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The XyloScope—A Field-Deployable Macroscopic Digital Imaging Device for Wood

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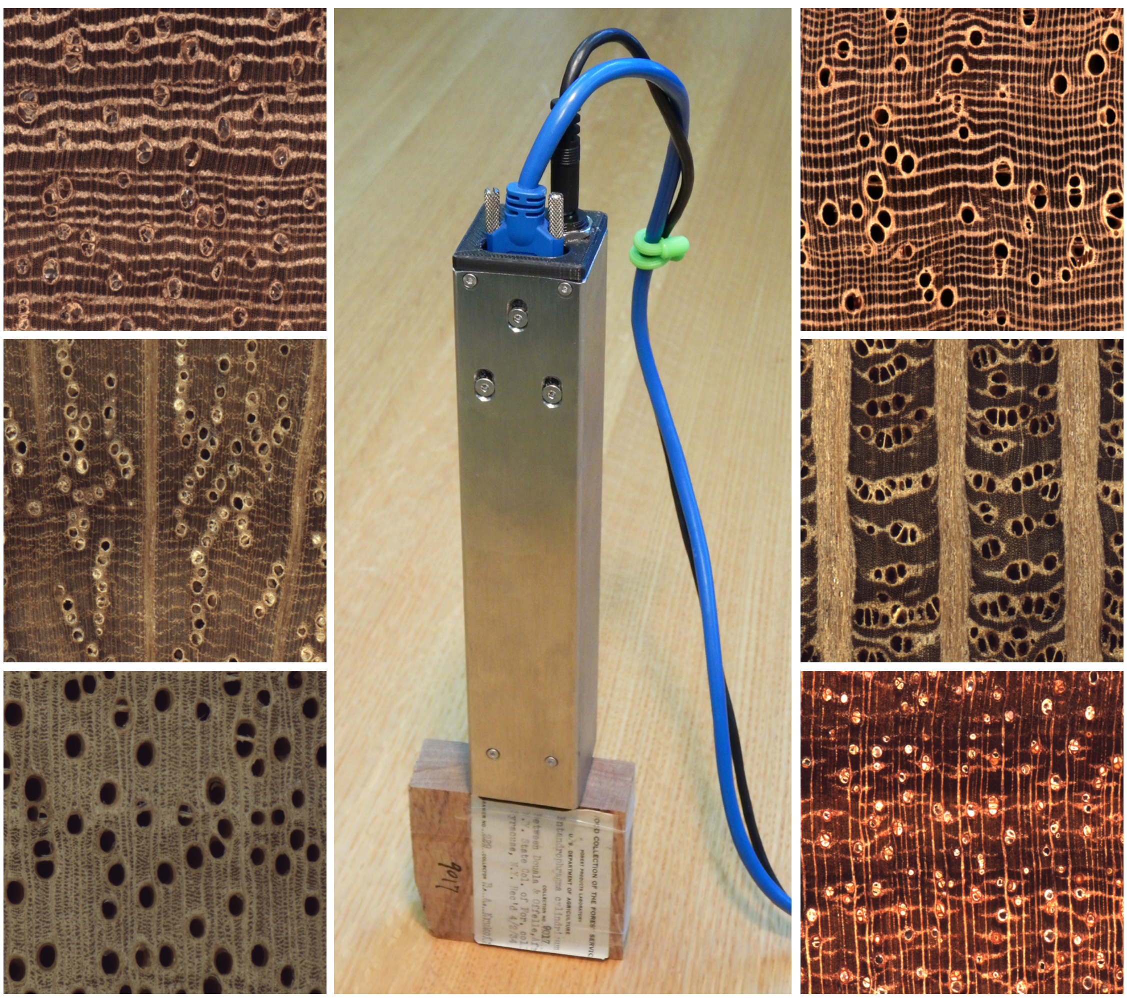

Forest Service

Forest Products Laboratory

Research Note FPL–RN–0367

October 2019

Abstract

This Research Note describes the rationale for and design of a XyloScope, a digital imaging system for viewing and recording macroscopic images of wood for a XyloTron machine-vision wood identification system, and provides a bill of materials and the associated technical drawings of its components.

Keywords: XyloTron, wood identification, machine vision, XyloScope

Contents

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The XyloScope—A Field-Deployable Macroscopic Digital Imaging Device for Wood

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Introduction

In 2010, in cooperation with Forest Service International Programs and with the support of the U.S. Department of State, the Forest Products Laboratory initiated a project to develop a prototype machine vision wood identification system, the XyloTron. The XyloTron is a field-deployable system for imaging and identifying wood species, thus requiring a robust digital imaging device, the XyloScope. From broad conception (Hermanson and Wiedenhoeft 2011) to early development (Hermanson and Wiedenhoeft 2015) to the first documentation in the scientific literature of its efficacy for wood identification (Ravindran et al. 2018), the XyloTron has been intended to be an open source, community-driven initiative. To facilitate the adoption of this technology, this note describes the XyloScope and provides a bill of materials (App. A) and drawings and files detailing its design and assembly (Apps. B and C) as deployed and distributed to cooperators since 2015. Additional research and development—with attendant design modifications and improvements—is ongoing, and subsequent designs will be published in the future as warranted.

The primary function of the XyloScope is to capture high-fidelity (evenly illuminated and in-focus) macroscopic images of wood suitable for human or machine vision evaluation for wood identification. Although many routes to such a result are possible, this project reflected several design constraints: a minimal requirement for machining; use of three-dimensional- (3D-) printed components; use of off-the-shelf components; field-portability and durability; uniform lighting; images that are recognizable by human wood anatomists as would be seen through a loupe; and a simple, intuitive design without moving parts or the requirement for extensive user expertise or decision-making in focusing, lighting, or setting camera parameters.

Each of the following sections corresponds to a component of the XyloScope, beginning with internal mechanical and optical components (Fig. 1), then the external steel housing, and concluding with electrical lighting components. Internal components are described starting from the front of the XyloScope and progressing toward the back of the device (left to right in Fig. 1). Dimensions in the engineering drawings and design files for the 3D-printed components are based on idiosyncrasies of the 3D printer and polymer we used to fabricate the printed components. As such, the dimensions will likely require slight modifications for other printers or polymers, especially features like small printed holes for thread-forming screws and slots for drop-in components. Each printed component is shown in a figure, and one or more engineering drawings with orthographic projections and an isometric view are included for each component in Appendix B. Section views are provided for the LED holder to better detail its intricate structure. Electrical diagrams are presented in Appendix C. A 3D graphics file created in FreeCAD (an open-source 3D parametric modeler) for each of the 3D-printed components is attached in Appendix D.

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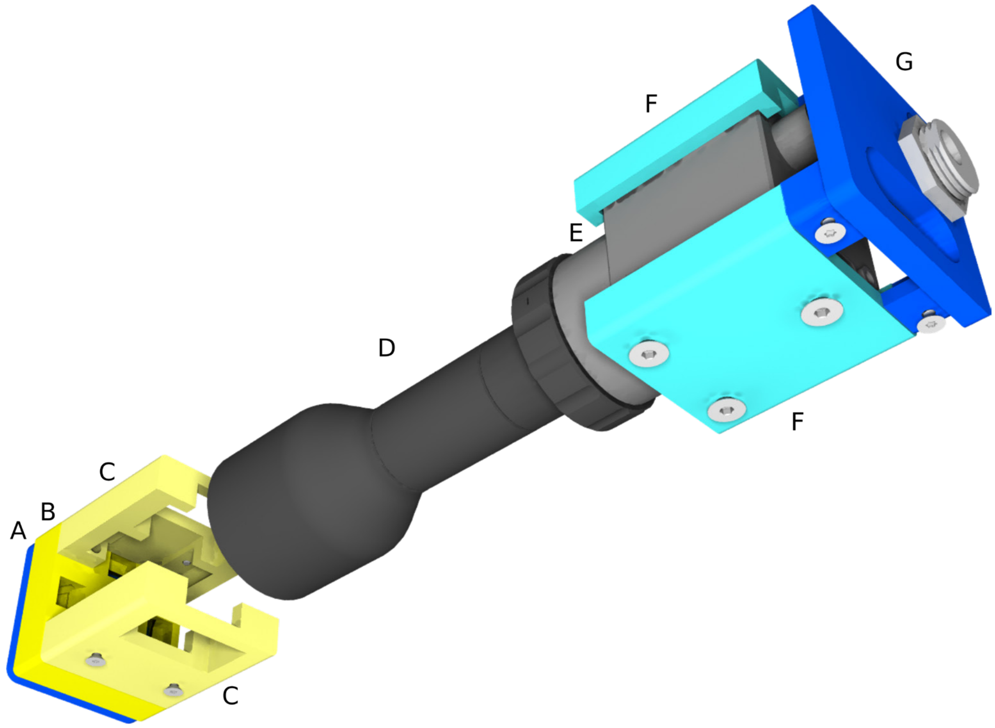

Figure 1—Ray tracing of the XyloScope internal components (wiring and some electrical components not shown, not all components placed to scale). The right side of the figure is the back of the device where the external cables are connected. From left to right: A, front cap; B, LED holder; C, LED driver holders (two); D, lens (ray tracing based on CAD drawing courtesy of Edmund Optics); E, camera (ray tracing based on CAD drawing downloaded from https://flir.app.boxcn.net/s/vyji6o86n7t0tidd2ilrtfd3cm84h3cj); F, camera shoes (two); G, back cap.

