SKSAS(/M)
Saturated Absorption Spectroscopy Kit

User Guide

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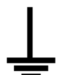
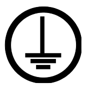
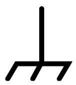
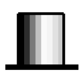
Chapter 1 Warning Symbol Definitions

Below is a list of warning symbols you may encounter in this manual or on your device.

Symbol	Description
	Direct Current
	Alternating Current
	Both Direct and Alternating Current
	Earth Ground Terminal
	Protective Conductor Terminal
	Frame or Chassis Terminal
	Equipotentiality
	On (Supply)
	Off (Supply)
	In Position of a Bi-Stable Push Control
	Out Position of a Bi-Stable Push Control
	Caution: Risk of Electric Shock
	Caution: Hot Surface
	Caution: Risk of Danger
	Warning: Laser Radiation
	Caution: Spinning Blades May Cause Harm

Chapter 2 Safety

All statements regarding safety of operation and technical data in this instruction manual will only apply when the unit is operated correctly.

WARNING

This unit must not be operated in explosive environments.

WARNING

Make sure you use appropriate laser safety glasses during setup and operation.

Chapter 3 Introduction

Saturated absorption spectroscopy has been in use since the 1960s as a tool to suppress the Doppler broadening of spectroscopy signals. In laser frequency stabilization, the Doppler effect would otherwise limit the width of the spectroscopy signal to a few hundred MHz for the principal transitions of alkalis at room temperature.

The use of counter-propagating beams in saturated absorption, however, allows access to the part of the atomic vapor that has vanishing velocity along the propagation axis of the laser, thus eliminating Doppler broadening. Saturated absorption spectroscopy is in widespread use in many atomic physics experiments that require long-term stable laser frequencies close to an atomic transition.

As a teaching tool, the balanced detector employed by the Thorlabs SKSAS kit allows simultaneous observation of the Doppler-broadened absorption signal and the saturated signal with and without the broadened background.

The Thorlabs SKSAS kit offers a proven set of components to construct a compact, fiber coupled spectroscopy setup. Optic mounting adapters specifically designed for this setup facilitate alignment and will save users time when adding such a stabilization technique to their experiment. The SKSAS/M kit provides the same functionality with metric components. Both can easily be integrated with Thorlabs tunable laser kits or third-party tunable sources to stabilize the laser frequency.

3.1. Kit Components

The table below lists all components included in the kit. In cases where the metric and imperial kits contain parts with different item numbers, metric part numbers and measurements are indicated by parentheses.

Item #	Quantity	Description
AD11F	1	SM1-Threaded Adapter for Ø11 mm ≥0.35" (8.9 mm) Long Cylindrical Components
AE8E25E (AE4M6M)	9	Adapter with Internal 8-32 (M4) Threads and External 1/4"-20 (M6) Threads 0.38" (10 mm) Length
BE1(/M)	6	Ø1.25" Studded Pedestal Base Adapter 1/4"-20 (M6) Thread
-	6	6-32 x 1/4" Cap Screw
BS011	1	50:50 Non-Polarizing Beamsplitter Cube 700 - 1100 nm 10mm
CF125	6	Clamping Fork 1.24" Counterbored Slot Universal
CP33(/M)	1	SM1-Threaded 30 mm Cage Plate 0.35" Thick 8-32 (M4) Tap
CP33B	1	30 mm Cage Mounting Bracket
CRM1T(/M)	1	Cage Rotation Mount for Ø1" Optics SM1 Threaded 8-32 (M4) Tap
ER2	4	Cage Assembly Rod 2" Long Ø6 mm
F220FC-780	1	780 nm f = 11.07 mm NA = 0.26 FC/PC Fiber Collimation Package
G14250	1	5-Minute Epoxy General Purpose - Two Part
GCH25-75	1	Heater Assembly for Ø9, Ø19, or Ø25 mm x 75 mm Glass Cells 15 W per Heating Element
-	1	0.050" Hex Key
-	1	3/16" (2.0 mm) Hex Key
-	1	5/64" (3.0 mm) Hex Key
-	1	9/64" (5.0 mm) Hex Key
KM100PM	2	Kinematic Prism Mount 1.00" Deep 6-32 Taps
KS05(/M)	4	Ø1/2" Precision Kinematic Mirror Mount 3 Adjusters 8-32 (M4) Taps
MRA10-M01	3	Right-Angle Prism Mirror Protected Gold L = 10.0 mm
PBS102	2	10 mm Polarizing Beamsplitter Cube 620 - 1000 nm

