Spectra-Physics

MODEL 470
INTERFEROMETER

Instruction Manual

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UNITS

System International (SI) units, abbreviations, and prefixes are used in this manual:

Quantity	Unit	Abbr
mass	kilogram	kg
length	meter	m
time	second	s
frequency	hertz	Hz
force	newton	N
energy	joule	J
power	watt	W
electric current	ampere	A
electric charge	coulomb	C
electric potential	volt	V
capacitance	farad	F
resistance	ohm	Ω
inductance	henry	H
magnetic flux	weber	Wb
magnetic flux density	tesla	T
luminous intensity	candela	cd
temperature	kelvin	K

Prefixes		
tera	(10^{12})	T
giga	(10^{9})	G
mega	(10^{6})	M
kilo	(10^{3})	k
deci	(10^{-1})	d
centi	(10^{-2})	c
milli	(10^{-3})	m
micro	(10^{-6})	μ
nano	(10^{-9})	n
pico	(10^{-12})	p
femto	(10^{-15})	f
atto	(10^{-18})	a

LIST OF FIGURES

ADDENDUM

The Model 470 Optical Spectrum Analyzer has two detector configurations which, if used incorrectly, will give substantially reduced performance.

The Model 471 detector with a clear anodized case was standard until September 1974. It contains a 1.5 KΩ load resistor and should be used only when displaying the output of the spectrum analyzer on an oscilloscope or strip chart recorder having a high input impedence. The resistor serves to convert the current from the photodiode into a voltage.

The Model 471 detector with a black anodized case is standard after September 1974 (unless otherwise noted on the order). The load resistor has been removed to allow the detector to be used with the Model 476 Interferometer Driver (whose vertical amplifier requires a current input). If the detector output is to be fed directly to an oscilloscope input, a 1.5 KΩ resistor should be placed across the input.

If you have any questions, please contact your local Spectra-Physics field sales engineer or customer service department.

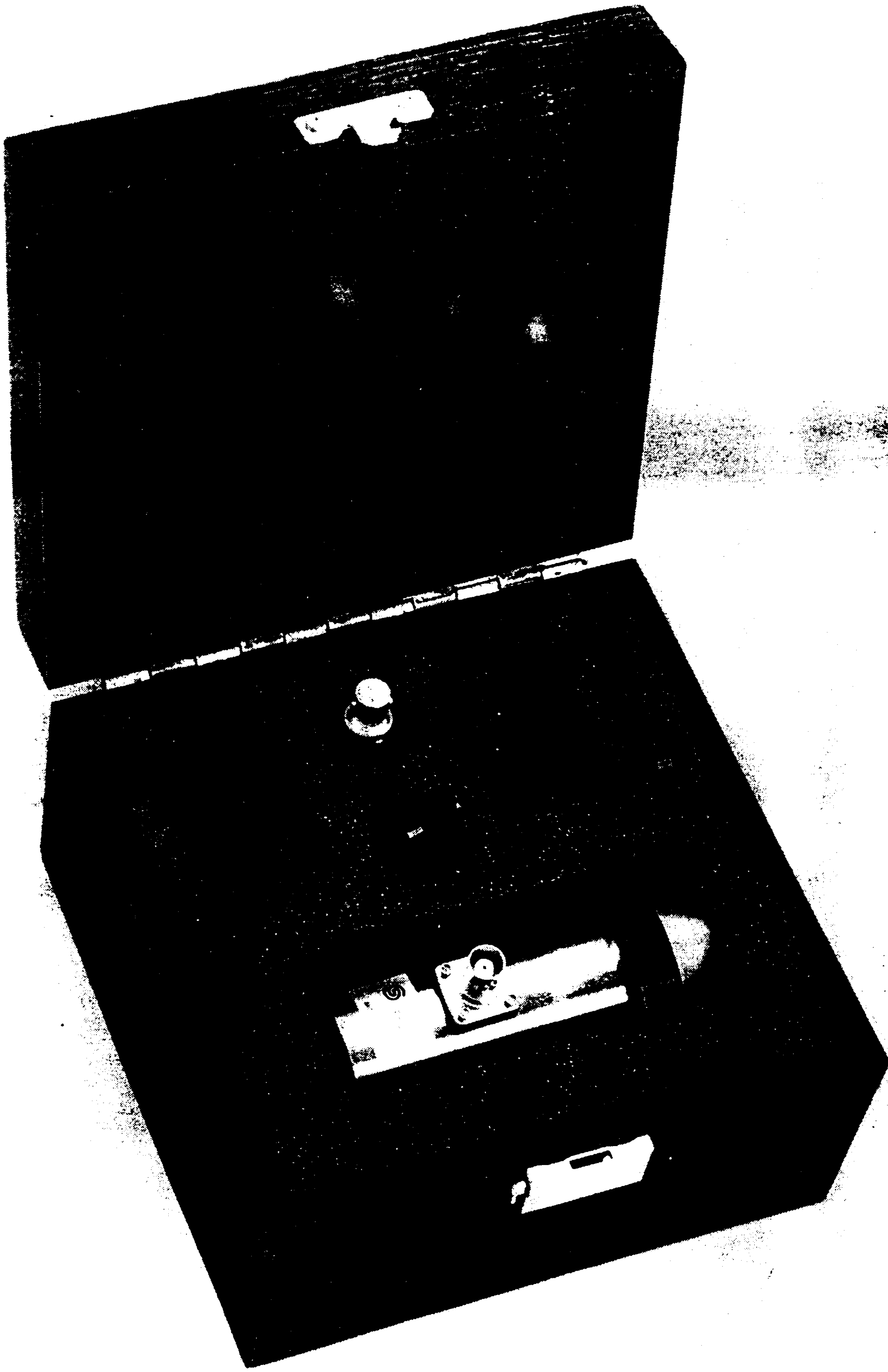


Figure 1-1 Model 470 Spectrum Analyzer in its Storage Case

SECTION ONE—INTRODUCTION

UNPACKING

The Model 470 Spectrum Analyzer was carefully packed for shipment. **If the packing box is damaged, have the shipper's agent present for unpacking.**

