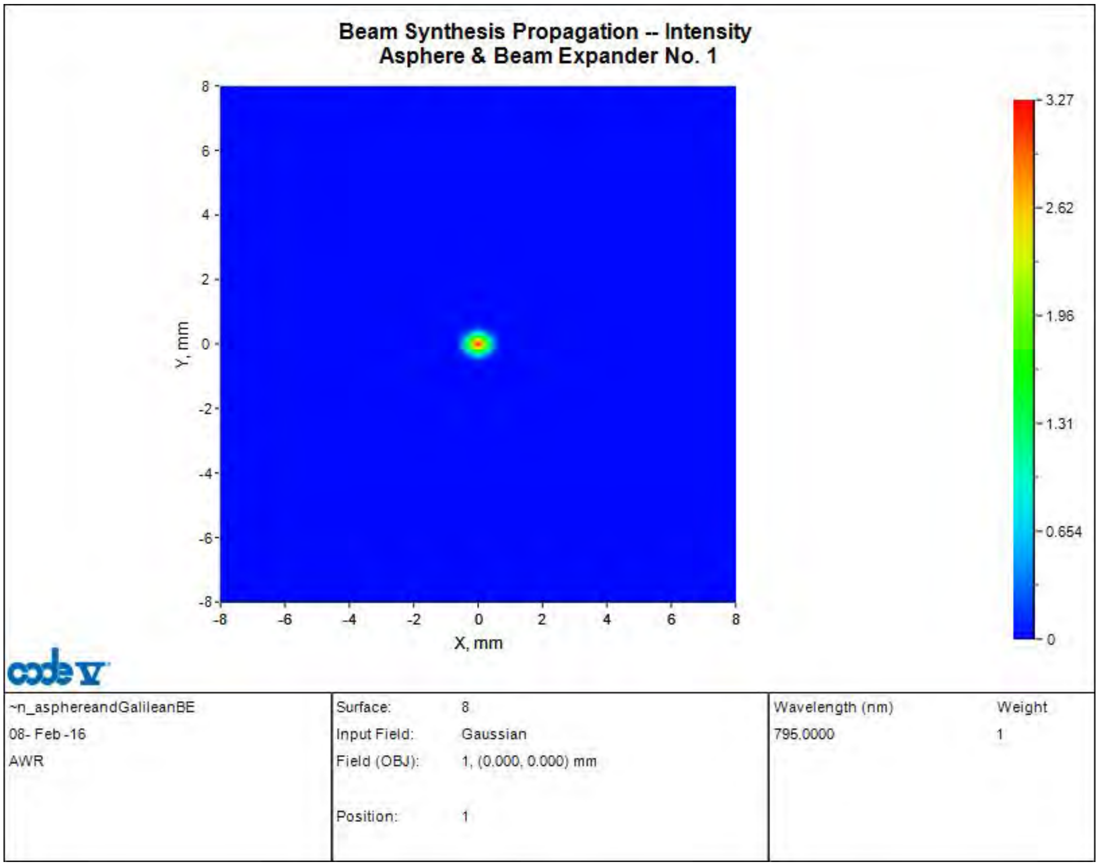


Example of BEA gaussian propagation in Code V. ω = 10µm beam waist is placed at the focus of the lens.

Thorlabs offers B coated (650nm-1.1um region) molded aspheres & NBK7 cylindrical lenses, which we will be using. The the anticipated cost is <$100 for each lens.



Example Code V BEA Gaussian beam trace for a collimating apshere and a Galilean beam expander. Beam waist is 10μm at the focus of the first lens.



Example Code V BSP Gaussian beam simulation for the Galilean beam expander. The beam waist was 10µm x 2µm (x,y), placed at the focus of the first lens. Plot is 100mm from last surface. Exact divergence angles and beam circularity need to be calculated.

We are talking with our customer with respect to beam circularity specifications. <10:9 ratio was suggested, but we need to confirm.

Beam circularity was never given a solid spec - we were told to eyeball it on the beam profiler and just go with what we thought was "good enough".

For our final design we used the combination of a collimating asphere and beam expander shown above. We cautioned our customer that this system would be very sensitive to small alignments but it was judged that overall cost was more important than alignment sensitivity.