PDB210A(/M)	1	Free-Space Balanced Photodetector Si 5 mm Active Diameter 320-1060 nm 8-32 (M4) Taps
PF05-03-M01	4	Ø1/2" Protected Gold Mirror
RS075 (RS19/M)	5	Ø1" Pillar Post 1/4"-20 Taps L = 0.75"
RS1 (RS25/M)	4	Ø1" (25.0 mm) Pillar Post 1/4"-20 (M6) Taps L = 1" (25 mm)
RS5M	2	Ø25.0 mm Post Spacer Thickness = 5 mm
SH25S038 (SH6MS12)[a]	6	1/4"-20 x 3/8" (M6 x 12 mm) Cap Screw
SH8S025 (SH4MS06)[b]	2	8-32 x 1/4" (M4 x 6 mm) Cap Screw
N/A	2	Platform for KM100PM Glue-In Optics
SM05L05	2	SM05 Lens Tube 0.50" Thread Depth One Retaining Ring Included
SPW602	1	Spanner Wrench for SM1-Threaded Retaining Rings Graduated Scale with 0.02" (0.5 mm) Increments Length = 3.88"
SS25S075 (SS6MS20)[a]	2	1/4"-20 x 3/4" (M6 x 20 mm) Set Screw
SS8S050 (SS4MS12)[b]	1	8-32 x 1/2" (M4 x12 mm) Cap Screw
VRC5	1	IR Detector Card 700 - 1400 nm
W25S050[c]	6	1/4" (M6) Washer
WPMH05M-780	1	Ø1/2" Mounted Multi-Order Half-Wave Plate Ø1" Mount 780 nm

a. This kit contains the number of screws indicated in the Quantity column; replacements, which are sold in packages of 25, are available by ordering the Item # listed.
b. This kit contains the number of screws indicated in the Quantity column; replacements, which are sold in packages of 50, are available by ordering the Item # listed.
c. This kit contains the number of screws indicated in the Quantity column; replacements, which are sold in packages of 100, are available by ordering the Item # listed.

Chapter 4 Setup and Operation

4.1. Overview

Figure 1 shows a top view of the SKSAS kit when properly aligned. Light is coupled into the setup using an optical fiber. An F220FC-780 collimates the light, which is then passed through a half wave plate and a polarizing beam splitting cube in order to split off power for the "pump" beam. The remaining light is split into two parallel beams, the "probe" and the "reference", which both pass through the vapor cell and are detected by the two photodiodes of a balanced detector.

The light split off for the "pump" beam counter propagates with the "probe" beam through the cell.

The complete setup will fit onto a 10" x 12" breadboard (item number MB1012 for imperial, MB2530/M for metric, not included).

