

TEKTRONIX®

J20/7J20
RAPID-SCANNING
SPECTROMETER

OPERATORS

INSTRUCTION MANUAL

Tektronix, Inc.
P.O. Box 500
Beaverton, Oregon 97005

Serial Number _____



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TABLE OF CONTENTS

| | | | |
|--|-----------|--|-----------|
| RAPID-SCANNING SPECTROMETER SYSTEM | 1 | CHARACTERISTICS OF THE RSS (cont) | |
| Description | 1 | Optical Coupling | 23 |
| Specifications | 1 | Positioning Of Source | 23 |
| Introduction | 1 | External Optical Systems | 23 |
| Category 1, Optical Specifications | 2 | Notes On Spectral Order | 24 |
| Category 2, General (Un-Normalized) Specifications | 3 | False Spectra | 24 |
| Category 3, Normalized Operation | 4 | | |
| Controls and Connectors | 6 | APPLICATIONS | 25 |
| Introduction | 6 | Introduction | 25 |
| 7J20 Spectrometer Plug-In | 7 | Transmittance & Absorption Measurements | 25 |
| J20 Spectrometer | 10 | Introduction | 25 |
| Initial Operation | 11 | Making Measurements | 25 |
| Introduction | 11 | Transmittance | 25 |
| Operation | 11 | Absorbance | 26 |
| CHARACTERISTICS OF THE RSS | 14 | Luminescence Measurements | 26 |
| Introduction | 14 | Introduction | 26 |
| System Components | 15 | Molecular Luminescence | 26 |
| Silicon-Target Vidicon | 15 | Radiometric Measurements | 27 |
| Measuring Vidicon Saturation | 15 | Introduction | 27 |
| Interchangeable Gratings | 17 | Display Readout | 27 |
| Electronic Normalizer | 19 | RSS Radiometric Calibration | 27 |
| Selectable Slit Widths | 19 | Making Radiometric Measurements | 29 |
| Selectable Filters | 19 | Continuous Spectra | 29 |
| System Operational Features | 20 | Line Spectra | 29 |
| Display Dispersion | 20 | Source Radiance | 31 |
| Vertical Gains | 20 | Wavelength Measurements | 32 |
| Linear Gains | 20 | Introduction | 32 |
| Logarithmic Gains | 20 | Digital Wavelength Readout | 32 |
| Absorbance | 20 | Wavelength Determined by Display | |
| Scan Rates | 21 | Dispersion | 33 |
| Continuous Scan | 21 | Comparison Against Known Wavelengths | 33 |
| Integrate Scan | 22 | | |
| Variable Time/Scan | 22 | GLOSSARY OF TERMS | 34 |
| Triggering Modes | 22 | | |
| Triggering The Display | 22 | ANNOTATED BIBLIOGRAPHY | 39 |
| Triggering Vidicon Scanning | 22 | | |



RAPID-SCANNING SPECTROMETER SYSTEM

DESCRIPTION

The J20 Spectrometer with the 7J20 Spectrometer Plug-In form a Rapid-Scanning Spectrometer system capable of scanning the optical spectrum from 250 nm (ultraviolet) to 1100 nm (near infrared). The resulting spectral display is time-resolved spectral power (incident optical power versus wavelength) in calibrated absolute terms.

The J20 Spectrometer uses a Czerny-Turner grating monochromator without an exit slit. The spectral output of the monochromator is focused onto the target of a vidicon tube where the spectrum is stored as an electrical charge image. An electron beam periodically scans across the vidicon target, converting the charge image into an electronic signal that is in turn processed by the 7J20 Spectrometer Plug-In. Design of the J20 Spectrometer features two switchable diffraction gratings, selection of entrance slit widths, and a choice of several optical filters, any of which can be placed in front of the entrance slit. The two switchable gratings in the J20 Spectrometer allow scanning wide (400 nanometers) or narrow (approximately 40 nanometers) portions of the 250 to 1100 nanometer spectrum.

The 7J20 Spectrometer Plug-In is a two-hole wide plug-in designed to operate in the Tektronix 7000-series family of oscilloscopes. It functions as an electronic signal-processor and controller between the J20 Spectrometer and the 7000-series oscilloscope mainframe. Design of the 7J20 Spectrometer Plug-In features some controls that allow signal manipulation to provide a variety of meaningful displays.

The VERTICAL GAIN switch provides three types of vertical deflection; linear, logarithmic, and inverse logarithmic (absorbance). The GAIN position of the switch displays a ramp signal on the crt to allow setting the

output signal amplitude of the 7J20 to match the input sensitivity of the oscilloscope mainframe being used. The TIME/SCAN switch selects the mode and time of scanning the vidicon target to provide either repetitive scanning or integration modes of operation. The DISPLAY DISPERSION switch provides crt display horizontal expansion to increase crt display dispersion. Expansion occurs centered around the intensified wavelength marker. The MARKER control allows horizontal positioning of the intensified wavelength marker in the crt display to permit wavelength identification of specific portions of a spectral display. The SPECTRAL NORMALIZER switch selects between normalized and un-normalized operation. Normalized operation provides radiometric calibration of the spectrometer system.

The 7J20 Spectrometer Plug-In, though it will operate in any 7000-series oscilloscope mainframe (even those without crt readout), is primarily intended to be operated in a 7613. The 7613 offers adequate vertical amplifier bandpass to ensure optimum spectrometer performance, and crt readout to take advantage of spectrometer operational features such as the wavelength MARKER control. Additionally, the storage capabilities of the 7613 allow retention of multiple displays to permit direct waveform comparisons in real-time terms. Because the same signals used to scan the vidicon detector are used to provide horizontal deflection in the crt display, no additional plug-ins are necessary for spectrometer operation.

The 7J20 Spectrometer Plug-In also features an Interface connector (located on the bottom of the plug-in) to facilitate signal interconnection between the spectrometer system and a recorder, a computer, or a digital signal processor such as the Tektronix 7000-series DPO system. Inquiries concerning specific applications of the Rapid-Scanning Spectrometer should be directed to the Marketing Group of Analytical Products at Tektronix, Inc. (refer to the Applications section of this Instruction Manual).

SPECIFICATIONS

INTRODUCTION

The following is a list of spectrometer system specifications. These specifications apply over the ambient temperature range of +15°C to +35°C (unless specifically noted otherwise) after a minimum warm-up time of 20 minutes. For additional specifications concerning individual elements of the spectrometer system, refer

to the Specifications section of the J20/7J20 Rapid-Scanning Spectrometer Service Instruction Manual.

The specifications that follow are divided into three categories: Optical, General, and Normalized. Those characteristics having their limits listed in the Primary Limit column are instrument specifications. Data in the Secondary Limit column does not constitute instrument specifications and is provided for reference use only.

CATEGORY 1

Optical Specifications

| Characteristic | Primary Limit | | | Secondary Limit |
|---|--|---------------------|---------------------|----------------------|
| Spectral Sensitivity Range | 250 nm to 1100 nm inclusive. 300 nm to 1100 nm first order. 250 nm to 330 nm second order with internal first-order blocking filter. | | | |
| Display Spectral Interval Grating A | 400 nm, ± 4 nm ($\pm 1\%$) full scan 200 nm, ± 6 nm ($\pm 3\%$) expanded 100 nm, ± 3 nm ($\pm 3\%$) expanded 40 nm, ± 1.2 nm ($\pm 3\%$) expanded | | | |
| Grating B | 300 nm ¹ | 650 nm ¹ | 900 nm ¹ | 1000 nm ¹ |
| 40 nm (Full Scan) | 46 nm $\pm 2\%$ | 40 nm $\pm 2\%$ | 34 nm $\pm 2\%$ | 30 nm $\pm 2\%$ |
| 20 nm (Expanded) | 23 nm $\pm 4\%$ | 20 nm $\pm 4\%$ | 17 nm $\pm 4\%$ | |
| 10 nm (Expanded) | 11.5 nm $\pm 4\%$ | 10 nm $\pm 4\%$ | 8.5 nm $\pm 4\%$ | |
| 4 nm (Expanded) | 4.6 nm $\pm 4\%$ | 4 nm $\pm 4\%$ | 3.4 nm $\pm 4\%$ | |
| Marker Wavelength Accuracy | Measured over the center two graticule divisions only. | | | |
| Grating A At +25°C | ± 10 nm | | | |
| From +15°C to +35°C | ± 12 nm at 300 nm ± 13 nm at 500 nm ± 14 nm at 1100 nm | | | |
| Grating B At +25°C | ± 3 nm | | | Typically ± 2 nm |
| From +15°C to +35°C | ± 5 nm from 300 nm to 500 nm ± 6 nm from 500 nm to 900 nm ± 7 nm from 900 nm to 1100 nm | | | |
| Wavelength Mechanical Repeatability ² Grating A | ± 4 nm | | | |
| Grating B | ± 0.4 nm | | | |
| Wavelength Repeatability ³ Grating A | | | | ± 1 nm |
| Grating B | | | | ± 0.5 nm |

¹Display Center Wavelength²Fixed temperature, includes grating change and wavelength interval adjustment, not including digital readout.³Fixed temperature, not including grating change, wavelength interval adjustment, and digital readout.

CATEGORY 1 (cont)

| Characteristic | Primary Limit | Secondary Limit |
|---|---|-----------------|
| Resolution (Bandwidth at Half Amplitude) | | |
| Grating A | ≤ 4 nm | |
| Grating B | ≤ 0.4 nm | |
| Stray Light | $\leq 1\%$ at 600 nm to a notch filter with tungsten illumination | |
| Steradiancy | 0.02 steradians, ± 0.0006 steradians ($\pm 3\%$) | |
| Field of View (Full Angle) | | |
| Horizontal | 8.2 degrees | |
| Vertical | 9.5 degrees | |
| Equivalent f-number | f/6.3 | |
| Ambient Light | 10,000 LUX (1000 foot candles) or less of sunlight | |

CATEGORY 2

General Specifications
(Un-Normalized)

| Characteristic | Primary Limit | | Secondary Limit |
|--|---|-----------------------|--|
| Display Vertical Drift (VERT GAIN 200) | ≤ 1.5 major crt graticule div/minute at $+25^{\circ}\text{C}$. (0.75 nA/min) | | ≤ 3 major crt graticule div/minute at $+25^{\circ}\text{C}$. |
| Display Baseline Flatness (VERT GAIN 200) | ≤ 6 major crt graticule div p-p (≤ 3 nA p-p) at $+25^{\circ}\text{C}$. | | |
| Display Noise (VERT GAIN 200) | ≤ 0.4 major crt graticule div p-p (≤ 0.2 nA p-p) for 10 ms and 20 ms scan rates. | | |
| Vertical Linearity Using Switched Attenuation (Linear Gains) | $\pm 4\%$ of light level with oscilloscope crt linearity excluded. | | $\pm 2\frac{1}{2}\%$ crt linearity additive to Vertical Linearity specification. |
| Logarithmic Gains Accuracy (300 nA Reference Level) | | | |
| | True Log I | | |
| | Measured Log I | Error % | |
| | 1.0 dB | -1.04 dB to -0.918 dB | |
| | 2.0 dB | -2.07 dB to -1.58 dB | +3 1/2, -8.2 |
| | 3.0 dB | -3.11 dB to -1.78 dB | +3 1/2, -21.1 |
| | | | +3 1/2, -40.7 |

CATEGORY 2 (cont)

| Characteristic | Primary Limit | | Secondary Limit | | | |
|--|---|--------------------|---------------------|--------------------|---------------------|---------------------|
| Absorbance Gains Accuracy (300 nA Zero Absorbance Reference Level) | | | | | | |
| True Absorbance | Measured Absorbance | Error % | | | | |
| 0 A | 0 | 0 | | | | |
| 0.3 A | 0.311–0.284 A | +3 1/2, –5.3 | | | | |
| 0.6 A | 0.621–0.563 A | +3 1/2, –6.2 | | | | |
| 1.0 A | 1.04–0.918 A | +3 1/2, –8.2 | | | | |
| 1.3 A | 1.35–1.16 A | +3 1/2, –10.8 | | | | |
| 1.6 A | 1.66–1.37 A | +3 1/2, –14.4 | | | | |
| 2.0 A | 2.07–1.58 A | +3 1/2, –21.1 | | | | |
| 3.0 A | 3.11–1.78 A | +3 1/2, –40.7 | | | | |
| Vertical Deflection Electrical Sensitivity (Linear Gains) | $\left(\frac{100 \text{ nA}}{\text{VERT GAIN}}\right)$ per div, $\pm 5\%$ | | Typical'y $\pm 3\%$ | | | |
| Characteristic | Secondary Limit | | | | | |
| Typical Response Times (Lag) from Initial Signal Level I_0 to $I_0 - 0.9 \Delta i$ | Initial Signal Intensity Level, I_0 | | | | | |
| Signal Change (Δi) | 500 nA | 200 nA | 100 nA | 50 nA | 20 nA | 10 nA |
| 500 nA | 40 ms ⁴ | | | | | |
| 200 nA | | 60 ms ⁴ | | | | |
| 100 nA | | 43 ms | 82 ms ⁴ | | | |
| 50 nA | | 35 ms | 46 ms | 97 ms ⁴ | | |
| 20 nA | | 34 ms | 44 ms | 64 ms | 250 ms ⁴ | |
| 10 nA | | 36 ms | 47 ms | 65 ms | 135 ms | 350 ms ⁴ |

CATEGORY 3

Normalized Operation

| Characteristic | Primary Limit | Secondary Limit |
|-------------------------------|--|-----------------|
| | <p>All normalized operation limits are specified with a 20 ms scan rate.</p> <p>All radiometric measurements are made to a ribbon filament radiance lamp traceable to NBS.</p> <p>Specification limits arrived at by quadrature (square root of sum of squares).</p> | |
| Radiometric Spectral Range | 400 nm to 967 nm for Grating A 367 nm to 900 nm for Grating B | |
| Vertical Scale Factor Readout | W/(nm·div) of crt deflection | |

⁴To full off.

CATEGORY 3 (cont)

| Characteristic | Primary Limit | | Secondary Limit |
|--|---|----------------------|---|
| Radiant Power Accuracy 400 nm - 600 nm | Grating A ± 20% | Grating B | |
| 600 nm - 967 nm | ± 12% | | |
| 367 nm - 600 nm | | ± 12% | |
| 600 nm - 900 nm | | ± 11% | |
| Radiant Power Repeatability (To Individual Calibration Curve Available for Each Instrument) 400 nm - 600 nm | ± 13% | | |
| 600 nm - 967 nm | ± 3.5% | | |
| 367 nm - 600 nm | | ± 5.5% | |
| 600 nm - 900 nm | | ± 3% | |
| Spectral Flatness | ± 15% | ± 15% | |
| Noise Equivalent Power (20 μ m Slit, VERT GAIN 200) | 50 pW/nm (1 div) | 500 pW/nm (1 div) | |
| Linearity | ± 6% not including oscilloscope linearity error. | | Over the range of noise level to 0.7 of saturation current. |
| Dynamic Range | ≥150:1 | | Lower limit of dynamic range is Noise Equivalent Power Level for each grating. |
| Photometric Accuracy | All normalized photometric limits are specified using an external normalizer with the system normalized to 300 nA vidicon signal current over a wavelength interval using a quartz iodine lamp. | | |
| Linear Gains | ± 4% T un-normalized ± 6% T normalized | | Not including linearity error of oscilloscope. |
| Absorbance Gains Un-normalized | Refer to limits specified in General Operation section. | | |
| Normalized | Random error of 2% additive to un-normalized tolerance. | | |

CONTROLS AND CONNECTORS

INTRODUCTION

The controls and connectors essential to the operation of the Rapid-Scanning Spectrometer are located on the front panel of the 7J20 Spectrometer Plug-In and the rear panel of the J20 Spectrometer. A brief description of each control and connector follows. Refer to the appropriate Instruction Manual for the oscilloscope used for oscilloscope operating instructions.

NOTE

All waveform illustrations that appear in this manual are artist's reproductions of actual photographs taken of the spectrometer display using a Tektronix, Inc. camera system. The wavelength marker readout in the waveform illustrations always indicates the wavelength represented by the center vertical crt graticule line.

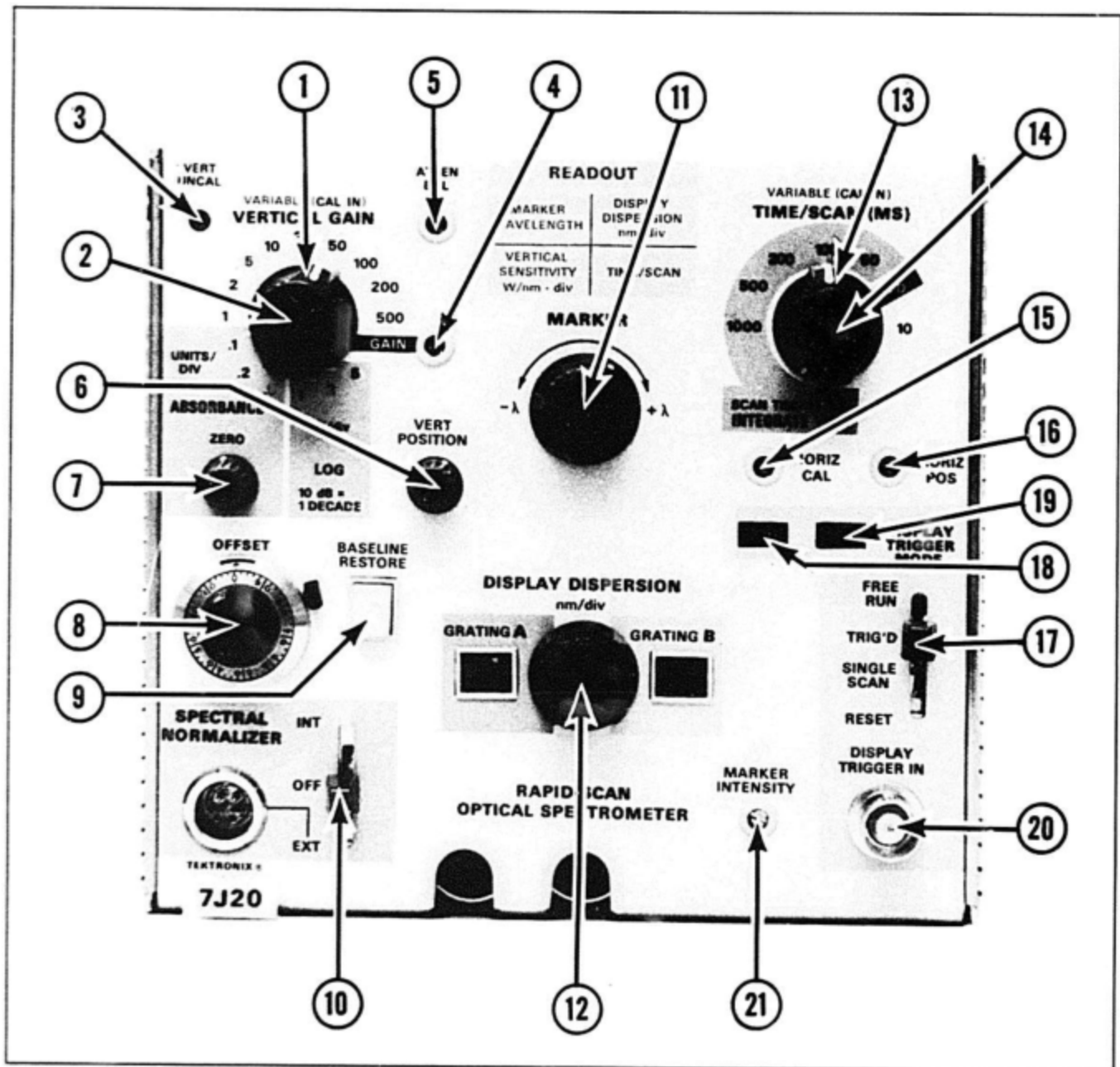


Fig. 1. 7J20 Spectrometer Plug-In controls and connectors.

