UCID-16497

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CHARACTERISTICS OF THE OPTICAL MULTICHANNEL ANALYZER AS
A SPECTROSCOPIC DETECTOR

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May 30, 1974

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Prepared for U. S. Atomic Energy Commission under contract no. W-7405-Eng-48

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CHARACTERISTICS OF THE OPTICAL MULTICHANNEL ANALYZER AS A SPECTROSCOPIC DETECTOR

ABSTRACT

Data and experiences gathered from using the SSRI Optical Multichannel Analyzer as a spectroscopic detector are presented. Model 1205B is discussed and compared to Model 1205F. Operating hints for the system and examples of its use in spectroscopy are given. This paper is an informal supplement to the SSRI manual, which is oriented toward the computer characteristics of the analyzer rather than the detector characteristics.

INTRODUCTION

I present experiences and data gathered from using the SSRI Optical Multichannel Analyzer* as a spectroscopic detector. This information is useful because the SSRI manual is oriented toward the use of the computer characteristics of the analyzer rather than its detector characteristics. I discuss problems I had in using the detector system, present operating hints in Appendix A, and give examples of the detector's use in spectroscopy in Appendix B.

The SSRI Optical Multichannel Analyzer is a silicon diode detector array with signal analysis capability. Although I used two models of the instrument in my work, data presented here is for Model 1205B (serial No. 572), which was purchased shortly after SSRI introduced the instrument in 1972. The instrument may be used in any experiment where the desired information is light intensity as a function of position. It can do the following:

- Detect light signals over the spectral range of 350 to 1100 nm,[†]
- Display a temporally changing signal (a "real time" signal, displaying changes over ~33 ms or longer),
- Integrate a signal for a specified time period,
- Store integrated signals,
- Subtract stored signals from one another,
- Automatically remove noise from the real time signal,
- Display the signal magnitude and its position for an element within the detector array,
- Sum the magnitudes of the signals between specified positions in the detector array,

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

[†]Model 1205F (described later) has a spectral range of 200 to 1100 nm.

- Provide a logarithmic display,
- Provide an analog signal from a selected detector element,
- Display data digitally (one element at a time), on CRT (all elements at once), and on a chart recorder (all elements sequentially or one element as a function of time).

The analyzer has 500 elements or channels, each composed of many diodes placed on a vidicon camera cathode (a RCA 4532 or 4532A for Model 1205B). The elements are each 25.4 μm wide and also 25.4 μm center-to-center spaced. The electron beam of the vidicon extracts the signal by scanning the elements about every 33 ms. The temporal (real time) display is therefore a result of a signal integration of at least 33 ms. The analyzer system can detect picosecond and cw sources.

SYSTEM CHARACTERISTICS

Spatial Resolution

The response of the analyzer to signals of spatial extent less than an individual channel is used to determine the optimal adjustment of the spectrometer and detector. Tests with a 10- μm -wide signal (from a spectrograph illuminated by a single wavelength source) on a single 25- μm channel show that the response of the adjacent channels is one-third or less of the illuminated channel. Appendix A discusses use of this fact in adjustment procedures.

Spectral Response

Measurements of spectral response were made on an uncalibrated spectrograph and therefore the responses obtained are of the analyzer-spectrograph system. The spectrograph had the following characteristics during the measurements: a slit area of $0.0025 \times 0.4 \text{ cm}^2$, a dispersion of 0.6 to 0.8 nm/mm over a range of 350 to 1100 nm, and a blaze wavelength of 1000 nm. Each detector element (25.4 μm wide) spans about 0.015 nm so that about 7.5 nm were observed per measurement. The 1200 l/mm grating was rotated to successively bring 7.5 nm portions of the 350- to 1100-nm spectral range of the detector for measurements. A QL-128 spectral irradiance ($\text{W}/\text{cm}^2 \cdot \text{nm}$) lamp, calibrated by the National Bureau of Standards, was used as the light source. The integration time of 3 s provided the energy at the slit shown in Fig. 1. When measurements were being made at 700 nm or above, a calibrated Corning 2-64 glass filter was used to block radiation below 600 nm. Figure 2 shows the spectral transmission of this filter. The relative spectral response of the analyzer-spectrometer system was obtained by integration of the lamp signal for 3 s followed by a 3-s integration without the lamp signal. After subtraction, the resultant signal was displayed on an oscilloscope and recorded by a calibrated chart recorder. Correction for the spectral transmission of the filter was made. Since the end points of each 7.5-nm measurement are duplicated by adjacent measurements, the end point data were averaged. The end point and midpoint

Fig. 1. Energy from a QL-128 spectral irradiance lamp at the spectrograph slit. Data used to plot the curve are given.

