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SuperCavity™ Optical Spectrum Analyzer Instruction Manual

Newport

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Warranty

Newport Corporation warrants this product to be free from defects in material and workmanship for a period of one year from the date of shipment. If found to be defective during the warranty period, the product will either be repaired or replaced at Newport's option.

To exercise this warranty, write or call your local Newport representative or contact Newport headquarters in Irvine, California. You will be given prompt assistance and return instructions. Send the instrument, transportation prepaid, to the indicated service facility. Repairs will be made and the instrument returned, transportation prepaid.

Repaired products are warranted for the balance of the original warranty period or 90 days, whichever is longer.

This warranty does not apply to defects resulting from modification or misuse of any product or part. This warranty also does not apply to fuses, batteries, or damage from battery leakage.

This warranty is in lieu of all other warranties, expressed or implied, including any implied warranty of merchantability or fitness for a particular use. Newport Corporation shall not be liable for any indirect, special, or consequential damages.

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Table of Contents

Warranty ii

List of Figures v

List of Tables vi

Safety Precautions vii

Specifications viii

Definitions xii

Certificate of Performance xiii

Section 1 - General Information and Typical SuperCavity Operation 1

1.1 Introduction 1

1.2 Unpacking and Inspection 1

1.3 SuperCavity System Configurations 1

1.4 Specifications 4

1.5 SuperCavity Technical Application Notes 4

1.6 Warranty Information 4

1.7 Safety Terms 5

1.8 Typical SuperCavity Setup 5

1.9 General Applications Guide 7

Section 2 - Principles of Operation 9

2.1 Fabry-Perot Interferometer 9

2.1.1 Plane Mirror Interferometer 9

2.1.2 Spherical-Mirror Non-Confocal Cavity Interferometer 12

2.1.3 Transverse Mode Distribution for Resonant Cavities 14

2.1.4 Mode Matching to SuperCavity 16

2.1.5 Frequency Calibration of the SuperCavity 22

2.1.6 Wavelength Dependance of Cavity Finesse 24

2.2 Frequently Asked Questions about SuperCavity 26

Section 3 - Universal SuperCavity Controller 29

3.1 Functional Description of SR-UCC 29

3.1.1 Signal Processing Electronics 29

3.1.2 Sweep and Bias Control Section 29

3.1.3 Temperature Stabilization Circuit 32

3.1.4 Fringe Lock Circuit 32

3.1.5 Control Logic 32

3.2 Panel features, SR-UCC 33

3.2.1 Front Panel Features, SR-UCC 33

3.2.2 Rear Panel Features, SR-UCC 34

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Section 4 - System Operation 37
4.1 Introduction 37
4.2 Preparing to use the SuperCavity 37
4.2.1 Line Voltage Selector 37
4.2.2 Additional Equipment 37
4.3 Turning ON the SuperCavity 37
4.4 Signal Input and Optical Alignment 38
4.5 Cavity Output and Oscilloscope Connections 40
4.6 Scanning the SuperCavity 41
Section 5 - Maintenance 43
5.1 Maintenance 43
5.1.1 Interferometer Optics Cleaning Procedure 43
Section 6 - Factory Service 45
6.1 Introduction 45
6.2 Obtaining Service 45
6.3 Packaging Instructions 45
6.4 Service Form 47
Appendix I - SuperCavity Controllers, Model SR-D, SR-D5 and SR-DHT 49
I.1 SR-D/SR-D5 Controllers 49
I.2 SR-DHT SuperCavity Controller 50
I.3 Amplifier Offset Adjustment Procedure 52
I.4 Temperature Servo Adjustment Procedure (Model SR-D/SR-D5 Controllers Only) 53
I.5 Trouble-shooting Guide 54
Appendix II - SuperCavity Alignment Training and Demonstration Unit 55
Appendix III - Reference Drawing SuperCavity/Universal Cavity Controller (SR-UCC) 67
Dwg. 17805 - SuperCavity system wiring diagram, SR-UCC 67

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List of Figures

Figure	Title	Page
S-1	SuperCavity housing dimensions	viii
S-2	Detector Spectral Responsivity	ix
1-1	SuperCavity components and System Configuration	3
1-2	Typical Setup for SuperCavity Optical Spectrum Analyzer System	5
2-1	Typical plane-mirror cavity Fabry-Perot interferometer	9
2-2	Peaks from mth and (m+1)th order of a typical Fabry-Perot interferometer	10
2-3	Resolution of two lines by a Fabry-Perot interferometer	11
2-4	Spherical mirror Fabry-Perot cavities	13
2-5	Beam profile of the fundamental mode of a spherical-mirror non-confocal cavity	13
2-6	SuperCavity mode structure in frequency space	14
2-7	Mode structure for confocal and non confocal cavities	15
2-8	Matching the waist of the input beam to the fundamental mode of the SuperCavity	17
2-9	Mode Matching Schematic	17
2-10	Cavity Mode Matching Chart	22
2-11	Change of Cavity Finesse with Wavelength	25
2-12	Tradeoff Between Cavity Finesse and Efficiency	25
3-1	Front & rear panel schematic for the Universal Cavity Controller, SR-UCC	30
3-2	System Block Diagram - SuperCavity	31
3-3	Sweep voltage waveform	32
3-4	Pin configuration of the PIEZO connector	34
3-5	Fringe Lock activity	35
4-1	SR-UCC Controller Front Panel	38
4-2	SR-UCC Controller Rear Panel	38
4-3	Distance to focal waist inside cavity	39
4-4	Cavity housing showing position of back-reflecting alignment mirror	39
4-5	Cavity mode spikes before final alignment	40
6-1	Schematic for packaging of SuperCavity and Fiber Input Adapter	45
I-1	Front and Rear Panels of the SR-D Series Controllers	49
I-2	System Block Diagram	51
II-1	Set-up and wiring for SuperCavity System	55
II-2	Install the mirrors and mounts MM-2	56
II-3	Laser installation	57
II-4	Laser interconnections	57
II-5	Beam alignment	58
II-6	Coarse alignment of beam	58
II-7	Install coupling lens and mount	59