7J20 SPECTROMETER PLUG-IN

1. VERTICAL GAIN SWITCH

This is a 16-position rotary switch that selects calibrated vertical deflection factors for the crt display. Three types of deflection are provided:

In the 1 through 500 positions of the switch, vertical deflection in the display is linear. The switch position numbers indicate amplification factors (i.e., in the 10 position, the vertical signal is amplified 10 times that in the 1 position).

In the LOG positions, vertical deflection is logarithmic and each vertical division in the display represents a specified number of decibels.

In the ABSORBANCE positions, vertical deflection is inverse logarithmic and each vertical division represents a specified number of absorbance units. The lower left portion of the crt readout indicates the vertical sensitivity.

2. VARIABLE CONTROL

This is a combination pushbutton switch/rotary control. When the switch is set to the uncalibrated (button out) position, the vertical deflection is uncalibrated. The rotary control provides uncalibrated deflection factors continuously variable between the calibrated settings of the VERTICAL GAIN switch. In the calibrated (button in) position, the vertical deflection factor is calibrated and the rotary VARIABLE control has no effect.

3. VERT UNCAL INDICATOR

This is a lamp to indicate when the vertical deflection factor is uncalibrated. The lamp will be lit when the vertical VARIABLE control is in the uncalibrated (button out) position, when the FILTER switch on the J20 Spectrometer is not in the 0, 1, or 2 positions, when the TIME SCAN switch on the 7J20 Plug-In is in the 10 ms position, when the SPECTRAL NORMALIZER switch on the 7J20 Plug-In is not in the INT position, or when the SLIT switch on the J20 Spectrometer is in the OPEN position.

4. GAIN ADJUST

A screwdriver adjustment used to set the vertical output signal amplitude of the 7J20 to match the input sensitivity of the vertical deflection system of the oscilloscope in which the plug-in is installed. Provides calibrated vertical deflection system operation.

5. ATTEN BAL ADJUST

A screwdriver adjustment to minimize baseline shift in the crt display when switching between adjacent positions of the VERTICAL GAIN switch.

6. VERT POSITION CONTROL

Controls the vertical position of the crt display.

7. ABSORBANCE ZERO CONTROL

This control positions the zero absorbance (100% T) reference line in the crt display. The control functions only in the three ABSORBANCE positions of the VERTICAL GAIN switch.

8. OFFSET CONTROL

This is a 10-turn control used to offset high-amplitude, vertically-overscanned displays to bring the area of interest back to within the limits of the crt graticule area.

9. BASELINE RESTORE PUSHBUTTON

This pushbutton switch, when pushed, closes the entrance slit shutter in the J20 Spectrometer. This provides a zero-light level reference baseline in the crt display and resets the dark-current restoring circuit.

10. SPECTRAL NORMALIZER SWITCH

This three-position lever switch allows selection of internal normalization, external normalization, or no normalization at all. When the switch is in the INT position, the system is radiometrically calibrated (provided the VERT UNCAL indicator is not lit).

11. MARKER CONTROL

This is a positioning control for the intensified wavelength marker in the crt display. The upper left portion of the crt readout indicates in nanometers the wavelength being highlighted by the intensified marker.

12. DISPLAY DISPERSION SWITCH

This is a four-position switch that selects one of four calibrated dispersion factors for the horizontal axis of the crt display. When using Grating A, the four dispersion factors are 40 nm/div, 20 nm/div, 10 nm/div, and 4 nm/div; when using Grating B, they are 4 nm/div, 2 nm/div, 1 nm/div, and 0.4 nm/div. The upper right portion of the crt readout indicates in nanometers the wavelength span displayed in one horizontal division of the crt graticule.

13. TIME/SCAN SWITCH

This seven-position rotary switch selects the mode and interval of scanning the vidicon target in the J20. In the 10 ms and 20 ms positions, the vidicon is scanned by successive sweeps, one immediately following another. In the 50 ms through 1 s positions, the vidicon is scanned by 20 ms sweeps, the start of each sweep separated from the start of the next by the amount of integration time selected. The lower right portion of the crt readout indicates in units of time the time/scan selected by this switch.

14. VARIABLE CONTROL

This is a combination pushbutton switch/rotary control. When the switch is set to the uncalibrated (button out) position, the time/scan is uncalibrated. The rotary control provides uncalibrated times/scan continuously variable between the calibrated settings of the TIME/SCAN switch. The VARIABLE control reduces the shortest scan interval (10 ms) to 4 ms or less. In the calibrated (button in) position, the time/scan is calibrated and the rotary VARIABLE control has no effect.

15. HORIZ CAL ADJUST

This screwdriver adjustment sets the horizontal output signal amplitude of the 7J20 to match the input sensitivity of the horizontal deflection system of the oscilloscope being used. Provides calibrated horizontal deflection system operation.

16. HORIZ POS ADJUST

A screwdriver adjustment that controls the horizontal position of the crt display.

17. DISPLAY TRIGGER MODE SWITCH

This four-position lever switch selects the mode of triggering a display. In the FREE RUN position, a display is continuously provided. In the TRIG'D position, a display is provided only when ground-closure logic is present at the DISPLAY TRIGGER IN connector. In the SINGLE SCAN position, one, and only one, scan is presented upon receipt of a ground-closure trigger signal. Two things are necessary for correct SINGLE SCAN operation. The DISPLAY TRIGGER MODE switch must be in the SINGLE SCAN position, and the circuit must be armed prior to receipt of the triggering signal. To arm the circuit, set the DISPLAY TRIGGER MODE switch to the RESET position briefly, then release it to return to the SINGLE SCAN position.

18. TRIG'D LIGHT

This lamp indicates when a display trigger signal is present at the DISPLAY TRIGGER IN connector.

19. READY LIGHT

This lamp indicates when the system is waiting for a trigger.

20. DISPLAY TRIGGER IN CONNECTOR

This is a BNC connector for application of external display trigger signals. Negative-going trigger signals, at least 1 μ s wide with the most negative excursion to a DC level of between +0.8 V and 0 V, will trigger a display. Ground-closure logic will provide adequate triggering.

21. MARKER INTENSITY ADJUST

This screwdriver adjustment provides the ability to vary the relative intensity level of the wavelength marker in the crt display.

INTERFACE CONNECTOR (Underside of instrument; not shown)

A 25-pin connector used to facilitate signal interconnection with a computer or data tape recorder.

Pin 1 — Marker output; a TTL signal that goes HI at the marker point. Capable of driving one load unit or less.

Pin 2 — Grating number output; a TTL signal that goes HI for B grating; LO for A grating. Capable of driving two load units or less

Pin 3 — Wavelength center signal output; signal represents wavelength at the center of the vidicon scan area. Zero volts represents 300 nanometers. One volt change in output signal represents 100 nm change in center wavelength, $\pm 2\%$ (e.g., 2.5 V = 550 nm).

Pin 4 — Ramp output; positive-going linear ramp signal with an amplitude of 0.8 V/horizontal division of deflection, $\pm 10\%$. Maximum loading is 50 k Ω paralleled by 500 pF.

Pins 5, 6, and 7 — Binary-coded decimal TTL output signals; indicate TIME/SCAN switch position. Pin 7 output signal (output A) is most significant digit; pin 5 output signal (output C) is least significant digit. Each output capable of driving two load units or less.

| A* | B* | C* | TIME/SCAN |
|----|----|----|-----------|
| 0 | 0 | 1 | 1000 ms |
| 0 | 1 | 0 | 500 ms |
| 0 | 1 | 1 | 200 ms |
| 1 | 0 | 0 | 100 ms |
| 1 | 0 | 1 | 50 ms |
| 1 | 1 | 0 | 20 ms |
| 1 | 1 | 1 | 10 ms |

*1 represents the HI state.

Pin 8 — Scan output; a TTL signal that goes HI when the vidicon target is being scanned. Capable of driving one load unit or less.

Pin 9 — Z-Axis output; a TTL signal that goes HI when a display is being presented. Capable of driving two load units or less.

Pin 10 — Scan Control input; a TTL signal that causes normal scanning when it is HI. When LO, the ramp is held in reset. Ramp will start when "Scan Control" goes HI. Minimum pulse width (HI) is 1 μ s. Loading is equal to one load unit or less (51 Ω paralleled by 1000 pF).

Pin 11 — Wavelength Marker Count Gate output; a TTL signal. While the Wavelength Marker Count Gate is HI, counting the negative transitions of the Wavelength Marker Clock will yield the Wavelength Marker readout in nanometers. Output is capable of driving two load units or less paralleled by 20 pF.

Pin 12 — Wavelength Clock output; a TTL signal approximately 100 kHz in frequency. Counting the negative transitions of this clock signal while the Wavelength Marker Count Gate is HI will yield the Wavelength Marker readout in nanometers. Output is capable of driving two load units or less paralleled by 200 pF.

Pin 13 — Ground.

Pin 14 — Vertical Signal output; positive-going analog signal 2 mV/nA, $\pm 5\%$ in amplitude referenced to ground. Signal includes Normalizer and dark current correction but excludes attenuators. Output is capable of driving 5 k Ω paralleled by 500 pF.

Pin 15 — Shield for center conductor of coaxial cable connected to pin 14.

Pin 16 — Uncorrected Vertical Signal output; positive-going analog signal 1 mV/nA, $\pm 5\%$ in amplitude referenced to ground. Does not include normalizer and dark current correction. Output is capable of driving 5 k Ω paralleled by 500 pF.

Pin 17 — Shield for center conductor of coaxial cable connected to pin 16.

Pin 18 — Display Vertical Signal output; positive-going analog signal 75 mV/div, $\pm 10\%$ in amplitude. Output is capable of driving 10 k Ω paralleled by 500 pF.

Pin 19 — Shield for center conductor of coaxial cable connected to pin 18.

Pin 20 — Not used.

Pin 21 — Uncal Buss output; a TTL signal that, when HI, indicates that radiometric calibration is valid.

Pin 22 — Baseline Restore. This is a combination input-output pin terminal.

Output: the output signal is high (approximately +15 V) when the BASELINE RESTORE pushbutton is not pressed, and low (zero volts) when the button is pressed. Peak output current is one ampere. Average output current is approximately 400 milliamperes.

Input: ground-closure logic at pin 22 causes the J20 Spectrometer shutter to close and also activates the dark-current restoring circuit in the 7J20 Spectrometer Plug-In.

Pin 23 — Slit Wheel Position output; an analog signal that in conjunction with the "Drop Zero" signal (pin 24), indicates which entrance slit is being used in the J20 Spectrometer. DC voltage levels output at this pin are accurate to within 0.2 volts.

| DC Level | "Drop Zero" | Slit Position |
|----------|-------------|---------------|
| 14 V | 1 | OPEN |
| 13.5 V | 1 | 10 μ m |
| 13.0 V | 1 | 20 μ m |
| 12.5 V | 1 | 50 μ m |
| 12.0 V | 1 | 100 μ m |
| 13.0 V | 0 | 200 μ m |
| 12.5 V | 0 | 500 μ m |
| 12.0 V | 0 | 1000 μ m |

Maximum loading for this output is one megohm.

Pin 24 — Drop Zero output: a TTL signal that is LO in 1000 μm , 500 μm , and 200 μm slit positions and HI for the remaining slit positions of the slit wheel in the J20 Spectrometer. This output is capable of driving two load units or less.

Pin 25 — Ground

J20 SPECTROMETER

22. SLIT WIDTH SWITCH

This is an 8-position switch used to select various dimensions for the entrance slit to the J20. All slits have the same (7 mm) height. Slit widths that can be selected

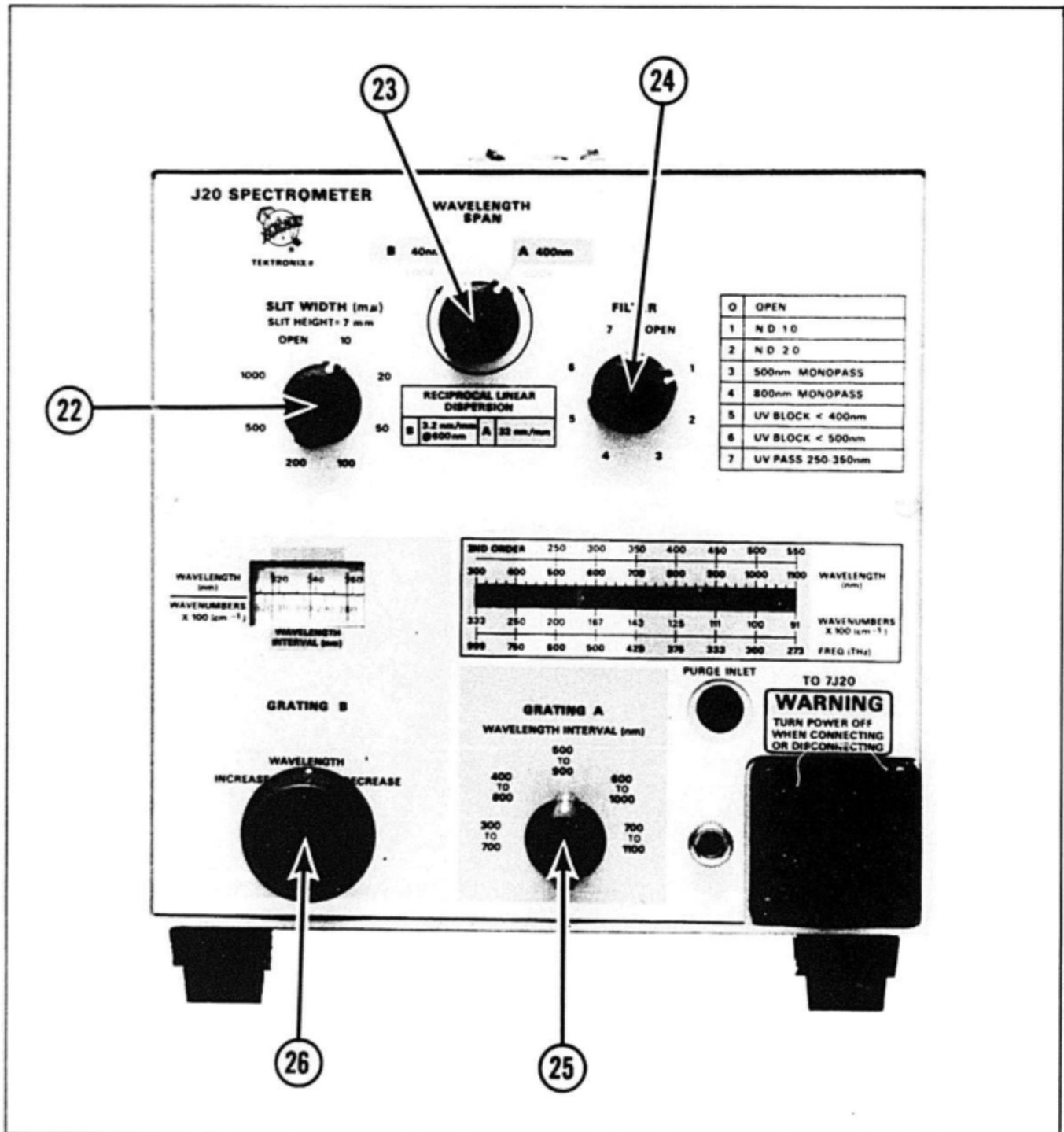


Fig. 2. J20 Spectrometer controls and connectors.

are 10 μm ($\pm 5\%$), 20 μm ($\pm 2.5\%$), 50 μm ($\pm 3\%$), 100 μm ($\pm 2\%$), 200 μm ($\pm 1\%$), 500 μm ($\pm 1\%$), 1000 μm ($\pm 1\%$), and fully open (5 mm).

23. WAVELENGTH INTERVAL SWITCH

This two-position switch selects one of two diffraction gratings. Grating A has a 400 nm wavelength span in the display with 32 nm/mm reciprocal linear dispersion at the vidicon target. Grating B has a 40 nm wavelength span in the display with 3.2 nm/mm reciprocal linear dispersion @ 650 nm at the vidicon target.

24. FILTER SWITCH

This 8-position switch determines which optical filter is placed in front of the spectrometer entrance slit. The selection contains the following filters:

- 0 Open (no filter)
- 1 Neutral Density 1.0
- 2 Neutral Density 2.0
- 3 500 Nanometer Monopass
- 4 800 Nanometer Monopass
- 5 Ultraviolet Block < 400 Nanometers
- 6 Ultraviolet Block < 500 Nanometers
- 7 Ultraviolet Pass 250 nm-330 nm Second Order

The neutral density filters will not vary in specified density more than $\pm 5\%$ over the 400-1000 nanometer range ($\pm 12\%$ from 250 nm to 400 nm and from 1000 nm to 1100 nm). The monopass filters exhibit very narrow bandpass characteristics with peak wavelength being within ± 1 nanometer of the specified value. Transmission at peak wavelength is at least 25% with a half bandwidth of less than 3 nanometers. The artwork shown in Fig. 3 depicts the typical transmittance characteristics of the ultraviolet blocking and monopass filters.

25. GRATING A WAVELENGTH INTERVAL SWITCH

This rotary switch selects one of five fixed wavelength intervals to be scanned when using diffraction Grating A. The five intervals are 300-700 nm, 400-800 nm, 500-900 nm, 600-1000 nm, and 700-1100 nm.

26. GRATING B WAVELENGTH CONTROL

When using Grating B, this multi-turn control determines where, in the instrument's 300-1100 nanometer spectral range, a 40-nanometer interval will be scanned. The 40-nanometer interval is continuously variable throughout the spectral range of the instrument.

INITIAL OPERATION

INTRODUCTION

The following procedure is designed to assist an operator unfamiliar with the J20/7J20 Rapid-Scanning Spectrometer system with putting the system into operation. Using this procedure will allow the operator to obtain one of the basic displays of which the instrument is capable. This basic display can be used as a starting point for becoming familiar with the effect the various instrument controls have on the spectrometer display.