Internal Components

Front Cap

The front cap (component A in Fig. 1 and shown in Fig. 2) provides a surface to place flush against a specimen. The opening size and the beveling of the opening edges of the front cap allow direct lighting of the specimen. The four cylindrical projections mate with the LED holder (Fig. 3) to reduce alignment error with the LED holder and camera. The diameter and length of the mating cylinders and the corresponding holes on the LED holder are designed to provide a tight fit. Specifications for this part are provided in Sheet 1 of 8 (App. B).

LED Holder

The role of the LED holder (component B in Fig. 1 and shown in Fig. 3) is to position the LEDs at a specified distance and angle to provide consistent illumination across the wood surface. Printed circuit boards with LEDs soldered in place slide into the slots provided. When the front cap (Fig. 2) is mated with the LED holder (Fig. 3), it secures the LEDs in place. Specifications for this part are provided in Sheets 2, 3, and 4 of 8 (App. B).

LED Driver Holders

The LED driver holders (component C in Fig. 1 and shown in Fig. 4) restrain the LED driver and the front cap–LED holder combination to the stainless steel tube (detailed below). Thread-forming screws for plastic pass through the preformed holes in the LED driver holder and LED holder into the cylindrical projections on the front cap. The screws pull the three components securely together, and this assembly is held in place at the front of the XyloScope by thread-forming screws passing through the stainless steel tube into the printed holes in the LED driver holders. Specifications for this part are provided in Sheet 5 of 8 (App. B).

Lens

An Edmund Optics 0.5×, 65-mm WD CompactTL™ Telecentric Lens #63-741 (Edmund Optics, Barrington, New Jersey, USA) (component D in Fig. 1 and shown in Fig. 5) is screwed directly to the camera using a C-mount connection. Table 1 provides the manufacturer’s specifications for this lens.

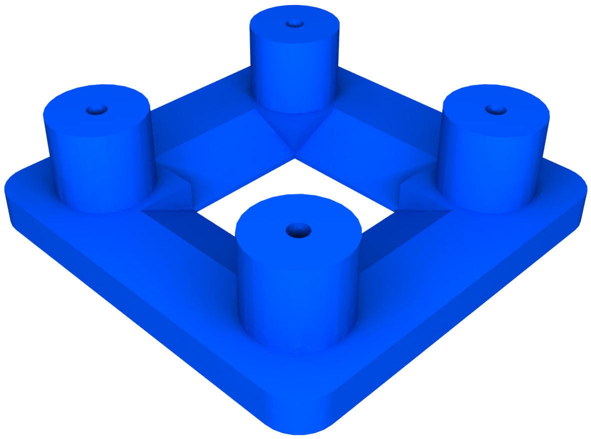

Figure 2—Front cap ray tracing viewed from internal surface. The beveled edges of the opening are designed to allow direct illumination of the specimen, and the cylinders mate with the LED driver holder.

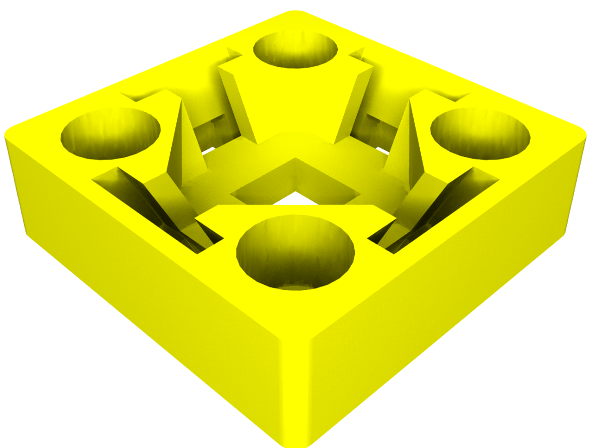

Figure 3—LED holder ray tracing viewed from the front (specimen-imaging) side. The printed circuit board assemblies, with LEDs soldered in place, slide into the slots with the surface shown and mate with the front cap (Fig. 2).

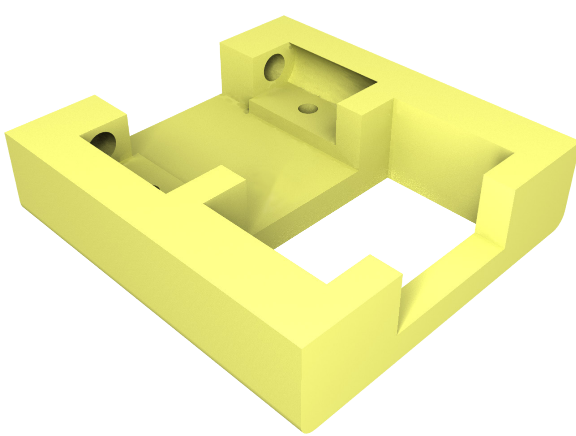

Figure 4—LED driver holder ray tracing. The LED driver seats in the square through-hole at the bottom right of the part. The top left of the part mates against the LED holder.

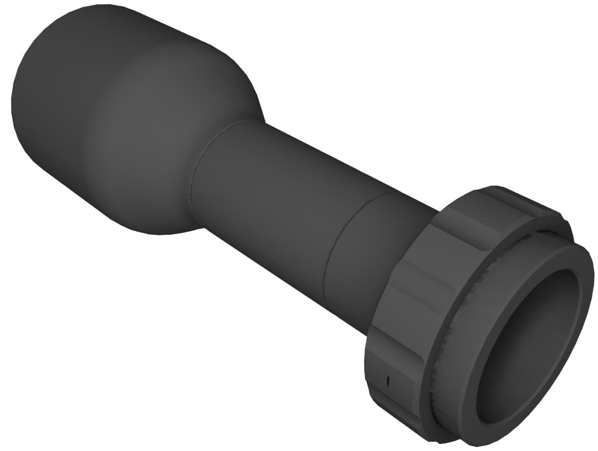

Figure 5—Edmund Optics 0.5×, 65 mm WD CompactTL™ Telecentric Lens #63-741. Ray tracing based on CAD drawing courtesy of Edmund Optics.

Table 1—Specifications of the Edmunds Optics 0.5×, 65 mm WD CompactTL™ Telecentric Lens #63-741 (information reproduced with permission of Edmund Optics)

Parameter	Value
Coating	MgF_2
Mount	C-mount
Type	Telecentric lens
Primary magnification PMAG	0.5×
Maximum camera sensor format (in.)	2/3
Aperture (f/#)	f/9
Working distance (mm)	65
Coating specification	$\lambda/4$ MgF_2 @ 550 nm
Depth of field (mm)	±1.85 (20% @ 20 lp/mm)
Field of view, 1/2-in. sensor (mm)	12.8
Field of view, 1/3-in. sensor (mm)	9.6
Field of view, 2/3-in. sensor (mm)	17.6
Length excluding threads (mm)	86.7
Maximum diameter (mm)	32
Number of elements (groups)	5 (3)
Numerical aperture NA, object side	0.028
Typical distortion @ 588 nm (%)	<0.035
Typical telecentricity @ 588 nm (°)	<0.025
Weight (g)	74
Working distance tolerance (mm)	±1

Table 2—Camera parameter settings for Flea3 cameras[a]

Parameter	Value	Remark
Brightness	0	
Sharpness	1000	Neither blurs nor sharpens the image
Gain	0	No signal amplification
Frames per second	10	Close to the maximum bandwidth achievable by USB 2.0 bus for the image size
Red and blue channels	Individually set	Adjusted to achieve the same mean pixel value as the green channel when imaging a neutral grey target
Gamma	100%	
Hue	0	
EV	0.799	Adjusted to give the best image of the wood transverse surface for the lens-lighting configuration presented here
Exposure	Floating	The only parameter allowed to float in automatic mode

[a]When either camera is coupled with the specified lens and a 2048- by 2048-pixel area of the detector is selected, the resulting image represents a 6.35- by 6.35-mm field of view.