Fig. 2. Spectral transmission of Corning 2-64 filter. The filter was used to block radiation below 600 nm.

values for each measurement were used to plot the relative spectral responses shown in Figs. 3 and 4. In Fig. 4 the end point and midpoint data are identified separately. This shows that the variations in Fig. 3 are a result of the differences in end and midpoint values. Since these values are taken 3.8 nm apart and the lamp is assumed not to vary that rapidly (NBS calibrated the lamps at 50- and 100-nm intervals with 10-nm bandpass filters), the cause of the variation is believed to be in the response of individual elements to a given intensity. Figure 5 shows an experimental determination of this response. The 696.5-nm line of argon was sequentially placed on each of the 500 channels for 10 s and the resultant real time signal recorded on a chart recorder. The response of the midpoint and end point channels to the line was rechecked for changes in lamp output at the end of the 2½-h run. From Fig. 5, I calculated a 6.6% difference between the response of the end point detectors, and a 16.9% difference between the response of the midpoint detector and the average response of the end point detectors. I suspected that the bow in channel response changed with signal amplitude and scale setting. However, the differences in the end point response to the QL-128 lamp were not found to be amplitude dependent. The range of deviations was found to be large (between 0 to 30%) with the average about 10%. To determine whether one end of the detector array always reads higher than the other, the end point variation data was plotted versus wavelength as shown in Fig. 6. The maximum response point and the scale change points are also shown. From 350 to 850 nm, a trend is seen that indicates the sign of the variation depends on whether the response is rising or falling. Beyond 850 nm, the evidence is less convincing.

I decided the best representation of relative spectral response for a given 7.5-nm measurement is the average of the midpoint and the four endpoints. I used these averages to determine the relative spectral response of the analyzer-spectrograph system. This is shown in Fig. 7 with the wild end point data at 700 nm from Fig. 4 removed.

Using these average values and the absolute values for the QL-128 lamp, I plotted the absolute spectral response (in counts per nanojoule at the slit) shown in Fig. 8. The ends of the vertical bars represent the extremes of the data used to compute the average values. The percent difference between the extremes and the average is also given. As before, filter response has been taken into account.

Spectral Linearity

To check the response of an individual channel as a function of wavelength and intensity, three single channel, real time spectral curves were made with the QL-128 lamp as the source. Each curve shows a sharp rise near 605 nm and then a more leisurely rise to the peak near 725 nm. Figures 3, 4, and 7 also show this 605-nm bump. Because it has been seen by a photomultiplier using another lamp as a source, it is believed to be a property of the spectrograph. A modulation with a 9.8-nm period appears on these curves after about 600 nm. This is not connected with the filter added at 700 nm for order sorting. This modulation has been observed in another lamp and

Fig. 3. Relative spectral response of the Optical Multichannel Analyzer.

Fig. 4. Relative spectral response of the Optical Multichannel Analyzer, including end point and midpoint values.

Fig. 5. Relative response of each channel to a constant signal.

Fig. 6. Variation of end point values with wavelength. Points where the scale changes and the point of peak response are also shown.

Fig. 7. Average relative spectral response of the Optical Multichannel Analyzer.

Fig. 8. Average absolute spectral response. Vertical bars show the extremes of data. Data used to plot the figure are also shown.

may also be a property of the spectrograph. Table 1 shows the percent difference of the three channels' response to the QL-128 lamp at 100-nm intervals. How much of this variation is a result of signal fluctuation is unknown. The QL-128 lamp was held at the NBS standard rated current throughout the tests.

Table 1. Channel response as a function of wavelength.

Wavelength (nm)	% Difference of channels 25 and 250	% Difference of channels 250 and 475
400	40.0	60.0
500	5.2	21.1
600	1.3	12.6
700	7.3	6.8
800	12.6	2.9
900	22.5	12.9
1000	8.6	34.3

Amplitude Linearity

To test the linearity of a channel with respect to incident intensity, the 696.5-nm line of argon was used to produce real time and integrated signals. The intensity of the signals was governed by calibrated neutral density filters. Table 2 shows the true and experimental values of the neutral density filter and the percent error. The maximum error is 45% for integrated measurements and 13% for real time – both for small signal changes. In the integrated case, noise was removed from the signal. We see that large errors can be expected in measuring small signal changes, while errors of 10% can be expected for large signal changes. These measurements were made on one channel.