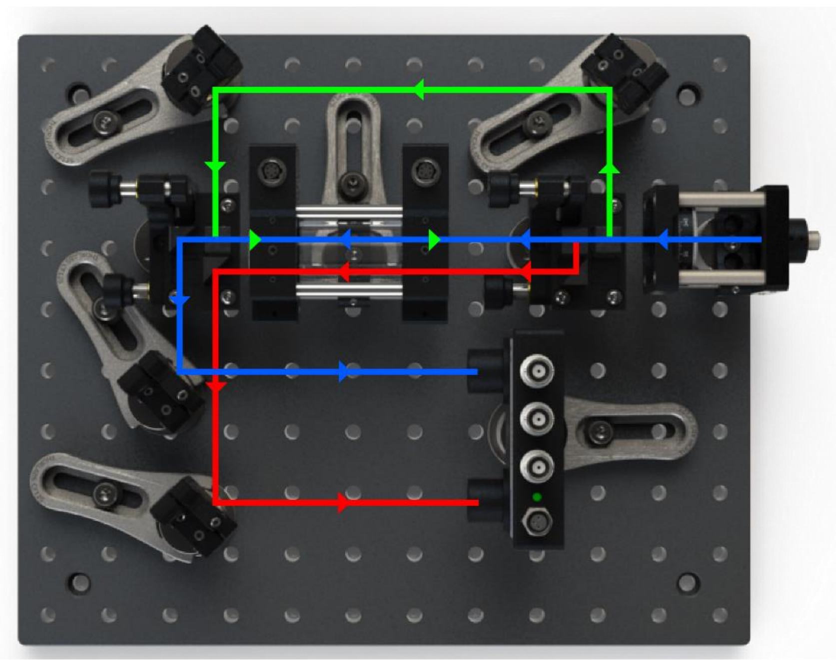


Figure 1 The Thorlabs SKSAS kit assembled on an MB1012 breadboard (not included). The blue line designates the path of the "probe" beam, the green line that of the "pump" beam, and the red line that of the reference beam path.

4.2. Basic Setup

The following instructions detail the setup of the SKSAS spectroscopy kit. The distances between parts given in these instructions and Figure 1 refer to the kit as set up with a minimum footprint. For teaching labs, it is advisable to leave more space between components to give easy access to individual optics. The instructions assume an imperial setup. In cases where the metric part numbers differ from their imperial counterparts, the metric part numbers are provided in parentheses.

4.2.1. Assembling the Fiber Input

- Mount the AD11F adapter in a CP33(/M) cage plate so that the set screws in the AD11F face up, and secure the position with an SM1RR retaining ring on the front face of the adapter.

- Insert the F220FC-780 fiber collimator into the adapter. Rotate it so that the alignment notch faces left (looking at the fiber input) and secure it using the AD11F's set screw.

- Remove the 4-40 set screws from four ER2 cage rods, and mount them in the CP33(/M) cage plate, so that one end of each is flush with the CP33(/M) and protrudes in the direction that the collimator lens faces.

- Mount the WPMH05M-780 wave plate in the CRM1T(/M) rotation mount, and install it on the ER2 cage rods, with the rotating drum facing towards the fiber collimator. Figure 3a shows the complete assembly.

- The assembly should be mounted on one of the RS075 (RS19/M) posts and a RS5M post spacer. Please refer to Figure 1 to get an idea about how to lay out the components on your optical table or breadboard. To simplify alignment later on, also mount the two RS075 (RS19/M) posts that will hold the prism assemblies onto the table or breadboard, and ensure that the collimated beam will pass centrally over both posts.

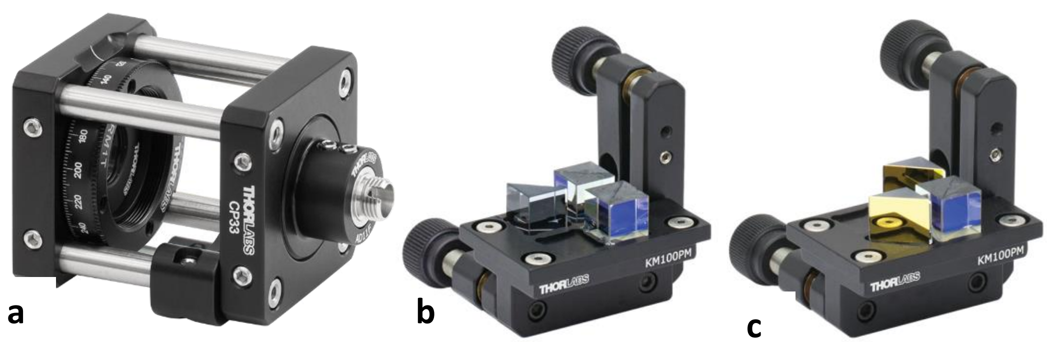


Figure 2 Sub-assemblies used in the SKSAS kit: a) fiber collimator and half wave plate b) input prism assembly and c) output prism assembly.

4.2.2. Installing the Input and Output Prisms

- Take the two supplied platforms and use epoxy (item number G14250, included) or optical adhesive to attach the PBS102, BS011 and MRA10-M01 prisms onto them. The orientation of the prisms is crucial, a diagram for which is shown below in Figure 4. The input faces of the cubes are marked with a dot on the optics. It is advisable to wear gloves while handling the prisms to avoid contaminating their surfaces.