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II-8 Install SuperCavity and LP-1 mount 59
II-9 Location of the front alignment and input aperture of SuperCavity ... 60
II-10 IR sensor card and pinhole positioning 60
II-11 Photo sequence of mode shape 61
II-12 Photo sequence of mode shape with different sweep setting 61
II-13 Motion of mode cluster envelope 62
II-14a A representative lab set-up 64
II-14b Cavity mode matching chart 64
II-14c Distance to focal waist inside cavity 64
II-15 SuperCavity Fiber input adapter system 65
Reference drawing 67

List of Tables

1.0 SuperCavity system configurations 2
1.1 SuperCavity Optical Spectrum Analyzer Order Information 4
1.2 Suggested Accessories for use with SuperCavity 7
2.1 SuperCavity Waist Diameters and Rayliegh Ranges 16

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Safety Precautions

This instrument is intended for use by qualified personnel who recognize shock hazards and are familiar with safety precautions required to avoid possible injury. Read the manual carefully before operating the instrument and heed all written warnings.

For your own safety and that of your equipment, always take the following precautions.

Disconnect the power plug under the following circumstances:

- If the power cord or plug any attached cables are frayed or damaged in any way
- If the unit is exposed to rain, excessive moisture, or liquids are spilled on the unit
- If the unit has been dropped or the case is damaged
- Whenever you clean the case

To protect the unit from damage, be sure to:

- Keep all air vents free of dirt and dust
- Do not expose the unit to excessive moisture or liquids
- Read the manual before using the unit for the first time

WARNING

This product is equipped with a 3 wire grounding type plug. Any interruption of the grounding connection can create an electric shock hazard.

All attachment plug receptacles to be used with this unit are to be of the 3 wire grounding type and properly polarized. Contact your electrician to check your receptacles and to assure that the green (green-yellow) wire is attached to earth ground.

WARNING

This product operates with voltages that can be lethal. Pushing objects of any kind into cabinet slots or holes, or spilling any liquid on the product, may touch hazardous voltage points or short out parts.

WARNING

Opening or removing covers will expose you to hazardous voltages. Refer all servicing internal to this instrument enclosure to qualified service personnel.

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Specifications

	Optical Spectrum Analyzer Series	Center Wavelength (nm)	Wavelength Range (nm)	Free Spectral Range[1]	Cavity Length	Linewidth (FWHM)-Resolution	Finesse[2]	Efficiency[3]	Insertion Loss	Typical Application
SR-100	High Finesse SuperCavity	495 550 620 810 1060	465-525 515-585 580-660 755-845 1000-1120	6 GHz 0.2 cm^{-1}, or 0.008 nm @ red	25 mm	<0.6 MHz	>10,000	>10%	<10dB	Narrowband optical filtering, Laser cavity stabilization, Laser linewidth diagnostics, High resolution spectroscopy
	High Transmission SuperCavity	1325 1550	1300-1350 1520-1580			<1.2 MHz	>5,000	>50%	<3dB	
	HiRez™ OSA	633 790 1060	615-650 775-815 1030-1090			<6 MHz	>1,000	>25%	<6dB	
SR-200	High Finesse SuperCavity	495 550 620 810 1060	465-525 515-585 580-660 755-845 1000-1120	8,000 GHz 250 cm^{-1}, or 10 nm @red (nominal)	20 µm (nominal)	<0.8 GHz	>10,000	>10%	<10dB	Mode Structure analysis, particularly diode, ion and solid state lasers, Spectroscopy of light scattering of materials
	High Transmission SuperCavity	1325 1550	1300-1350 1520-1580			<1.6 GHz	>5,000	>50%	<3dB	
	HiRez™ OSA	633 790 1060	615-650 775-815 1030-1090			<8 GHz	>1,000	>25%	<6dB	

[1] *Custom Free Spectral Ranges between 6GHz and 8000 GHz readily available.*

[2] *Finesse values for specified wavelength range. Typical Finesse values are 20,000 to 40,000 for High Finesse cavities. High Transmission cavities have typical Finesse values of 5,500 to 7,000. Highest Finesse occurs at the center of cavity passband.*

[3] *Typical efficiency (throughput) for High Finesse cavities range from 10% to 40%, while High Transmission cavities have values from 55% to 80%. Longer wavelength cavities have higher transmission values.*

Custom Free Spectral Range (FSR):	>6 GHz, <8,000 GHz
Suggested Custom FSR:	25, 100, 200, 500, 2000 GHz
Mirror radius of curvature:	300 mm ± 0.3 mm
Cavity housing weight:	8.3 oz. (234 g.) head only 23 oz. (653 g.) head with LP-1B
Storage environment:	0°C to 50°C
Operating environment:	25°C ± 5°C

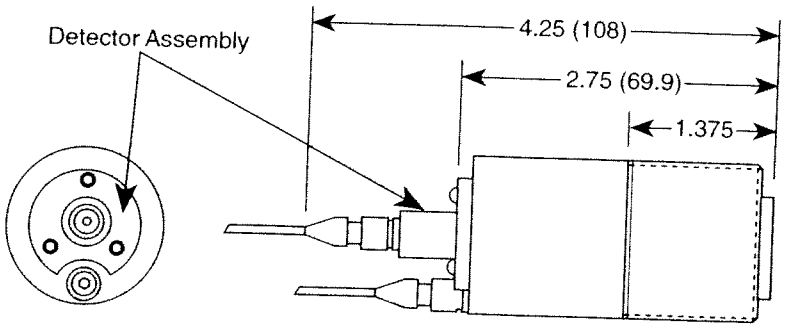


Figure S-1. SuperCavity housing dimensions.