NOTE

To avoid unnecessary vidicon-detector aging and degradation, turn off the spectrometer system when not being used.

OPERATION

To place the J20/7J20 Rapid-Scanning Spectrometer into operation, proceed as follows:

1. Connect the J20 Spectrometer to the 7J20 Spectrometer Plug-In, using the interconnect cable provided with the instrument. Lock the cable onto the Spectrometer connector of the 7J20 using a small tool (such as a small-bladed screwdriver) to push the connector lock into place. Slide the cable retainer into place on the bottom of the 7J20.

2. Install the 7J20 Spectrometer Plug-In into the oscilloscope. Make sure the plug-in occupies one horizontal and one vertical plug-in compartment of the oscilloscope.

3. Set the following oscilloscope controls to the positions indicated.

| | |
|------------------------------------|------------------------|
| VERTICAL MODE | Right |
| HORIZONTAL MODE (If applicable) | A |
| STORE (If applicable) | Button out (non-store) |

4. Set the following J20 Spectrometer controls as indicated.

| | |
|-------------------------------|-------------------------------|
| SLIT WIDTH | 20 μm |
| WAVELENGTH SPAN | A400 nm |
| FILTER | Position #3 (500 nm Monopass) |
| GRATING A WAVELENGTH INTERVAL | 300-700 nm |

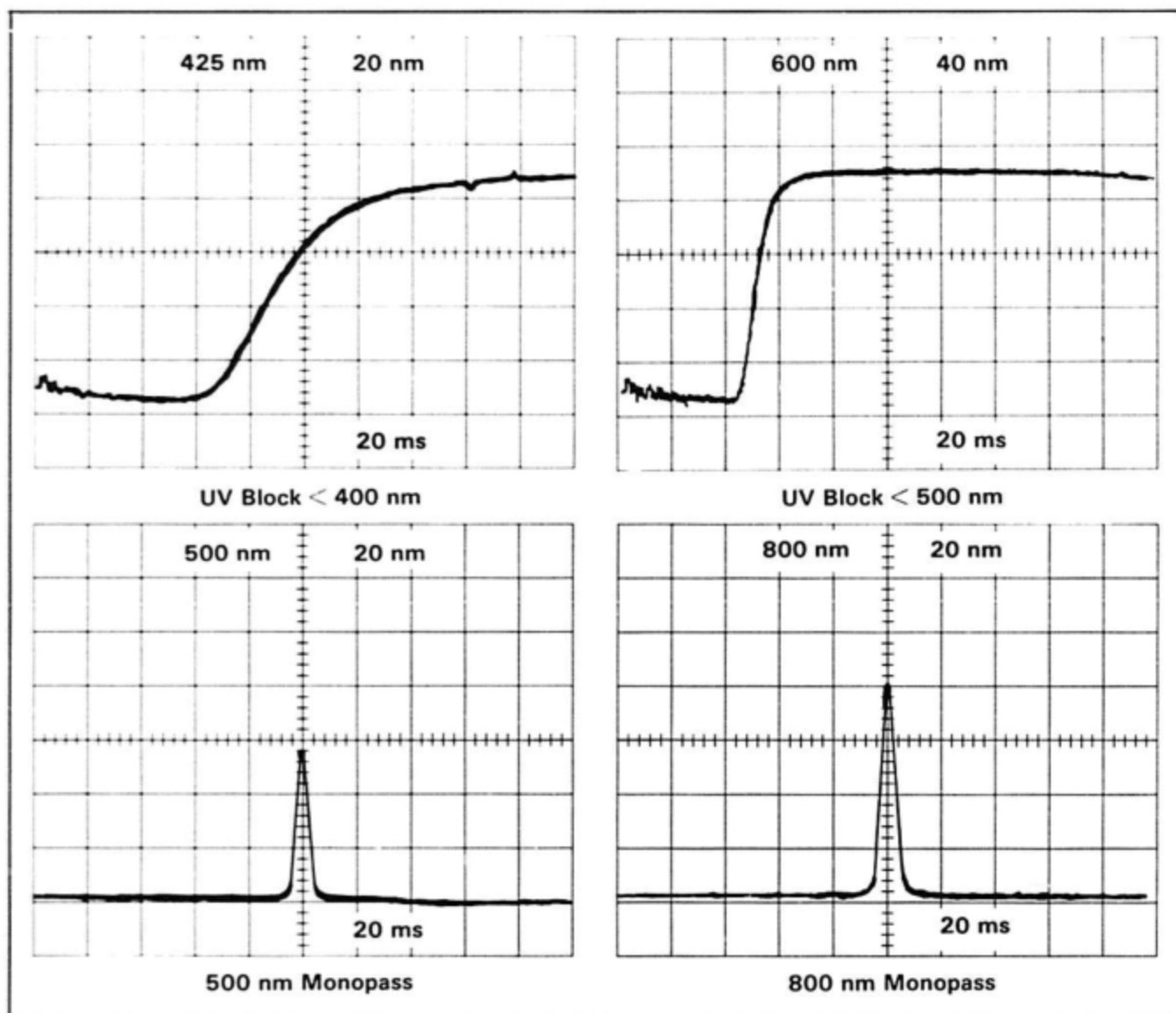


Fig. 3. Typical transmission characteristics for the ultraviolet-blocking filters used in the J20 Spectrometer.

5. Set the following 7J20 Spectrometer Plug-In controls as indicated.

| | |
|----------------------|-----------------|
| VERTICAL GAIN | 1 |
| VARIABLE | CAL IN |
| TIME SCAN | 20 ms |
| VARIABLE | CAL IN |
| DISPLAY DISPERSION | 40 nm/div |
| OFFSET | 0.00 and locked |
| SPECTRAL NORMALIZER | OFF |
| DISPLAY TRIGGER MODE | FREE RUN |

6. Turn the oscilloscope power on, adjust the 7J20 MARKER control for a reading of 500 nm, and allow 20 minutes warmup.

7. Using the VERT POSITION control, position the display baseline on screen and adjust the oscilloscope INTENSITY and READOUT INTENSITY controls for a comfortable viewing level. Adjust the oscilloscope FOCUS control for a well-focused display.

8. Push the BASELINE RESTORE pushbutton briefly and release.

9. Vertically position the display baseline to the bottom crt graticule line.

10. Position a tungsten light source (such as a 60-watt incandescent lamp) in front of the spectrometer entrance slit. Observe the spectrometer display and position the lamp to obtain maximum signal amplitude.

11. Adjust the VERTICAL GAIN switch to a linear gain position that will provide approximately four divisions or more of vertical deflection.

The spectrum present in the spectrometer display is the transmission spectrum of a narrow bandpass filter. Use this display as a starting point while reading the explanation of instrument controls given in this manual, and observing the effect the various instrument controls have on the display.

CHARACTERISTICS OF THE RSS

INTRODUCTION

The J20/7J20 Rapid-Scanning Spectrometer functions as a rapid electronically-scanned spectrometer optimized for kinetic studies, and also as a general purpose analytical instrument with features new to spectroscopic instrumentation. The following discussions briefly outline details of instrument operation and some of the operational trade-offs to be considered when using the spectrometer.

The spectrometer system can electronically scan a 400 nm (4000 angstroms) segment of the spectrum (using Grating A) in less than 10 ms. This wide range is useful for obtaining an overview of the spectrum. For detailed analysis, an approximately 40 nm segment can be scanned (using Grating B) with resolution of at least 0.4 nm (4 angstroms) in first order. The 40 nm scanned segment can be continuously varied over the spectral range of 300 nm to 1100 nm (first order). Variable scan rates allow slow scanning modes with integration of up to one second (for scanning low light-level spectra) without using digital techniques.

The output spectral display on the crt can be automatically corrected for the spectral response of the optical system and detector. Automatic spectral correction can also be made for external optical devices such as light sources, filters, collection optics, etc. Absorption measurements made in this manner do not require dual-beam techniques. In addition, the instrument is radiometrically calibrated; therefore, direct real-time measurements of spectral radiant power are possible with this instrument. Figure 4 shows a spectrum containing the 365 nm Mercury triplet as it appears in the display on the oscilloscope crt. Note that the important scale factors such as spectral power, scan time, marker wavelength, and wavelength span appear in the crt display along with the scanned spectrum. The intensified wavelength marker spot can be moved horizontally across the displayed spectrum by rotating the front panel MARKER control.

The Czerny-Turner grating spectrometer provides high throughput, coma correction, and is nonvignetting. Nonvignetting means that every point in the entrance slit (even

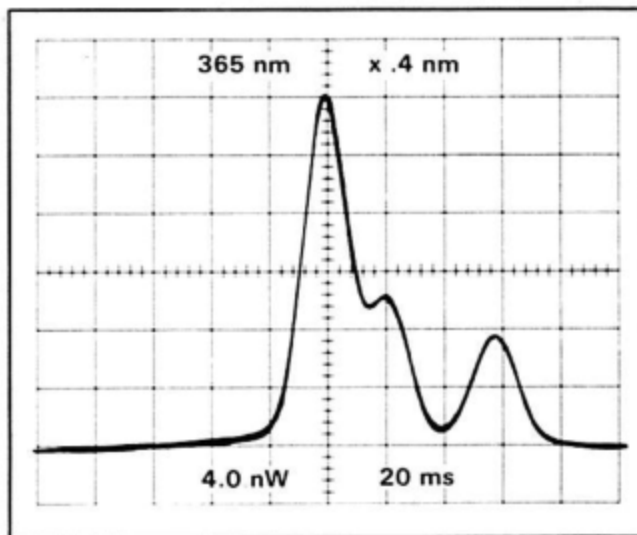


Fig. 4. Spectrum display of 365 nanometer mercury triplet.

top and bottom) will accept the full $f/6.3$ aperture. This is essential to making accurate radiometric measurements. As a point of reference, if this system were specified in the often used manner of focal length divided by the diameter of the entrance mirror, it would be an $f/3.8$ system.

In lieu of an exit slit, the spectrometer images the dispersed spectrum onto the target of a vidicon image tube. The photosensitive target of the vidicon consists of an array of photodiodes on a silicon substrate. Incident photons are absorbed into the silicon substrate, creating hole-electron pairs. Absorption of ultraviolet light occurs near the surface of the silicon, while infrared penetrates deeply before being absorbed. The holes, which are minority carriers, diffuse into the space charge field and are immediately swept across the photodiode junction into the p-type region. The p-type region, which had been charged by a previous scan of an electron beam, is discharged proportionally to the number of photon-induced holes. When the scanning beam again sweeps the region, it will have to supply current to recharge the diode. This current flow is thus proportional to the number of photons incident on the vidicon target and becomes the video signal.

SYSTEM COMPONENTS

SILICON-TARGET VIDICON

Use of a silicon-target vidicon as the detector in the spectrometer offers the following advantages:

1. Wide spectral response (250 nm to 1100 nm).
2. High sensitivity (quantum efficiency greater than 80% at 400 nm)
3. Impervious to damage due to high light levels.
4. Charge storage (multiplex advantage).
5. Fast response and low lag.
6. Linear response to optical intensity.
7. Wide dynamic range.
8. Variable scan rates and modes.

The last feature results from electrostatically deflecting the scanning electron beam. The vidicon gun structure is a unique Tektronix, Inc. design. A special deflectron configuration, in conjunction with magnetic focus, results in excellent resolution in addition to little "shading" error due to beam landing.

The charge storage feature of a silicon-target vidicon is quite advantageous for spectroscopy applications, particularly rapid scan. As a spectrometer detector, the silicon vidicon is analogous to a super-sensitive spectrograph plate that can be exposed for the desired time, then rapidly developed (scanned electronically) with the resultant optical spectrum displayed on an oscilloscope crt.

The vidicon can scan the spectrum rapidly or slowly. Slow-scanning offers the advantages of increased sensitivity and the smoothing out of fluctuating spectra when time resolution is not desired (such as with arc or spark spectra). Highest sensitivity is achieved by holding off scanning the vidicon for as long as one second to integrate the incident photons; then the vidicon is rapidly swept and the spectrum displayed in 20 ms. Low light-level optical spectra not normally detectable with rapid-scanning are more easily detected in the integrate mode. Conversely, because the intrinsic response of the silicon-diode target is quite fast, the tube can be rapidly swept for time-resolved applications. Rapid scanning and immediate display are very useful for routine spectral analysis and for previewing experiments. Experimental apparatus can be quickly checked out, and small changes are readily detected when the spectrum is continuously displayed.

Scanning more rapidly than 10 ms is possible with a vidicon detector; however, the time resolution of the tube is limited by intrinsic lag. Lag is a phenomenon that occurs in charge storage type tubes, i.e., when the light input is removed, it takes a finite amount of time for a charge storage detector to fully return to its uncharged or dark condition. The time response of the storage detector then becomes limited by this lag phenomenon.

If the rapid-scan spectrometer used a mechanical method of scanning with a photomultiplier-tube detector, or electronic scanning with an image dissector tube, the multiplex advantage would be lost. With these sorts of devices, a short-lived fluorescence or laser pulse occurring at a wavelength other than the exact wavelength the detector is sampling would not be detected. However, a storage detector such as the silicon vidicon will detect all spectral events, even of picosecond durations, though time resolution will be limited by the lag characteristics of the detector. The multiplex advantage of the storage tube detector system, coupled with the high quantum efficiency of the silicon vidicon target, results in sensitivities on a par with the best photomultiplier systems for rapid-scanning spectroscopy.

In the J20 Spectrometer, the projected spectral image from the monochromator is scanned off the vidicon target in the following manner. A two-megahertz sinusoidal signal is applied to the "vertical" plates of the vidicon so that the electron beam is rapidly deflected in a direction parallel to the slit image. Simultaneously, a much slower scanning ramp is applied to the horizontal plates so that the slit-shaped electron beam is scanned along the wavelength axis of the spectral image. This same scanning ramp signal is also used to provide horizontal deflection in the display on the oscilloscope crt. The bandwidth of the vertical preamplifier in the 7J20 is limited so that any intensity variations that might be detected along the slit length will be integrated out. The signal from the low-noise preamplifier is next electronically processed and normalized for spectral response. The resulting signal, representing spectral intensity, drives the vertical axis of the oscilloscope crt.

MEASURING VIDICON SATURATION

A silicon-diode vidicon exhibits a light-transfer response such as that shown in Fig. 5. Vidicon saturation (a non-linearity or "leveling off" of response) occurs at high light levels. Occasionally saturating the vidicon will not permanently damage the tube. The saturation level of the vidicon can change as the tube ages and should be measured periodically to prevent unwanted measurement errors that occur at or above saturation.

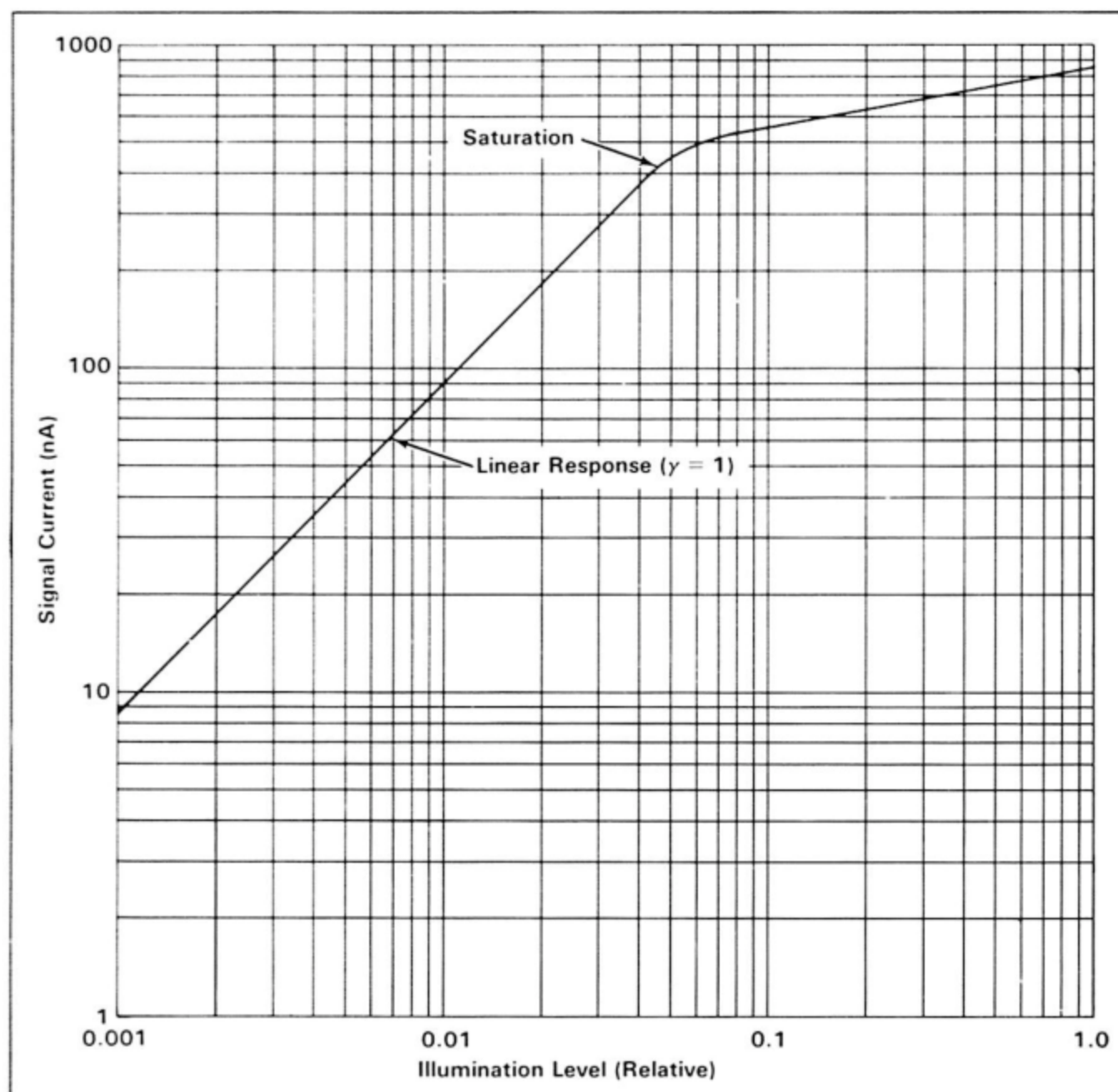


Fig. 5. Typical vidicon light-transfer curve at a 20 ms scan rate.

The following procedure provides instructions for determining vidicon saturation level and when a measurement level is near saturation.