The 470 is shipped with the mirrors prealigned and tested at the factory. The Model 471 photodetector, mirror adjusting tool, aperture, and circular polarizer will be in their separate slots within the walnut case. The 35 X 45 mm cutouts in the foam insert are for storage of extra mirror sets or the 470A beamsplitter attachment.

INSPECTION

The 470 should be inspected as soon as possible after it is received. The analyzer should have an audible buzz when hooked up to a ramp voltage source of approximately 100 volts @ 0.1 second duration.

DESCRIPTION

The Spectra-Physics 470 Spectrum Analyzer is a mode degenerate, spherical mirror, Fabry-Perot interferometer for use in high resolution optical spectroscopy. It can be used as a scanning spectrum analyzer (completing a single scan in less than a millisecond), as a static fringe interferometer, or as a tunable optical filter with a bandpass of between 10 and 100 MHz (i.e.: between 0.001 and 0.01 nm, or 1 to 10 pm). The light-gathering power and transmission of the Model 470 Spectrum Analyzer are exceptionally high, and it is generally possible to trade off spectral resolution for light-gathering power, and vice-versa. This type of optical spectrum analyzer is exceptionally simple to use and retains its internal alignment indefinitely. The alignment between the source of light and the spectrum analyzer is not critical and is facilitated by the built-in optical system.

The Model 470 is available with two different free spectral ranges (2GHz and 8GHz) and with mirrors coated for two different spectral regions. It is intended primarily for observing laser spectra and for recording the spectral characteristics of scattered laser radiation. It is particularly effective in the latter application because of its high light-gathering power. The Model 470 Spectrum Analyzer can also be used to spectrally filter laser radiation or to observe spectra of narrowband incoherent sources.

DEFINITION OF TERMS:

d = Mirror separation = radius of curvature

ρ = Radius of incoming light

λ = Wavelength

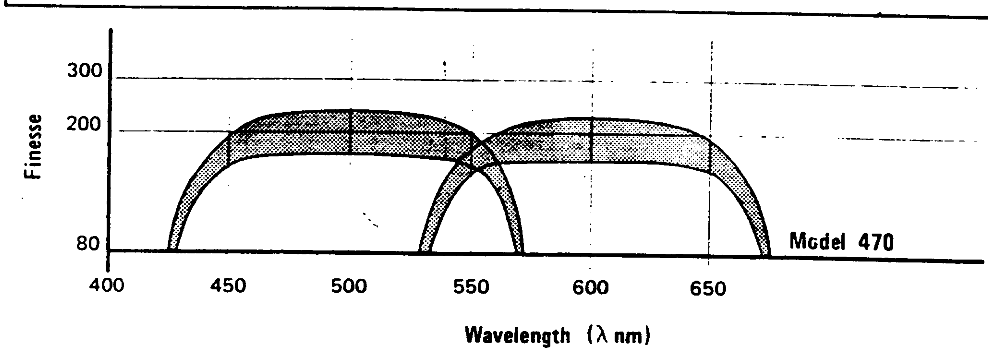
F.S.R. = Free Spectral Range

F = Finesse

C = Speed of light = 2.99793 X 10^{10}cm/sec

SPECIFICATIONS

Model	Operating Wavelength	Free Spectral Range	(Max.) Bandwidth	(Min.) Finesse	Aperture
470-01	450-550 nm	2 GHz	13 MHz	150	Entrance
470-02	450-550 nm	8 GHz	53 MHz	150	Aperture 19 mm
470-03	550-650 nm	2 GHz	13 MHz	150	With isolator 13 mm
→ 470-04	550-650 nm	8 GHz	53 MHz	150	With pinhole 2 mm



SECTION TWO—THEORY OF OPERATION

ELEMENTARY THEORY OF OPERATION & DEFINITION OF TERMS

When a collimated beam of monochromatic light is incident along the axis of a spherical mirror Fabry-Perot interferometer, a multiple beam interference fringe pattern is formed in the central plane of the interferometer (Fig 2-1). Bright fringes occur at radii ρ_m which satisfy the expression:

(1) $4d - (\rho^4\ m/d^3) = m\lambda$, m an integer

where d is the axial mirror separation which, to within a few micrometers, is equal to the radius of curvature of each mirror.

If the diameter of the incident beam is sufficiently small compared to the diameter of the first off-axis fringe, then the interferometer acts essentially as a narrow bandpass filter, transmitting those wavelengths which satisfy the resonance conditions:

(2) $4d = m\lambda$, m an integer.