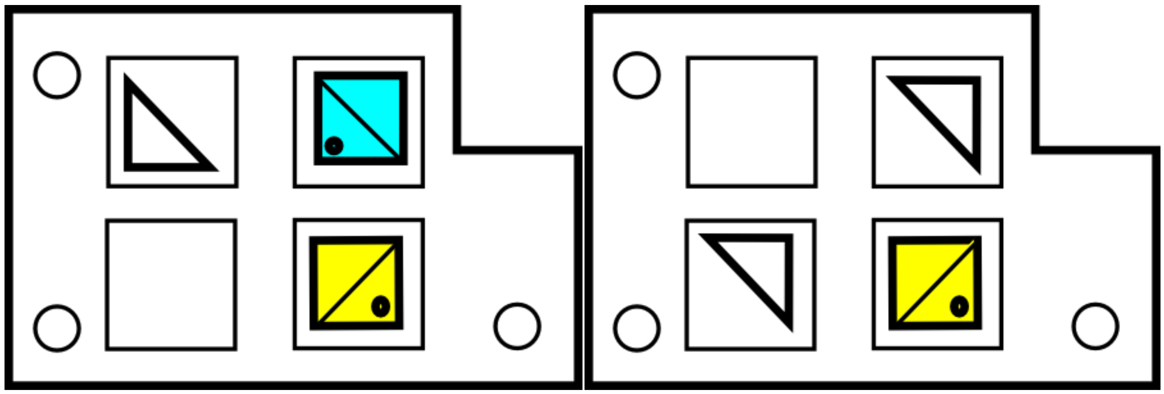


Figure 3 Prism placement on the two supplied platforms. Dots denote the marked input faces on the beam splitting cubes. The positions of the PBS102 beam splitters are marked yellow, the position of the BS011 is marked in cyan. The left schematic gives the layout of the input prisms, the right schematic of the output prisms

- After the adhesive has dried, mount the two supplied platforms to KM100PM mounts, using the included 6-32 button head cap screws. The required 1/16" hex key is included.

- The two prism platforms are mounted onto the RS075 (RS19/M) posts, which were mounted in step 4.2.1. Roughly rotate the input prism mount such that the two beams propagating in the forward direction hit the prism mirrors on the output prism assembly.

4.2.3. Mounting the Vapor Cell

- Mount the GCH25-75 gas cell heater on a RS075 (RS19/M) post, and add a BE1(/M) adapter to the bottom of the post.

- Mount the vapor cell in the GCH25-75 according to its instruction manual.

- The vapor cell is placed in between the two prism assemblies such that both beams exiting the input prism assembly pass through the cell without being clipped. Use a CF125 clamp to secure the cell assembly in place.

4.2.4. Mounting the Pump and Folding Mirrors

- Mount the four PF05-03-M01 Ø1/2" gold mirrors in KS05(/M) mounts.

- Mount the KS05s on top of RS1 (RS25/M) posts using the AE8E25E (AE4M6M) adapters. Add BE1(/M) adapters to the bottom of the posts.

- Refer to Figure 1 for rough placement of the mirrors. The two mirrors that form the pump beam path should be placed such that they form a rectangle with the PBS102 cubes. This will facilitate further alignment. The other two mirrors should be placed such that the reference and probe beam are incident on the balanced detector’s photodiodes (see section 4.3).

4.2.5. Mounting the Balanced Detector

- Mount the PDB210A(/M) detector on an RS075 (RS19/M) post with an RS5M spacer and add a BE1(/M) pedestal adapter to the bottom.
- Attach two SM05L05 lens tubes to the PDB210A(/M) photodiode inputs.
- Use a CF125 clamp to secure the balanced detector in position.

4.3. Aligning the *SKSAS*

Check that the LDS12B power supply is set to the correct voltage level for your country. Failure to set the correct voltage can damage the power supply and the balanced detector!