- 1 Pre-set instrument controls to the following settings

| J20 | |
|-------------------------------|--------------|
| WAVELENGTH SPAN | A 400 nm/div |
| GRATING A WAVELENGTH INTERVAL | 400-800 nm |
| SLIT WIDTH | 100 μ m |
| FILTER | OPEN |

| 7J20 | |
|------------------------|----------------|
| VERTICAL GAIN | 1 |
| VARIABLE VERTICAL GAIN | CAL IN |
| OFFSET | Locked at 0.00 |
| TIME/SCAN | 20 ms |
| VARIABLE TIME/SCAN | CAL IN |
| DISPLAY DISPERSION | 40 nm/div |
| SPECTRAL NORMALIZER | OFF |

2. Press the BASELINE RESTORE pushbutton and hold. Using the VERT POSITION control, position the display baseline to the bottom crt graticule line. Release the BASELINE RESTORE pushbutton.

3. Place a tungsten incandescent lamp in front of the spectrometer entrance slit. While monitoring the spectrometer display, position the lamp to achieve a signal amplitude to the point where further movement of the lamp produces little further increase in signal amplitude. Also, note that the characteristic curve of the lamp will change and narrow spectral lines will broaden above this level.

As a final check for saturation, change the TIME/SCAN switch to 10 ms. The vidicon will saturate at a higher signal current level at this scan rate. Non-saturated signals will not significantly change their levels when the scan rate is increased.

4. Determine the saturation level of the vidicon by counting the number of divisions up from the bottom crt graticule line to the level at which the lamp's characteristic curve became distorted and ceased to increase in amplitude. If the saturation level is above eight divisions, rotate the OFFSET control to bring the display back into the crt display area.

5. Multiply the number of divisions counted times 100 nA (signal current sensitivity = 100 nA/div in the 1 position of the VERTICAL GAIN switch) to determine vidicon saturation current. Take into account any offset provided by the OFFSET control (one revolution = 100 nA).

INTERCHANGEABLE GRATINGS

Often it is desirable to initially scan a broad spectral range, then, later investigate specific regions of interest using greater dispersion and improved resolution. The use of two interchangeable gratings in the J20 Spectrometer allows this zoom-in capability, as illustrated in Fig. 7. The

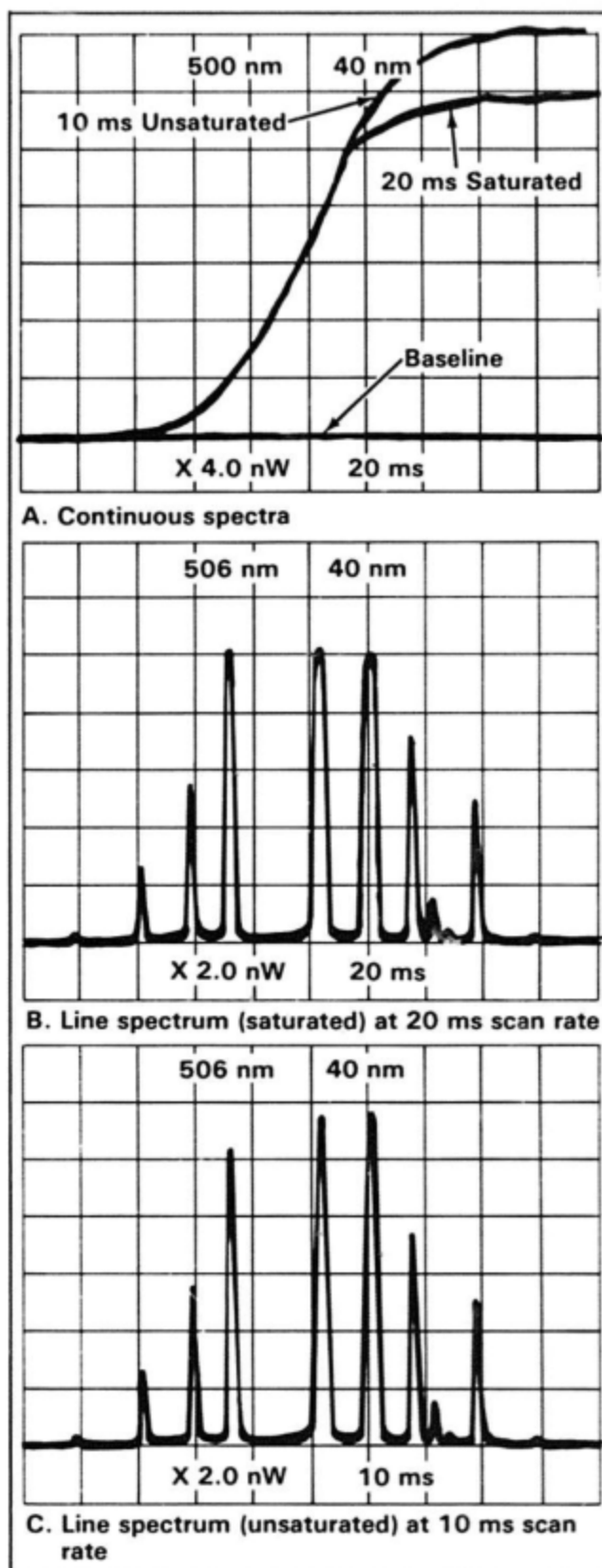


Fig. 6. The effect of vidicon saturation on line and continuous spectra.

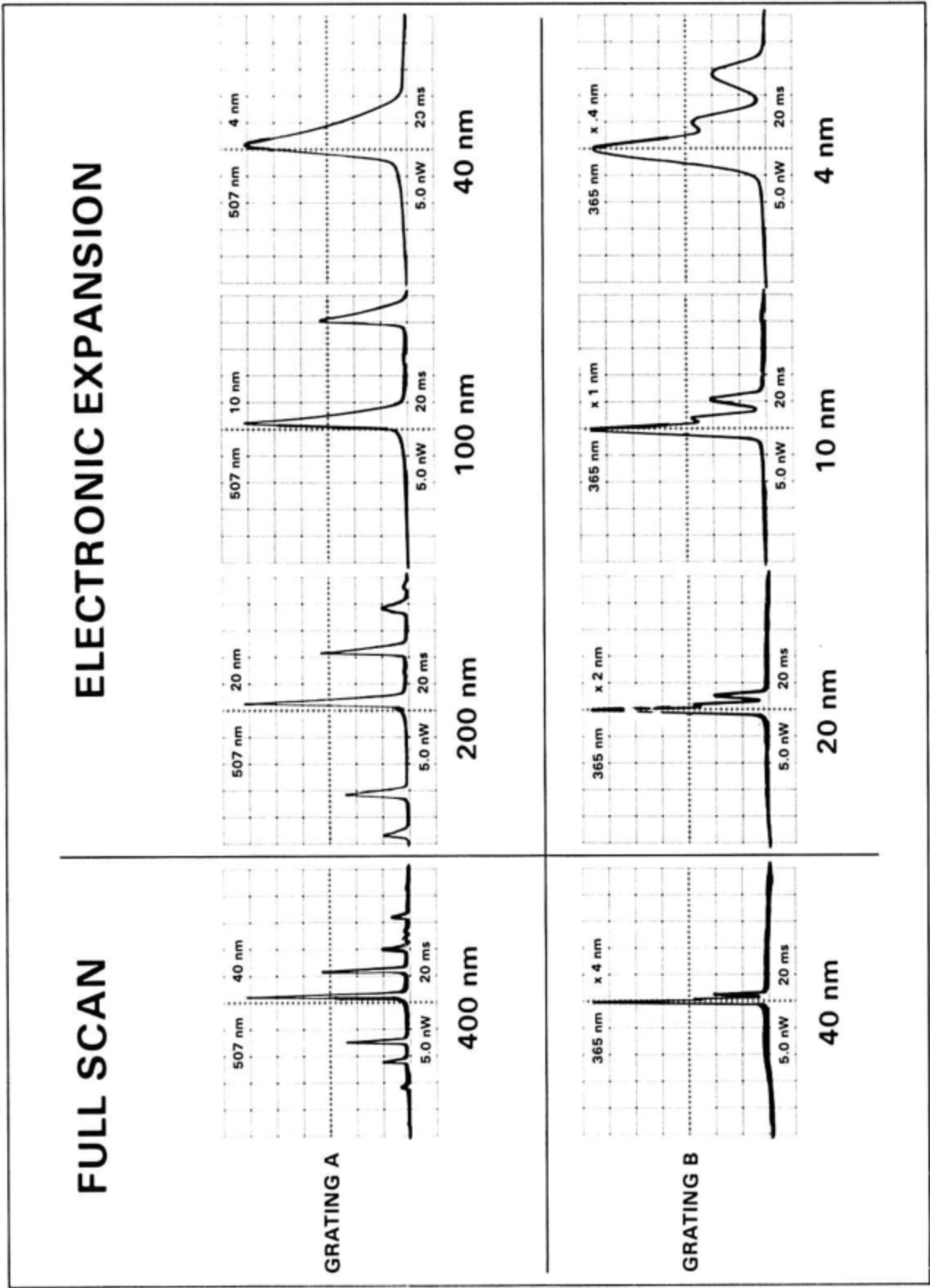


Fig. 7. Spectrum displays illustrating spectrometer display dispersion capabilities.

top set of spectra was obtained using Grating A, which images a 400 nm segment on the vidicon. Grating B scans only a 40 nm segment of the spectrum, but offers a ten-fold improvement in resolution over Grating A. In Fig. 7, full-scan displays for each grating are shown to the left, while electronically expanded displays are shown on the right. The numbers in the upper right-hand portion of the crt readout indicate the wavelength span for each display, both full scan and when electronically expanded.

A sodium lamp and a low-pressure mercury lamp were used to obtain these spectra. The wavelength readout indicates the wavelength at which the intensified marker spot is set. As the display is electronically expanded, the intensified marker spot automatically moves to the center of the display and expansion occurs centered around this spot. Switching to Grating B provides a dramatic increase in resolution for detailed analysis. As with Grating A, the display expands around the intensified marker spot with maximum expansion providing a display with a total scan of 4 nm. In the Grating B spectra examples, the triplet around which the display is expanded is the 365 nm mercury triplet. Note that throughout all of the examples shown, the amplitudes of the lines remain constant as would be expected in a radiometrically calibrated system.

ELECTRONIC NORMALIZER

An important feature of the Tektronix J20/7J20 Spectrometer system is a unique electronic method of correcting for the spectral response of the system. Specially designed integrated circuits detect wavelengths at every instant the electron beam is scanning the vidicon target, and amplify the signal in such a way that the displayed output signal is equivalent to one coming from a blackbody detector and perfect optical system. This results in the system being automatically radiometrically corrected and calibrated. The crt display readout indicates vertical scale factors of spectral radiant power in terms of optical power per spectral bandwidth interval (microwatts per nanometer) within the solid angle subtended by the instrument. Switching the gain of the instrument, changing entrance slitwidth dimensions, changing gratings, etc., is all taken into account automatically and the crt display readout changes accordingly.

SELECTABLE SLIT WIDTHS

For best radiant energy transfer (throughput) and resolution, the optimum slit width is one where the projected slit image approximately equals the smallest width that the vidicon can resolve. For the J20 Spectrometer, this optimum slit width is 20 μm . In special cases, it is desirable to sacrifice either resolution or sensitivity to gain the other.

The 10 μm slit width improves resolution slightly over the 20 μm slit, although sensitivity will be decreased by one-

half. This is useful with bright monochromatic sources such as lasers, gas discharge lamps, etc.

Above 20 μm , doubling the slit width doubles sensitivity while resolvable bandwidth is halved (less resolution). Wider slits can be used when detecting broad-band emissions such as some molecular phosphorescence and fluorescence spectra where there is no line detail. To determine the best slit-width compromise for low light-level detection, begin with 20 μm and increase the slit width until the spectral characteristic under study begins to lose spectral detail.

SELECTABLE FILTERS

All filters used in the J20 Spectrometer are placed in the optical path in front of the monochromator entrance slit and can be easily interchanged by rotating the FILTER switch. Typical filter response curves are shown in Fig. 3 in the section entitled CONTROLS AND CONNECTORS.

The following is a description of all of the positions of the FILTER switch.

- 0 — Open position. No filters are placed in the optical path. Used when making radiometry measurements and during normal operation.
- 1 — Neutral Density 1.0. This filter transmits only 10% of the incident light and is used to attenuate bright sources. Neutral-density accuracy is $\pm 5\%$ of N.D. 1.0 from 400 nm to 1000 nm (i.e., transmission could be between 11.22% and 8.91%), and $\pm 12\%$ from 250 nm to 400 nm and from 1000 nm to 1100 nm.
- 2 — Neutral Density 2.0. This filter transmits only 1% of the incident light and is also used to attenuate bright sources. Neutral-density accuracy is $\pm 5\%$ of N.D. 2.0 from 400 nm to 1000 nm and $\pm 12\%$ from 250 nm to 400 nm and from 1000 nm to 1100 nm.
- 3 — 500 nm Monopass. This filter transmits only a very narrow band of wavelengths centered around 500 nm. It is used for spectral calibration when a spectral calibration emitter is not available. The spectral source used must contain 500 nm radiation (such as a tungsten lamp, fluorescent lamp, etc.)
- 4 — 800 nm Monopass. This filter transmits only a very narrow band of wavelengths centered around 800 nm. Also used as a calibration aid as was position #3.

RSS Characteristics—J20/7J20 Operators

5 — UV Block < 400 nm. This filter attenuates wavelengths below 400 nm and passes those wavelengths above 400 nm relatively unattenuated. It is used for blocking higher order ultraviolet wavelengths below 400 nm.

6 — UV Block < 500 nm. This filter attenuates wavelengths below 500 nm and passes those wavelengths above 500 nm relatively unattenuated. It is used for blocking higher order radiation below 500 nm.

NOTE

The UV block filters cut-on over a wavelength band of approximately 50 nm with 50% transmission occurring at the specified wavelength. When using these filters near the "cut" knee, use caution in interpreting measurements and consult the typical filter curves shown in the section entitled CONTROLS AND CONNECTORS.

7 — UV Pass. This order-sorter filter passes ultraviolet wavelengths ($\geq 50\%$ transmission) between 250 nm and 400 nm and blocks radiation from 440 nm to 660 nm. To avoid confusing first and second order spectra, use this filter only in the wavelength range of 250 nm to 330 nm.

SYSTEM OPERATIONAL FEATURES

DISPLAY DISPERSION

The DISPLAY DISPERSION control electronically expands the display centered around the intensified wavelength marker spot. Using display expansion can clarify a complex display by displaying only the region of interest, or it can be used to detect or measure narrow spectral lines.

NOTE

The DISPLAY DISPERSION control affects only the crt display and there is no change in the system resolution when it is used.

By using both gratings and the display expansion control, the J20/7J20 Rapid-Scanning Spectrometer can be used to initially scan a broad spectral range and then to investigate specific regions of interest using greater dispersion and improved resolution.

VERTICAL GAINS

LINEAR GAINS. With the VERTICAL GAIN switch set to 1, the display vertical current sensitivity is 100 nA/div. This gain setting will display spectral signals from 0 nA to 800 nA in amplitude when the baseline is positioned to the lowest graticule line. For other gain settings, determine display current sensitivity by using the formula:

$$\frac{100 \text{ nA/div}}{\text{Relative Gain}}$$

Use linear mode vertical deflection whenever an accurate representation of spectral amplitudes is desired or when making radiometric measurements.



Vidicon response becomes non-linear when operated at or above vidicon saturation level (typically around 500 nA initially). See the instructions given in the section entitled SYSTEM COMPONENTS for determining vidicon saturation level.

LOGARITHMIC GAINS. Three logarithmic gain positions of the VERTICAL GAIN switch give sensitivities in terms of decibels (dB) per division (10 dB = one decade). These logarithmic sensitivities facilitate simultaneous display of both weak and strong spectral emissions. Use of the optional accessory 016-1000-00 RSS External Normalizer, in conjunction with logarithmic vertical deflection, permits display of the logarithmic transmission characteristics of filters, solutions, etc.

Because baseline variations represent a "false" signal to the logarithmic amplifier circuitry, the accuracy of the logarithmic display depends on the current level of the measured signal. From the logarithmic gains accuracy specifications, it is evident that logarithmic display accuracies improve at higher signal current levels. The greatest %T measurement accuracy occurs when the 100%T level is as high a signal current as possible, yet still below vidicon saturation.

ABSORBANCE. Absorbance is the inverse of logarithmic transmission. Three absorbance gain positions on the VERTICAL GAIN switch provide deflection calibrated in terms of absorbance units (1 A = one decade).

As with logarithmic gain, baseline variations represent "false" signals to the logarithmic amplifier circuitry which

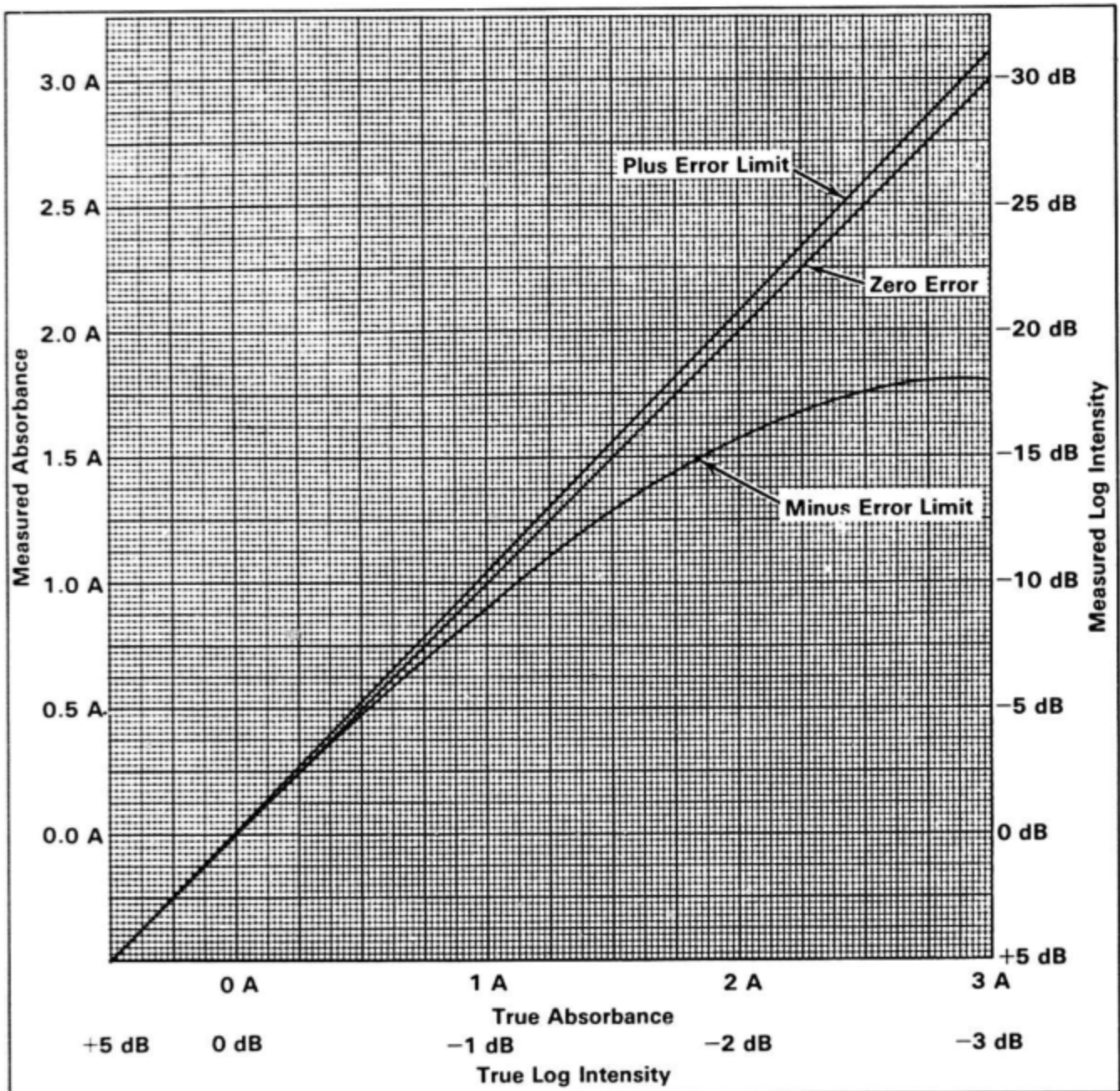


Fig. 8. Graph depicting accuracy limits for logarithmic and inverse-logarithmic (absorbance) vertical gains.

results in larger measurement errors at high absorbance values. Greatest absorbance measurement accuracy occurs when the zero absorbance level is set as high as possible, yet still below the vidicon saturation level.