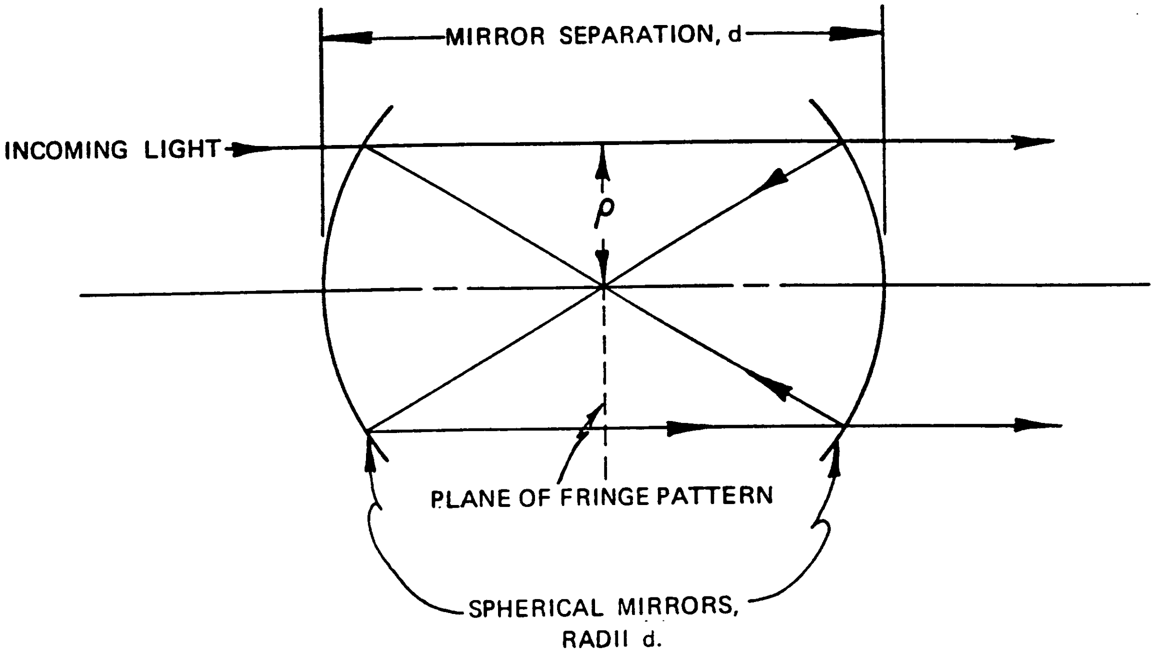


Figure 2-1 Spherical Mirror Fabry-Perot Interferometer

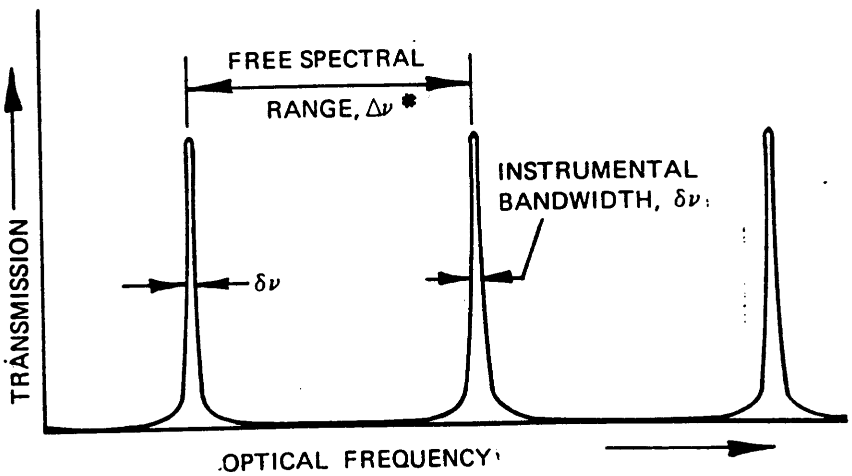


Figure 2-2 Transmission vs. Frequency of a Fabry-Perot Interferometer

The transmission curve for a spherical mirror Fabry-Perot interferometer used in this way is shown in Fig. 2-2.

A number of the characteristics of a spherical mirror Fabry-Perot interferometer are conveniently illustrated by the transmission curve shown in Fig. 2-2.

FREE SPECTRAL RANGE (F.S.R.)

Free spectral range is the separation (measured either in terms of frequency, wavenumber, or wavelength) between adjacent transmission maxima (or 'orders'); hence, the maximum spectral bandwidth of incoming light which can be observed without overlapping orders. Expressions for the free spectral range of a confocal spherical mirror interferometer of spacing d are:

$$\Delta\nu^* = c/4d \text{ (frequency)} \qquad \Delta\sigma^* = 1/4d \text{ (wavenumber)}$$

$$\Delta\lambda^* = \lambda^2/4d \text{ (wavelength)}$$

INSTRUMENTAL BANDWIDTH

The apparent or observed spectral width of a true monochromatic spectral line:

$\delta\nu$ (frequency) $\delta\sigma$ (wavenumber) $\delta\lambda$ (wavelength)

FINESSE

The finesse of a multiple-beam interferometer may be defined as the ratio of the free spectral range to the instrumental bandwidth. As such, it is a fundamental measure of the spectral resolving capability of the instrument. The finesse may be interpreted as the effective number of beams contributing to the multiple beam interference and is thus analagous to the number of rulings on a diffraction grating.

$$F = \Delta\nu^*/\delta\nu = \Delta\sigma^*/\delta\sigma = \Delta\lambda^*/\delta\lambda.$$

