ACOUSTO-OPTIC TUNABLE FILTER
EXPERIMENT SUMMARY

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Introduction

The AOTF instrument acquired by Penn State University during fall 1995 was used for several experiments geared towards applications development. Various tests were conducted to evaluate the performance and characterize the filter response of the instrument. This report outlines some of the work done at Penn State along with the working principle of the AOTF.

This AOTF instrument was developed by Prof. Vladislav I. Pustovoit of the Institute of Radio Engineering & Electronics of the Russian Academy of Sciences in Moscow. It is an electronically tunable filter in the region 400-800 nm. The accuracy of the filter is very high (< 5 Å) and dependent only on the quality of the acoustic control signal applied to it. This provides a very repeatable narrowband filter capability with a spectral resolution of 1.5-2.0 Å.

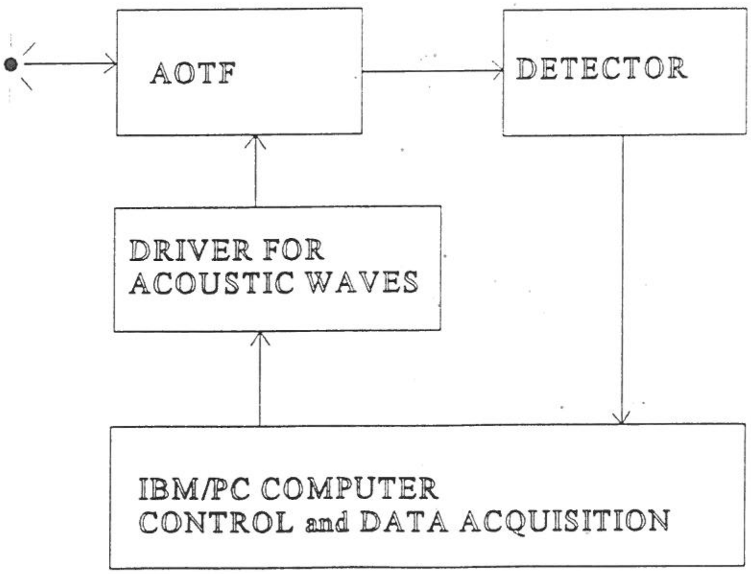


Figure 1: AOTF setup

Figure 1 shows the AOTF setup used in all our experiments. An IBM compatible computer is used to control the acoustic wave driver. The typical range of frequencies of the driver is between 60

MHZ and 130 MHZ at 1V p-p. Each acoustic frequency can be mapped to a unique center wavelength for the filter passband in the 400-800 nm range. One of the highlights of this system is the ability to have software control over the filter characteristics. This allows us to change between wavelengths of interest or to perform a sweep over a band via software. In addition, the filter can be operated in continuous or pulsed mode. The filter gain can be controlled in software to allow for a large dynamic range.

Working Principle of the AOTF

Figure 2 shows a schematic of the AOTF. We first trace an optical path through the AOTF to help explain its operation.

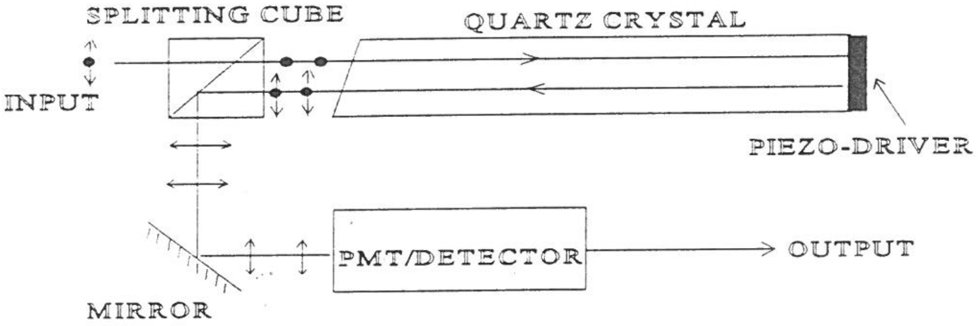


Figure 2: AOTF schematic

Light is incident on the front face of the splitting cube. The incident light can be assumed to be unpolarized. The splitting cube passes only one polarization through it, as shown by dots (polarization direction perpendicular to the plane of the paper) [1]. The piezo-driver sets up the acoustic waves that propagate in a direction collinear to the incoming light. The frequency and the amplitude of the acoustic wave causes the polarization of the light, at the wavelength of interest, to change to the orthogonal direction. As a result, we get light in both polarizations coming out of the crystal. The desired wave (polarization shown by arrowheads) is filtered out by the splitting cube. It is then reflected by the mirror into the photo multiplier tube.