SCAN RATES

CONTINUOUS SCAN. When the TIME/SCAN switch on the 7J20 is set to 10 ms or 20 ms, the RSS continuously scans the vidicon target with negligible hold-off time between scans. This mode of scanning provides the

widest dynamic range of detectable signal levels and the most rapid time response to changing optical events. For these reasons, this scanning mode is preferred for the majority of general purpose uses.

The 20 ms scan rate offers a better signal-to-noise ratio than the 10 ms rate. Additionally, all radiometric calibration is done with the TIME/SCAN switch set to 20 ms; therefore, the spectrometer system radiometric calibration specifications apply only when making radiometric measurements at a 20 ms scan rate. When the

RSS Characteristics—J20/7J20 Operators

TIME/SCAN switch is set to 10 ms, the VERT UNCAL light will be on to indicate that the system is not radiometrically calibrated (Vertical Sensitivity deleted from readout in integrate mode).

The 10 ms scan rate offers slightly faster time response than the 20 ms scan rate. The 10 ms rate also produces larger maximum usable signal levels below vidicon saturation than the 20 ms rate. The large variations in baseline level remain the same but noise will increase slightly. As a result, the 10 ms rate offers an increased dynamic signal range (defined as the difference between baseline variations and vidicon saturation) over the 20 ms rate. This feature facilitates detection of strong signals when an "apparently" flatter baseline is desired. This feature is beneficial when searching out weak spectral lines in the presence of very strong lines (while using logarithmic vertical gains) and with most absorbance applications.

INTEGRATE SCAN. Photons absorbed into the vidicon silicon-diode target induce a charge into the target. The target stores this charge in much the same manner as a capacitor stores a charge. If the optical emission is continuous, the amplitude of the vidicon signal current increases directly as the time between scans is increased, provided the signal level remains below target saturation. Simultaneously, however, the target leakage level increases as the time interval between scans increases. The net result is an increased signal-to-noise ratio (increases with the square root of the integrate time), and a decreased dynamic range.

The numbers adjacent to the INTEGRATE TIME positions of the TIME/SCAN switch refer to the total time interval between sequential examinations of a single point on the vidicon target. In the 100 ms position, for example, the 100 ms is made up of 80 ms of holdoff time between 20 ms scanning ramps. Using the integrate scanning mode facilitates detection of low light levels which would be difficult in the rapid-scan mode. The integrate mode also provides time averaging of a fluctuating light source. For example, the integrate mode of scanning will largely reduce the jitter present in a gas-discharge light source that is powered by 60 Hz ac. The integrate mode is useful when a computer memory or a storage crt display is being cluttered with unneeded scans.

NOTE

The spectrometer system is not radiometrically calibrated when operating in the integrate mode. In this mode, the Vertical Sensitivity numbers will be eliminated from the crt display readout.

VARIABLE TIME/SCAN. In the uncalibrated (button out) position, the VARIABLE TIME/SCAN control can increase scan rates by a factor of at least 2.5:1. The fastest uncalibrated scan rate achievable using this control is 4 ms.

NOTE

A slight loss in system resolution can occur when the VARIABLE TIME/SCAN control is in the uncalibrated (button out) position and rotated fully clockwise. The loss occurs because the frequency of the scanning signals approaches the bandwidth limit of the preamplifier circuitry in the 7J20 Spectrometer Plug-In.

TRIGGERING MODES

The spectrometer normally operates in a free-run scanning mode. Continuous scanning of the vidicon eliminates any extraneous charges stored in the target prior to measuring a signal level. Without benefit of this pre-measurement discharge scanning, effects could occur that would make calibrated use of the spectrometer difficult. External trigger signals connected to the DISPLAY TRIGGER IN connector can turn the spectrometer display on and off; however, the spectrometer will continue to scan the vidicon target, even in the absence of a display. Unusual applications requiring actual control of the vidicon scan can be accomplished by application of TTL logic signals to the proper pins of the Interface connector located on the underside of the 7J20.

TRIGGERING THE DISPLAY. The free-run mode of display presentation is useful for most situations. Occasionally, however, an operator may desire to present display scans only while a certain segment of an experiment is in process. A trigger signal from a stopped-flow apparatus, for example, could trigger the spectrometer to display only those scans that occur during solution mixing. This mode of triggering would keep a storage crt display free of unnecessary clutter, or would facilitate use of a camera to photograph the display using the camera's "bulb" shutter mode. Similarly, single-scan triggering could be used whereby one and only one scan is presented following receipt of an adequate trigger signal.

TRIGGERING VIDICON SCANNING. A TTL (transistor-transistor logic) logically LO level applied to pin 10 of the Interface connector disables generation of the vidicon scanning ramp waveform. When the logic level at pin 10 goes HI, scanning ramp waveform generation resumes. This design feature offers the ability to synchronize vidicon scanning with events external to the spectrometer. For example, the 10 ms scan rate can be readily synchronized to the 60-Hz ac power-line frequency. This would constitute a mode of operation similar to

the integrate mode of scanning where the integrate time would be 16.7 ms with 6.7 ms of hold-off between the 10 ms scanning ramps.

NOTE

The spectrometer will not make calibrated radiometric measurements while vidicon scanning is being externally triggered.

OPTICAL COUPLING

POSITIONING OF SOURCE. The optical system of the J20 Spectrometer has a relatively large field of view. Complete filling of the field of view and the spectrometer entrance slit area produces the highest system throughput. Detection of low light-level events (such as phosphorescence, fluorescence, or astronomical events) requires high throughput. Best resolution, however, results when only the center portion of the field of view or the center of the entrance slit are utilized.

Non-vignetting of the entrance slit requires a non-circular field of view. Figure 9 shows the actual field to which the J20 Spectrometer responds. If the field of view of the J20 were circular, its f-number would be equivalent to f/6.3. If an external circular optical system is used to image onto the J20 entrance slit, the aperture required is f/6.0 or faster.

EXTERNAL OPTICAL SYSTEMS. Camera lenses readily available from commercial sources provide the most common means of external light collection for the J20. The bayonette ring on the J20 fits Petri lenses or those T-mount lenses adapted to the Petri mounting system. The Petri ring was chosen for mounting lenses onto the J20 primarily because of its built-in indexing feature. It should be noted that most common camera lenses will not pass UV below approximately 300 nm.

The optional accessory 016-0580-00 RSS Fiber Optics Probe facilitates transferring light to the entrance slit of the spectrometer from as far away as 36 inches. Due to the

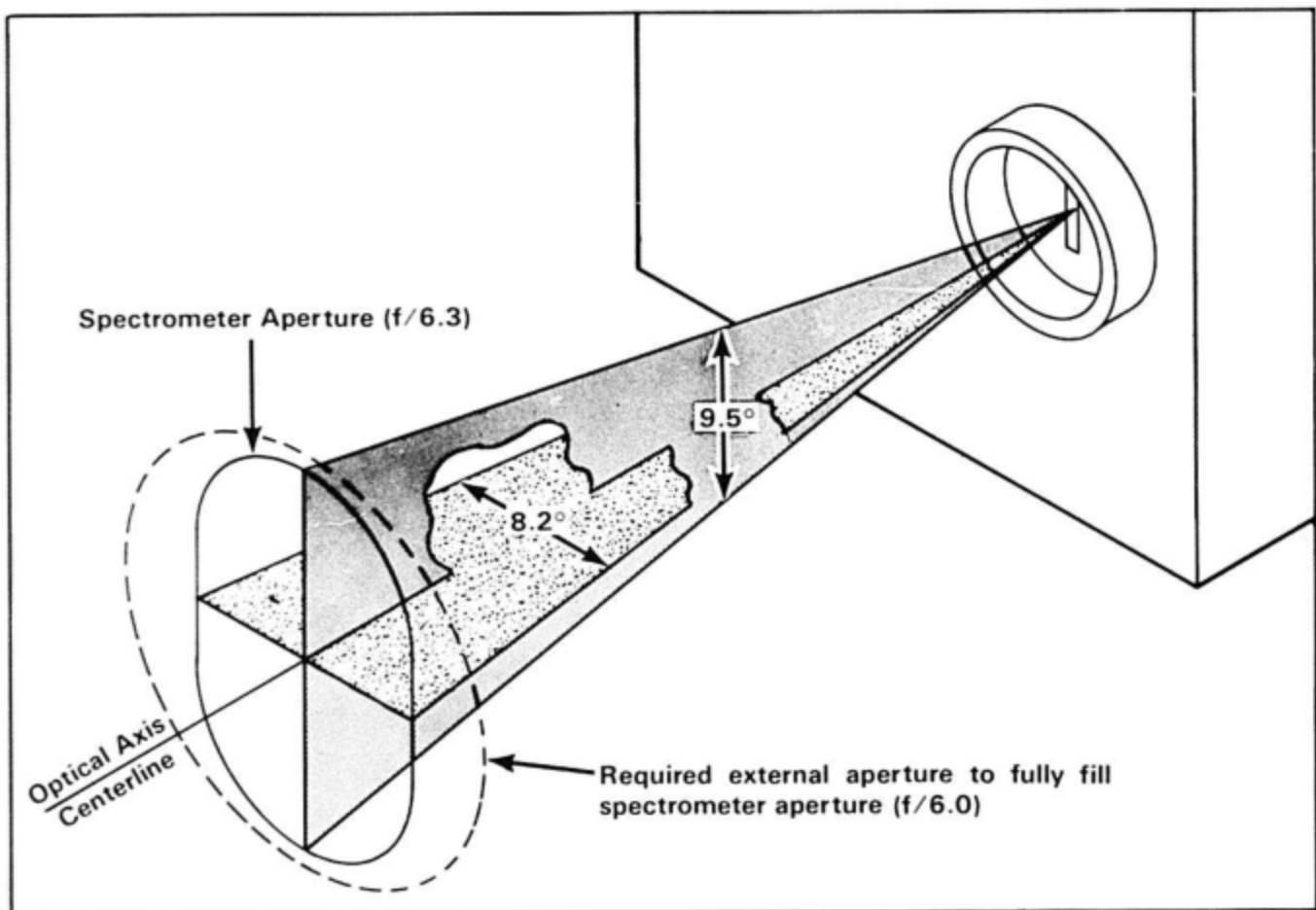


Fig. 9. J20 Spectrometer field of view.

RSS Characteristics—J20/7J20 Operators

properties of fiber optics, the distribution of the light output from the fiber optics probe will be over a much wider angle than the J20 field of view. Additionally, the output end of the fiber optics probe is spaced away from the spectrometer entrance slit, thereby causing further loss. These features result in a low efficiency of light transfer using the probe, but this is unimportant for many applications (such as stopped flow, process control, and most absorbance applications).

The J20 can be coupled to Celestron series telescopes and any other telescope that uses the T-mount adapter. For maximum light transfer, the telescope being used should be f/6.0 or faster and the desired image should fill the J20 entrance slit.

NOTES ON SPECTRAL ORDER

Diffraction gratings cause a wavelength λ_1 to be diffracted at an angle that also equals the angle of diffraction of wavelengths $2\lambda_1, 3\lambda_1, 4\lambda_1, \dots, m\lambda_1$ where m is an integer and is called diffraction order. For example, a 250 nm spectral line will also show up in second order at 500 nm, in third order at 750 nm, etc. In the J20 Spectrometer, filters eliminate higher orders (lower wavelength) when the higher orders are not desired, or conversely pass them when they are desired.

Two shortwave blocking filters and one shortwave pass filter are provided in the J20. Filter position #5 blocks wavelengths below 400 nm while filter position #6 blocks below 500 nm. If the source spectrum does not emit below these points, use of these UV-blocking filters is not required. If, however, there is some doubt about the content of the source spectrum, these filters can be switched into the optical path.

NOTE

These optical filters are not switched into the optical path during radiometric calibration because of the low UV emission of tungsten filament calibration lamps.

Occasionally it is desirable to use higher orders of diffraction. The J20 Spectrometer is sensitive to at least 250 nm, but neither Grating A nor Grating B can mechanically track below 300 nm. Therefore, second order must be used to detect between 250 nm and 330 nm. This has two advantages.

1. Diffraction efficiency of the gratings is near its peak at 500 nm first order which means 250 nm second order will also have a maximum diffraction efficiency.

2. Because dispersion doubles in second order (triples in third order, etc.), resolution in second order also

doubles. Second order resolution at half-intensity becomes 2 nm instead of 4 nm for Grating A.

Filter position #7 blocks radiation from 440 nm to 660 nm, and passes wavelengths from 250 nm to 400 nm. This filter should be used when examining second order wavelengths from 250 nm to 330 nm.

FALSE SPECTRA

Occasionally, the J20/7J20 Rapid-Scanning Spectrometer display will exhibit false spectra that a spectrometer user could construe as being real spectral emission. This discussion concerns itself with two types of false spectra that can occur in the J20/7J20 spectrometer that a spectrometer operator should be aware of and able to identify. False spectra caused by stray light are not included in this discussion.

FIXED-POSITION FALSE SPECTRA. One type of false spectra that can occur appears when observing the characteristic baseline signal (no light input) of the RSS. The baseline can contain narrow, positive-going spikes similar to narrow spectral lines. These spikes are caused by leaky diodes in the vidicon target, and will remain fixed in position in the spectrometer display when adjusting the display center wavelength.

Opaque or non-conductive diodes in the vidicon target can also cause false spectra. These will appear as "dark" spots (similar to absorption lines) while viewing a continuous spectrum and will also remain fixed in position in the spectrometer display when adjusting the display center wavelength. Some "dark" lines can occur when viewing infrared radiation at wavelengths above approximately 700 nm. These are caused by spots in the silicon substrate of the vidicon target that exhibit reduced infrared sensitivity.

NOTE

Real absorption bands often occur in the spectrum of incandescent lamps at wavelengths above approximately 700 nm. These absorption lines will move in the display when adjusting display center wavelength and can be readily differentiated from vidicon target IR spots using this method.

VARIABLE-POSITION FALSE SPECTRA. The basic design of the Czerny-Turner monochromator used in the RSS can cause false spectra to be exhibited under certain operational conditions when using Grating B. For example, when examining the radiation from an incandescent lamp, a false spectra step (negative or positive-going) can appear in the displayed spectrum when the unexpanded-display center wavelength is approximately 385 nm, 425 nm, or 680 nm.

APPLICATIONS

INTRODUCTION

This section of the manual provides information concerning specific applications of the J20/7J20 Rapid-Scanning Spectrometer. The applications listed here represent only a few of the instrument's capabilities. Users having questions concerning specific measurement

applications not included in this section should direct their inquiries to the Marketing group of Analytical Products at Tektronix, Inc., P.O. Box 500, Beaverton, Oregon, 97005. As new applications are documented, they will be made available to interested customers and can subsequently be added to this section of the manual.

TRANSMITTANCE & ABSORPTION MEASUREMENTS

INTRODUCTION

Spectrophotometry is a very convenient and accurate method of observing relatively fast chemical reactions. It requires, of course, that the absorption spectrum of the material being examined must change during the reaction and that the changes can be related to the concentration of a chemical species, whether it be reactant, product, or intermediate. Following chemical kinetics spectrophotometrically is nonperturbational; that is, it does not measurably affect the reaction to make spectral absorption measurements.

A very useful and popular method of studying chemical reactions is stopped-flow kinetics where the reactants are very quickly mixed and placed in a light path to observe the changes in absorption that occur in time. The reactants flow together in a mixing chamber and then into an absorption cell. The flow is then stopped suddenly and spectral changes are observed. Normally monochromatized light is passed through the reaction cell in a spectral region of interest to observe the reactants or products as their absorption changes. Such observations can be quite accurate if the peak being observed follows Beer's Law. This requires that there be no wavelength shifts, no changes in bandshape, and no interfering absorptions during the reaction.

The J20/7J20 Rapid-Scanning Spectrometer system allows such observations in a single experiment by observing a relatively large spectral region and its time evolution in real time. If there are wavelength shifts, bandshape changes, or intermediate absorptions that occur, they can be viewed directly. Such observations can give information regarding the mechanism of a reaction as well as quantitative data for determining the relevant kinetic constants. The interface of the J20/7J20 Rapid-Scanning Spectrometer with stopped-flow kinetics instrumentation can be readily accomplished whether this instrumentation is custom-made or commercially available.

MAKING MEASUREMENTS

Basically, to measure the absorbance (or transmittance) of a sample, the sample is placed between the spectrometer and a light source. Physical limitations may not permit a direct optical placement, in which case fibre optics can be employed. The choice of plastic, glass, or quartz fibre optics depends on the wavelength range being studied. Generally, wavelength studies in the ultraviolet region require the use of quartz fibre optics. Either absorbance or transmittance can be displayed by selecting the proper switch position of the VERTICAL GAIN switch on the 7J20 Spectrometer Plug-In. The linear gain positions (1 through 500) are used for transmittance and the ABSORBANCE positions (.1 through .5) are used for absorbance.

TRANSMITTANCE. Making a transmittance measurement requires knowledge of what the measurement extremes can be. These extremes are 100% transmission (the light reaches the spectrometer unattenuated; no sample in the optical path) and 0% transmission (no light reaches the spectrometer). To establish these measurement extremes, set the OFFSET control to 0.00 and the VERTICAL GAIN switch to linear position 1. Push the BASELINE RESTORE button and set the display baseline to a convenient reference line in the lower portion of the crt graticule area (such as the bottom horizontal graticule line) using the Vertical POSITION control. Release the BASELINE RESTORE button and allow light from the light source to enter the spectrometer entrance slit unattenuated (no sample in the optical path). Select a linear VERTICAL GAIN switch position that allows maximum vertical deflection with the display remaining within the limits of the crt graticule area. Do not readjust the Vertical POSITION control except to ensure that the 0% transmission reference remains at the reference line. The number of divisions of deflection between the 0% T and 100% T lines at a given wavelength divided into 100 represents % T per division at that wavelength.