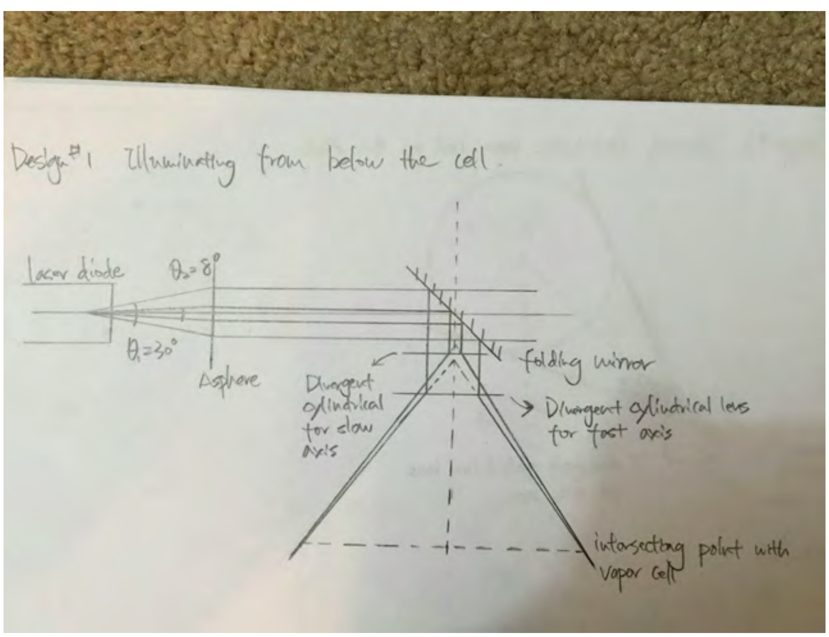
The procedure to align this system is as follows:

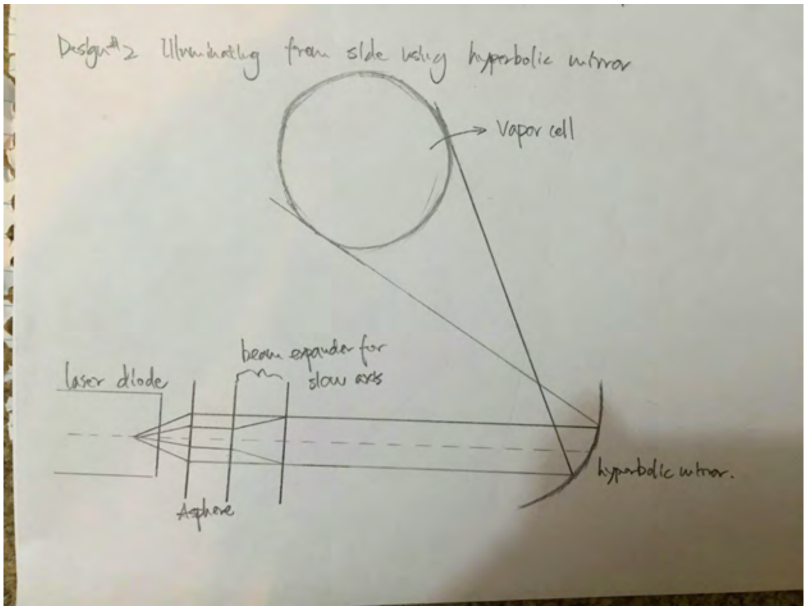
1. Mount laser on breadboard. Mount rail for beam profiler ~1.5meters down from laser, making sure laser and rail are collinear.
2. Mount cage rods to front of laser.
3. Mount asphere to CXY1 and S1TM09 and then mount to rails on front of laser. Adjust until fast diverging axis is roughly collimated, then lock in place.
    a. Use IR card to eyeball this and then look at the near field with a beam profiler.