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Detector Specifications:

	Silicon	Germanium
Active area	2.4x2.8mm	3mm dia
Spectral range	320-1100nm	800-1800nm
Spectral responsivity peak	960nm	1550nm
Peak responsivity	0.58 typ.A/W	0.9 typ. A/W
Capacitance, typical (1)	200pF	7nF
Rise time, typ.	0.5usec[1]	1usec[2]
Dark current, max	20pAmp[2]	30µAmp[3]

(1) no reverse voltage. (2) reverse voltage=1V. (3) reverse voltage=10V.

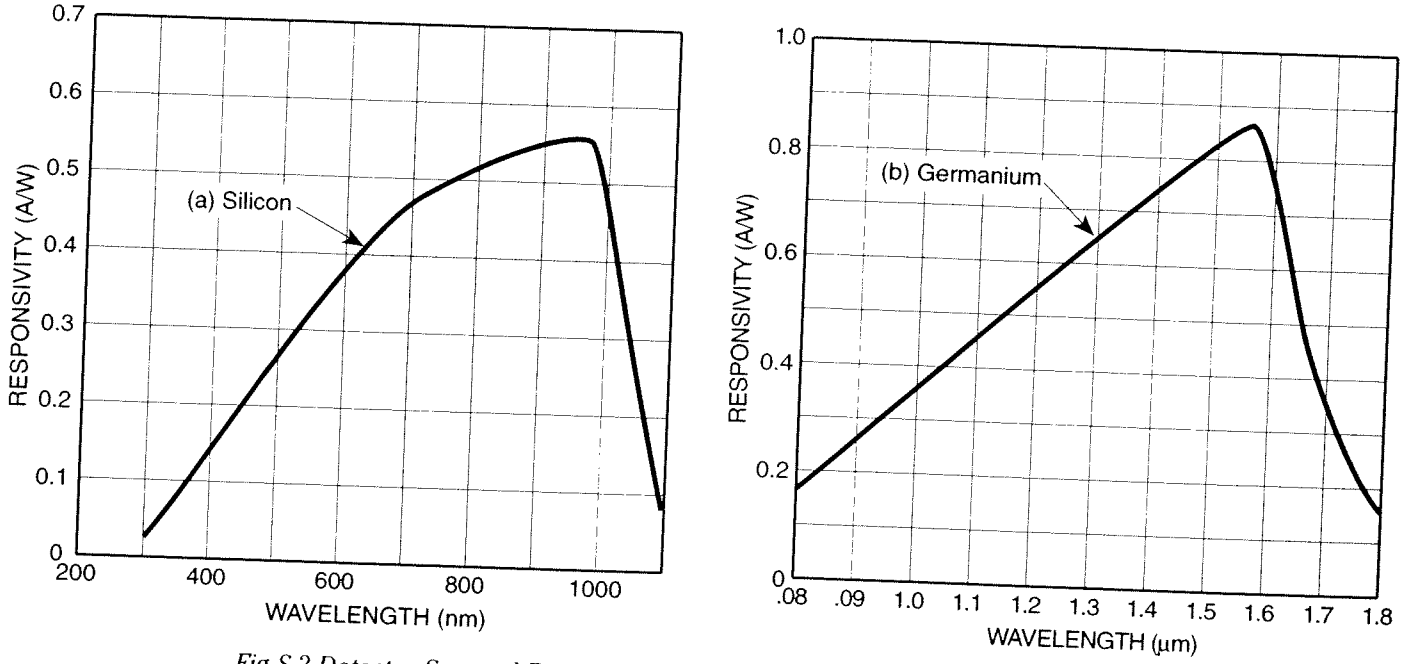


Fig S-2 Detector Spectral Responsivity. Typical responsivity at 25 deg C for the (a) Silicon and (b) Germanium detectors used with SuperCavity.

Universal Controller (SR-UCC) Specifications:

Gain Settings:	×1, ×5, ×25, ×125 (±10%)
Gain Sensitivity:	@ ×125: 0.3 V/µA (Type) i.e., 3V output for 10µA input of detector current.
Amplifier background noise:	@×125 gain setting; 5mV with filter inactive, 2mV with filter active and without the detector. - with Ge det; additional 10mV - with Si det; additional 5mV
Low pass filter:	-3 dB at 10 KHz
Maximum sweep amplitude supplied to the piezo:	100V peak to peak (±10%). Switch selectable in four increments; ±15, 30, 40, and 50V (bipolar). See Fig. 3-3.
Fringe Lock Feature:	reference level adjustment: 0 to ≈4.5V reference level LED: toggle ON/OFF