The finesse of an instrument is determined by a number of factors, chief among which are the reflectivity of the mirrors and the surface figure of the mirrors. The approximation for high reflectivity reflection-limited finesse is given by:

$$F_r = \pi R/(1 - R)^2 \simeq \pi/2(1-R).$$

SPECTRAL RESOLVING POWER

This is defined as the ratio of the frequency (or wavelength) to the instrumental bandwidth in frequency (or wavelength) units:

$$RP = \nu/\delta\nu = \sigma/\delta\sigma = \lambda/\delta\lambda.$$

The transmitted wavelength can be varied simply by varying the mirror separation, d. The required change in mirror separation is very small: a quarter-wavelength change is sufficient to scan through a complete free spectral range. The central fringe width (the diameter of the central spot in the interference pattern when the instrument is set at resonance with an incoming monochromatic beam) determines the upper limit on both the diameter and angular divergence of the incoming beam which can be used without appreciable degradation of finesse. This central spot diameter, for a specified finesse F, is given by:

(3) $D_s = 2(d^3 \lambda/F)1/4$

In order to achieve a finesse of F, the incident beam diameter should be appreciably smaller than this value for D_s. If the beam diameter is just D_s, then the realizable finesse will be approximately 0.7F.

In a similar way, the angular divergence of the incident beam should be restricted to an angle of less than:

(4) $\theta_s = 2(\lambda/Fd)1/4$

in order to approach an observed finesse F.

ETENDUE

The net light-gathering power of an instrument of this type is expressed quantitatively in terms of its etendue. Etendue is defined as the product of the maximum allowed aperture area and the maximum allowed solid angle divergence which will permit a realization of a specified finesse.

$$\text{etendue} = U = (\pi D_s{}^2/4).\ (\pi\theta_s{}^2/4) = \pi^2 d\lambda/F.$$

It is worth pointing out that, in order to realize a finesse F with a given aperture, the mirrors must be perfectly spherical to within approximately $\lambda/2F$ across that aperture. This requirement often dictates the use of a restricted aperture for very high spectral resolution.

In normal use as a scanning spectrum analyzer, the Model 470 employs an auxiliary lens as shown in Fig. 2-3. This lens makes the use of the Model 470 with a laser more convenient by increasing the effective aperture diameter at the expense of reducing the acceptable angular divergence of the incoming beam. The upper limits on the beam diameter and angular divergence in order to realize a finesse of approximately 0.7F with the auxiliary lens in place are given by:

(5) $D_L = (f/d)D_s$, and $\theta_L = D_s/f$,

where f is the focal length of the auxiliary lens (approximately 5cm) and D_s is the spot diameter given by eq(3).

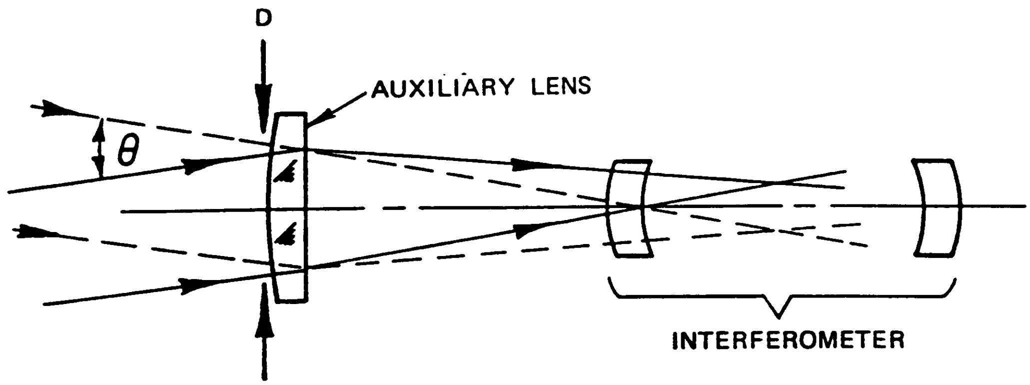


Figure 2-3 *Incident Beam Diameter and Angular Divergence with Auxiliary Lens*

The light-gathering power, or etendue, is unaffected by the use of the auxiliary lens.

The etendue of a spectrometer is directly proportional to the amount of power from an incoherent extended source which can be transmitted by the instrument within its specified bandpass. As such, it is a particularly important parameter when working with extended sources (such as scattered laser light). When working with a laser, however, a high value for the etendue means a large tolerance in the alignment of the laser beam relative to the instrument. This is because a laser, being in most cases very nearly diffraction-limited, has an invariant (aperture area) X (solid angle divergence) product whose value is on the order of the square of the wavelength—small enough to be accommodated by most spectrometric instruments without difficulty.

SCANNING MODE

Initial Alignment

The Model 470 Spectrum Analyzer should be initially set up so that its longitudinal axis is approximately coincident with the incoming light beam. Alignment is greatly facilitated by the use of a Spectra-Physics Model 381 Optical Mount, which securely holds the Spectrum Analyzer and allows a wide range of angular orientations. The auxiliary aperture and circular polarizer are removed from in front of the lens (see Fig. 3-1), and the incoming beam is directed into the center of the lens aperture. When properly aligned, the incoming beam will be reflected (by the interferometer mirror) back along itself. This is particularly easy to accomplish when the source is a laser, since both the incident and reflected beams will be clearly visible as spots on the lens surface. Alignment consists of putting the incoming spot in the center of the lens and then making angular adjustments to superpose the return spot on the incoming spot. If the source is a plane-polarized laser, then the circular polarizer should be replaced over the lens aperture in order to eliminate feedback from the spectrum analyzer to the laser (this type of feedback produces laser frequency instability). The auxiliary aperture can also be replaced if maximum spectral resolving power is desired. Note: Rotate the polarizer for maximum signal through the spectrum analyzer.