The crystal is made of quartz (SiO_2), which is an anisotropic material and exhibits birefringence. The interaction between the optical and the acoustic wave occurs as a result of the photoelastic effect in the crystal [2]. This interaction causes light of one polarization to couple or diffract into light of the orthogonal polarization. At a given acoustic frequency, only the light in a narrowband region satisfies the coupling condition. A detailed treatment of the photoelastic effect can be found in references [2-3]. The relationship between the acoustic frequency f_a and the filtered optical wavelength λ_0 is given by

$$f_a = \frac{V}{\lambda_0}(n_o - n_e) \tag{1}$$

where, V is the acoustic velocity in the crystal, n_o and n_e are the indices of refraction in the ordinary and extraordinary directions of the crystal.

Applications

In order to evaluate the performance of the instrument, we conducted some simple experiments with colored light sources. Figure 3 shows the setup for the experiment. A piece of white paper was illuminated using an incandescent lamp. Different colored gels were inserted in front of the AOTF and spectra were measured. Figure 4 shows the spectra for various color gels. The line colors on the plot are representative of the gel colors.

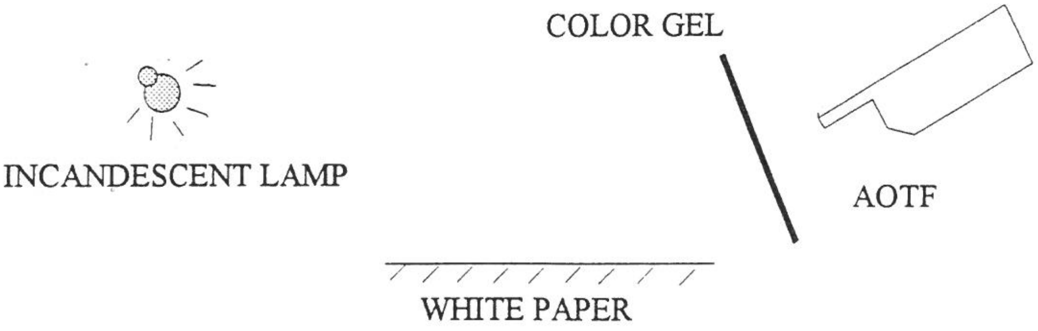
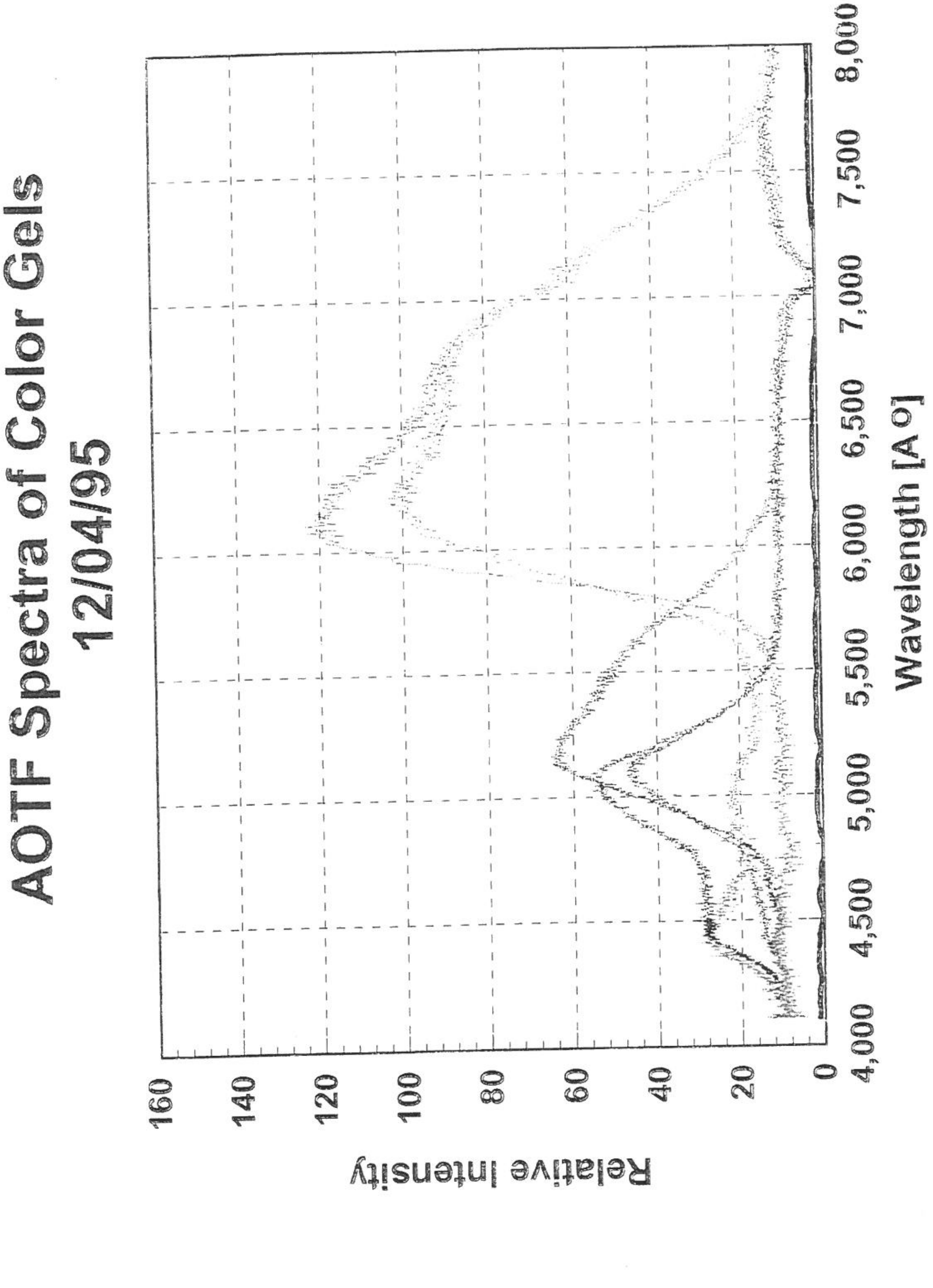