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Cavity Resonance stabilization:	temperature control provides cavity resonance stabilization of <1% of an FSR (24 hrs) and <±.1% of an FSR (1 hr). This is measured as % of an FSR after steady state conditions have been reached. Note: Full thermal stabilization may require as much as six hours of system warm-up.
Scan Rate:	int: 30 Hz ext: dc to 50 Hz with +10 to -10 volt external input. dc to 100 Hz with +1 to -1 volt external input. Note: For cavities of lower finesse (<10,000) you may use external scan of 40 Hz to reduce oscilloscope flicker.
External Sweep Input Impedance:	10 K ohm.
External Sweep Sensitivity:	5 V out per V in., for example: 10 volt input at EXT IN leads to 50 volts across the piezo surface (with switches number 1 and 2 at back panel set 11).
Output x and y BNC Load Impedance Requirements:	10 K ohm load impedance or higher. Back panel BNC outputs for piezo voltage reference requires 1Kohm or higher of load impedance.
Detector Back Bias:	10V
AC Power Requirements:	25 Watt maximum
VAC Input:	selectable to 100, 120, 220 and 240 VAC accepts ±10% variation and 50-60 Hz (use the appropriate fuse if voltage is changed)
Fuse Requirements:	500 mA @ 100 VAC, 3AG, slow-blow type 500 mA @ 120 VAC, 3AG, slow-blow type 250 mA @ 220 VAC, 3AG, slow-blow type 250 mA @ 240 VAC, 3AG, slow-blow type
Controller Dimensions:	3.5 in. (88 mm) high X 7.5 in. (188 mm) wide X 9.25 in. (234 mm) deep
Controller Weight:	5 lbs 12 oz (2.6 kgm)
Storage Environment:	0 to 50° C
Operating Environment:	15 to 35° C

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Definitions

λ ..... Wavelength

L ..... Cavity spacing

FSR ..... Free Spectral Range

$\mathcal{F}$ ..... Finesse

r ..... Mirror Radius

w ..... Beam Waist

R ..... Reflectivity

T ..... Transmission

A ..... Absorption

δ ..... Phase difference

γ ..... Full-width-half-maximum

$A(\delta)$ ..... Airy function

m ..... Order of interference

c ..... Velocity of Light

F ..... Coefficient of Finesse

f_m ..... Lens focal lenght

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Certificate of Performance

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Product: **SuperCavity™ Optical Spectrum Analyzer System**

System Model Number _____ Cavity Serial Number _____

Controller Model Number _____ Controller Serial Number _____

Wavelength Range _____

Measured Bandwidth Center _____

Test Wavelength _____

Test Method for Finesse Specification:

☐ Fractional Mode Splitting ☐ Acousto-Optic Modulation ☐ Ringdown Test

☐ Other _____

Parameter	Specification	Measured Performance
Finesse*	_____	_____
Efficiency	_____	_____
Free Spectral Range	_____	_____

Quality Control _____

Quality Control Check Date _____ Quality Control Stamp _____

Options _____

Newport Order No. _____ Customer's Purchase Order No. _____

User Name _____

Organization Name _____

Address _____

City _____ State _____ Zip _____

Specified over the Wavelength Range specification

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Section 1
General Information

1.1 Introduction

This instruction manual contains the necessary information for operating and maintaining the Model SR-100 and 200 Series SuperCavity Optical Spectrum Analyzer. This information is divided into the following sections:

Section 1 Contains general information and provides guidelines for using this manual. Important safety information is also presented here.

Section 2 Reviews the principles of the operation of the Fabry-Perot interferometer cavity and the controller. This section defines terms which are used in later sections.

Section 3 Describes the features of the Universal Cavity Controller, Model SR-UCC.

Section 4 Describes the procedures for operating the Model SR-100 and 200 Series SuperCavity Optical Spectrum Analyzer.

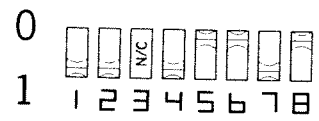
Section 5 Provides maintenance information for the user.

Section 6 Gives information regarding factory service and repairs.

Please carefully read and understand this instruction manual before using the SuperCavity. Alignment of the SuperCavity requires care and patience for optimum performance. Be especially careful in observing the safety warnings and cautions throughout the manual (see Section 1.7). If any of the operating instructions are not clear, contact Newport Corporation before beginning to use the SuperCavity.

1.2 Unpacking and Inspection

All SuperCavity Optical Spectrum Analyzers are carefully inspected mechanically, electrically, and optically before shipment. Upon receiving the SuperCavity, check for any obvious signs of physical damage that might have occurred during shipment. See Section 1.3 SuperCavity System Configurations to ensure all components ordered are present. The following is the SR-UCC shipping switch setting. The rear panel DIP switches are set as follows:



Rear panel DIP switch position.

Also the rear panel sweep select switch should be set to internal (INT).

Report any such damage to the shipping agent immediately. Retain the original packing materials in case reshipment becomes necessary.

1.3 SuperCavity System Configurations

SuperCavity is a modular instrument that may be ordered in a number of configurations. Additionally, the options that make up a given configuration can often be ordered seperately or as an upgrade to an existing SuperCavity system. In general, the attributes that need to be decided before ordering a SuperCavity are:

- Wavelength range
- Free spectral range, FSR

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- Finesse of the cavity, (or equivalently the resolution of the cavity)
- Fiber optic input

The specifications table on page viii of this manual identifies the allowable combinations of wavelength range, FSR, and finesse. Note that the finesse selection identifies what SuperCavity family, (High Finesse, High Transmission or HiRez‰) your final model number will be selected from. The table below and Figure 1.1 describe the items that make up the various SuperCavity systems.