When using the Model 470 Spectrum Analyzer with an incoherent source, initial alignment is most conveniently obtained by temporarily replacing the incoherent source with a low power gas laser.

Scanning and Final Alignment

There are a number of techniques for operating the Model 470 Spectrum Analyzer in the scanning mode; some of these are illustrated in Fig. 3-2. One of the simplest methods requires the use of an auxiliary oscilloscope capable of supplying a horizontal sweep voltage of 50 volts or more (this output is labelled SAWTOOTH on some oscilloscopes). The horizontal sweep voltage is connected to the scanning voltage terminal of the spectrum analyzer, and the sweep speed is initially set to 2 ms/cm. Triggering is set to LINE, thus providing 30 scans/second with a duration of 20 ms/scan. The detector output is next applied to the input of the oscilloscope's vertical amplifier. The resultant scope display will be a stable and linear plot of the source's spectrum. For best results, a resistive load of $\approx 1.5\ k\Omega$ should be used across the leads of the detector.

A free spectral range will be scanned in the time taken to change the mirror separation by ¼ wavelength. If the Spectra-Physics Model 476 Scanning Interferometer Driver is used, the spectral dispersion, position of the displayed spectra,

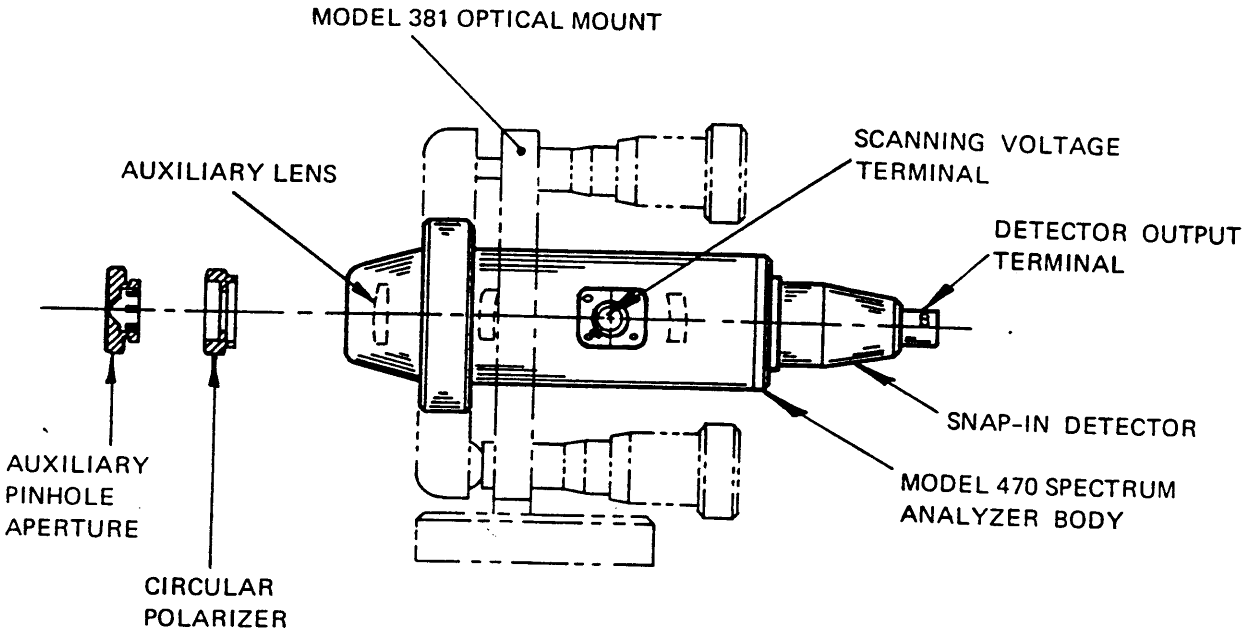
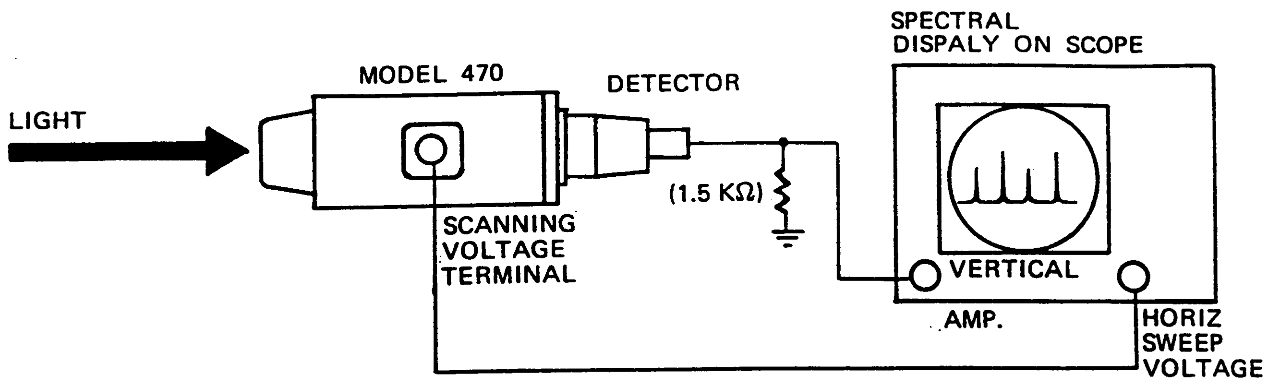
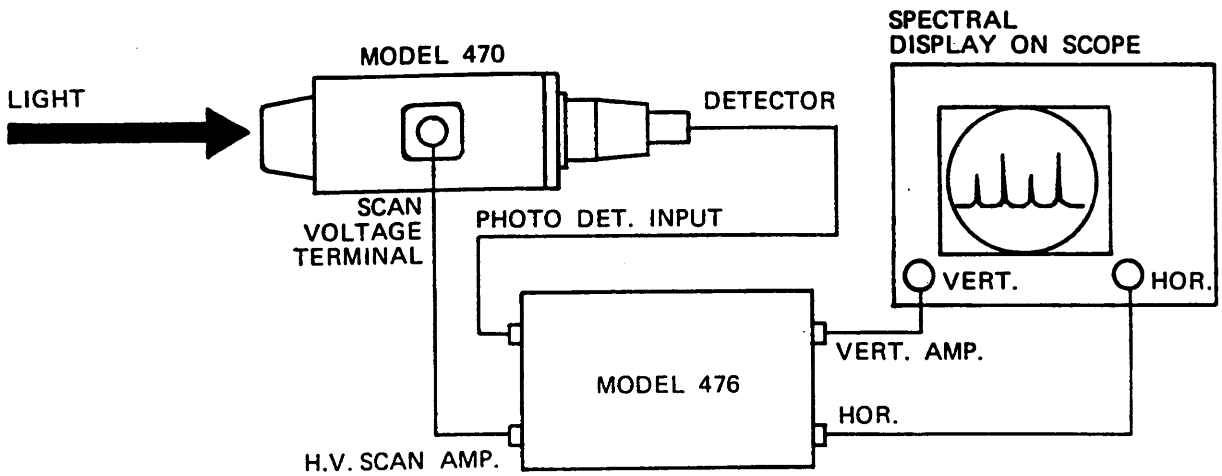