Table 2. Comparison of true and experimental values for neutral density filters.

True values	Experimental values		% Error	
	Integrated	Real time	Integrated	Real time
0.102	0.056	0.115	45	13
0.211	0.171	0.214	19	1
0.312	0.289	0.280	7	10
0.416	0.478	0.400	15	4
0.683	0.710	0.635	11	0.5
0.762	0.836	0.760	10	0.4
0.824	0.903	0.806	10	3
0.959	1.036	0.950	8	0.9
1.004	1.083	1.020	8	2
2.009	2.188	2.090	9	4

The assumption that although channel response may vary, the linearity of an individual channel will be the same for all channels has not been verified.

Dynamic Range

From the linearity data we can see that the dynamic range of the instrument is greater than 10^2 but less than $10^{3.3}$ (neutral density 3.3 filter produces no signal) for either real time or integrated signals. The signal-to-noise ratio for 50-s integrated noise was 0.04 for a comfortably detectable signal.

Noise Characteristics

The system has a strange noise "spectrum": amplitude as a function of channel position. There is a large (14 counts) noise signal near channel 000 that looks like a spectral feature at the highest sensitivity of the instrument. The single sweep noise amplitude is positive and less than 14 counts up to about channel 250. There it becomes negative out to channel 499. Subtraction of noise from noise always yields a straight line with small (5 count) fluctuations. This noise subtraction feature is very desirable in data taking.

POSSIBLE PROBLEMS

Operation of the Analyzer with the SSRI Spectrograph

Pictures (Figs. 9 to 11) tell the story – the spectrograph displayed false spectral features that were dependent on the position of the source. Before the measurements were made, the spectrograph was focused and the detector adjusted. Figure 9 shows the appearance of false features in the spectrum as the source position is changed at the slit. The lower two curves are of argon (with two lines showing) with the source position changed between measurements. The upper curve is the difference between the lower curves. Figures 10 and 11 show the response of the instrument to filtered incandescent light with and without the slit lens present. For Fig. 10 only the source wavelength was changed. Figure 11 shows the same experiment along with rotation of the grating. I was unable to correct for or eliminate the problem of false spectral features. It apparently resulted from undiffracted light reaching the detector. (SSRI has fixed the unit. The information on spectrograph problems is included as an aid in understanding the strange signals a faulty system may give.)

Response to Very High Pulsed Signals

When using pulsed sources it is not always possible to control the energy at the detector. The interesting response shown in Fig. 12 resulted from a 3 ns, 1.06- μm laser pulse presented to the detector through the McPherson spectrograph with a 100 μm slit. The spectrum returned to normal when a 15- μm slit was used. The

Fig. 9. Argon spectrum with SSRI spectrography (with lens) showing the effect of moving the source on a faulty instrument.

Fig. 10. Effect of changing the source spectrum for a faulty SSRI spectrograph (without lens). An incandescent lamp with a tunable 10-nm bandpass filter was used for the source.

Fig. 11. Effect of rotating the faulty SSRI spectrograph (with lens). An incandescent lamp with a 10-nm bandpass filter was used for the source.

Fig. 12. Response of the Optical Multichannel Analyzer to very high signals.

appearance of a negative spectrum and/or sharp discontinuities in the spectrum of pulsed sources is an indication of detector saturation. Signal recovery in such a situation does not seem to be possible.

MODEL B AND MODEL F COMPARISON

Comparison tests were made of the Model 1205B and the Model 1205F detector heads. Each unit was run by its own factory-matched electronics. Each detector head was attached to the McPherson spectrometer which was then focused for it. Each head was rotated to produce the narrowest spectral lines. Both produced FWHM of one channel with the two adjacent channels about one-third of the maximum.

Tests of the relative spectral response of the two detectors were made by recording the real time output of channel 250 while the spectrometer scanned a 200-W quartz-halogen lamp. The results are shown in Fig. 13. No filters were used so only relative response can be assessed. The difference in response at 700 nm is probably because the F model is more sensitive to second order 350-nm radiation than the B model. Figure 14 shows an expanded view of the response of the two detectors in the 200- to 400-nm spectral region.