Description	Model	Items Included	Illustration
SuperCavity) (Cavity alone)	SR-XXX-C	SuperCavity Container Box Cavity Certificate of Performance	Figure 1.1 (a)
Universal Cavity Controller (Controller alone)	SR-UCC	SR-UCC Controller LP-1B Mount System Instruction Manual Cables	Figure 1.1 (c)
SuperCavity System (Complete system)	SR-XXX	SR-XXX-C (above) SR-UCC Controller LP-1B Mount System Instruction Manual Cables	Figure 1.1 (a) + Figure 1.1 (c)
Fiber Adapted SuperCavity (Fiber adapted cavity alone)	SR-XXX-OPT 01 XX	SR-XXX-C (above) Fiber Input Adaptor (matched) Container Box (replaces first box) Adaptor Certificate of Performance Ring adaptor and post mount Fiber Adaptor Instruction Manual	Figure 1.1 (a) + Figure 1.1 (b)
Fiber Adapter SuperCavitySystem (Fiber adapted system)	SR-XXX-OPT 02 XX	SR-XXX-OPT 01 XX (above) SR-UCC Controller LP-1B Mount System Instruction Manual Cables	Figure 1.1 (a) + Figure 1.1 (b) + Figure 1.1 (c)
Retrofit Fiber Adapter SuperCavity System (Fiber adapted retrofitted to previously purchased SuperCavity)	SR-XXX-OPT XX	SR-XXX-OPT 01 XX (above) (You will need to return your cavity for retrofitting when ordering this)	Figure 1.1 (b)

Table 1.0 SuperCavity System configurations

SuperCavity may also be ordered with a custom free spectral range. FSR's between 6 GHz and 8000 GHz with ±10% accuracy are available. These custom cavities can only be ordered from our High Finesse or High Transmission cavity families. The Fiber Input Adaptor can not be ordered with any custom FSR cavity. Some recommended custom FSR values are:

FSR = 25, 100, 200, 500, 2000 GHz

Ordering information for SuperCavity systems can be found in table 1.1 on page 4.

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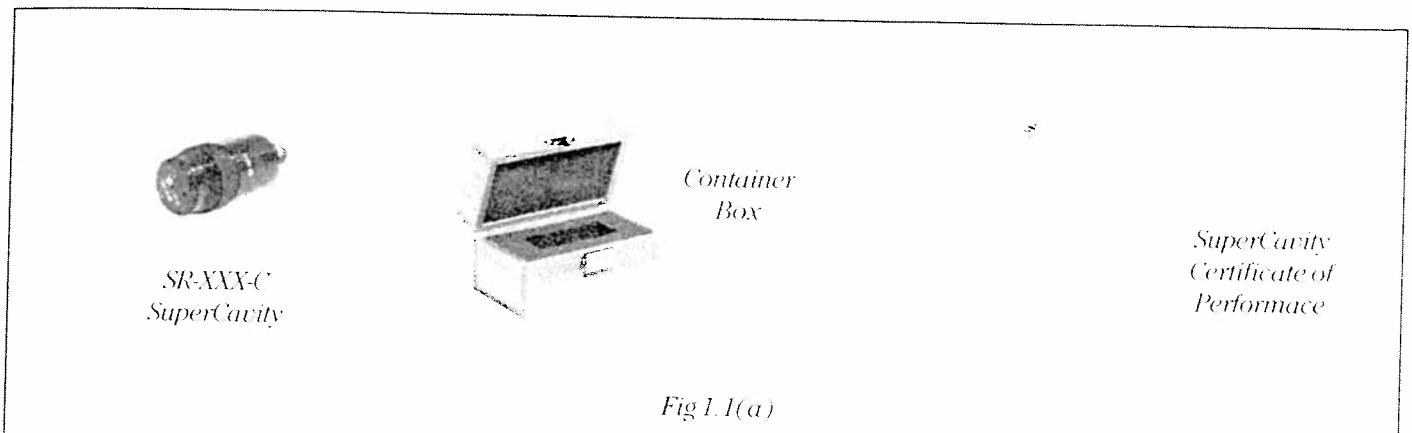


Fig 1.1(a)