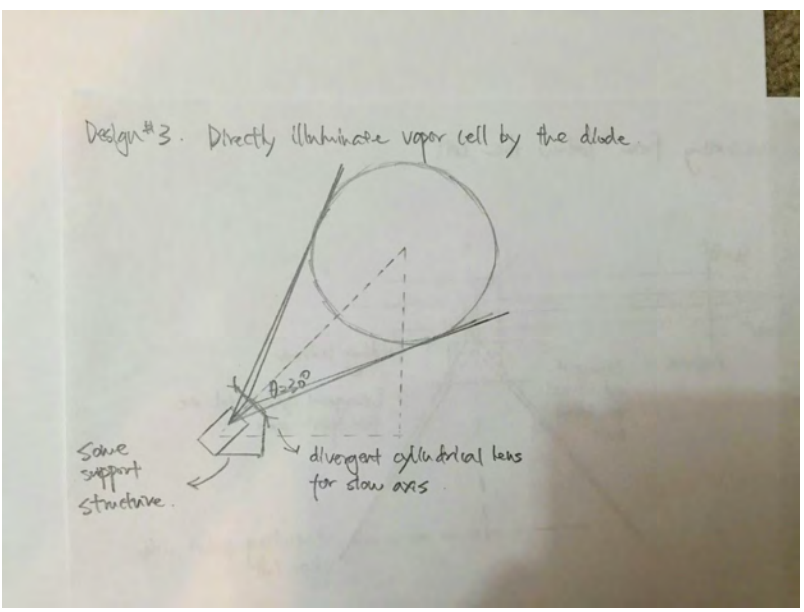
   b. Adjust the x and y of the asphere to center it - this is achieved when the center of the beam travels straight down the optical axis.
4. Add negative lens mounted in CYCP and add to rails - make sure to position close enough to the asphere to not clip the beam. Lock in place.
5. Add positive lens mounted in CYCP. Adjust the distance between the positive lens and negative lens until the beam is fairly circular on the beam profiler at ~1meter away. Move beam profiler back to 1.5meters and check to make sure beam remains circular and size doesn't change too much.
6. Mount isolator and rotate until output is high as possible. Lock down.

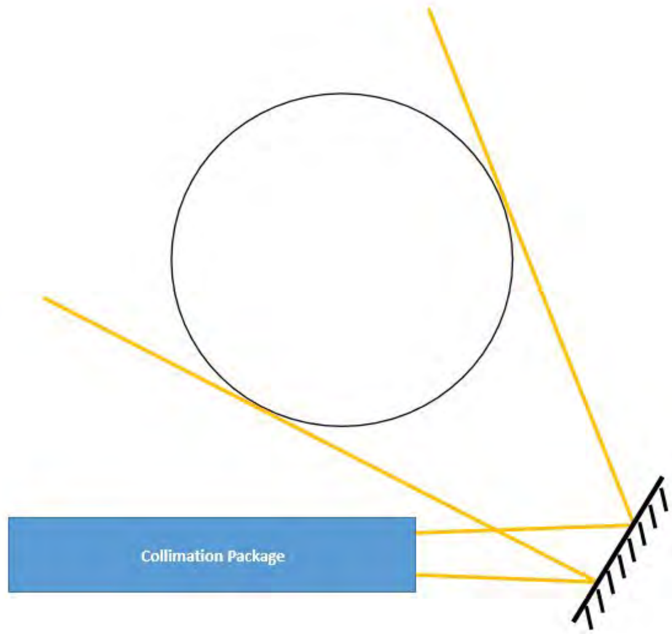
Flood Beam Design

Our customer challenged us to design an optical system for the fourth laser that would illuminate the vapor cell from underneath. The goal was to fill a 6" radius volume of the vapor cell with the laser. The same combination of collimating asphere and beam expander in the intersecting lasers was used. The focal lengths for the two lenses in the beam expander have a slightly different ratio than the ones used for other lasers due to the diode has a different beam divergence $\theta_{||} \times \theta_{\perp}$ = 6° x 32° (FWHM) rather than $\theta_{||} \times \theta_{\perp}$ = 6° x 28° (FWHM). Two spherical divergent lenses were set 12mm apart and 1" in front of the folding mirror in order to provide enough optical power to expand to beam. We do not know any more specifics about this system - for IP reasons our customer has not told us more than we need to know.




Design#2 Illuminating from side using hyperbolic mirror
Vapor cell
beam expander for slow axis
laser diode
Asphere
hyperbolic mirror.


Design#3. Directly illuminate vapor cell by the diode
θ=30°
Some support structure.
divergent cylindrical lens for slow axis



All parts for the flood beam have been ordered but not yet received by the time our project is finished therefore no testing or assembling was performed on the beam. However, based on modeling and testing results from other lasers, the design should meet our customer's expectation.

Optical Transmission

Our primary goal is to steer the beam into the sphere. The lasers were selected for highest power possible with the knowledge that the system transmission losses are largely unavoidable. This section includes some basic calculations about the transmission of our delivery optics.