Tests of the relative integrated response of the detectors were made with the 265-nm mercury lines (Figs. 15 and 16). Preset integration times of 4 and 10 cycles were used. An equal integration time of noise was collected and subtracted from the signal and the result recorded on a strip chart. The increased noise of the Model F is obvious. Longer integration times did not increase the visibility of the 366.3-nm line as is the case of the Model B. The Model F was returned to SSRI for testing and was found to be misadjusted and to contain several bad memory units. The results of testing the corrected unit are shown in Figs. 17 through 20. The advantage of the Model F in the region of 200 to 300 nm is now obvious.

Fig. 13. Comparison of the spectral response of the Models F and B detectors for the 200-to 1050-nm region.

Fig. 14. Comparison of the spectral response of the Models F and B detectors for the 200-to 400-nm region with expanded scale.

Fig. 15. Comparison of the spectral response of the Models F and B detectors for line sources. Preset 4 integrating mode. Note excessive noise on F model.

Fig. 16. Comparison of the spectral response of the Models F and B detectors for line sources. Preset 10 integrating mode. Note excessive noise on F model.

Fig. 17. Comparison of the spectral response of the Models F and B detectors for the 200- to 1100-nm region. Model F has been repaired.

Fig. 18. Comparison of the spectral response of the Models F and B detectors for the 200- to 400-nm region with expanded scale. Model F has been repaired.

Fig. 19. Comparison of the spectral response of the Models F and B detectors for line sources. Preset 4 integrating mode. Model F has been repaired.

Fig. 20. Comparison of the spectral response of the Models F and B detectors for line sources. Preset 10 integrating mode. Model F has been repaired.

APPENDIX A
OPERATING HINTS FOR THE OPTICAL MULTICHANNEL ANALYZER AS A
SPECTROSCOPIC DETECTOR

ALIGNMENT AND OPERATION

Detector Mounting and Adjustments

The following should be considered when mounting the detector on a spectrograph:

1. position of spectrograph film plane,
2. masking of the reference channels,
3. focus of the spectrum on the detector, and
4. rotation of the spectrum.

Item 1 refers to the fact that some spectrographs have film planes that are not perpendicular to the mounting area. Items 2 and 3 may be taken care of by adjustments built into the spectrograph. Masking may be done at the film plane on the entrance slit. Item 4 is built into the detector head - be sure the mount does not hinder this operation.

Adjustment should be made using the "real time" display mode to check progress in alignment. Table A-1 may be used as an adjustment guide. The goal of the adjustments is a non-negative, nearly single channel signal from a narrow (less than a channel width) source. The adjacent channels should display signals not greater than a third of the maximum signal. Repositioning of the line on the channels may have to be done several times during alignment so that the true signal does not lie on two channels. Once this has been achieved, the line source should be swept across the 500 channels to insure the film plane lies on the detector plane.

Table A-1. Adjustment guide.

Source	Display	Adjustment
Continuum	Negative signal	Move mask
Line	Negative signal on one side of line	Rotate detector
Line	Adjacent channels with greater than one-third the peak signal	Focus spectrograph or move detector

DISPLAY EQUIPMENT

The following oscilloscope and chart recorder equipment were used for the data presented in the report. (Equipment of similar characteristics may be substituted.)

The oscilloscope was a Tektronix 536. It was used to display the Optical Multi-channel Analyzer output. The analyzer and oscilloscope electrical connections are shown below.

<u>Oscilloscope input connections</u>	<u>Analyzer output connections</u>
Horizontal: 0.10 V/cm	CRT X
Vertical: 0.05 V/cm	CRT Y
Modulated intensity: (ac)	CRT Hi Z

An HP 680 chart recorder with a chart rate of 8 in./min (units on instrument) and a 1-V full scale signal setting was used. The form of the chart recording also depends on the analyzer plot rate. (The plot rate switch is on the back panel.) The following information is helpful in using the equipment.

- A plot rate of 9 and a chart speed of 8 in./min yields one channel per mm of chart.
- Faster plot rates compress the display.
- A plot rate of 0 can be used with an incremental recorder or single channel real time display.

OPERATION

Operating Notes

A "delay" of zero is recommended. A delay of N provides a sweep of the detector array after each $N \times 33.4$ -ms integration time. This integration is effective for both real time and stored signals. Delays of one or more increase the noise of the system.

A "preset" of M causes the analyzer to sum the sweeps of the detectors for $M \times 33.4$ ms. For pulsed signals, M is made large enough to collect one or more pulses during the summation time.