Figure 3: Setup for color gels spectra

Figure 4


AOTF Spectra of Color Gels
12/04/95
Relative Intensity
160
140
120
100
80
60
40
20
0
4,000
4,500
5,000
5,500
6,000
6,500
7,000
7,500
8,000
Wavelength [A º]

The black line shows the background signal of the instrument. Among other features, we notice a few interesting characteristics from Figure 4. There is a marked contrast in the transmission of the yellow gel as opposed to the blue gel. Also, the magenta gel shows a small blue component in addition to a large red component. This is consistent with the color composition scheme of magenta. There is a roll-off in the spectra above 7000 Å because of the response of the PMT in that region.

Another application that we have investigated is the observation of the solar spectrum, in particular of the Fraunhofer lines. We were able to identify several of the lines corresponding to various hydrogen and oxygen absorption lines. Figure 5 shows the solar spectrum measured at noon on 12/08/95 at Penn State. The AOTF was pointed directly at the sun with an integration time of approximately 5 minutes. Table 1 lists the wavelengths of some of the Fraunhofer lines observed in Figure 5.

Table 1

Element	Line	Wavelength [nm]	Element	Line	Wavelength [nm]
O_2	B	687	H_α	C	656
Na	D	589	H_β	F	486

As an example of the AOTF's resolution capability, we present the spectrum of a thallium lamp. Thallium has a spectral peak at 535 nm in the visible region. Figure 6 shows this peak to be at 534 nm. This can be attributed to the calibration error of the AOTF. The FWHM of this peak is 0.5 nm. The AOTF is capable of a finer resolution of about 0.2 nm at shorter wavelengths and can be used to capture relatively narrow lines in the spectrum.