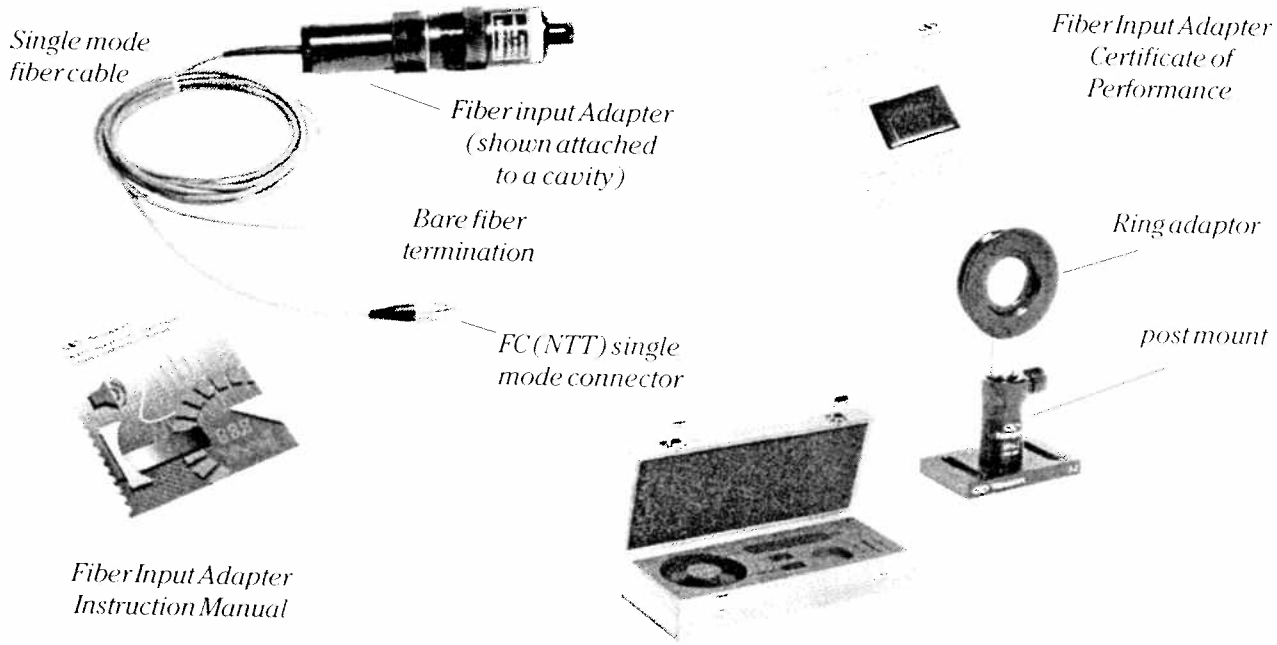


Fig 1.1(b)

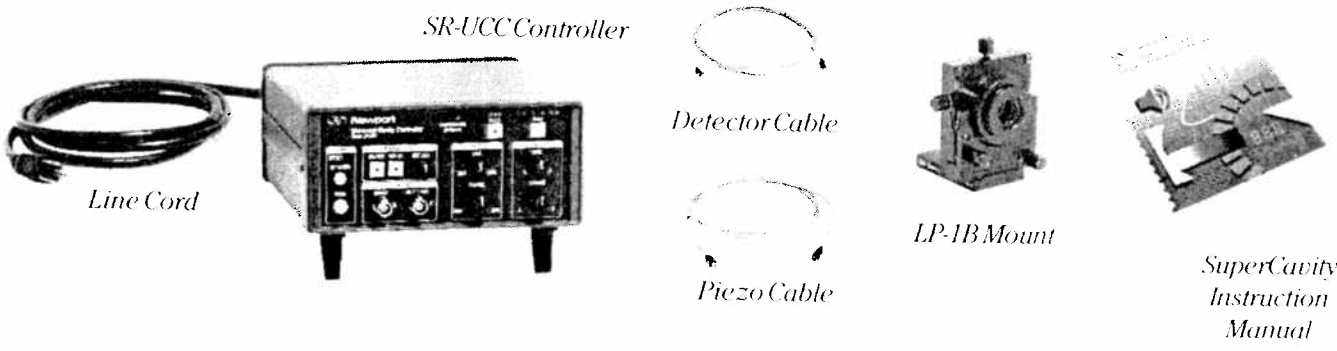


Fig 1.1(c)

Fig. 1-1 SuperCavity system componets

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SuperCavity™ Optical Spectrum Analyzer Ordering Information

Wavelength Range (nm)	Center Wavelength λ_c (nm)	Free Spectral Range[1] (nominal)	SuperCavity (Head only)	Fiber Adapted SuperCavity[2] (Head only with Fiber Input Adapter)	Retrofit SuperCavity[3] (with Fiber Input Adapter)
High Finesse SuperCavity™:					
465 - 525	495	6 GHz	SR-110-C	N/A	N/A
515 - 585	550	6 GHz	SR-120-C	N/A	N/A
580 - 660	620	6 GHz	SR-130-C	SR-130-CF	SC-FR
755 - 845	810	6 GHz	SR-140-C	SR-140-CF	SC-FR
1000 - 1120	1060	6 GHz	SR-150-C	SR-150-CF	SC-FR
465 - 525	495	8,000 GHz	SR-210-C	N/A	N/A
515 - 585	550	8,000 GHz	SR-220-C	N/A	N/A
580 - 660	620	8,000 GHz	SR-230-C	SR-230-CF	SC-FR
755 - 845	810	8,000 GHz	SR-240-C	SR-240-CF	SC-FR
1000 - 1120	1060	8,000 GHz	SR-250-C	SR-250-CF	SC-FR
High Transmission SuperCavity™:					
1300 - 1350	1325	6 GHz	SR-160-C	SR-160-CF	SC-FR
1520 - 1580	1550	6 GHz	SR-170-C	SR-170-CF	SC-FR
1300 - 1350	1325	8,000 GHz	SR-260-C	SR-260-CF	SC-FR
1520 - 1580	1550	8,000 GHz	SR-270-C	SR-270-CF	SC-FR
HiRez™ OSA:					
615 - 650	633	6 GHz	SR-135-C	SR-135-CF	SC-FR
775 - 815	790	6 GHz	SR-145-C	SR-145-CF	SC-FR
1030 - 1090	1064	6 GHz	SR-155-C	SR-155-CF	SC-FR
615 - 650	633	8,000 GHz	SR-235-C	SR-235-CF	SC-FR
775 - 815	790	8,000 GHz	SR-245-C	SR-245-CF	SC-FR
1030 - 1090	1064	8,000 GHz	SR-255-C	SR-255-CF	SC-FR

Fiber Input Adaptor
Choose Fiber Termination XX = 01 Bare Fiber
03 FC (NTT) Connector

N/A: not available
1. Custom free spectral ranges are available. Controllers are purchased separately. Call Newport for price and availability.
2. Fiber terminated with FC (NTT) connector.
3. You will be asked to send us your SuperCavity at the time you place the order.