"Full scale hold" causes the analyzer to sum sweeps until one channel reaches its maximum.

If a manually selected summation time is used, the number of sweeps made can be read by pressing "Accum Cycles."

The results of storing a signal with the display controls in their various positions are shown in Table A-2.

Modes of Storing Signals

1. Storage Without Noise Removal - Select "A" or "B" display. Set "Preset" number (for cw signals - one is a convenient number to collect the display seen in real time; for pulsed sources - any number that allows enough time to collect the pulse may be used). Press "Preset Hold." Select "A" or "B Accum."

(When this is done immediately after pressing "Preset Hold," signal storage begins. Thereafter, the "A erase" or "B erase" buttons start signal storage). Press "A erase" or "B erase."

Table A-2. Various analyzer settings and signal storage results.

Analyzer settings		Action erase	Result
Display	Mode		
Real time	A accum	A	None
	B accum	B	Signal in B
	A and B accum	A and B	Signal in B
A or B	A accum	A	Signal in A
	B accum	B	Signal in B
	A and B accum	A and B	Signal in A and B
A-B	A accum	A	Signal in A
	B accum	B	Inverted signal in B
	A and B accum	A	Signal in A
		B	Signal in B
		A and B	None

2. Storage of Signal with Noise (or Other Signal) Subtraction – Select "A-B" display and proceed as above for both A and B channels, blocking the signal when B is used. (If the signal is put in B and noise in A, the display will be inverted.)

3. Repetitive Signal Storage – Bypassing the "Preset Hold" and erase buttons allows one to add a signal to a desired storage channel as long and often as the "accum" buttons are pressed. The "Accum Cycles" display will show the total signal integration time.

4. Position or Width of a Feature – Display a calibration signal and move the cursor to a calibration point. The difference in channel numbers from the calibration point to the feature under investigation plus the change in position with change in channel number, $\Delta x/\Delta ch$ (a function of the optics directing light to the detector array), will give the position of the feature. For widths, $\Delta x/\Delta ch$ times the width in channels gives the desired result.

5. FWHM of a Feature – This can be obtained by reading the peak amplitude of the feature and looking for the two channels where the amplitude is one-half that of the peak. This difference in these channel numbers leads to the desired result.

6. Plot of a Feature – Move the cursor to the low channel number side of the feature and press "Plot/Print." When the feature has been recorded, press "Plot/Print" again.

7. Real Time Display of a Single Channel – Set the Plot Rate to 0 and move the cursor to the desired channel. With the analyzer in the real time mode and "Plot/Print" pressed, a chart recorder will display the real time signal from the channel selected.

Caution – If the signal amplitude is greater than the scale factor selected, the display (CRT and chart) is folded so that the peak is displayed somewhere but is not the highest visible point. Always check that the peak selected by the cursor is the true peak by changing scales. False double features may result if the scale factor is not set properly.

The detector is quite sensitive to stray electromagnetic fields (such as ac current in a high voltage supply or motors used for grating rotation). Care should be taken when placing electronic equipment near the detector.

APPENDIX B

OPTICAL MULTICHANNEL ANALYZER SPECTRA

The spectra discussed in this appendix are typical of those that can be produced by the Optical Multichannel Analyzer. These spectra were taken with the McPherson 1-M spectrograph described in the report.

Figure B-1 is a composite of the fluorescence spectrum of an Nd YAG rod and the inverted spectrum of the same rod used in an oscillator. The oscillator produced about 100-ps duration pulses spaced about 2 s apart. Integration time for the fluorescence spectrum (channel A) and the laser spectrum (channel B) was about 1.5 s. The display is A-B.

Figure B-2 is the spectrum of a tunable dye laser before line narrowing adjustments were made. The system was used in a real time display mode so that changes in the spectrum could be observed while cavity adjustments were being made. The figure represents the real time display obtained by using a preset of one.

Figure B-3 shows laser and laser-produced plasma spectra resulting from a single 3-ns laser pulse. An integration time of 3 s was used and noise was subtracted after the shot. This spectrum is of an iron target viewed at a 45° angle to the laser beam.

Fig. B-1. Pulsed laser and fluorescence spectra. Dispersion was 0.015 nm/mm.

Fig. B-2. CW dye laser spectrum. Dispersion was 0.007 nm/mm.

Fig. B-3. Laser and laser-produced plasma spectra. Dispersion was 0.0145 nm/mm.

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