Conclusions

The AOTF instrument has been described as a versatile detector system. Its operation has been explained by means of geometric ray tracing and references to photoelastic effect. Some of the experiments conducted at Penn State have been presented along with their results. The merits of the AOTF have been highlighted along the way with various results. The versatility of the instrument makes it suitable for a scanning lidar system. It can also be used to observe solar spectra along varying optical paths throughout the day to observe the variation of certain absorption lines with the

Figure 5

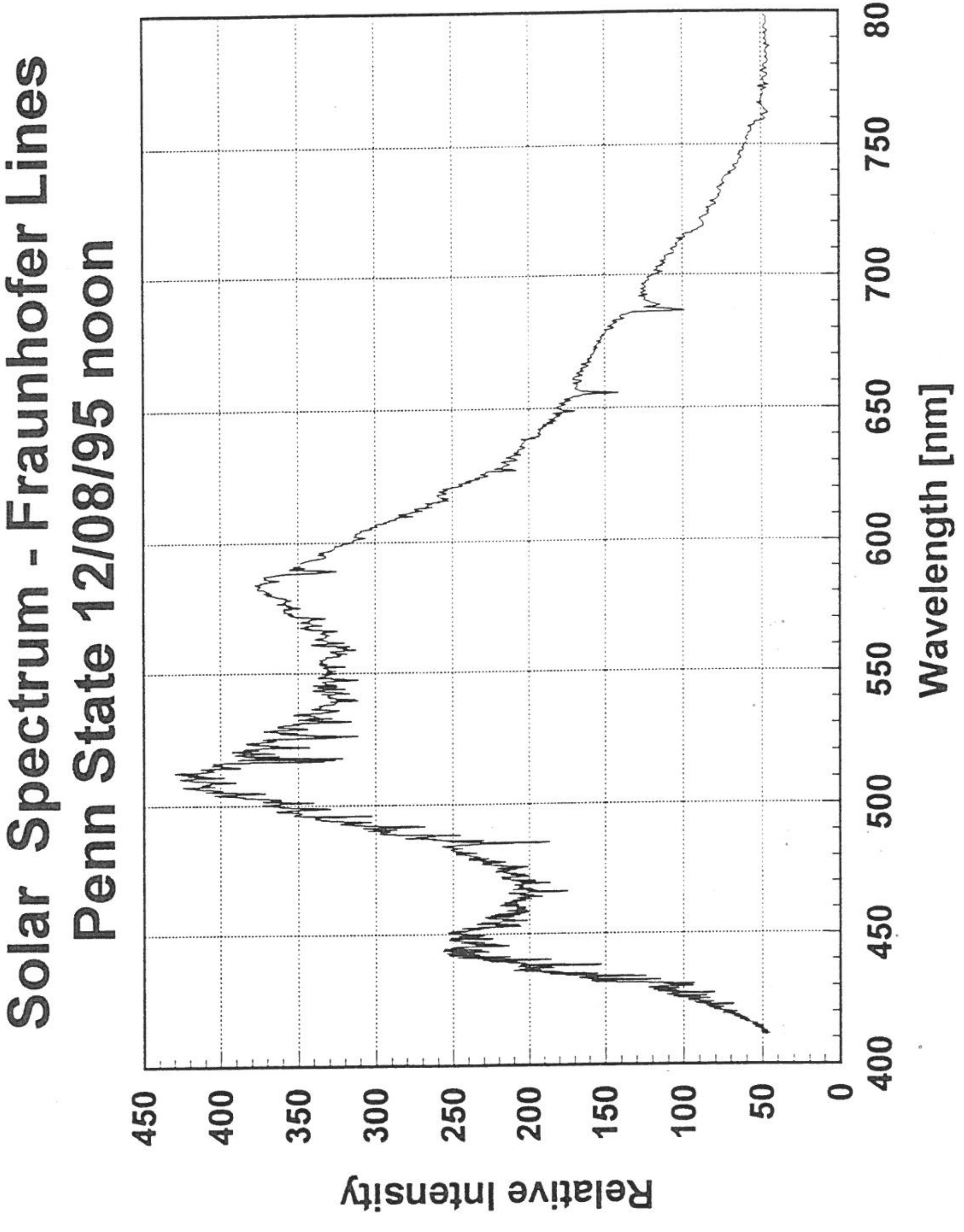
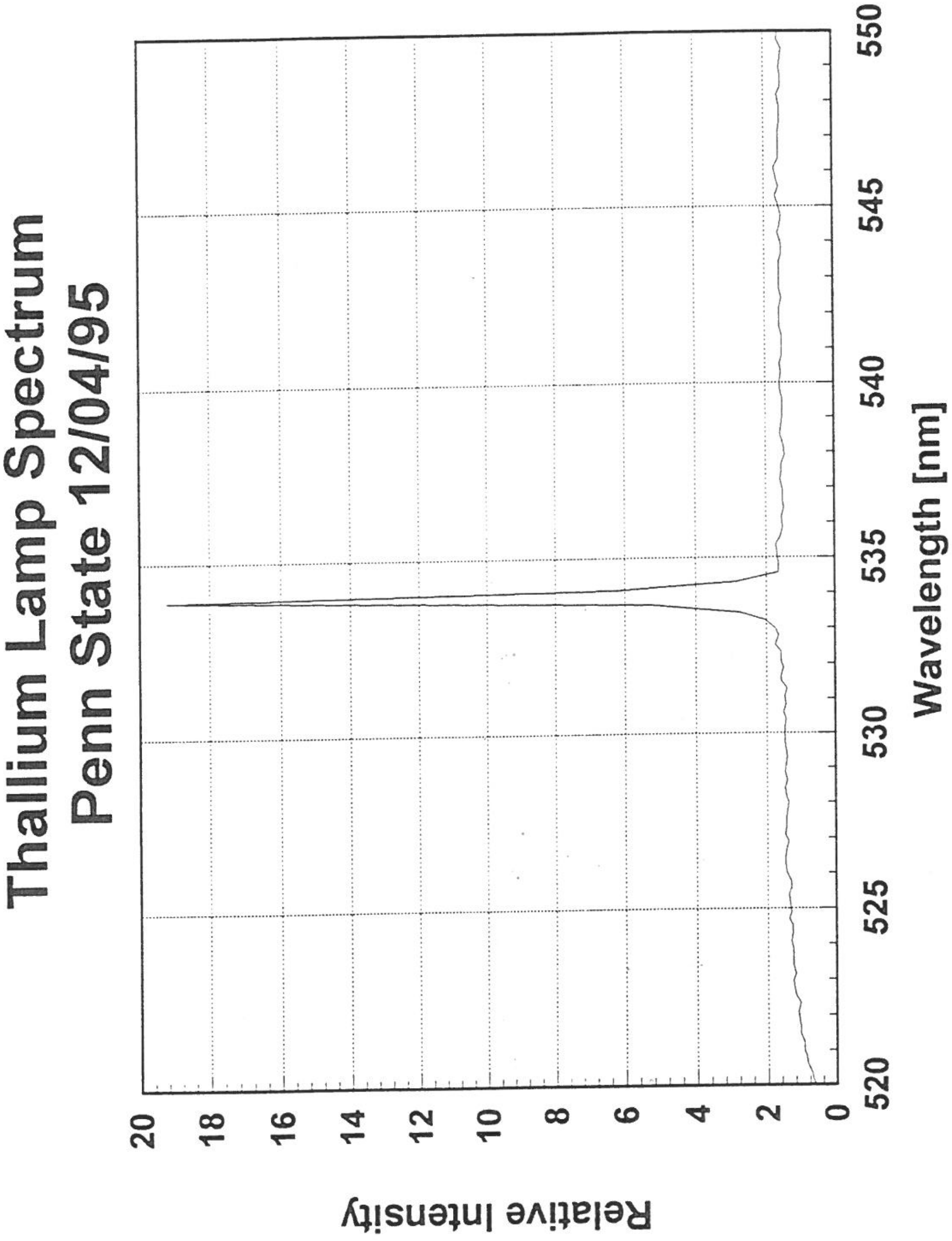

Solar Spectrum - Fraunhofer Lines
Penn State 12/08/95 noon
Relative Intensity
0
50
100
150
200
250
300
350
400
450
Wavelength [nm]
400
450
500
550
600
650
700
750
800

Figure 6


Thallium Lamp Spectrum
Penn State 12/04/95
Relative Intensity
0
2
4
6
8
10
12
14
16
18
20
520
525
530
535
540
545
550
Wavelength [nm]

solar zenith angle. Such a measurement could, for example, be compared with the LOWTRAN or HITRAN databases for atmospheric transmission of lines from minor species.

References

[1] Pustovoit, V.I., Private Communication and AOTF Documentation, 1995.

[2] Harris, S.E. and R.W. Wallace, Acousto-Optic Tunable Filter, *Journal of the Optical Society of America*, **59**, pp. 744-747, 1969.

[3] Dixon, R.W., Acoustic Diffraction of Light in Anisotropic Media, *IEEE Journal of Quantum Electronics*, **QE-3**, pp. 85-93, 1967.