- Attach the LDS12B power supply to the balanced detector, and check that the detector turns on (i.e. the green LED on top lights up).
- Couple a small amount of power, roughly 1 mW, into a polarization maintaining optical fiber. For a Rubidium setup, Thorlabs part number P1-780PM-FC-5 is a suitable fiber, for Potassium, P1-630PM-FC-5 may be used. When using 3^{rd} party fiber cables, ensure that the slow axis of the fiber is aligned with the connector key.
- First, rotate the half wave plate such that no power is present in the pump path. Then adjust the fiber collimator assembly and the input prism assembly, so that the probe and reference beams pass the vapor cell without clipping.
- Adjust the output fiber assembly and the two folding mirrors such that the probe and reference beams are incident on the two photodiodes of the balanced detector.
- Rotate the half wave plate so that you have most of the power in the pump path. Now use the two mirrors of the pump path to overlap the pump and probe beams both before and after the vapor cell. This part of the alignment can be tricky – it is best performed in a darkened room. A helpful trick in overlapping the two beams is to increase the power in the pump path so that you can see it leak through the VRC5 IR viewing card. This way you can see both beams on the front surface of the card. Alternatively, look at scattered light from a piece of paper with a small hole pierced into it.
- Once pump and probe paths are overlapped, connect an oscilloscope or voltmeter to the monitoring outputs (labeled MONITOR+ and MONITOR-) of the balanced detector, and use the two folding mirrors to maximize the signals. This is best performed while the laser is detuned off resonance with the atoms in the cell.
- Connect your oscilloscope to the RF OUTPUT connector of the balanced detector and adjust the folding mirrors until the RF output is nulled.

Your SKSAS system is now aligned. If you set your laser to scan over a resonance, you should be able to observe a spectrum as shown in Figure 4. Once you observe the resonance, you can tweak the pump path mirrors to maximize the signal. If the signal is very low, chopping the pump beam with a piece of paper can help make the resonance peaks visible. Tweaking the overall power in the system and the balance between pump and probe path allows you to make trade-offs between signal strength and width of the resonances.

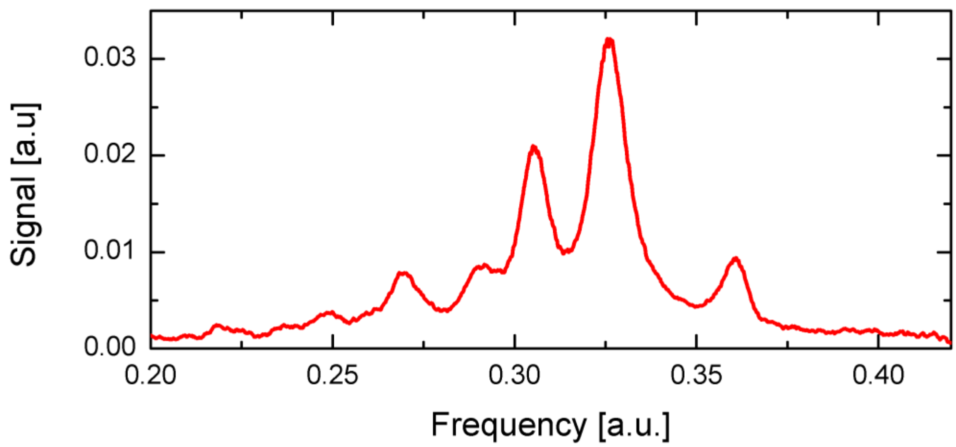


Figure 4 Saturated absorption signal of the 87Rb 5S1/2 F=2 to 5P3/2 F=1,2,3 transitions and crossovers. The spectrum was recorded using a Thorlabs previous-generation TLK-L780M tunable laser kit.

4.4. Heating and Temperature Stabilization of the Vapor Cell

The Thorlabs SKSAS spectroscopy kit allows for the heating and temperature stabilization of the vapor cell (not included). For this purpose, two 6-pin Hirose connectors are available on the top of the gas cell holder.

The Thorlabs TC300B temperature controller (not included) can directly interface with these connectors. Please refer to the TC300B user manual for setup instructions.

For use with 3rd party controllers, the pin-out for the gas cell heater connectors are defined in Figure 5. The mating connector is Hirose part number HR10A-7P-6PC(73), and can be procured from various electronics suppliers (e.g. DigiKey part number HR1665-ND).

The sensor employed in the spectroscopy system is a TH100PT platinum resistive sensor. The sensor response is given by

$$R(t) = 100\Omega \cdot \left(1 + 3.9083 \cdot 10^{-3} \frac{1}{{}^\circ C} t - 5.775 \cdot 10^{-7} \frac{1}{{}^\circ C^2} t^2\right)$$

Here, R(t) is the temperature dependent resistance of the sensor, and t is the temperature in degrees Celsius.