Table 1-1. SuperCavity Optical Spectrum Analyzer ordering information

1.4 Specifications

Detailed specifications for SuperCavity Model SR-100 and 200 Series, and Model SR-UCC controller may be found immediately preceding this section of the instruction manual.

1.5 SuperCavity Technical Application Notes

Following is a list of technical notes for SuperCavity Optical Spectrum Analyzer. These technical application notes may be obtained by contacting the local Newport representative.

SR-001 Mode matching to the SuperCavity.

SR-002 Frequency calibration of the Series 100 and Series 200 SuperCavity.

SR-003 Broadband and Multiline Source Analysis with SuperCavity.

SR-004 Cavity Resonance Frequency Drift and Methods of Stabilization in the Newport SuperCavity High Finesse Optical Spectrum Analyzer.

SR-005 Spectral Analysis of Laser; SuperCavity Optical Spectrum Analyzer Alignment Instruction and Demonstration.

1.6 Warranty Information

Warranty information may be found on the page preceding the Table of Contents of this manual. Should it be necessary to exercise the warranty, contact your Newport representative or the factory to determine the correct course of action. Newport Corporation maintains offices worldwide. Information concerning the application, operation, or service of your instrument may be directed to any of these locations. Check the back cover of this manual for addresses.

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1.7 Safety Terms

The following safety terms are used in this manual:

The **Warning** heading in this manual explains dangers that could result in personal injury or death.

The **Caution** heading in this manual explains hazards that could damage the instrument.

1.8 Typical SuperCavity Setup

Alignment Digest

This section is a description of typical system setup and wiring, together with some instructions for a quick start. Please note that this section is not meant as a substitute for other detailed instructions in this manual. This is particularly applicable for light sources having less than 100 micro watts in power.

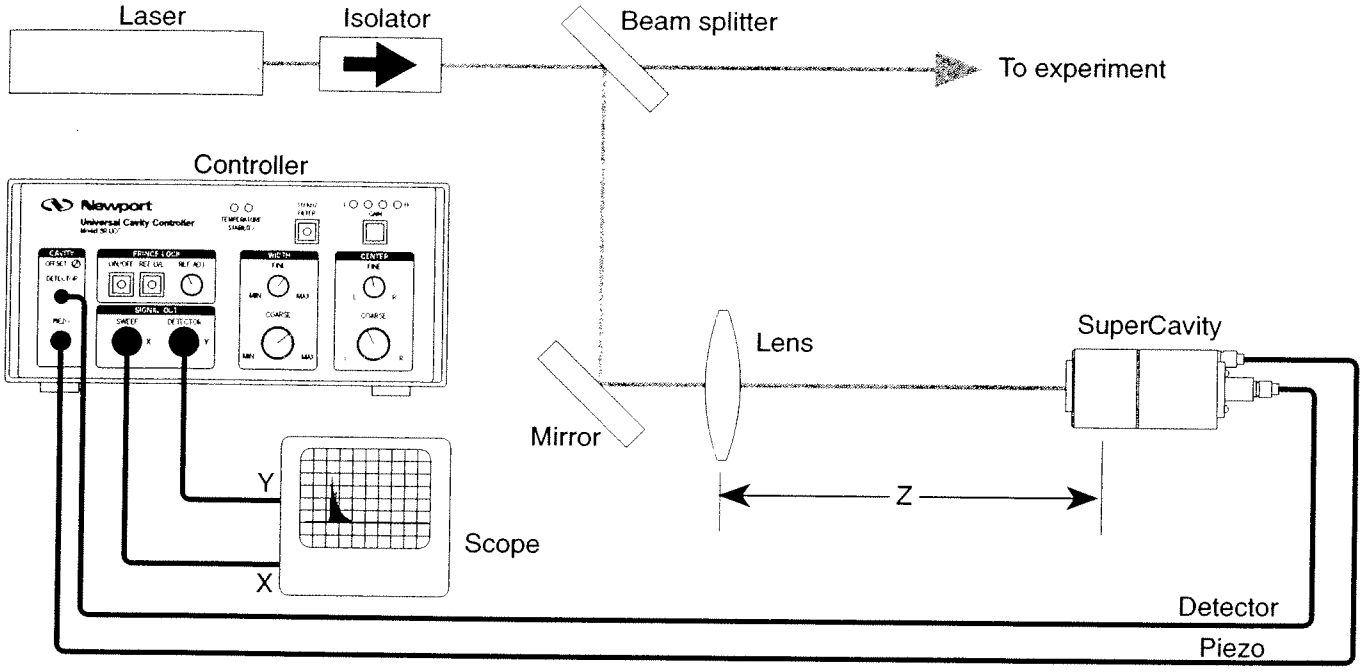


Fig. 1-2. Typical Setup for SuperCavity optical spectral analysis system.

Fig. 1-2 is a representative lab setup. Following is an abbreviated instruction set for SuperCavity alignment and setup. For details regarding mode matching into the SuperCavity see Sec. 2.2. For more details regarding alignment see Sec. 4.4 and Appendix III. See Table 1.2 for suggested accessories for use with SuperCavity.

Setup and Alignment Summary:

1. Mount the SuperCavity onto the LP-1B five axis mount.
2. Connect the SuperCavity to the controller as shown in Fig. 1-2, and turn the controller ON. The ON/OFF switch is located in the back. In 15 minutes the TEMPERATURE STABILITY green light should turn ON indicating the system is reaching thermal equilibrium.
3. Connect the controller to the scope, and turn the scope to the X-Y mode.
4. It is necessary to use an optical isolator after the laser to eliminate back reflections from the spectrum analyzer to the laser. This is especially important in narrow linewidth lasers. See Sec. 4.2.2. for some suggested optical isolators.