Camera

The original camera for the XyloScope was the Point Grey Research Flea3: FL3-U3-88S2C-C, chosen in part for the ability to manually define the imaging parameters (Table 2). The Flea3 series cameras are small volume, 29- by 29- by 30-mm (component E in Fig. 1 and shown in Fig. 6). The FL3-U3-88S2C-C was discontinued and has been superseded by the FLIR FL3-U3-120S3C-C (FLIR, Wilsonville, Oregon, USA). The parameters used for the FL3-U3-88S2C-C (Table 2) are the same used in the FL3-U3-120S3C-C camera.

Camera Shoes

The camera is placed between two camera shoes (component F in Fig. 1 and shown in Fig. 7). The camera shoes situate the camera near the center of the stainless steel tube case. Three screws pass through the stainless steel tube (detailed below) and the bottom camera shoe and thread into the camera. By loosening these screws and sliding the assembly, the XyloScope can be focused, and then by tightening the screws, the focus is fixed. The second camera shoe on the top side of the camera is held in place by the tube and the camera body. The camera shoes are dimensioned to provide a secure fit between the shoes and the stainless steel case. It can be necessary to alter the outer wall thickness of the mounting-side camera shoe to center the camera, and sometimes to reduce the outer wall thickness of the nonmounting side shoe accordingly. Specifications for this part are provided in Sheet 6 of 8 (App. B).

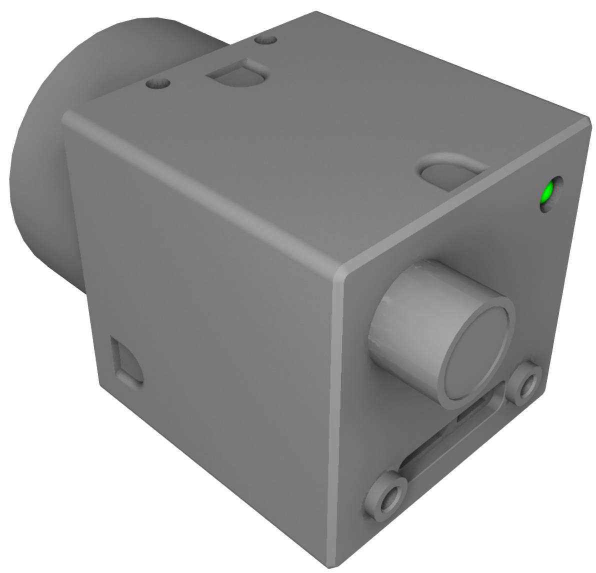

Figure 6—FLIR Flea3, FL3-U3-120S3C-C. Ray tracing based on CAD drawing downloaded from https://flir.app.boxcn.net/s/vyji6o86n7t0tidd2ilrtfd3cm84h3cj.

Back Cap

The back cap (component G in Fig. 1 and shown in Fig. 8) protects the camera, provides a mount for the barrel connector to power the LED lights, permits the passage of the USB 3.0 cable to connect to the camera, and includes a small port to observe the camera's LED status light. This piece is held in place by three thread-forming screws passing through the milled holes in the stainless steel tube and into printed holes in the three posts. Specifications for this part are provided in Sheet 7 of 8 (App. B).

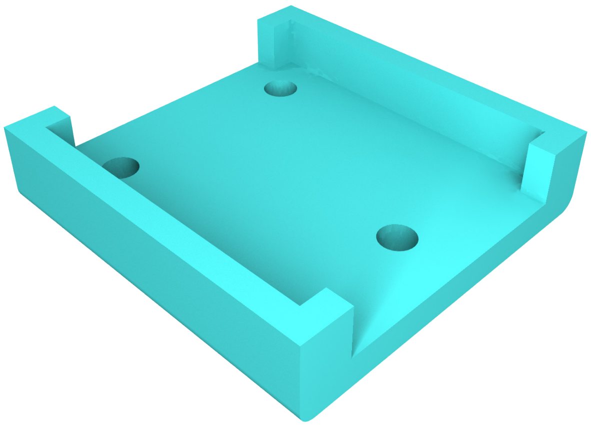

Figure 7—Camera shoe ray tracing. The orientation of the camera shoes will be dictated by the threaded mounting holes on the camera and the stainless steel tube.

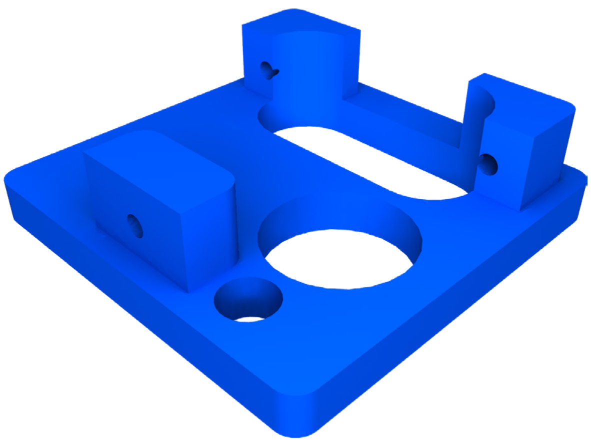

Figure 8—Back cap ray tracing. The orientation of the back cap is determined by the milled holes in the stainless steel tube.

Figure 9—Stainless steel tube ray tracing. All components except the front and back caps are completely enclosed in the tube.

External Component—Stainless Steel Tube

The external case of the XyloScope is a 1.5- by 1.5-in. (38.1- by 38.1-mm) brushed stainless steel tube (Fig. 9) and serves two purposes: (1) It encloses and protects the optical components, lighting, lens, and camera. (2) It acts as a structural frame to position the camera and lens at the correct focal length so that the object is in focus. Three slots are milled in the tube for adjusting the position of the camera to bring the wood for imaging into focus—tightening the camera mounting screws locks the focal position for use. The tube has seven additional holes for mounting or securing internal XyloScope components. If the tube has a welded seam, it is advisable to grind down the internal weld prior to assembling a XyloScope, and it is recommended to mill the camera mounting slots such that the welded seam is on a lateral wall (the left or right wall in Fig. 9). Specifications for this part are provided in Sheet 8 of 8 (App. B).

Electrical Components—Lighting

The lighting system incorporates four Lite-On LTPL-P00DWS57 light emitting diodes (Lite-On, Taipei, Taiwan) driven by a RECOM RCD-24-0.30 constant-current LED driver (RECOM Power, Arvada, Colorado, USA). The current output of the RECOM LED driver in this design is analog and fixed. The analog voltage is set using an

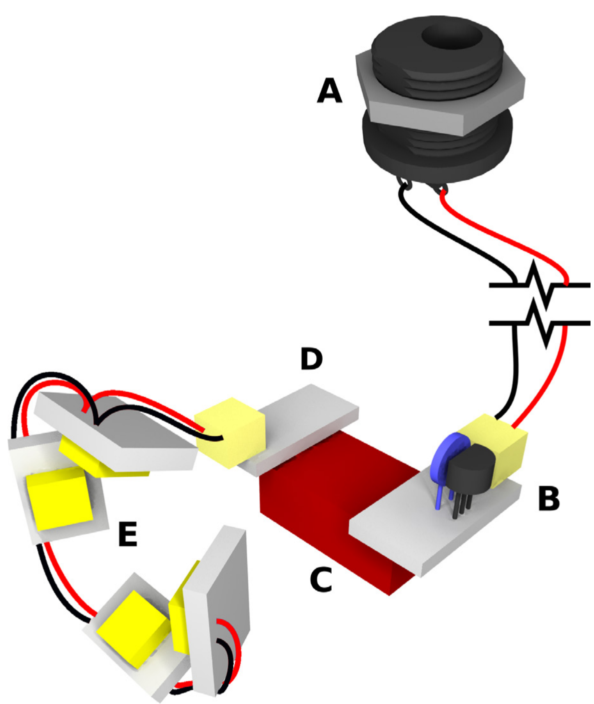

Figure 10—Lighting components: A, barrel connector; B, LED driver input printed circuit board with components; C, LED driver; D, LED driver output printed circuit board with component; E, four LED printed circuit board assemblies. Components are not to scale.

Analog Devices AD680 low-power, low-cost 2.5-V voltage reference (Analog Devices, Norwood, Massachusetts, USA). The system is powered by 3.5 to 18 V supplied to a barrel connector affixed to the back cap. Figure 10 illustrates the lighting components and Sheet 1 of 2 (App. C) provides a schematic. The printed circuit boards ease interconnecting the barrel connector, LED driver, and LEDs. Dimensioned drawings of the printed circuit boards are provided in Sheet 2 of 2 (App. C).