ABSORBANCE. Making absorbance measurements, like transmittance measurements, requires the establishment of some reference points in the display. To establish these references, set the VERTICAL GAIN switch to the linear gain 1 position and the OFFSET control to 0.00. Push the BASELINE RESTORE button and set the display baseline to a convenient reference line in the lower portion of the crt graticule area (such as the bottom horizontal graticule line) using the Vertical POSITION control. Release the BASELINE RESTORE button and set the VERTICAL GAIN switch to one of the ABSORBANCE positions (.1, .2, or .5). Allow the light from the light source

to enter the spectrometer entrance slit unattenuated (no sample in the optical path). Using the ABSORBANCE ZERO control, vertically position the wavelength area of interest in the display to the same horizontal graticule reference line used when the BASELINE RESTORE button was pressed. Specific wavelengths of interest can be readily identified by using the MARKER control to horizontally position the intensified wavelength marker in the crt display. Each vertical graticule division of deflection from the reference line at the specific wavelength area of interest now represents a specified number of absorbance units as indicated by the VERTICAL GAIN switch.

LUMINESCENCE MEASUREMENTS

INTRODUCTION

The Tektronix J20/7J20 Rapid-Scanning Spectrometer system has the capability of performing virtually any spectral measurement associated with ultraviolet-visible-near infrared luminescence. The general term "luminescence" describes any emission of light (not necessarily visible) from any source. This discussion concerns itself with the luminescence associated with fluorescence and phosphorescence in chemical, biological, and physical systems of interest. These luminescences span the full ranges of intensities, spectral regions, spectral shapes, and lifetimes of decay. The Tektronix spectrometer system can detect a significant proportion of these luminescent phenomena.

MOLECULAR LUMINESCENCE

The two types of molecular luminescence most often encountered are fluorescence and phosphorescence. For large unsaturated organic molecules and transition-metal molecules and ions, these emissions generally occur in the ultraviolet and visible regions with a few occurring in the near IR. We are dealing with the emission of light as the result of the relaxation of an electronically excited species. The means of excitation may vary. It could be the result of light irradiation (luminescence), electrical discharge (plasma emission), chemical reaction (chemiluminescence, bioluminescence, or electroluminescence), or physical stimuli (thermoluminescence or triboluminescence). The spectra from these sources can be line spectra, broadened line spectra, unresolved band spectra, or continua. The quantities of interest are wavelength of spectral peaks or

features, intensities, overall shape, separation of peaks, and decay characteristics. The J20/7J20 Rapid-Scanning Spectrometer can measure these quantities, provided there is a spectral flux of at least 50 pW of spectroradiant power for Grating A and 500 pW for Grating B entering the effective aperture of the spectrometer.

Generally, luminescence is measured from an extended source. As an example, let us consider a phosphorescence or fluorescence. The sample is often about 1 cm by 2 or 3 cm. The emission emanates from a rather large volume. In order to record the spectrum of this light, it must be focused on the aperture of the instrument. A lens can be used but its f-number should be f/6.0 or faster. All external optics for focusing the sample onto the entrance slit, including any mirrors used to reflect the luminescence back on itself, should be f/6.0 or faster. The image-to-object size ratio should be optimized so that the image is very nearly the size of the entrance slit aperture of the J20 Spectrometer. The entrance slit height is 7 mm, with widths selectable from 10 μm to 1000 μm in 1-2-5 steps. The entrance slit width should be chosen to provide sufficient resolution to yield an accurate spectrum, but no narrower. This is usually done by selecting successively narrower entrance slit widths until no further sharpening of the spectrum occurs. The spectral bandwidth of the instrument varies with the entrance slit width selected down to a slit width of 20 μm . Below this point, the vidicon detector becomes the limiting factor in determining resolution. Decreasing the entrance slit width further merely attenuates the amplitude of the spectrum. To get radiometric power readings of lines narrower than the spectral bandwidth of the instrument, it is necessary to integrate the spectral peaks.

RADIOMETRIC MEASUREMENTS

INTRODUCTION

Optical spectral power measurements in calibrated absolute terms, while seemingly simple in principle, are somewhat difficult to accomplish. The design of the J20/7J20 Rapid-Scanning Spectrometer alleviates some of these difficulties. The spectrometer measures power entering the entrance slit and a spectrometer operator can relate this measurement back to the actual source mathematically.

Knowing only relative spectral power will suffice for most radiometric applications. For example, a spectrally "flat" spectrometer that does not have calibration traceable to the National Bureau of Standards can still provide comparison of spectral power distribution of lamps or comparison of one phosphor luminescence to another. For these applications it is necessary to ensure only that the positions of the samples and of any external optics are not altered between measurements. Spectral power measured in this manner will probably not be absolutely accurate and would be referred to as relative spectral power.

Occasionally, however, spectral power needs to be measured in absolute terms traceable to a standard. The J20/7J20 Rapid-Scanning Spectrometer becomes a calibrated spectroradiometer with calibration traceable to the National Bureau of Standards when the SPECTRAL NORMALIZER switch is set to the INT position. While in principle the instrument detects spectral radiance, the throughput (area of slit multiplied by solid angle subtended) of the J20 optics is internally calculated out, resulting in displayed sensitivity in terms of spectral power (watts/nanometer). Therefore, no instrument measurement error will occur if the entire field of view of the instrument is not filled or if the entrance slit is not fully illuminated. If so desired, a user can calculate spectral radiance of the source from the displayed spectral power.

Radiometric calibration for the J20/7J20 Rapid-Scanning Spectrometer extends over the wavelength range of 400 nm to 967 nm for Grating A, and 367 nm to 900 nm for Grating B. For greatest accuracy (with two exceptions), make all radiometric measurements within the center two crt divisions. On Grating A, exclude the two center crt divisions when making radiometric measurements for wavelengths of 400 nm to 460 nm and 940 nm to 967 nm.

DISPLAY READOUT

The spectrometer system automatically corrects the Vertical Sensitivity portion of the crt readout for changes in vertical gain settings, and filter selection. The readout

will display an X in front of the sensitivity numbers when the system is radiometrically uncalibrated, and deletes the sensitivity portion of the readout when operating in the integrate scanning mode. The formula used to calculate spectral sensitivity is as follows:

$$\text{Grating A} = \frac{10^{(D_N-8)}}{G} \quad \text{watts/(nm}\cdot\text{div)}$$

$$\text{Grating B} = \frac{10^{(D_N-7)}}{G} \quad \text{watts/(nm}\cdot\text{div)}$$

where D_N = Neutral Density (0, 1, or 2)

G = Relative linear gain

RSS RADIOMETRIC CALIBRATION

The J20/7J20 Rapid-Scanning Spectrometer is radiometrically calibrated using a tungsten ribbon-filament lamp that is traceable to the National Bureau of Standards. RSS radiometric calibration and inter-lamp comparisons are accomplished in the manner described by Stair, et al¹, and the National Bureau of Standards². The only significant variations to their procedure required in calibration of the RSS are:

1. The angular field of view is 5.5° instead of 2.5° half angle.
2. Seven millimeters of filament ribbon is detected instead of five millimeters.

The effect of both of these changes is carefully measured for each lamp, and corrections are made on spectral radiance. Uncertainties which result are accounted for in error analysis.

¹Stair, R., Johnston, R.G., and Halback, E.W., Standard of Spectral Radiance for the Region of 0.25 to 2.6 microns, J. Res. Nat. Bur. Stand. (U.S.) 64A, No. 4, 291-296 (July-Aug. 1960).

²Instructions for using the NBS Standards of Spectral Radiance, Nat. Bur. Stand. (U.S.), unpublished, issued with purchase of standard lamps (Feb. 1961).

Applications — J20/7J20 Operators

Figure 10 depicts the layout of the RSS calibration apparatus. Some of the important features are:

1. Spectral radiance standard: tungsten ribbon-filament lamp with quartz window; equivalent to G. E. type 30A/T24/17.
2. Concave spherical mirror: 20 cm in diameter, 36 cm focal length, mounted on a rotatable mount. The spherical mirror is masked to $f/4.7$ (RSS internal masking limits steradiance).
3. Inconel neutral optical density filters: individually calibrated, spaced and tilted ($\sim 4^\circ$) to prevent multiple reflections.
4. Alignment laser: used to align lamp filament, lamp window, mirror, and the J20 entrance slit.
5. Current monitor: used to control lamp current to $\pm 0.2\%$. This current variation will cause a 1% light output change at 400 nm, and a 0.4% light output change at 1200 nm.

Normalized radiometric accuracies listed under the heading SPECIFICATIONS at the front of this manual include the following uncertainties:

1. NBS lamp
2. Secondary lamp intercomparisons
3. Mirror reflectivity
4. Neutral-density filters
5. Lamp drift
6. Variance from NBS procedure
7. J20 throughput
8. J20/7J20 linearity and electronic transfer accuracy
9. Wavelength accuracy
10. Oscilloscope display linearity and readability
11. Calibration solidarity
12. Interpolation between calibration wavelength points

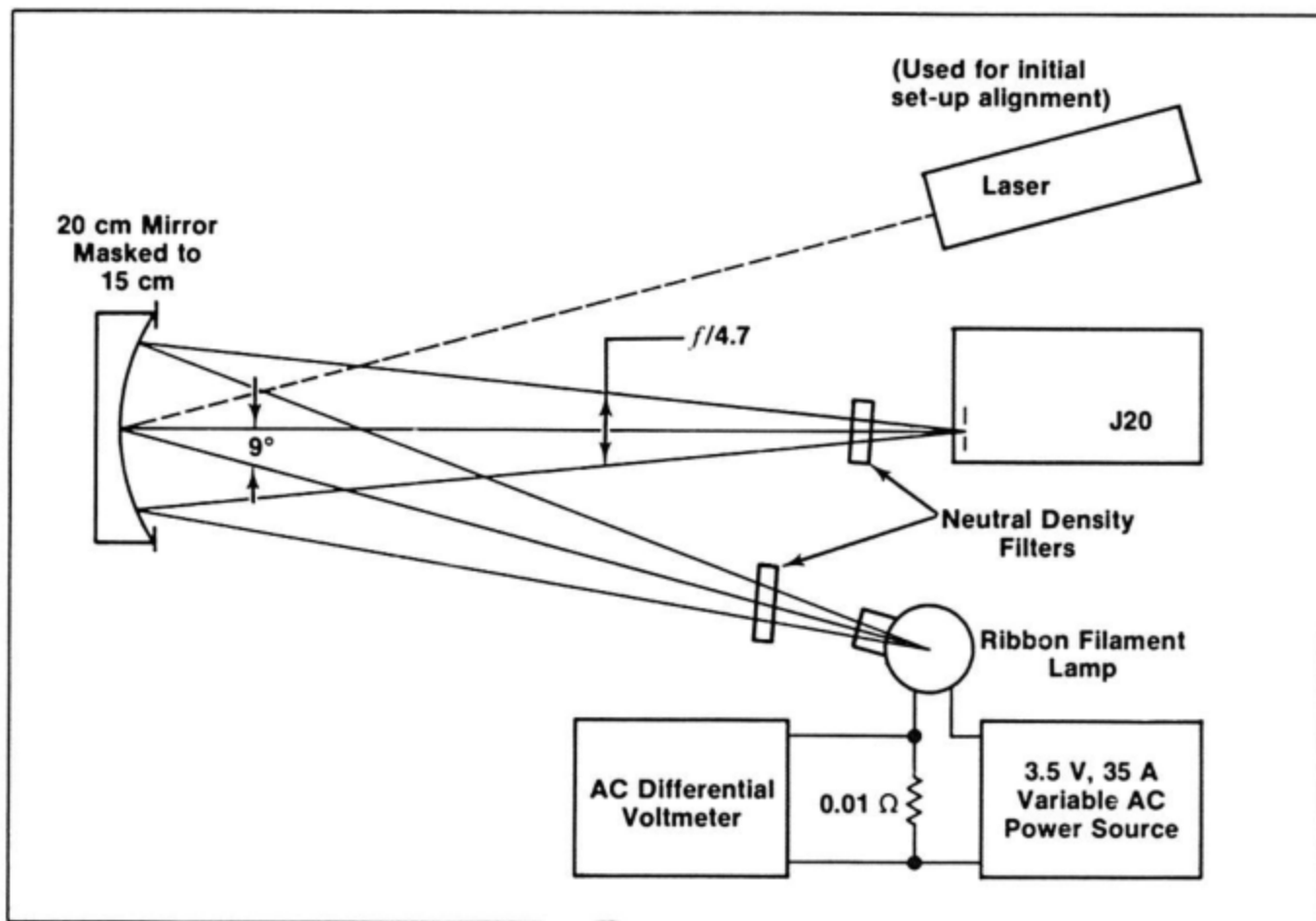


Fig. 10. Equipment set-up required for RSS radiometric calibration.

Using the method recommended by NBS, total uncertainties are determined by quadrature (square root of sum of squares) for random errors.

MAKING RADIOMETRIC MEASUREMENTS

A spectrometer operator can measure spectral power of continuous spectra directly from the amplitude observed in the crt display. For monochromatic lines, however, the spectrometer will spread out the emitted spectral power within the resolution limits of the instrument. One must integrate the total intensity within a line to determine absolute spectral power emitted by such a line.

CONTINUOUS SPECTRA. To make a radiometric measurement of a continuous spectrum, proceed as follows.

1. Pre-set the instrument controls to positions that provide radiometric calibration. For example:

| J20 | |
|------------------------|------------------|
| SLIT WIDTH | 20 μm |
| FILTER | OPEN |
| 7J20 | |
| VERTICAL GAIN | 1 |
| VARIABLE VERTICAL GAIN | CAL IN |
| TIME/SCAN | 20 ms |
| VARIABLE TIME/SCAN | CAL IN |
| SPECTRAL NORMALIZER | INT |

2. Perform a quick wavelength calibration check. Any convenient line source (such as the mercury lines in the fluorescent lamp spectrum) or the 500 nm and 800 nm monopass filters will suffice. Center the emission source on the optical axis of the J20 Spectrometer. The two 1/4-20 mounting holes on the bottom of the J20 Spectrometer (see Fig. 11) align with the J20's optical axis and provide a convenient method of aligning external optics with the J20 optical axis when the system is mounted on an optical bench.

3. Set the OFFSET control to 0.00 and lock.

4. Press the BASELINE RESTORE pushbutton and hold. Adjust the VERT POSITION control to position the display baseline to a convenient reference point in the crt display. Release the BASELINE RESTORE pushbutton.

5. Begin the measurement with the FILTER switch in the OPEN position and the SLIT WIDTH set to 20 μm . Measure deflection on the crt between the baseline (no light) level and the spectrum of the source at each wavelength. Switch in the neutral density filters to provide light source attenuation if the light source intensity is high enough to cause vidicon saturation. Should the source spectrum be low in intensity, increasing the entrance slit width will increase sensitivity; however, resolution becomes worse with larger slit widths.

6. Calculate the spectral power entering the entrance slit by multiplying the number of divisions of deflection by the spectral sensitivity. This calculation yields spectral power in terms of watts/nanometer.

LINE SPECTRA: The precise dimensions of the selectable entrance slits facilitate direct power measurements of line spectra. To measure line spectra, select a slit width of 200 μm or 500 μm . Again, switch in neutral density filters as required to ensure signal levels below vidicon saturation. Measure the amplitude of the spectral line and multiply this amplitude by the spectral sensitivity indicated in the crt readout. Next, multiply the result by the optical bandwidth of the grating/slit width combination being used. The result will be power in terms of watts.

As an example, assume the 456 nm line in the mercury spectrum is being examined using Grating A with an entrance slit width of 500 μm , a VERTICAL GAIN setting of 2, and a signal amplitude of 4.5 divisions. This combination of control settings results in a spectral sensitivity of 5 nW/(nm·div) and an optical bandwidth of 16 nm (see the following chart for optical bandwidths). Spectral power of the 456 nm line for these conditions will be:

$$\Phi_e = [5 \text{ nW}/(\text{nm} \cdot \text{div})] [4.5 \text{ div}] [16 \text{ nm}] = 360 \text{ nW}$$

J20 OPTICAL BANDWIDTHS

| Slit Width (μm) | Grating A | Grating B (@ 650 nm) |
|---------------------------------|--------------|-------------------------|
| 10 | 0.32 nm | 0.032 nm |
| 20 | 0.64 nm | 0.064 nm |
| 50 | 1.6 nm | 0.16 nm |
| 100 | 3.2 nm | 0.32 nm |
| 200 | 6.4 nm | 0.64 nm |
| 500 | 16.0 nm | 1.6 nm |
| 1000 | 32.0 nm | 3.2 nm |

The optical bandwidth chart provides bandwidth figures for Grating B when the unexpanded display center

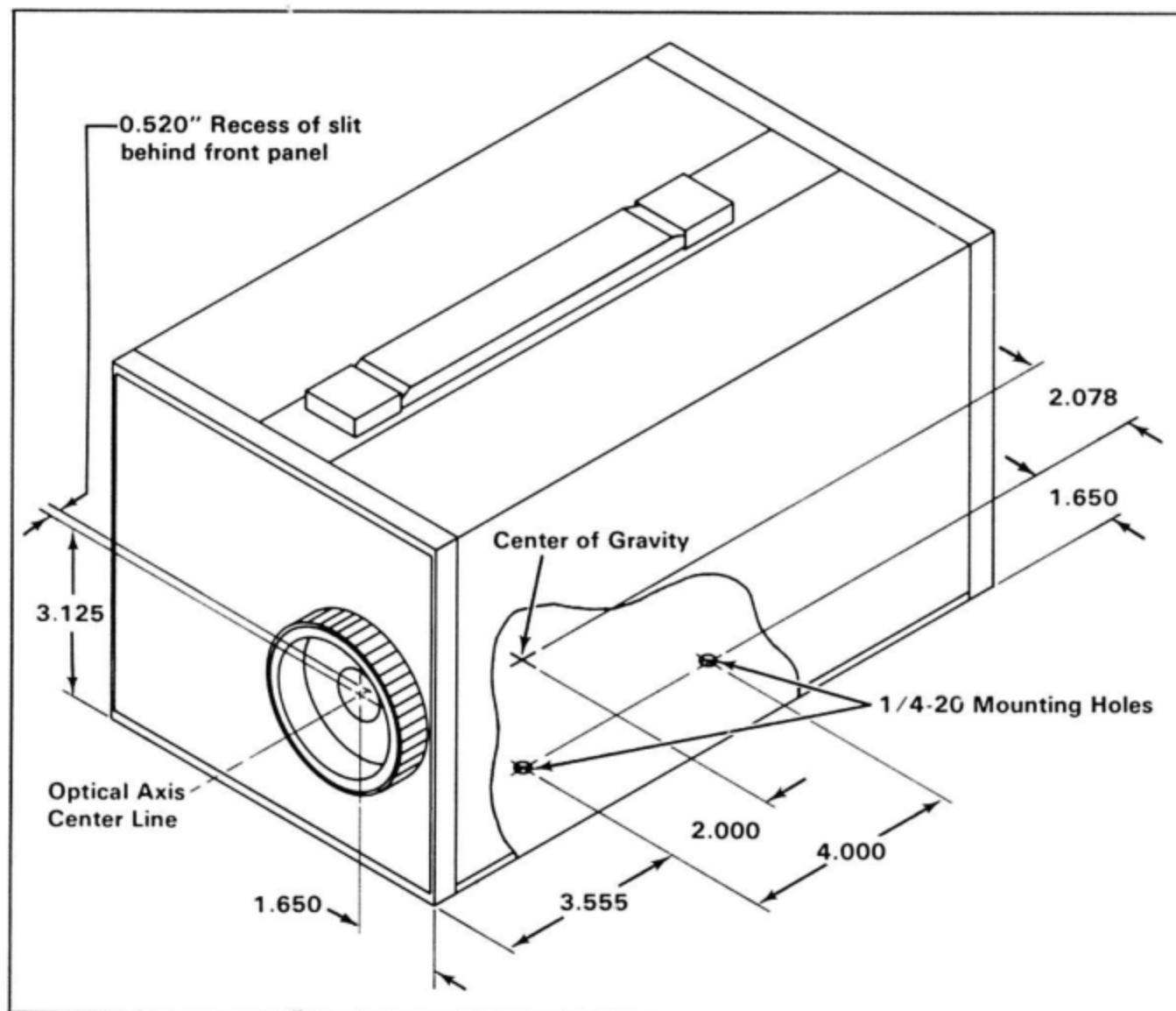


Fig. 11. Location of J20 Spectrometer mounting holes and center of gravity.

wavelength is 650 nm. Since the reciprocal linear dispersion (one of the determinants of optical bandwidth) for Grating B varies as the display center wavelength is varied (not so for Grating A), those bandwidth figures for Grating B are approximately accurate only when the display center wavelength is 650 nm. A spectrometer operator can, however, readily calculate other Grating B optical bandwidths by multiplying reciprocal linear dispersion (in terms of nm/mm) by the width of the entrance slit (in terms of mm) being used. Grating B reciprocal linear dispersion versus display center wavelength is plotted in the graph given in Fig. 12. The display center wavelengths given in the graph are those wavelengths represented by the center vertical crt graticule line in an unexpanded display using Grating B.