Pin	Function
1	Heater
2	Heater Return
3	Reserved
4	Temperature Sensor
5	Temperature Sensor Return
6	Reserved

Figure 5 The gas cell heater connector employs a Hirose 6-pin connector. The pin-out is given on the right.

Chapter 5 Theory of Operation

When performing spectroscopy on gases, the measured width of a transition line is limited by several effects. The fundamental limit is the natural linewidth, which is determined by the lifetime of the excited state. For the fundamental transitions of the alkali metals, the natural linewidth is on the order of few megahertz.

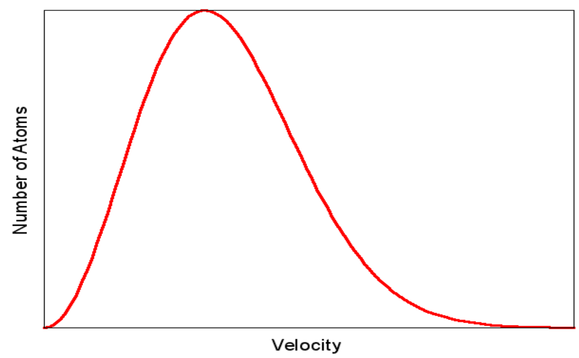


Figure 6 Maxwell-Boltzmann velocity distribution in a thermal gas. The non-zero velocity leads to a spectral broadening of absorption features.

Under ambient conditions, however, the transitions are broadened due to Doppler broadening. Depending on the speed of an atom relative to the exciting photon, the transition frequency appears shifted. The shift can be described to first order by $\Delta f = \frac{v_{atom}}{c} f$. Here, v_{atom} is the atom's velocity, f the transition frequency and c the speed of light.

In a gas at finite temperature, atoms have a velocity distribution given by the Maxwell-Boltzmann distribution (see Figure 7). This distribution of velocities in turn leads to a distribution of Doppler shift frequencies. This effectively leads to a broadening of the observed absorption line. As a guideline, the Doppler-broadened absorption feature is on the order of a few hundred MHz wide at room temperature, two orders of magnitude larger than the natural linewidth. The broadened absorption feature is shown in the left panel of Figure 7 (red curve).

Several methods exist to overcome the limit imposed by Doppler broadening. In saturated absorption spectroscopy, a second, counter-propagating beam is introduced. For this beam, dubbed the pump beam, the Doppler shift has the opposite sign than for the probe beam. Since Δf only has a linear term, the Doppler shift for the two beams is only identical if it is zero, i.e. the velocity of the atoms along the beam propagation axis is zero. For all other cases, the beams are in resonance with a different velocity class of atoms and therefore the pump beam does not perturb the transmission of the probe beam.

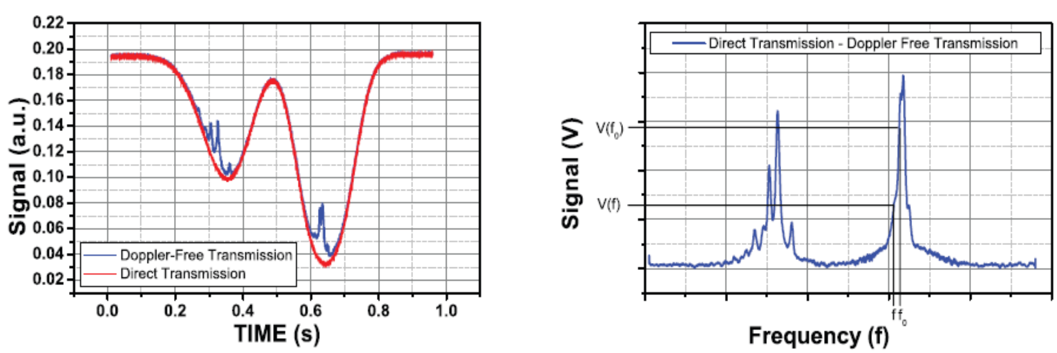


Figure 7 Saturated absorption data for the Rubidium D2 line. Left panel: The red trace shows transmission of the probe beam without saturation, the blue trace shows transmission with a pump beam saturating the vapor. The difference signal between the two signals shown on the left, as output by the SKSAS system. The spectra have been recorded using Thorlabs' previous-generation TLK-L780M tunable laser kit.