Literature Cited

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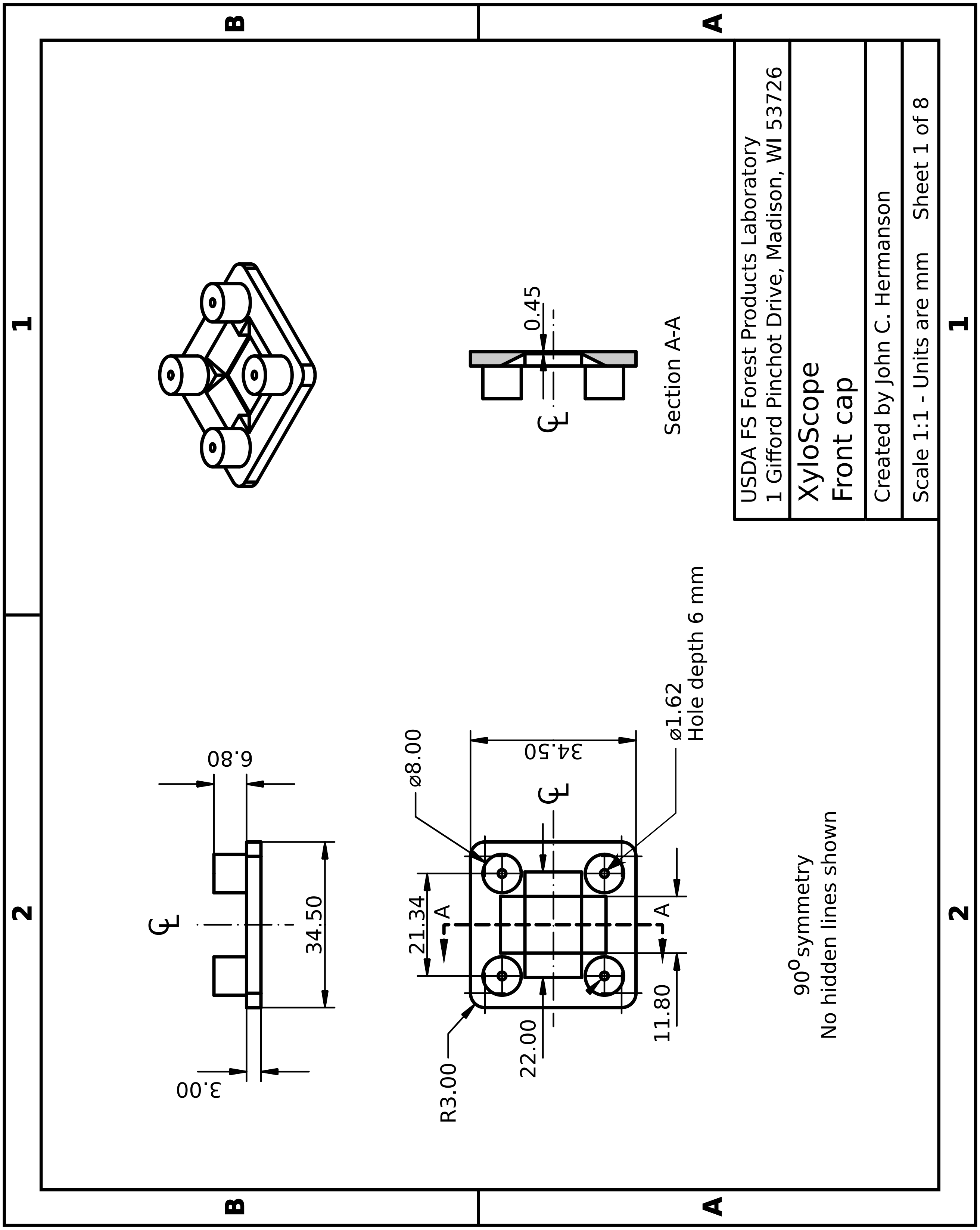
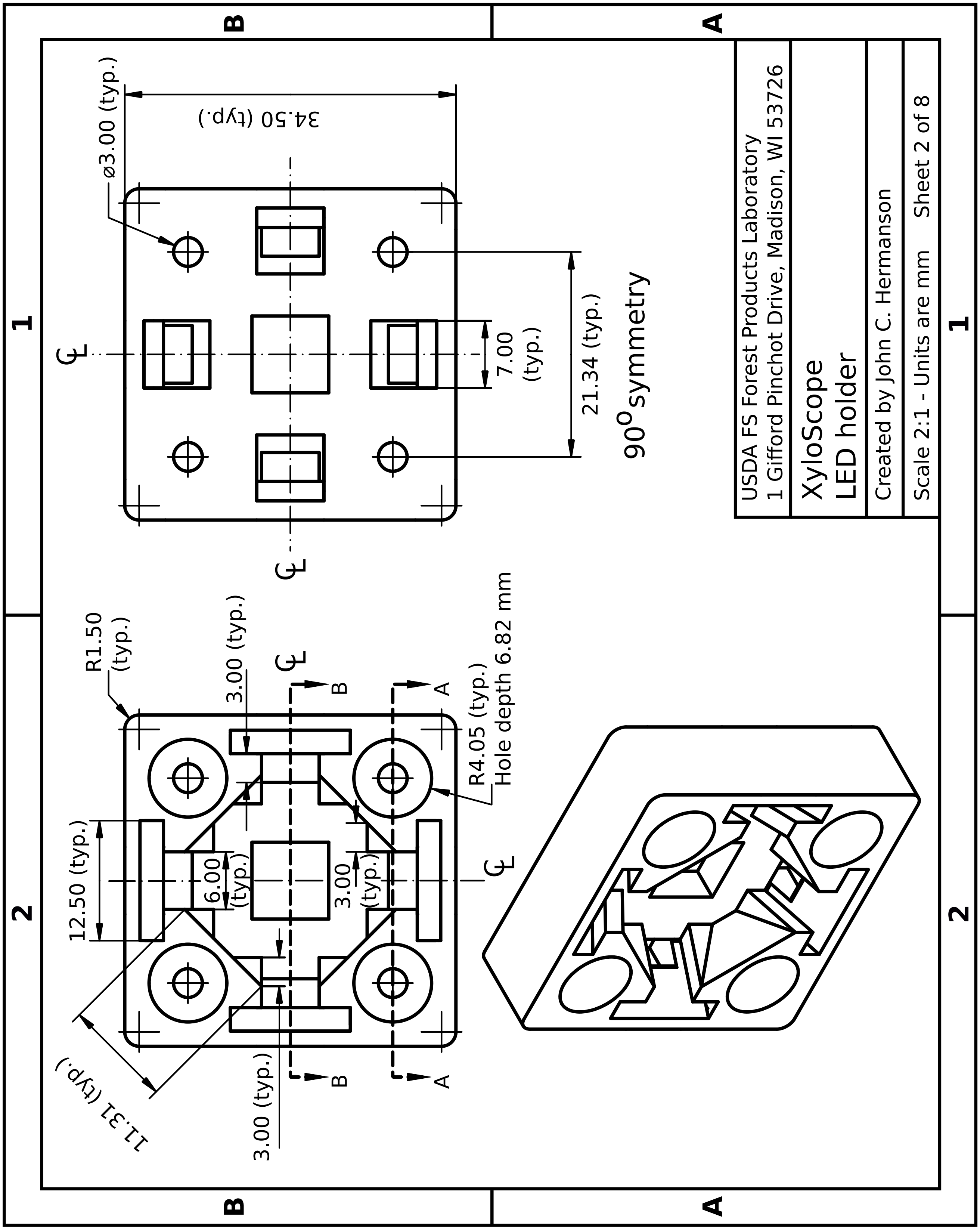
Ravindran, P.; Costa, A.; Soares, R.; Wiedenhoeft, A.C. 2018. Classification of CITES-listed and other neotropical Meliaceae wood images using convolutional neural networks. Plant Methods. 14:25. 10 pp. https://doi.org/10.1186/s13007-018-0292-9

Appendix A—Bill of Materials

1	203-mm 304 stainless steel tube, brushed finish, 0.065-in. thick, 1-1/2 by 1-1/2 in.
1	3D-printed front cap
1	3D-printed LED holder
2	3D-printed LED driver holders
1	Edmund Optics 0.5×, 65-mm WD CompactTL™ Telecentric Lens #63-7431
1	FLIR Flea3, FL3-U3-120S3C-C
2	3D-printed camera shoes
1	3D-printed back cap
1	CUI Inc. PJ-011A power connector 2×5.5 mm
1	USB 3.1 type micro B cable
1	USB-A 5.5 × 2.1 center position cable
3	M3 × 0.5 mm thread size by 8 mm (or two of these and one M3 × 0.5 mm thread size by 5 mm for the FLIR FL3-U3-120S3C-C camera)
11	Number 2 × 1/2-in. stainless steel thread forming screws
4	Lite-On LTPL-P00DWS57 light emitting diodes
4	LED printed circuit boards
1	LED driver input printed circuit board
1	LED driver output printed circuit board
1	RECOM RCD-24-0.30 constant-current LED driver
1	Analog Devices AD680 Low Power Low Cost 2.5 V voltage reference TO-92-3
1	0.1µF 50 V 10% radial ceramic capacitor
2	JST right-angle connector, through-hole two-pin
2	JST Jumper 2 Wire Assembly
200 mm	Two-conductor hook-up wire
	Solder