As an example, assume Grating B is being used in conjunction with a 50 μ m slit to display a wavelength segment having a center wavelength of 870 nm. Referring to the graph in Fig. 12 yields a reciprocal linear dispersion figure of 2.8 nm/mm. Calculated optical bandwidth for this combination of components is:

$$(5 \cdot 10^{-2} \text{ mm}) (2.8 \text{ nm/mm}) =$$

$$14 \cdot 10^{-2} \left[\frac{(\cancel{\text{mm}}) (\text{nm})}{(\cancel{\text{mm}})} \right] =$$

$$14 \cdot 10^{-2} \text{ nm} = 0.14 \text{ nm.}$$

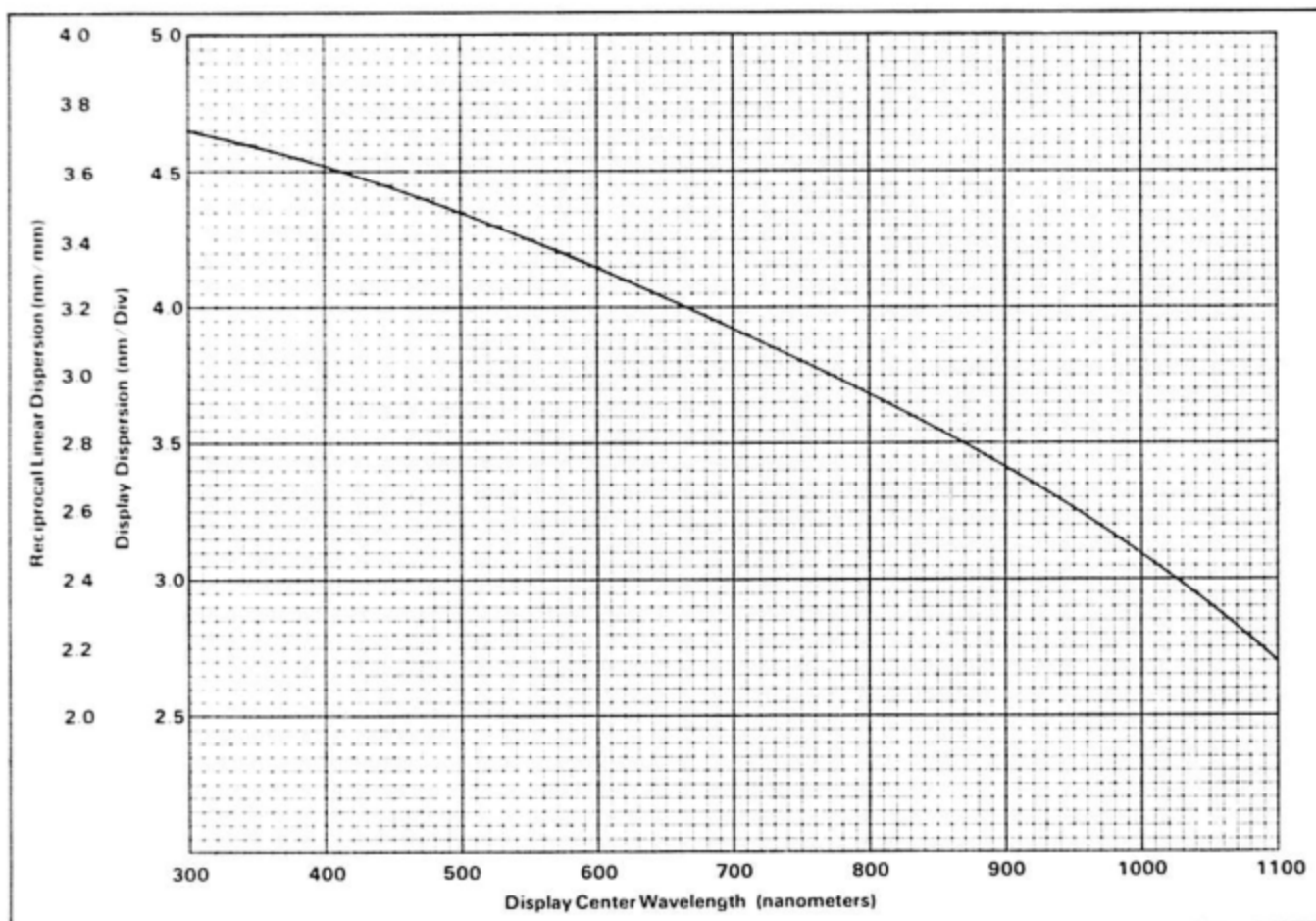


Fig. 12. Typical Grating B display dispersion plotted as a function of display center wavelength.

SOURCE RADIANCE

If the image of the emission source fills or exceeds the slit area and the angular field of view of the J20 entrance slit, the spectrometer operator can calculate the spectral radiance of the source as measured at the J20 slit. The formula for calculating source radiance for these conditions is:

$$L_r = \frac{\Phi(\lambda)}{W_s H_s \Omega} = \frac{[7.14] [\Phi(\lambda)]}{W_s}$$

with the answer given in terms of $W/(\text{nm} \cdot \text{mm}^2 \cdot \text{sr})$ where

$\Phi(\lambda)$ = measured spectral power in W/nm

W_s = slit width in mm

H_s = slit height in mm (7 mm)

Ω = solid angle of acceptance in steradians (0.02 sr)

The operator can directly relate spectral radiance at the J20 slit to source spectral radiance if there are no optical elements between the emission source and the J20

entrance slit. However, if there are intervening optical elements, the operator must take into account spectral transmission and magnification of these elements to determine source spectral radiance.

If the source image does not completely fill the slit area or the J20 angular field of view, the spectrometer operator can still calculate source spectral radiance, using a slightly different but similar approach. As an example, Fig. 13 shows a spherical source focused onto the J20 entrance slit with an external lens. The image diameter (d_i) projected onto the slit multiplied by slit width (W_s) equals the area of image (A_i) detected ($A_i = W_s \cdot d_i$). The solid angle Ω for the semi-vertex angle θ equals $2\pi (1 - \cos \theta)$. The spectral radiance (L_r) of the source image at the J20 entrance slit equals

$$L_r = \frac{\Phi(\lambda)}{(A_i)(\Omega)}$$

in terms of $W/(\text{nm} \cdot \text{mm}^2 \cdot \text{sr})$. Again the operator must take into consideration the effect of any optical elements positioned between the emission source and the J20 entrance slit.

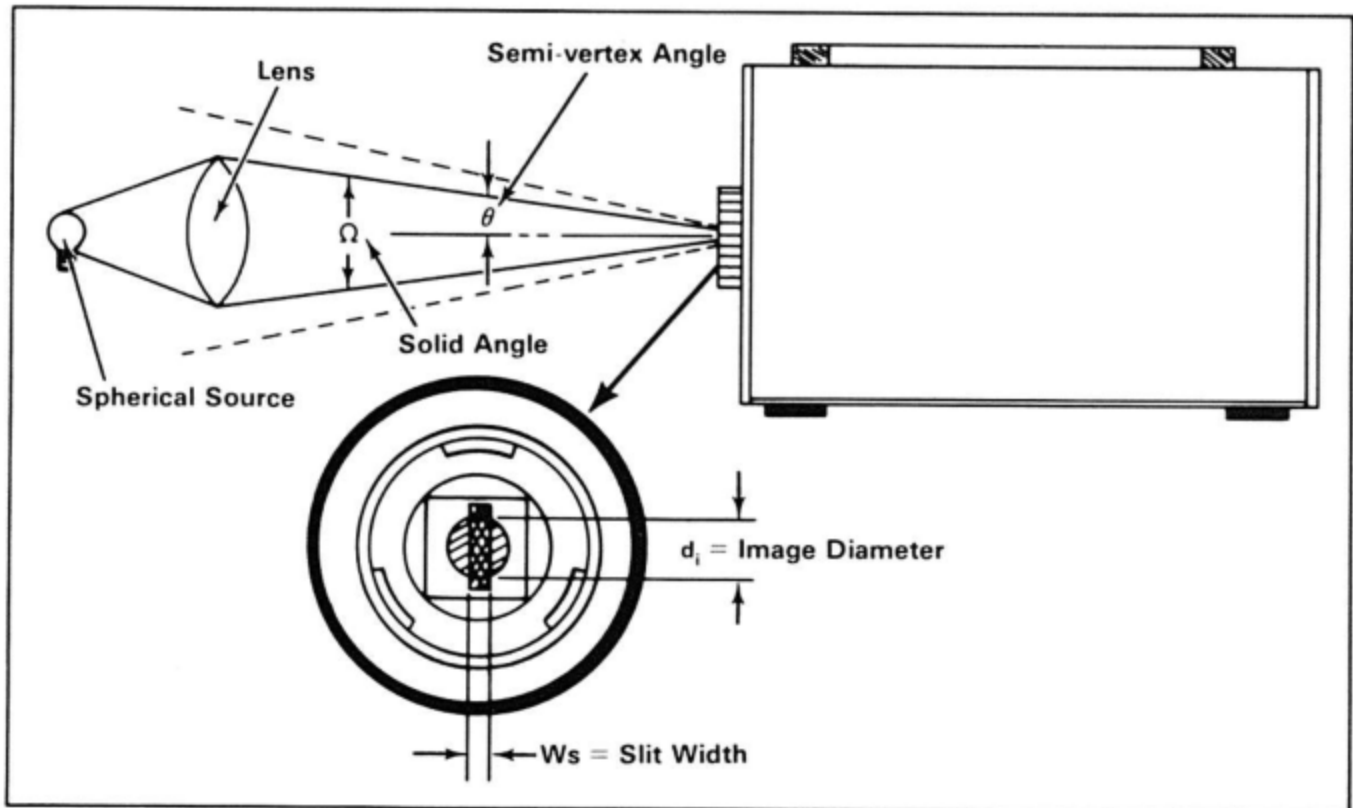


Fig. 13. Calculating radiance of a light source that does not completely fill the J20 field of view.

WAVELENGTH MEASUREMENTS

INTRODUCTION

When using the J20/7J20 RSS system, there are basically three methods of making wavelength measurements of spectral events. The three methods are:

1. Using the calibrated wavelength MARKER control.
2. Using the calibrated dispersion of the spectrometer display.
3. Comparing unknown spectral event to a spectral event of known wavelength.

The following discussion examines these methods and the different accuracies they provide.

DIGITAL WAVELENGTH READOUT

Specific spectral wavelengths can be determined by positioning the marker spot in the spectrometer display to the spectral area of interest and reading the digital wavelength readout directly from the spectrometer display.

It is sometimes beneficial to expand the display in order to more precisely position the marker spot to the area of interest. The position of the marker spot in the spectrometer display in the non-expand mode determines the absolute wavelength accuracy when measuring wavelength in the expanded mode. Wavelengths measured within the center two unexpanded divisions of the spectrometer display will be the most accurate. Outside of these two divisions, the dispersion tolerances of both the oscilloscope and the optics in the spectrometer reduce the absolute wavelength measurement capabilities of the spectrometer system. Resulting wavelength measurement accuracies using the marker spot with the spectrometer operating in a 7704A Oscilloscope will typically be:

| Measurement Region | Accuracy |
|-----------------------------------|----------|
| Grating A | |
| Div 0 - div 2 & Div 8 - div 10 | ±12 nm |
| Div 2 - div 4 & Div 6 - div 8 | ±11 nm |
| Div 4 - div 6 | ±10 nm |

| Measurement Region | Accuracy | | |
|--|----------------------------|----------------------------|----------------------------|
| | Center λ 300 nm | Center λ 650 nm | Center λ 900 nm |
| Grating B Div 0 - div 2 & Div 8 - div 10 | ± 6 nm | ± 3.5 nm | ± 7 nm |
| Div 2 - div 4 & Div 6 - div 8 | ± 4.5 nm | ± 3.3 nm | ± 5 nm |
| Div 4 - div 6 | ± 3 nm | ± 3 nm | ± 3 nm |

WAVELENGTH DETERMINED BY DISPLAY DISPERSION

If the oscilloscope in which the spectrometer is installed lacks crt readout, absolute wavelengths can be determined directly from the spectrometer display with reasonable accuracies. This method, however, requires that the HORIZ CAL and HORIZ POS adjustments be accomplished as accurately as possible immediately prior to making a measurement, and that an unexpanded display be used.

Basically, the operator determines an unknown wavelength by selecting a scan interval that contains the area of interest and counting the number of divisions between the left edge of the crt graticule and the spectral event in the display. Multiply the number of divisions counted by the display dispersion factor and add the result to the wavelength represented by the left edge of the crt graticule. For example, assume Grating B is selected with a display dispersion factor of 4 nm/div, the Grating B WAVELENGTH INTERVAL dial tape indicates a scan interval of 600 nm to 640 nm, and the spectral wavelength in question is 6.4 divisions from the left edge of the graticule. The wavelength in question would be:

$$600 \text{ nm} + (6.4 \text{ div}) (4 \text{ nm/div}) =$$

$$600 \text{ nm} + 25.6 \text{ nm} = 625.6 \text{ nm}$$

The accuracy of this method is a function of the linearity of the horizontal deflection system of the os-

cilloscope, the optical dispersion and mechanical repeatability of the J20 Spectrometer, and the accuracy of the dial tape readout (for Grating B only). With the spectrometer installed in a 7704A Oscilloscope, typical accuracies for Grating A will be the same as those possible when using the digital marker wavelength readout. For Grating B, errors will be approximately 2 nm greater than normal due primarily to the dial tape readability.

COMPARISON AGAINST KNOWN WAVELENGTHS

The most accurate way of measuring unknown wavelengths is by comparing them directly against known wavelengths. Second order as well as first order wavelengths are acceptable for comparison. To use this method, project on to the entrance slit a light source having two known wavelengths within the spectral area of interest. The exact display dispersion can be calculated by dividing the difference in wavelength between the two reference wavelengths by the number of divisions in the display separating the two reference wavelengths. Counting the number of divisions from one of the reference wavelengths to the unknown wavelength and multiplying this distance by the calculated display dispersion factor results in the wavelength difference between the reference and the unknown wavelength. Typical accuracies using this method are ± 5 nm for Grating A and ± 0.5 nm for Grating B.

Comparing the digital wavelength marker readout with a known wavelength improves wavelength marker measurement accuracies. For example, display a spectral event of known wavelength. Then, position the marker in the display to this spectral event and check the wavelength readout in the display. Subtract the readout from the known wavelength of the spectral event to determine readout error. Now, position the marker in the display to the spectral event of unknown wavelength and take the readout error previously determined into consideration. Unknown wavelengths can be determined routinely using this method with accuracies of ± 3 nm on Grating A.

GLOSSARY OF TERMS

INTRODUCTION

The following glossary of terms is intended to give the spectrometer user a better understanding of the definition of terms as they are used in Tektronix publications. The glossary is organized in alphabetical order.

ABSORPTION SPECTRUM

The spectrum absorbed when gas, liquid, or solid are interposed between a continuous emitter and the spectrometer. This absorption spectrum appears dark on a light background. It can resemble a line or continuous spectrum. An example is low-pressure monoatomic gas at a lower temperature than the light source. This is the case with the Fraunhofer lines in the solar spectrum.

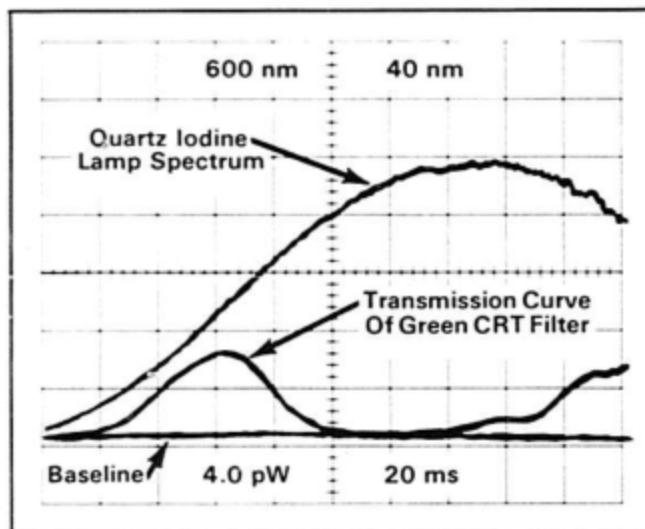


Fig. 14. An example of an absorption spectrum. The difference between the quartz iodine lamp spectrum and the transmission of the green crt filter is the absorption curve of the filter.