We will have a maximum of 4 lenses for each laser system. The coating on these lenses are 650-1050 nm broadband. In our wavelength range the minimum transmission is 99.5%. The isolators have a transmission of 85%. ScannerMax does not provide specs for mirror reflectance, so we will assume 99.5% for each mirror, as well as 99.5% for at max two additional mirrors for steering the beam.

The uncoated pyrex sphere has an index of n = 1.474 and an on axis transmission of 96.79% (fresnel coefficients).

$T = (\text{mirror})^4 * (\text{isolator}) * (\text{lens surface})^8 * (\text{sphere})$

$T = (0.995)^4 * (0.85) * (0.995)^8 * (.9679) = .775$

Our system has an estimated minimum transmission of ~ 78%. This does not include the off axis reflectance changes for the pyrex sphere. Our lasers are ~400mW, so we expect to have ~310 mW of power in the sphere.

Mechanical Housings for Optics

The customer specified ½" optics except for the scanner mirrors. We chose to use kinematic mounts available from Thorlabs to keep the price low. The mounts we chose are as follows:

Mounts for the aspheres in each collimation package: CXY1 and S1TM09


Mounts for the cylinders in each collimation package: CYCP


Mounts added for the stability of the isolator: CP12

Mounts for the beam-steering mirrors: KM05

See the 3D drawings section for our design of the scanner mount.

~~Beam Deviation in Sphere~~

This calculation has been phased out of our project. This prototype will be used to display close to the center of the sphere where this isn't seen to be an issue. Also, as we do not know the actual surface roughness of the sphere this calculation may not be entirely correct. The previous prototype had this parameter determined by trial and error.

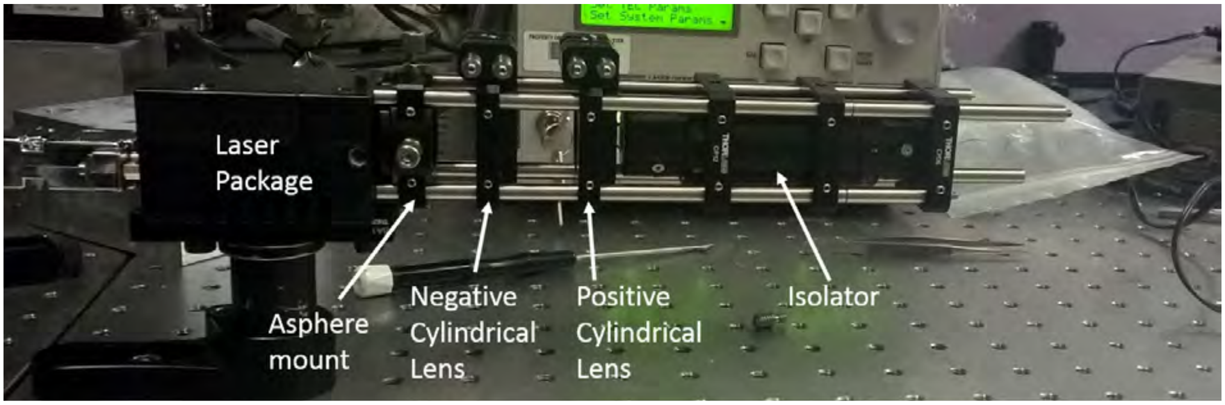
Test Plan / Validation

The test plan consists of multiple parts:

1. Test the proof of concept (POC)
    a. Includes a full design, with optical layout and CAD layout. Pending funds and customer approval, we will then move onto stage 2.
2. Assist in prototype system assembly

With funding approved we assist in the assembly of the designed collimation packages for the new system

Below is the picture of the assembled laser package.



Risk Assessment

Currently the most amount of risk lies in the steering of the beam through the side of the glass sphere. At oblique angles there will be a mild amount of deviation as well as optical aberrations that may change the beam size.

The alignment of the lenses is also an issue, as they are all fairly fast and there is no repeatable way to align them besides rough alignment followed by trial and error fine alignment. Our customer understands this and accepts it as it as lowers the cost of the overall system.

Transition Plans

As the semester draws to a close, we have delivered a system design to our customer via AutoCad, in addition to a parts' list with associated prices. Since we were able to do this early enough to get some of the parts ordered, we also collimated the lasers for the project, handing over three lasers ready to be used in testing. The rest of the parts have also been ordered, and our customer is expecting to finish a prototype to start sharing with investors by early July.