Appendix B—Specifications of Component Parts

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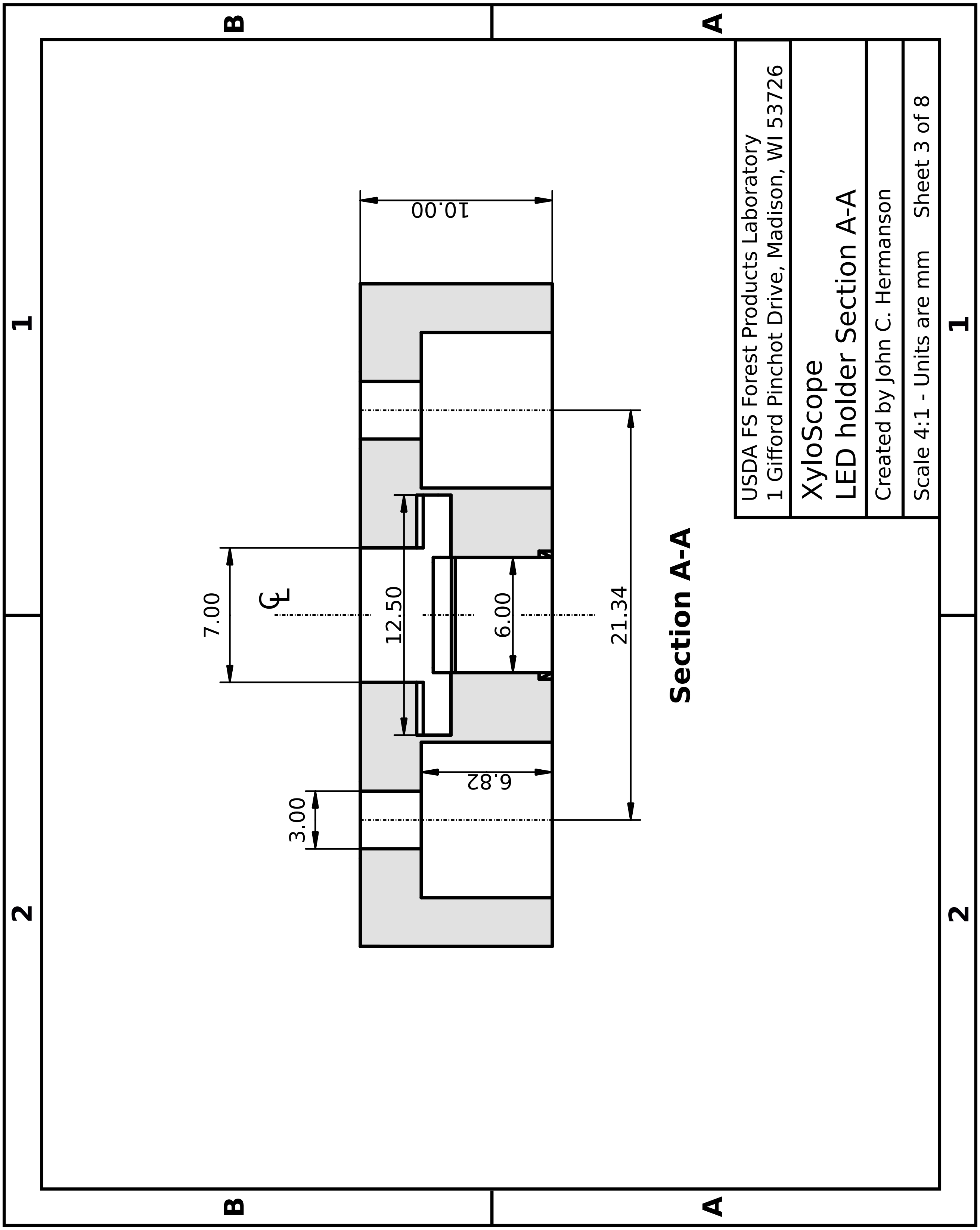
1 Gifford Pinchot Drive, Madison, WI 53726
XyloScope
LED holder
Created by John C. Hermanson
Scale 2:1 - Units are mm
Sheet 2 of 8
ø3.00 (typ.)
34.50 (typ.)
7.00 (typ.)
21.34 (typ.)
90° symmetry
R1.50 (typ.)
3.00 (typ.)
12.50 (typ.)
6.00 (typ.)
3.00 (typ.)
R4.05 (typ.)
Hole depth 6.82 mm
11.31 (typ.)
3.00 (typ.)
A
B
1
2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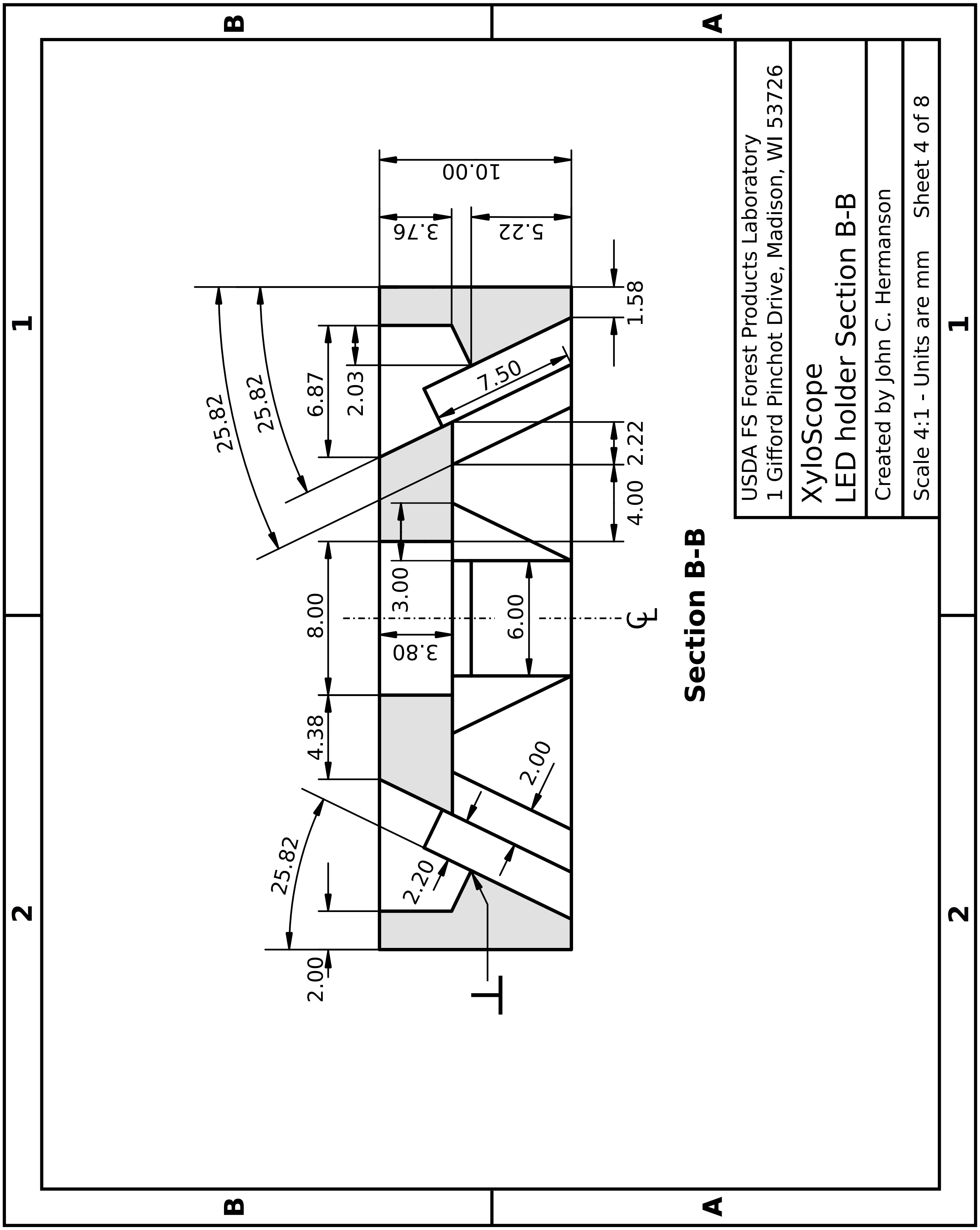
XyloScope
LED holder Section A-A
Created by John C. Hermanson
Scale 4:1 - Units are mm
Sheet 3 of 8
Section A-A
10.00
7.00
12.50
6.00
21.34
6.82
3.00
A
B
1
2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XyloScope
LED holder Section B-B