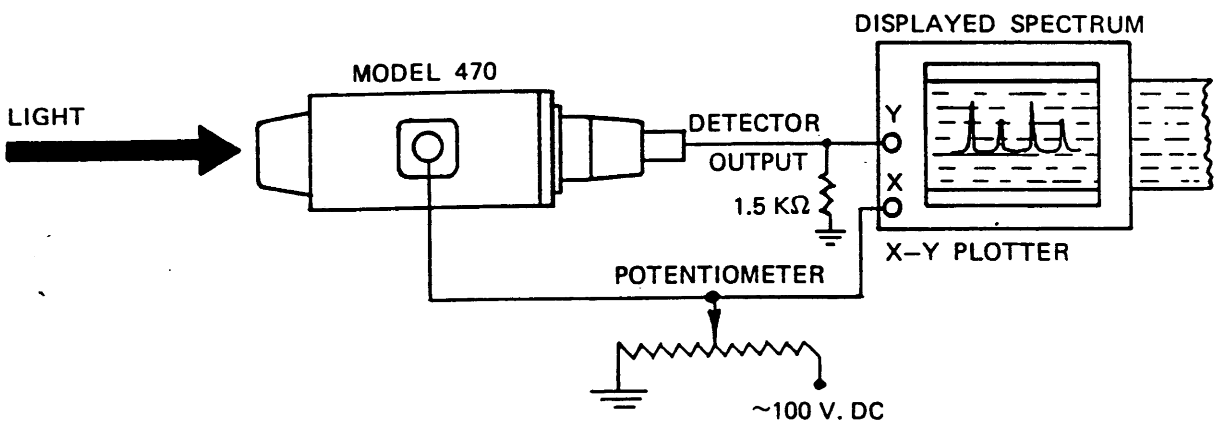
Figure 3-1 Model 470 Spectrum Analyzer Components



(a) WITH OSCILLOSCOPE DISPLAY; SCOPE PROVIDING SCAN VOLTAGE
(Scope on Internal Sweep, Trigger Line)



(b) SCOPE DISPLAY; SCAN GENERATOR FOR SCAN VOLTAGE



(c) X – Y PLOTTER OUTPUT

Figure 3-2 Model 470 Operating Configurations repetition rate, and amplitude of the signal can be varied over a continuous range. As long as the scan voltage exceeds approximately 50 volts, the spectral scan will cover in excess of one free spectral range, thus providing a repetitive spectral display. This repetitive feature of the display can be used to calibrate the observed spectrum, since the free spectral range of the spectrum analyzer is known to be either 2 Ghz (0.0667 cm^{-1}) or 8 Ghz (0.2667 cm^{-1}).

Once the initial spectral display is obtained, the alignment of the spectrum analyzer relative to the source can be adjusted to optimize the displayed spectrum.

Note: Although the suggested scan rate (2 ms/cm with line triggering) is convenient for most purposes, it is possible to scan at any other rate up to about one kHz. Above this scan rate, a sawtooth driving voltage invariably produces a distorted response. Although not recommended, higher scan rates can be obtained using sinusoidal scanning voltages. If necessary, in the absence of a scanning voltage source, direct line voltage can be used to give quite satisfactory results which will be linear over several free spectral ranges on either side of zero voltage.

FRINGE DISPLAY MODE

When a quasi-collimated beam of light is incident along the axis of a spherical mirror Fabry-Perot interferometer, a pattern of multiple beam interference fringes is formed in the plane lying midway between the mirrors and perpendicular to their axis. In order to observe this fringe pattern most conveniently, the incident light should be directed into the rear aperture of the Model 470 where the snap-in detector is normally located. The auxiliary lens can be now used to observe the fringe pattern. Since the focal plane of the auxiliary lens is approximately coincident with the plane in which the fringes are localized, the fringes will be seen in sharp focus by an otherwise unaided visual observer or by a camera focused at infinity (Fig. 3-3).