Appendix 1: PRD

3D Volumetric Display

Product Requirements Document

UR Ventures / Curtis Broadbent

Amy Entin, Alex Rainville,

Yucheng Wang, Lindsey Willstatter

Document Number 00005

Revisions Level Date

E 12-03-2015

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Authentication Block

.ev	escription	ate	uthorization
	iitial PRD	0-25-2015	W
	pdated specs per first customer meeting: pdates to vision, environment, and fitness for use sections.	1-02-2015	W
	pdated specifications from first three customer meetings	1-09-2015	W
	urther revisions as to what we are actually providing, included table of contents, timeline, student roles	1-29-2015	W
	nproved wording throughout the document, pdated roles	2-03-2015	W

Table of Contents:

Statement of Advisors:

The 3D Volumetric Display is a customer driven product. As such, all of its design requirements are derived from the direction of Curtis Broadbent, our customer and faculty advisor. John Marciante has been serving in an advisory role regarding the laser system.

Vision:

The full product is a 3D volumetric display and the subsystem designs being developed by the senior project team are an upgraded laser system and a beam scanning system for improved beam control.

Environment:

As a device intended for entertainment, it needs to operate in the following environment:

Temperature

55-105 °F – operation range

Relative Humidity

non-condensing

It will operate under outlet power, 120VAC.

Regulatory Issues:

The system involves at least two lasers, one at 852nm and one at 917nm. These lasers will both have a maximum of CW power of 500mW. The vapor display is most likely regulated by the FDA as a "Demonstration Laser Product." The lasers we will use will most likely be Class IIIb.

Fitness for use:

The laser system is designed to excite cesium to an energy level that exhibits radiative decay. Each laser individually cannot induce radiative decay; accordingly, the lasers themselves will not be seen in the atomic cloud but the intersections (voxels) are visible.

Each of these transitions can tolerate a bandwidth of <10GHz. The laser output must have the correct wavelength and a suitable bandwidth. They need not be frequency tunable (as the current lasers are), but should be continuously temperature tunable, to +/- 0.1nm with a wavelength resolution of 0.01nm. Should have a 3000hr lifetime for all systems.

The laser system:

Will have two laser outputs

Will fit on an 18" diameter plate along with the scanning system

The total cost of the laser system will be <$15,000

Laser system includes all laser diodes/amplifiers, laser temperature and amplitude controllers, and isolators

Each individual laser should be <$4000

	Cesium D-line Transition	Cesium Upper-Level Transition

Wavelengths:	852.35nm	917.23nm
Bandwidth	<10GHz	<10GHz
Frequency stability	1/2 bandwidth/ 5min	1/2 bandwidth/ 5min
Power (on target)	150-500mW	150-500mW
Beam waist (half width) in center of sphere	300-500um at 12”-15”	300-500um at 12”-15”
Spatial mode and shape	single spatial mode, round beam shape	single spatial mode, round beam shape
Polarization	Not applicable	Not applicable
Beam Quality*	Twice beam waist at edge of sphere is tolerable. $M^2 < 4$	Twice beam waist at edge of sphere is tolerable. $M^2 < 4$

The customer requires a new laser meeting these specifications with the primary goal of reducing cost. It is also desired that the system can be turned on and off at a high rate to allow for blanking when moving between non-neighboring voxels.

The scanning system:

Will consist of a system that moves the two partially focused laser beams through a spherical vapor cell.

Will fit on an 18” diameter plate with the laser system.

Can be aligned by a non-expert given basic instructions.

Target resolution	500um
Repeatability	500um

small angle access time range	100ns-100us
Full range deviation	16”
Scanning Rate	60,000 voxels/sec

Parameters of scanning system will be derived from the scanning rate

The cost of the full scanning system is <$6000.