Created by John C. Hermanson
Scale 4:1 - Units are mm
Sheet 4 of 8
Section B-B
10.00
3.76
5.22
1.58
7.50
6.87
2.03
25.82
25.82
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3.00
8.00
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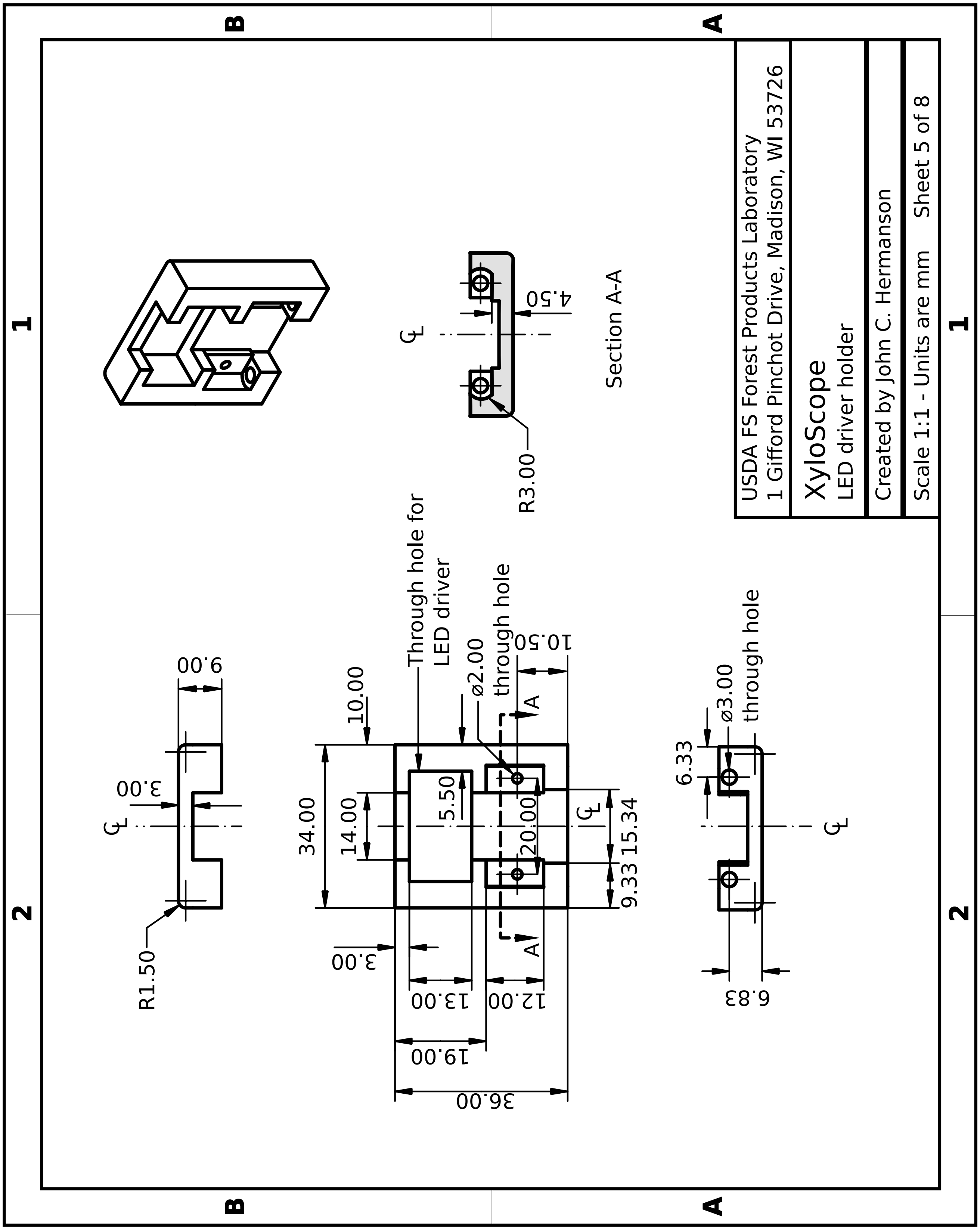
2.00
2.20
25.82
2.00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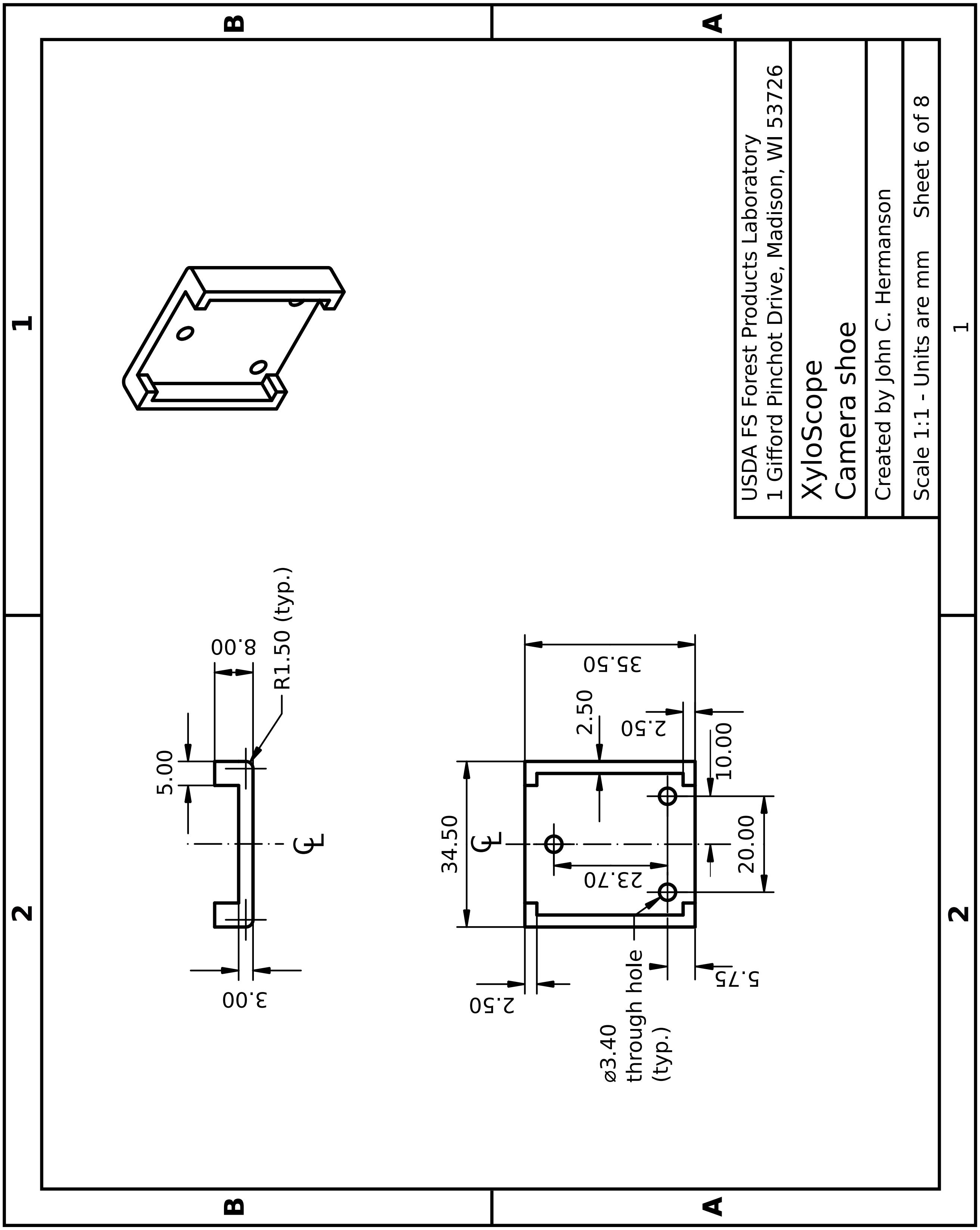
XyloScope
LED driver holder
Created by John C. Hermanson
Scale 1:1 - Units are mm
Sheet 5 of 8
Section A-A
R3.00
4.50
Through hole for LED driver
ø2.00 through hole
ø3.00 through hole
10.50
10.00
34.00
14.00
5.50
20.00
9.33
15.34
3.00
13.00
12.00
19.00
36.00
9.00
R1.50
6.33
6.83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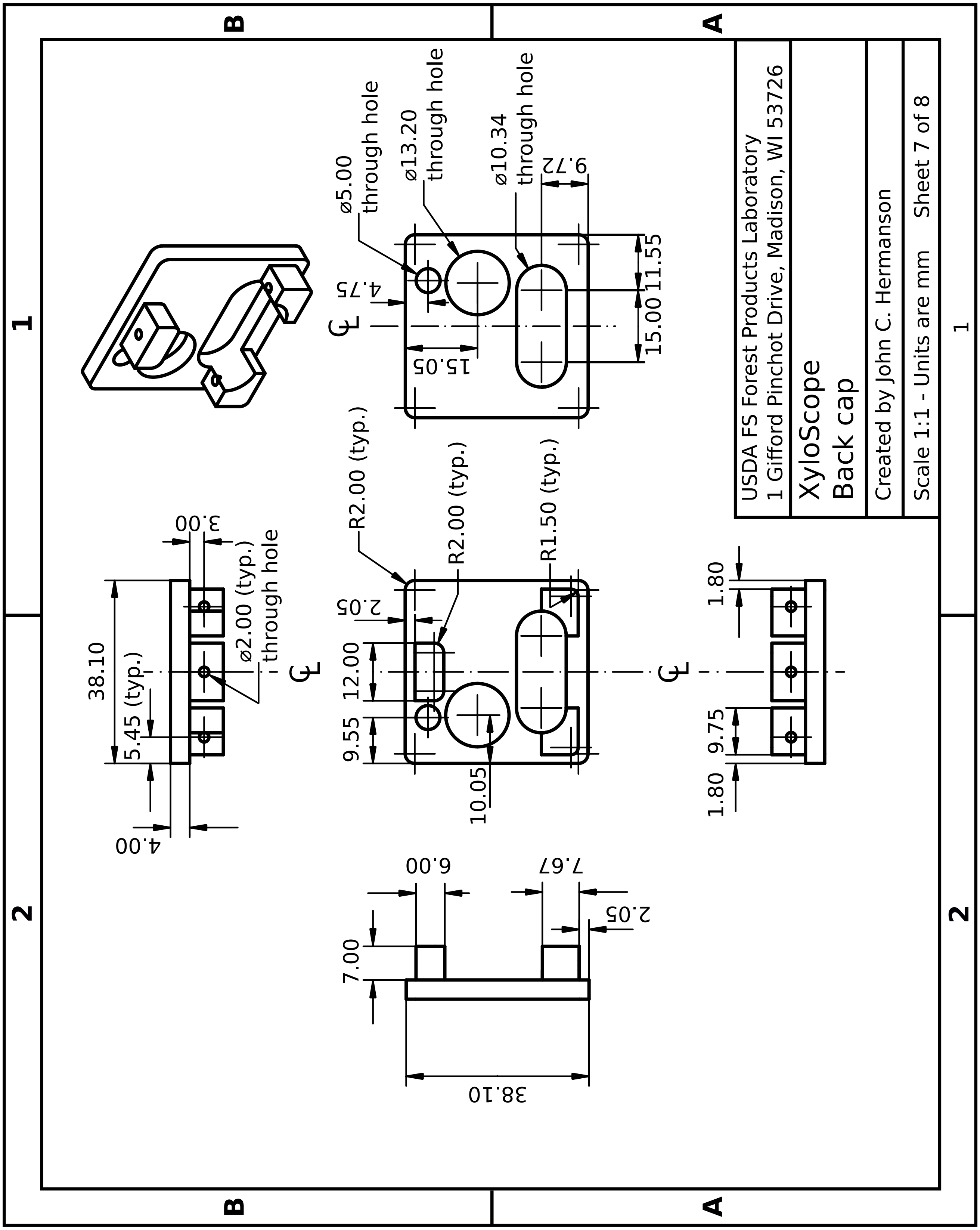
XyloScope
Camera shoe