When Δf = 0, however, the pump beam will excite ground-state atoms that the probe beam is also in resonance with. Because the pump beam reduces the amount of ground-state atoms of zero velocity, the probe beam will experience less absorption. This leads to a dip in the absorption of the probe beam at the location of the resonance, as is shown in the left panel of Figure 7 (blue line). In order to achieve a significant dip in the absorption of the probe beam, the pump beam is typically operated at a higher power than the probe beam.

The same effect of reduced probe beam absorption occurs if the pump and probe beam are in resonance with different transitions with different ground states. This leads to additional resonances, termed "cross-over" resonances, halfway between transitions. These "artificial" transitions can be useful, because they allow the stabilization of a laser slightly detuned from actual transitions.

The Thorlabs SKSAS system performs an absorption measurement and a saturated absorption measurement at the same time and subtracts the two signals using a balanced detector (see Figure 8). The resulting signal then shows the resonances without the Doppler-broadened background.

An example is shown in the right panel of Figure 7.

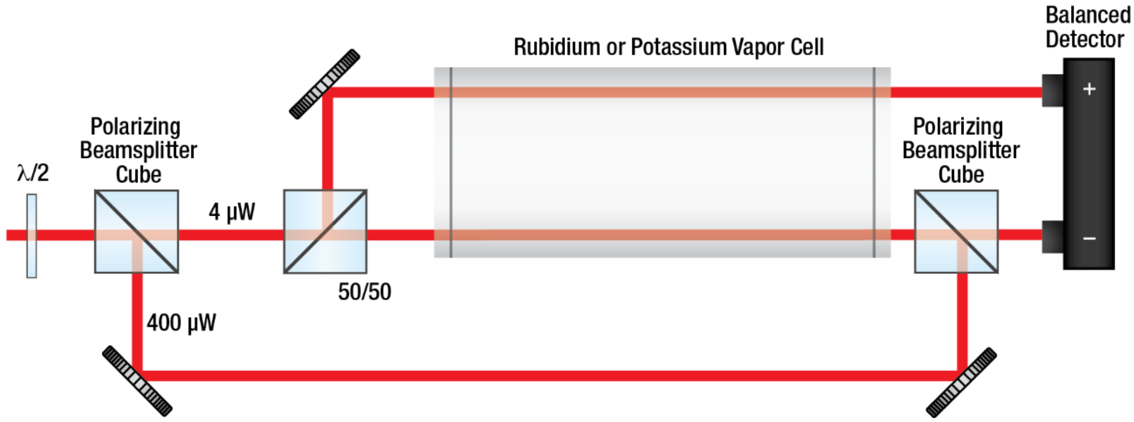


Figure 8 Schematic representation of the Thorlabs SKSAS kit. The SKSAS performs both a regular absorption measurement (topmost beam path) and a saturated absorption measurement (center beam path). The output signal is the difference between both signals, showing only the nonbroadened transitions, as shown in the right panel of Figure 7.

- Rotate the fiber input assembly, and the input prism holder, and move the gas cell so that two beams are passing the gas cell in parallel, so that they are incident on the two mirror on the output prism assembly.
- Move the two folding mirrors, so that the two beams are incident on them, without clipping.
- Align the folding mirrors, so that the beams are incident on the two photodetectors. Connect a voltmeter to the two "Reference" outputs to determine the optimum beam position, then use the density filter wheel to null the output of the "Signal" output.
- Hook the signal output up to an oscilloscope, and set the input laser to scan over the resonances. Now use the two side mirrors to overlap the pump with the probe beam. To get initial alignment, it is helpful to increase the input power, and set the pump/probe balance so that there is about equal amounts of power in the beams. Using an IR viewing card, rough alignment can be performed. Once this is achieved, the signal can be fine-tuned by observing the oscilloscope output.