It is desirable that:

The cost of the scanning system is <$2000 USD for all components (components include scanners, drivers, scanning controls, beam shaping optics)

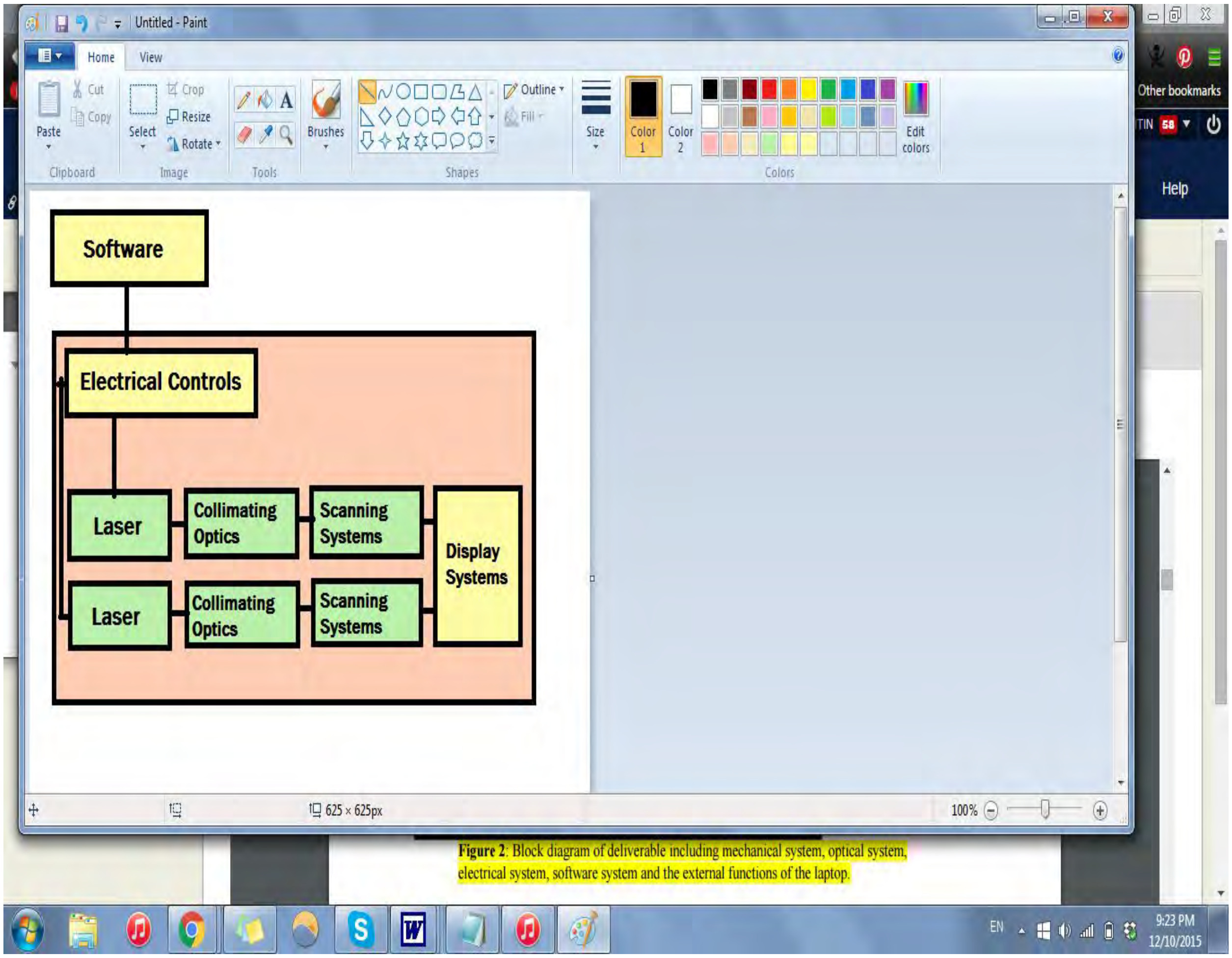
The cost of the laser system is <<$15,000 USD for all components (components include lasers, controllers, isolators, immediate optics)

An algorithm is derived to calculate mirror angles to hit any arbitrary voxel.

The prototype is light enough to ship for less than $500

Project scope:

System block diagram green boxes are our responsibilities.



What we are responsible for:

We are responsible for a detailed design study and computer design of a complete system including optical design of a scanning system with lenses, scanners and mirrors. Scanner mounts will be designed for fabrication in a machine shop. A budget and bill of materials will be provided as well.