Reference 1 contains a detailed discussion of the accurate interpretation of spherical mirror Fabry-Perot fringe patterns.

OBSERVING SCANNED SPECTRA WITH WEAK SOURCES

Because of the exceptionally high light-gathering power, or etendue, of the Model 470 Spectrum Analyzer, it is especially well-suited for observing weak spectra with high resolution. There are a number of optical arrangements which can be used to bring the light into the Spectrum Analyzer and thence to the detector, but the setup shown in Fig. 3-4 is particularly versatile and allows a convenient trade-off between light-gathering power and spectral resolution.

As shown in Figure 3-4, both the auxiliary lens and the snap-in detector are removed. Since the (source area) X (source solid angle) product has an upper limit equal to the instrumental etendue, the user must determine whether he wishes to limit the source area, the source solid angle, or both. Refer to Section 2, Fig. 2-3. Lens L_1 is selected to form an image of the source in the vicinity of the central plane of the interferometer (the exact image location is not important). The size of this image should be on the order of the central fringe spot size. Lens L_2, on the other side of the spectrum analyzer, relays the image of the source to the plane of an adjustable aperture stop, A_2. Another adjustable aperture stop, A_1, is located at lens L_1. The detector, which would ordinarily be a photomultiplier, is located just behind aperture A_2. In this arrangement, aperture stop A_1 serves to limit the solid angle of light collected from any point on the source, and stop A_2 effectively limits the size of the part of the source from which light is detected. For highest spectral resolution at the expense of light, both stops are closed down.

Initial alignment of this system is most easily accomplished by substituting a laser for the incoherent source during the alignment.

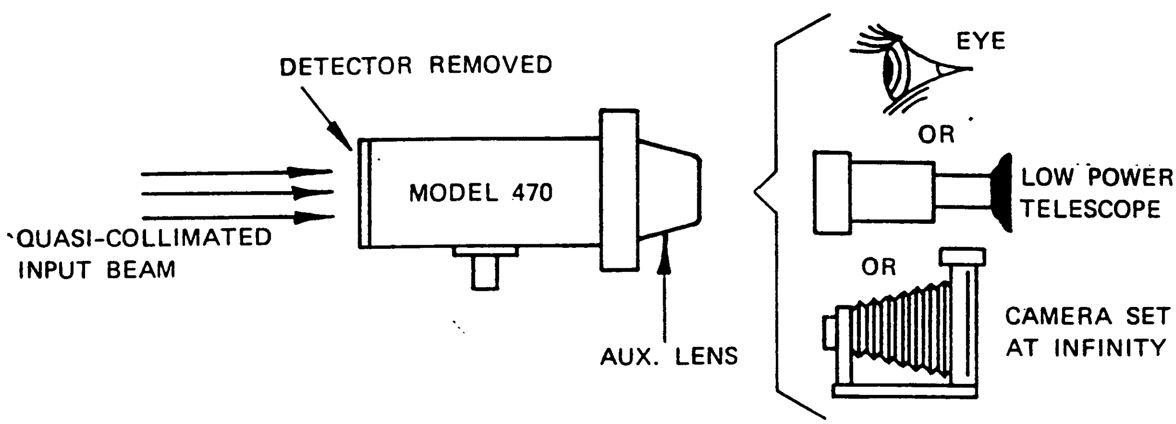


Figure 3-3 Optical Setup for Observing Fringe Patterns

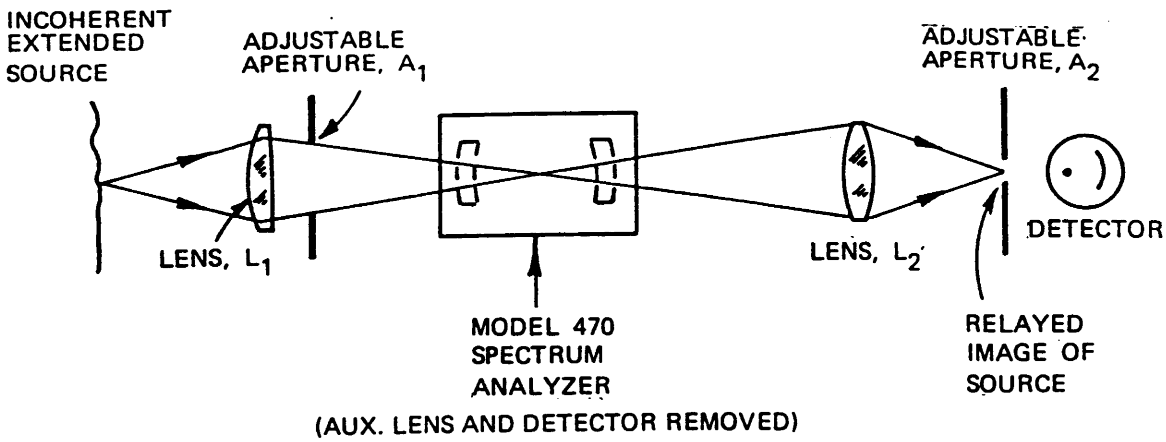


Figure 3-4 Setup for Recording Spectrum of a Weak Extended Source

FILTER MODE OF OPERATION

For an on-axis beam of quasi-collimated light, the Model 470 Spectrum Analyzer can be regarded as an ultra-narrow bandpass filter whose transmission peaks occur every free spectral range. These peaks may be moved by the application of a DC voltage to the scanning voltage terminal. The Model 470 is designed so that if the incoming beam of light is well-collimated and the lens is removed, then the transmitted beam will also be well-collimated.