Created by John C. Hermanson
Scale 1:1 - Units are mm
Sheet 6 of 8
8.00
R1.50 (typ.)
5.00
3.00
35.50
2.50
2.50
10.00
34.50
20.00
23.70
2.50
5.75
ø3.40
through hole
(typ.)
A
B
1
2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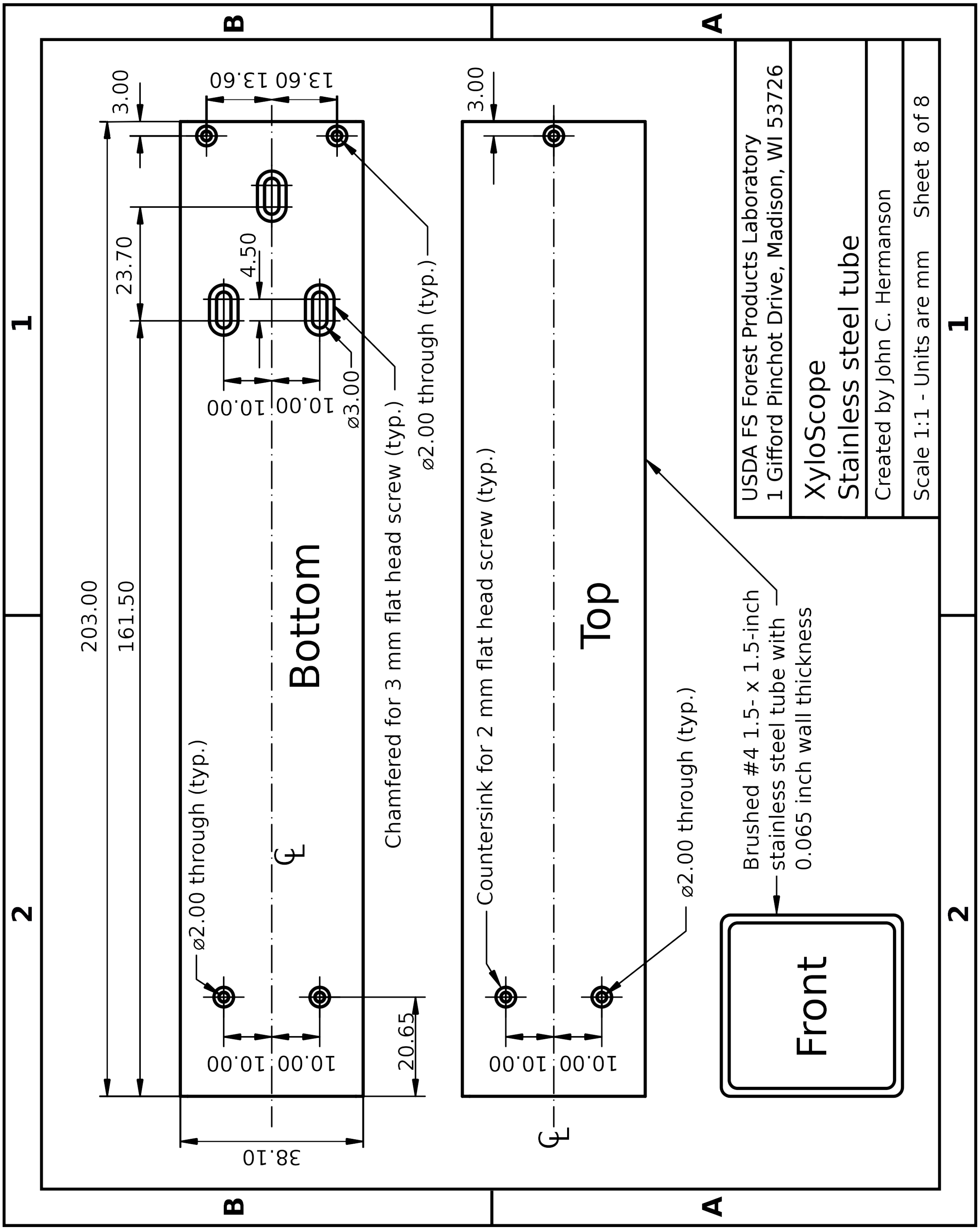
XyloScope
Back cap
Created by John C. Hermanson
Scale 1:1 - Units are mm
Sheet 7 of 8
ø5.00 through hole
ø13.20 through hole
ø10.34 through hole
9.72
4.75
15.05
15.00
11.55
R2.00 (typ.)
R2.00 (typ.)
R1.50 (typ.)
2.05
12.00
9.55
10.05
1.80
9.75
1.80
3.00
ø2.00 (typ.) through hole
38.10
5.45 (typ.)
4.00
6.00
7.67
2.05
7.00
38.10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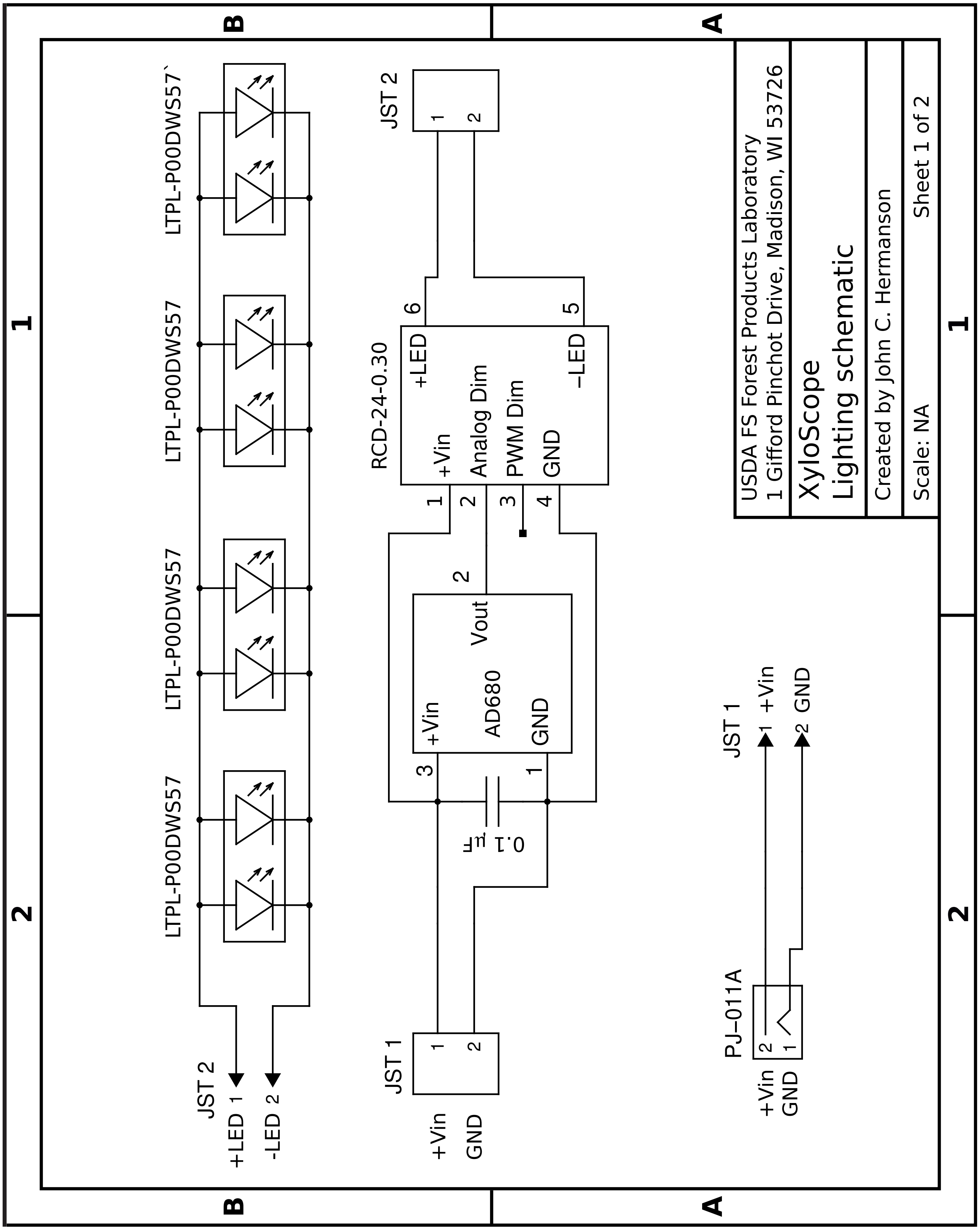
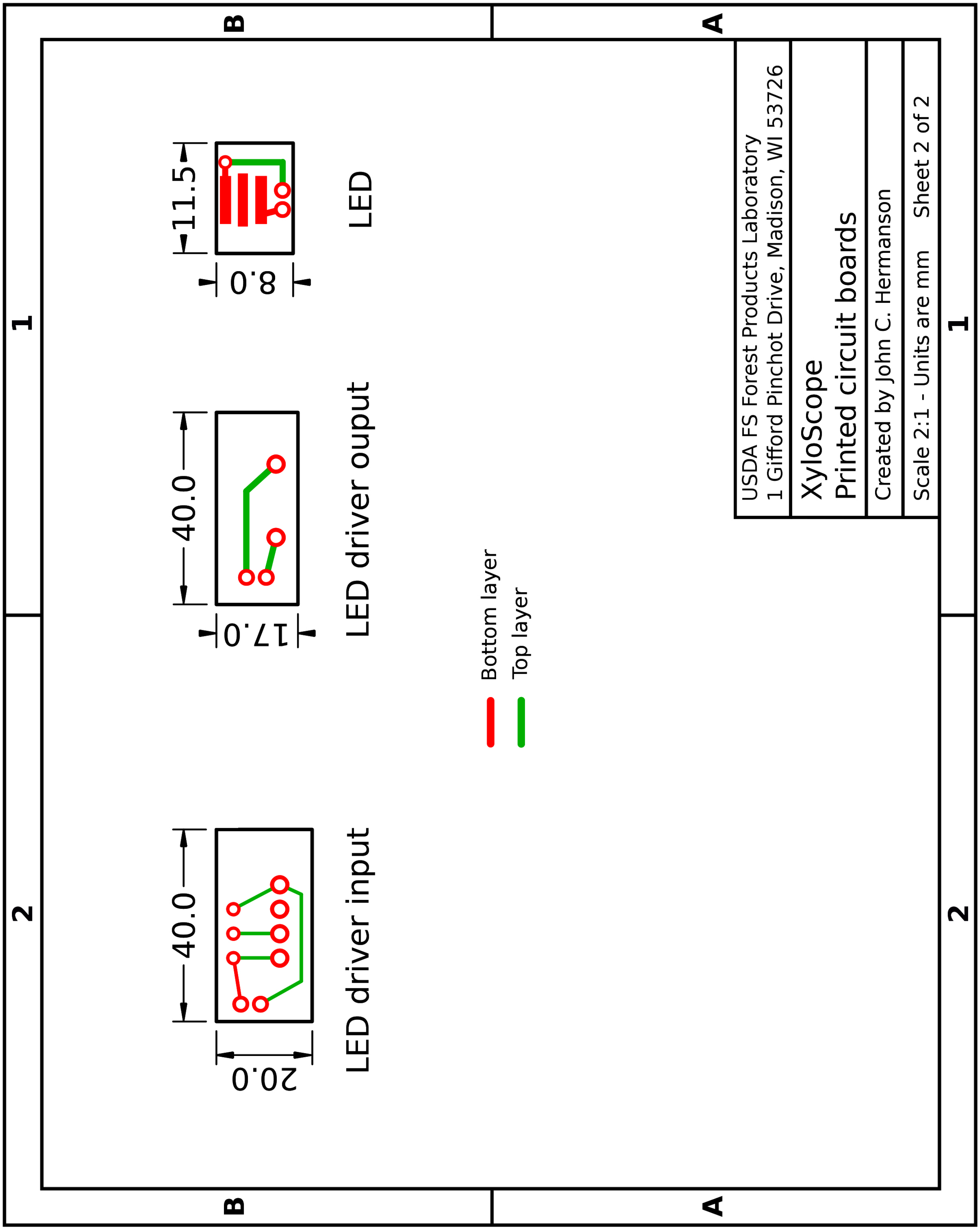
XyloScope
Stainless steel tube
Created by John C. Hermanson
Scale 1:1 - Units are mm
Sheet 8 of 8
Bottom
Top
Front
Chamfered for 3 mm flat head screw (typ.)
ø2.00 through (typ.)
Countersink for 2 mm flat head screw (typ.)
Brushed #4 1.5- x 1.5-inch
stainless steel tube with
0.065 inch wall thickness
ø3.00
203.00
161.50
23.70
4.50
3.00
13.60
10.00
20.65
38.10
A
B
1
2

Appendix C—Specifications of Electrical Components




B
1
2
A
11.5
8.0
LED
40.0
17.0
LED driver ouput
40.0
20.0
LED driver input
Bottom layer
Top layer
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XyloScope
Printed circuit boards
Created by John C. Hermanson
Scale 2:1 - Units are mm
Sheet 2 of 2

Appendix D—Graphics File for 3D-Printed Components

The attached file is a 3D graphics file created in FreeCAD (an open-source 3D parametric modeler) for each of the 3D-printed components.