ANGULAR DISPERSION

This is defined as $\Delta\theta/\Delta\lambda$ where $\Delta\theta$ is the difference in the diffraction angles of two frequencies which differ by $\Delta\lambda$ in wavelength. For a diffraction grating,

$$\frac{\Delta\theta}{\Delta\lambda} = \frac{m}{d \cos \theta}$$

where m is the order of diffraction, d is the space between the grating rulings, and θ is the average angle of the diffracted light measured from the grating normal. Typical units of measure are degrees/nanometer.

BAND SPECTRUM

Band spectra occur throughout the optical spectrum as a result of vibrational and rotational structure. For large molecules in condensed media, only the vibrational structure appears and is broadened over the gas-phase spectrum. Such structure occurs in both absorption and emission. For small molecules (such as diatomic molecules), both rotational and vibrational bands are present. Vibrational structure is shown in the emission spectrum (phosphorescence) of quinoxaline in Fig. 15.

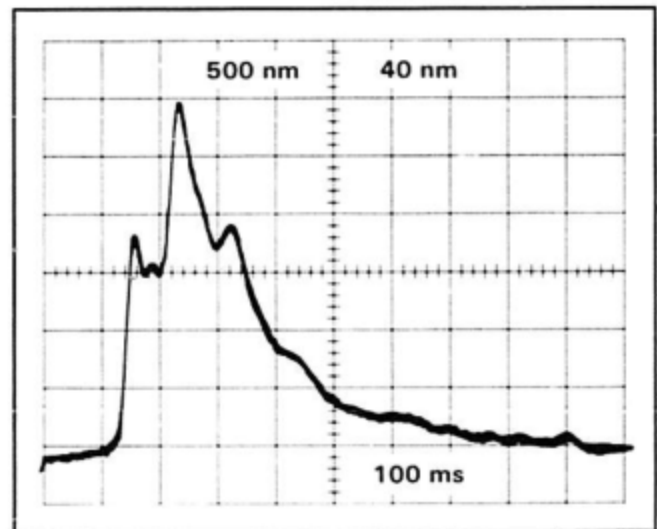


Fig. 15. Vibrational structure in phosphorescence spectrum of biphenyl.

COLLIMATED LIGHT

Parallel or non-diverging beam of light. Lasers can produce the most collimated beams.

CONTINUOUS SPECTRUM

These spectra appear as smooth variations in intensity as a function of wavelength. They may contain suggestions of structure such as in the spectrum of a high-pressure xenon arc. The emission from a heated tungsten filament is a good example of a continuous spectrum and such spectra are characteristic of thermal sources.

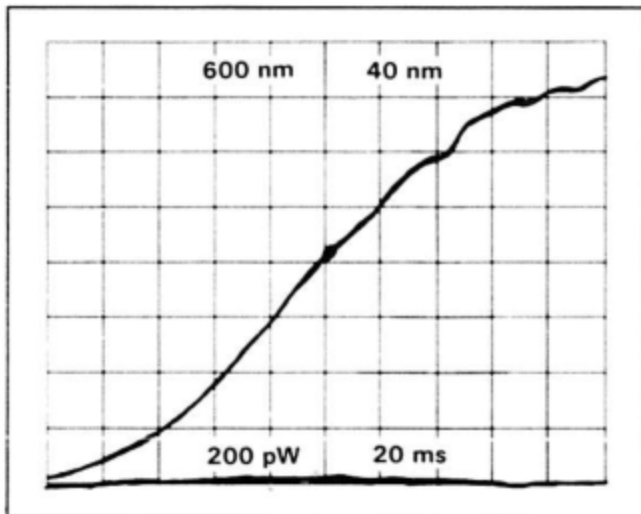


Fig. 16. Example of a continuous spectra (tungsten light source).

DIFFRACTION GRATING

A grating of finely ruled parallel grooves used to disperse light into the optical spectrum. There are many types, two of which are:

1. Blazed Grating — the grating rulings are slanted in such a way that most of the diffracted light is concentrated in one order, rather than spread out over all orders.
2. Plane Grating — a grating or grating replica mounted on plane (flat) backing material. This type is the most common in use today. It has a general advantage over the concave grating in that no focus adjustment is necessary when the spectrum is scanned. Also, the mountings are stigmatic and thus more efficient with the available light. Further, the cost is lower than concave gratings. However, plane gratings always require additional focusing optics.

DISPERSION

The separation of white light into its component colors (or spectrum). There are two ways of defining dispersion in optical instruments: linear and angular. In addition, dispersion of an optical spectrum as seen in the display is called Display Dispersion.

DISPLAY DISPERSION

The final dispersion of the entire optical system as seen in the oscilloscope display, expressed in either wavelength/division or wavenumbers/division.

EXTENDED SOURCE

A source that is spread over an emitting area that is large compared to the distance between source and detector. A ground glass plate illuminated by a lamp is an example of an extended source.

LINE SPECTRUM

Line spectra occur in the absorption and emission spectra of many atoms, ions, and molecules. The spectra appear as sharp, discrete spikes in an intensity versus wavelength display. Such spectra can be obtained from gaseous systems, crystals, and condensed media at very low temperatures.

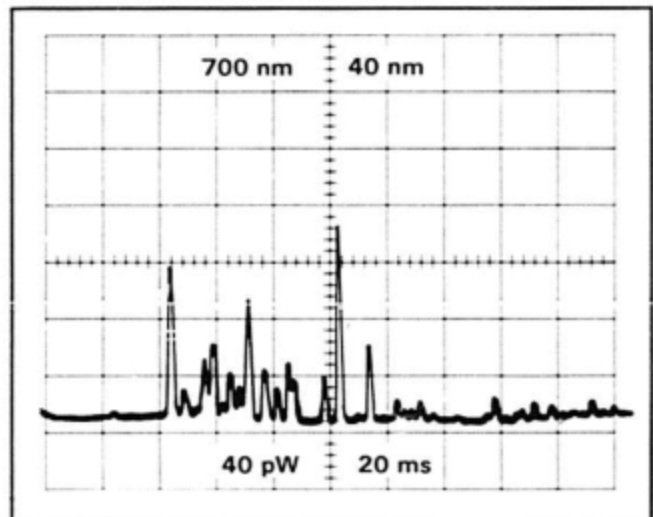


Fig. 17. An example of a line spectra (neon light source).

LINEAR DISPERSION

Defined as $\Delta x / \Delta \lambda$ where Δx is the linear spacing of two frequencies which differ by $\Delta \lambda$ in wavelength. When a lens or mirror of effective focal length f is used to transform collimated beams of angular dispersion $\Delta \theta / \Delta \lambda$ into an image dispersed linearly, the linear dispersion will be

$$\frac{\Delta x}{\Delta \lambda} = f \frac{\Delta \theta}{\Delta \lambda}$$

Typical units will be mm/nm. The reciprocal of this term is conveniently used to calculate optical bandwidth.

MONOCHROMATIC LIGHT

In practical terms, light which is composed of a very narrow band of frequencies is considered to be monochromatic. The spectrum of monochromatic light is a spike or a peak. The width of the peak is a measure of the monochromaticity.

MONOCHROMATOR

This is an instrument that accepts broad-band radiation and transmits only a very narrow band. The wavelength of maximum transmission is usually adjustable.

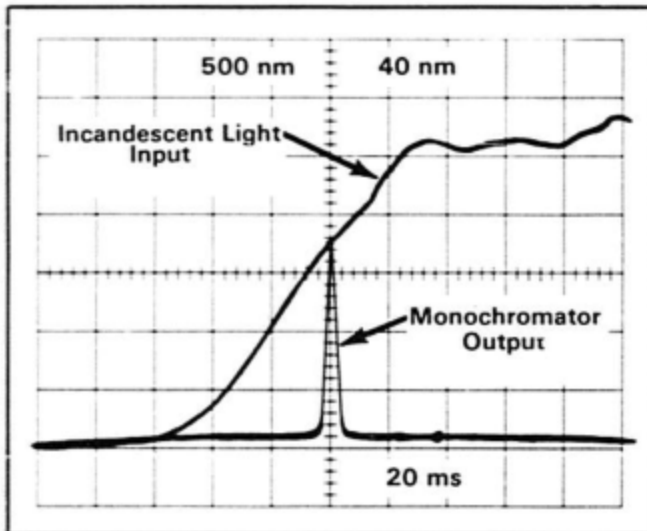


Fig. 18. The output signal of a monochromator versus its input signal.

OPTICAL BANDWIDTH

The image of a monochromatic light at the exit plane of a spectrometer contains a range of wavelengths determined by the optical bandwidth of the spectrometer. Optical bandwidth is calculated using the equation

$$BW = W \cdot \frac{\Delta\lambda}{\Delta\chi}$$

where W is the width of the entrance slit and $\Delta\lambda/\Delta\chi$ is reciprocal linear dispersion. When slit width is given in terms of millimeters and reciprocal linear dispersion is given in terms of nanometers/millimeter, optical bandwidth is calculated in terms of nanometers. See the Optical Bandwidth discussion in the Radiometric Measurement portion of the APPLICATIONS section of this manual.

OPTICAL SPECTRUM

The wavelength distribution of light from an optical emitter or absorber. The resulting spectrum of the ab-

sorber or emitter can be classed in one of three ways: continuous, line, or band spectrum. The spectra of materials is often useful in identification and quantitation of chemical substances.

ORDER SORTERS

A means of isolating a desired wavelength range to reduce overlapping orders in a grating spectrometer system. Can be another low-dispersion spectrometer or filters placed in front of the primary spectrometer.

PHOTOMETER

In visible light measurements, this is a device that measures the brightness of sources or reflecting surfaces in units of measure which are based on the spectral response (photopic) of the human eye. Typical quantities are luminance and illuminance in analogy with radiance and irradiance.

In spectrometric measurements, a spectrophotometer is a device that measures relative light levels without regard to human eye response. The units of measure, called photometric units, are transmittance and absorbance. Transmittance is a ratio of radiant (or spectroradiant) powers impinging upon, and transmitted by a substance. Absorbance is the negative common logarithm of transmittance. See the definition of SPECTROPHOTOMETER.

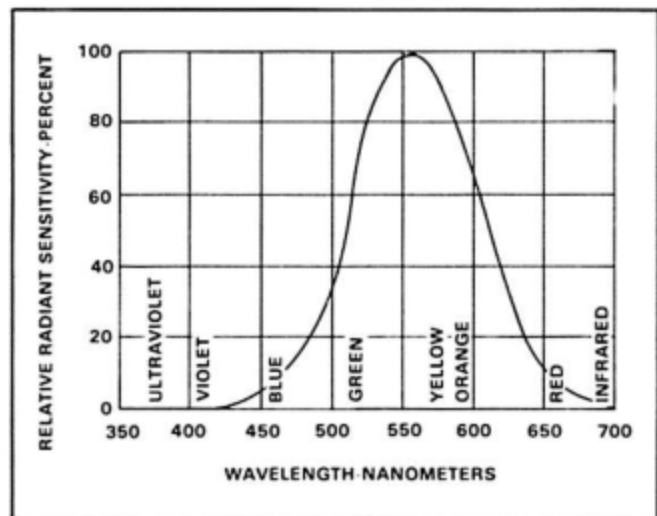


Fig. 19. CIE photopic curve depicting relative sensitivity of the human eye.

POINT SOURCE

A source whose emitting area is small compared to the distance from source to receiver. A star is a good example of a point source.

RADIOMETER

A radiometer is an instrument which measures various quantities associated with radiant power. The most common ones are radiance and irradiance. Irradiance is the amount of optical power incident upon a surface per unit area (i.e., watts/cm²). Radiance is the amount of optical power radiated through a surface per unit area into a solid angle [i.e., watts/(cm²-steradian)].

RAPID-SCAN SPECTROMETER

A device that rapidly displays a spectrum. The instruments can be:

1. Conventional spectrometers which are modified to rapidly scan a spectrum by means of rotating mirrors, prisms, or gratings.
2. Devices that focus a spectrum onto an electronically scanned detector such as an image tube.

RESOLUTION

The smallest element that can be resolved by an optical system, expressed in wavelength, wavenumber, frequency, et al. With films, image tubes, etc., it is expressed in lines/mm, which are just resolvable.

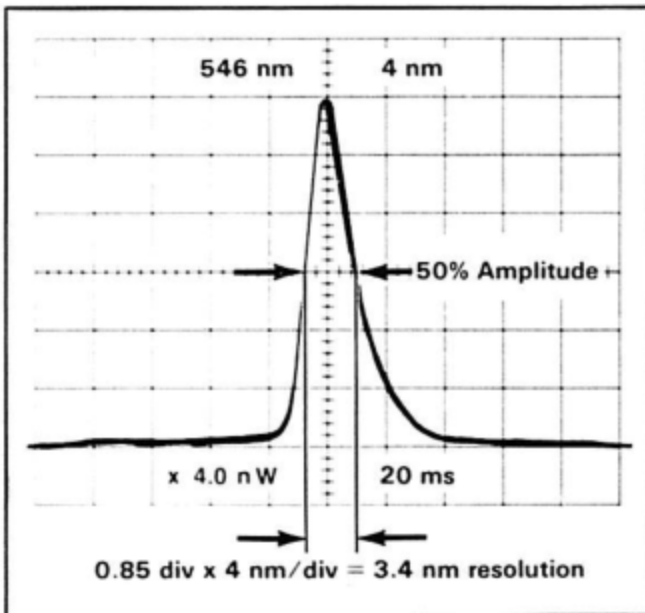


Fig. 20. Spectrometer system resolution definition illustrated using 546 nanometer spectral line from mercury light source.

SPECTROGRAPH

The instrument that separates the wavelengths for producing a spectrogram (photographic image of a spectrum).

SPECTROMETER

The instrument used to determine optical spectra, usually with wavelength readout.

SPECTROPHOTOMETER

This is a device that measures absorption spectra. It can cover any spectral region from the far infrared to the vacuum ultraviolet. The quantities measured are transmittance and absorbance.

SPECTRORADIOMETER

This is a device that measures radiance or irradiance, like a radiometer, but the light is spectrally dispersed. The radiant power integrated over the spectral bandwidth of the instrument and the units are now watts/(cm²-nanometer) for spectral irradiance and watts/(cm²-steradian-nanometer) for radiance. The J20 Spectrometer measures spectral radiance and has a steradiancy of 0.02 steradians with fixed slits. The net quantity read out therefore is spectral power measured in watts/nanometer with the acceptance angle and slit area being automatically taken into account.

SPECTROSCOPE

The instrument used to separate the wavelengths for visual observation. This is like the spectrograph, except that the spectroscope has an eyepiece where the film would be.

SPECTRUM

A visual display, a photographic record, or a plot of the energy or wavelength distribution of the intensity of a given kind of radiation.

THROUGHPUT

The capacity of a system to collect light. It is a measure of the amount of light collected (or transmitted) by an instrument of a given aperture accepting a given solid angle. The formula to calculate throughput is:

$$T = A \cdot \Omega = m^2 \cdot sr$$

where A equals the area of the field stop in meters² (which equals the entrance slit area of the J20 Spectrometer), and Ω equals the solid angle subtended by the field stop in steradians.

Glossary of Terms—J20/7J20 Operators

VACUUM WAVENUMBER

The reciprocal of the wavelength in centimeters in a vacuum. It is given the symbol $\bar{\nu}$ and is given in terms of cm^{-1} units. The formula for deriving vacuum wavenumber is:

$$\bar{\nu} = \frac{1}{\lambda_{\text{vac}}} = \frac{\nu}{c} = \frac{E}{hc}$$

where ν = frequency in Hz, c = the speed of light in cm/sec, E = energy in ergs, h = Planck's constant in erg sec, and λ_{vac} = wavelength measured in a vacuum.

ANNOTATED BIBLIOGRAPHY

INTRODUCTION

The following bibliography provides the spectrometer operator with a few good reference sources concerned with spectroscopy and its instrumentation.

Bair, E. J., "Introduction To Chemical Instrumentation", McGraw-Hill, 1962.

An overview of analytical chemical measurements with primary emphasis on electronic instrumentation.

Bauman, Robert P., "Absorption Spectroscopy", John Wiley, 1962.

Good treatment of the whole field of absorption spectroscopy, including matrix method of analysis, molecular spectroscopy, and electronic spectroscopy.

Bausch & Lomb, "Diffraction Grating Handbook", Bausch & Lomb, 1970.

A good paperback booklet on diffraction grating manufacturing techniques and grating error evaluation. An interesting elementary level booklet.

Girard, A., Jacquinet, P., "Principles Of Instrumental Methods In Spectroscopy", Chapter 3 of Advanced Optical Techniques, Wiley, 1967.

An excellent theoretical treatment of spectrometers and use of them effectively.

Harrison, Cord, and Lodfbourow, "Practical Spectroscopy", Prentice-Hall, Inc., 1948.

A very comprehensive book on the technology of spectroscopic measurements. Covers the fields of interferometric spectroscopy, IR spectroscopy, quantitative analysis, atomic and molecular spectra, spectroscopic equipment, and Raman, although most of these topics are not covered in much depth. The equipment mentioned is out of date, although many techniques are still used today.

Hercules, David M., "Fluorescence And Phosphorescence Analysis", Wiley, 1966.

This book illustrates the experimental techniques and theoretical foundation behind molecular spectroscopic

techniques. It is probably the only book available that even alludes to experimental methods.

James, J.F., Sternberg, R. S., "The Design Of Optical Spectrometers", Chapman and Hall, Ltd., 1969.

A recent treatment of the spectroscopy instrumentation field. It includes Fourier transform spectrometers and recent grating spectrometers.

McGlynn, S. P., "Molecular Spectroscopy Of The Triplet State", Prentice-Hall, 1969.

This book deals mainly with the molecular mechanisms of luminescence but contains much useful data about specific molecules (lifetimes, intensities, etc.) plus many published spectra.

Meehan, E. J., "Optical Methods Of Analysis", John Wiley & Sons, Interscience Publishers, 1969.

This is a college level paperback that discusses all analytical methods of analysis mostly from an experimental standpoint.

Sawyer, Ralph A., "Experimental Spectroscopy", Dover, 1944, Revised 1951.

A very complete review of experimental methods of spectroscopy and spectroscopic instruments as they existed 20 to 30 years ago. Because this field has changed so rapidly since this time, this book should be taken very cautiously.

Wiffen, D. H., "Spectroscopy", John Wiley and Sons, 1966.

A good review of the theory of spectroscopy. Very little experimental treatment. About college level.

Jobin-Yvon Optical Systems, "Handbook of Diffraction Gratings, Ruled & Holographic", Jobin-Yvon, 1973.

An up-to-date primer on the manufacturing procedures of diffraction gratings, diffraction grating physics, and comparisons of holographic with ruled diffraction gratings.