MODE-MATCHING

The free spectral range of the Model 470 can be extended by mode-matching. This gain is accompanied by a twofold increase in both finesse and instrument transmission; therefore, no loss of spectral resolution will occur. There will be a great reduction in allowable tolerance of misalignment between the axis of the 470 Spectrum Analyzer and the incident light beam. Precision alignment requires interferometric stability between the source and the 470 Spectrum Analyzer.

Alignment

The basic problem is to locate the source, or its image, and both centers of curvature on a single straight line. This is simplified when the source is at infinity, i.e.: collimated, in that only angular adjustments are required. With the incident light collimated, the procedure is as follows:

First, mount the 470 Spectrum Analyzer in an angular mount, such as the Model 381, with the scan voltage applied. Then while observing the fringe pattern on the screen, adjust the angular alignment until a two-beam interference pattern of straight fringes can be seen superimposed on the circular fringes. Next, make fine adjustments to increase the straight-fringe spacing until it is greater than the detector aperature.

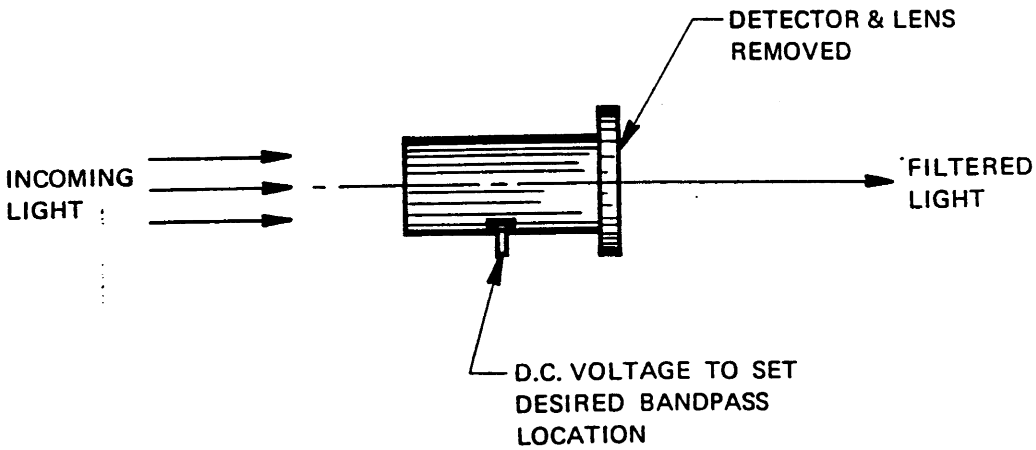


Figure 3-5 Model 470, Filter Mode of Operation

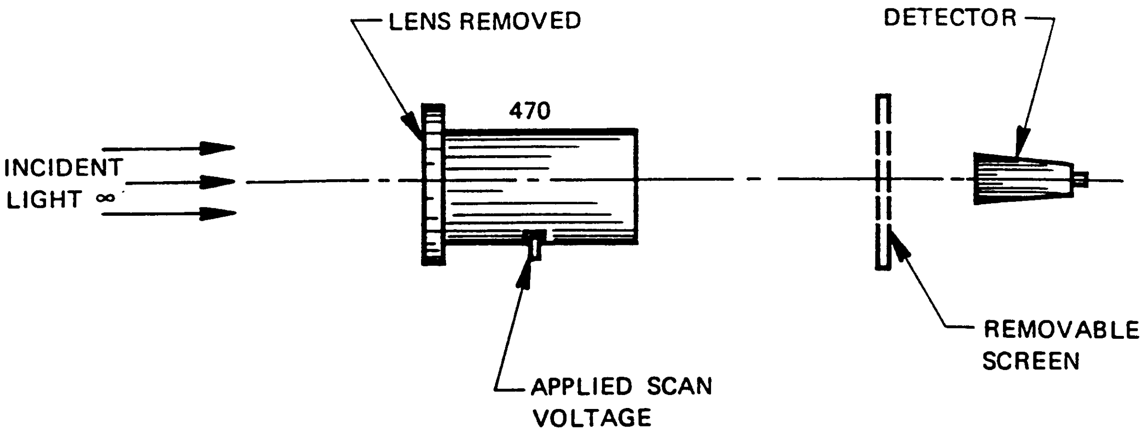


Figure 3-6 Mode-Matching Setup

Remove the screen, observe the scan displays, and touch up the tilt alignment as required. As the proper alignment is approached, the spectral display at every other spectral peak will increase in amplitude while the remaining portion approaches zero. This procedure is somewhat inefficient in that much of the light in the collimated beam fails to reach the detector.[1]

As an alternate procedure, one can use the technique described by Fork[2] for mode matching to a general curved mirror cavity. This is more efficient in that greater than 70% of the available light will be transmitted. However, the alignment requires x, y, and z axis translation as well as angular adjustments.

References

(1) "The Spherical Mirror Fabry-Perot Interferometer", M. Hercher, Applied Optics 7, 951 (May, 1968)

(2) "A Scanning Spherical Mirror Interferometer for Spectral Analysis of Laser Radiation", R. L. Fork, D. R. Herriott, & H. Kogelnik, Applied Optics 3, 1471 (1964).