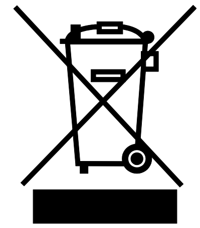
Chapter 6 Troubleshooting

Issue	Resolution
There is no spectroscopy signal present	• Ensure that your laser is on resonance using a wavemeter or spectrum analyzer, and that it is scanning over a few GHz. Alternatively, you can use a camera that is sensitive at the transition wavelength to observe fluorescence from the vapor cell. • Check that the power supply is connected to the housing, that the power supply is turned on and set to the correct voltage setting for your region. • Ensure that there is light coupled into the input fiber, and that it has the correct polarization.
The spectroscopy signal is small	• Increase input power • Check power balance between pump and probe beam
The spectroscopy signal shows artifacts and is distorted	• Decrease input power

Chapter 7 Regulatory

As required by the WEEE (Waste Electrical and Electronic Equipment Directive) of the European Community and the corresponding national laws, Thorlabs offers all end users in the EC the possibility to return “end of life” units without incurring disposal charges.

- This offer is valid for Thorlabs electrical and electronic equipment:
- Sold after August 13, 2005
- Marked correspondingly with the crossed out “wheelie bin” logo (see right)
- Sold to a company or institute within the EC
- Currently owned by a company or institute within the EC
- Still complete, not disassembled and not contaminated



Wheelie Bin Logo

As the WEEE directive applies to self-contained operational electrical and electronic products, this end of life take back service does not refer to other Thorlabs products, such as:

- Pure OEM products, that means assemblies to be built into a unit by the user (e. g. OEM laser driver cards)
- Components
- Mechanics and optics
- Left over parts of units disassembled by the user (PCB’s, housings etc.).

If you wish to return a Thorlabs unit for waste recovery, please contact Thorlabs or your nearest dealer for further information.

7.1. Waste Treatment is Your Own Responsibility

If you do not return an “end of life” unit to Thorlabs, you must hand it to a company specialized in waste recovery. Do not dispose of the unit in a litter bin or at a public waste disposal site.

7.2. Ecological Background

It is well known that WEEE pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.

The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of life products will thereby avoid negative impacts on the environment.

Chapter 8 Thorlabs Worldwide Contacts

USA, Canada, and South America
Thorlabs, Inc.
56 Sparta Avenue
Newton, NJ 07860
USA
Tel: 973-300-3000
Fax: 973-300-3600
www.thorlabs.com
www.thorlabs.us (West Coast)
Email: sales@thorlabs.com
Support: techsupport@thorlabs.com

Europe
Thorlabs GmbH
Hans-Böckler-Str. 6
85221 Dachau
Germany
Tel: +49-(0)8131-5956-0
Fax: +49-(0)8131-5956-99
www.thorlabs.de
Email: europe@thorlabs.com

France
Thorlabs SAS
109, rue des Côtes
78600 Maisons-Laffitte
France
Tel: +33 (0) 970 444 844
Fax: +33 (0) 825 744 800
www.thorlabs.com
Email: sales.fr@thorlabs.com

Japan
Thorlabs Japan, Inc.
Higashi-Ikebukuro Q Building 1F
2-23-2, Higashi-Ikebukuro,
Toshima-ku, Tokyo 170-0013
Japan
Tel: +81-3-5979-8889
Fax: +81-3-5979-7285
www.thorlabs.jp
Email: sales@thorlabs.jp

UK and Ireland
Thorlabs Ltd.
1 Saint Thomas Place, Ely
Cambridgeshire CB7 4EX
Great Britain
Tel: +44 (0)1353-654440
Fax: +44 (0)1353-654444
www.thorlabs.com
Email: sales.uk@thorlabs.co.uk
Support: techsupport.uk@thorlabs.com

Scandinavia
Thorlabs Sweden AB
Mölndalsvägen 3
412 63 Göteborg
Sweden
Tel: +46-31-733-30-00
Fax: +46-31-703-40-45
www.thorlabs.com
Email: scandinavia@thorlabs.com

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Thorlabs Vendas de Fotônicos Ltda.
Rua Riachuelo, 171
São Carlos, SP 13560-110
Brazil
Tel: +55-16-3413 7062
Fax: +55-16-3413 7064
www.thorlabs.com
Email: brasil@thorlabs.com

China
Thorlabs China
Room A101, No. 100
Lane 2891, South Qilianshan Road
Putuo District
Shanghai
China
Tel: +86 (0) 21-60561122
Fax: +86 (0)21-32513480
www.thorlabschina.cn
Email: chinasales@thorlabs.com