What we are not responsible for:

Any software upgrades

We are not responsible for any physically built systems only for designs (pending changes from our customer & our team status mid-spring)

Timeline:

Fall Semester	• List of possible secondary laser option

(prior to semester end)	● List of possible scanner options and their specifications ● PRD finalized
Spring Semester	● Preliminary design done: Jan 28 ● Mounts designed, preliminary: early-Feb ● Laser design finalized: mid-Feb ● Collimation optics design: mid-Feb ● Deliver final full design for possibility of building a prototype

Team member responsibilities:

Alex: Project coordinator, laser system design

Lindsey: Document Handling, optical modeling, putting the final optical design

Amy: Scribe, CAD modeling, optical modeling

Yucheng: Customer liaison, choosing scanner, communicating with manufacturers

Appendix II: Bill of Materials

795 laser collimation and isolation package				
Part	Cost	Description	Mounting Note	Distance note
ER6-4	$31.42	cage rods	mounted to laser	
ST1XY-A	$328.76	XY translating cage system with 100 TPI screws and locking set screws	holds asphere mounted with labels toward laser	
S1TM09	$22.00	SM1 to M9 lens adapter	allows asphere to attach to xy mount	

C330TMD-B	$74.70	mounted geltech asphere efl=3.1 mm wd=1.76mm	mounted in adapter with threads to laser	asphere should be about 1.5mm from laser mount.
CYCP	$80.00	cylindrical lens holder	mounted rods down, clamp down stream	should have a few mm gap with CXY1
LK1087L1-B	$60.50	divergent cylindrical lens f=-6.5	first lens of Galilean beam expander, mounted vertically with flat side to laser	see note below
CYCP	$80.00	cylindrical lens holder	mounted with rods up, clamp down stream	see note below
LJ1014L1-B	$77.50	cylindrical lens f=25.4	second lens of Galilean beam expander mounted vertically with flat side to laser	the distance between lenses needs to be (24.5-6.4)mm
CP12	$20.00	double bore cage plate	holds isolator	see note below
IO-5-780-VLP	$1,050.00	optical isolator	saddle must be removed and replaced with CP12	the isolator should have a few mm gap from second CYCP
CP12	$20.00	double bore cage plate	holds isolator (2 plates to provide stability)	
CP06	$16.75	post-mountable cage plate	mounted to base to provide stability	should be a few mm gap from final surface of isolator
Total	**$1,861.63**			
852 laser collimation and isolation package				
Part	Cost	Description	Mounting Note	Distance note
ER6-4	$31.42	cage rods	mounted to laser	

ST1XY-A	$328.76	XY translating cage system with 100 TPI screws and locking set screws	holds asphere mounted with labels toward laser	
S1TM09	$22.00	SM1 to M9 lens adapter	allows asphere to attach to xy mount	
C330TMD-B	$74.70	mounted geltech asphere efl=3.1 mm wd=1.76mm	mounted in adapter with threads to laser	asphere should be about 1.5mm from laser mount.
CYCP	$80.00	cylindrical lens holder	mounted rods down, clamp down stream	should have a few mm gap with CXY1
LK1087L1-B	$60.50	divergent cylindrical lens f=-6.5	first lens of Galilean beam expander, mounted vertically with flat side to laser	see note below
CYCP	$80.00	cylindrical lens holder	mounted with rods up, clamp down stream	see note below
LJ1014L1-B	$77.50	cylindrical lens f=25.4	second lens of Galilean beam expander mounted vertically with flat side to laser	the distance between lenses needs to be (24.5-6.4)mm
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CP06	$16.75	post-mountable cage plate	mounted to base to provide stability	should be a few mm gap from final surface of isolator
Total	**$1,861.63**			

Company/Equipment	Quantity	Model #
Photodigm Lasers	(4)	MERC_1-4_HS SEISO
Pangolin Scanners	(2)	Saturn 1B

895 Laser Collimation Package and Divergent Beam Expander			
Part	**Price**	**Description**	**Distance note**
C330TMD-B	$74.70	mounted geltech asphere efl=3.1 mm wd=1.76mm	asphere should be about 1.5mm from laser mount.
LK1523L1-B	$54.80	first lens of Galilean beam expander. mounted horizontally with flat side to laser	See note below
LJ1212L1-B	$87.10	Second lens of Galilean beam expander.mounted vertically with flat side to laser	The distance between lenses should be (40-7.6)mm.
LD2746-B	$34.48	First divergent spherical lens for expanding beam. f=-6.0mm.	See note below
LD2586-B	$34.48	Second divergent spherical lens for expanding beam. f=-9.0mm.	The distance between divergent lenses should be 12mm to provide desired optical power to expand the beam

TBD: Collimation optics for additional laser, mirror for illuminating laser, materials needed to machine scanner base