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5. Locate a convenient point to place the focusing lens. Measure approximately the size of the beam (to an accuracy of 0.5 mm). This is called D mm.

6. Go to Fig. 2-10, p. 22 in this manual. Use the left vertical axis with the top curve if you have a Series 100 cavity, and the right vertical axis with the bottom curve if you have a Series 200 cavity. Read the lens focal length f_m (per mm) for the wavelength you are using.

7. The needed focal length for your lens is approximately $f = Df_m$. Pick a focal length that is close to that and place the lens in a lens holder at its location. Section 2.2 discusses the principles and approximations that led to Fig. 2-10.

8. Roughly align the axis of the input beam with that of the lens.

9. Roughly locate the waist of the beam after the lens. That location will be the center of SuperCavity as given by Fig. 4-3, p. 39.

10. This is the most important step in the alignment process. Translate the cavity such that the input beam is reflected by the front alignment mirror on the face of SuperCavity. Correct the angle as good as possible by using the angular adjustments on the five-axis mount. Translate the SuperCavity such that the input beam enters the aperture at the center of the face plate.

11. Set scope to the X-Y mode. Suggested initial gain settings are 1 V/div for X, and 100 mV/div for Y.

12. Controller settings: Set the gain on high, sweep to MIN and CENTER to midway between R and L. Look on the scope for signals similar to those shown in Appendix II, Figs. 2 and 3.

13. Fine tune the translation and angle of the cavity to maximize the first fringe (pulse or peak) on the scope. The first fringe represents the TEM_{00} mode of the cavity. This should minimize the amplitude of the other transverse modes.

14. Replacing the lens with an achromat may improve the coupling efficiency into the fundamental mode.

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Suggested Accessories from Newport Corporation:

Description	Wavelength	Model Number	Comment
optical isolator	633 nm	05 RP14	¼ waveplate
		05 FC16PB.3	polarizing beamsplitter cube
		MLH-0.5	optic mount
		CH-0.5	cube holder
	800 nm	ISO-7885	faraday isolator
	1060 nm	05 RP14	l/4 waveplate
		05 FC16PB.7	polarizing beamsplitter cube
		MLH-0.5	optic mount
		CH-0.5	cube holder
	1300 nm	ISO-1315 (or)	faraday isolator
		ISO-13H (or)	
		ISO-13 FIB	
	1500 nm	ISO-1315 (or)	faraday isolator
		ISO-15H (or)	
		ISO-15 FIB	
mirrors	visible	10D10ER.2	
	0.7 - 2 µm		
beam splitter	visible	10B10BS.1	
	700-950 nm	10B10BS.2	
	1290-1580 nm	10B10BS.3	
mirror mount	N/A	MM2-1A-B3	
lenses	N/A	LKIT-1	lens kit
lens holder	N/A	AC1-BC3	

Table 1.2 Suggested Accessories for use with SuperCavity

1.9 General Applications Guide

Application	SuperCavity type
Narrowband optical filtering, laser cavity stabilization, laser linewidth diagnostics, high resolution spectroscopy Doppler shift measurements, modulation spectroscopy	Series 100 SuperCavity (sub-MHz resolution)
Mode structure analysis, laser diode/device mode analysis, spectroscopy of light scattering, florescence spectroscopy material signature analysis, Raman spectroscopy	Series 200 SuperCavity (20µm mirror spacing, 8000GHz free spectral range)

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Section 2
Principles of Operation

2.1 Fabry-Perot Interferometer

In this section, the principles of the Fabry-Perot interferometer are reviewed. Terms will be defined which are used in the following sections describing the operation and applications of the SuperCavity. The SuperCavity is a **spherical-mirror non-confocal cavity**. It is made up of two spherical mirrors with a radius of curvature r separated by a distance L. The radius of curvature r of the mirrors is not equal to the distance L, so the cavity is not confocal. However, most of the terms used in specifying the parameters and operation of both a confocal and plane geometry Fabry-Perot interferometer can be applied to the SuperCavity. This section will therefore begin with a discussion of the plane-mirror Fabry-Perot interferometer. The peculiarities of the spherical mirror interferometer are outlined in Section 2.1.2.

2.1.1 Plane-Mirror Interferometer

This section outlines the definitions of terms using the plane-mirror Fabry-Perot interferometer. It does not contain a detailed derivation of all of the terms; the user can find such a discussion in Chapter 9 of Optics 2nd Edition by E. Hecht (Addison-Wesley, Reading, MA, 1987).

The plane-mirror interferometer in Fig. 2-1 is illuminated by an incoherent source. The light from the source is focused into the cavity. This light is trapped for a time by multiple reflections within the gap between the two mirrors. Eventually the light is transmitted through the interferometer, collected by a lens, and brought to a focus at a point P on a screen.

The transmitted intensity can be written a

$$\frac{I_t}{I_i} = \frac{1}{1+\left[4R/(1-R)^2\right]\sin^2(\delta/2)}, \qquad (2\text{-}1)$$

where I_t is the transmitted light intensity, I_i is the incident light intensity, T is the **transmittance** of each of the mirrors, R is the **reflectivity** of each of the mirrors and δ is the phase difference between two successively transmitted waves. Two other important definitions arise from Equation 2-1. The first is the **coefficient of finesse**, F, (also called the **contrast ratio**) which is

$$F = \frac{4R}{(1-R)^2}. \qquad (2\text{-}2)$$

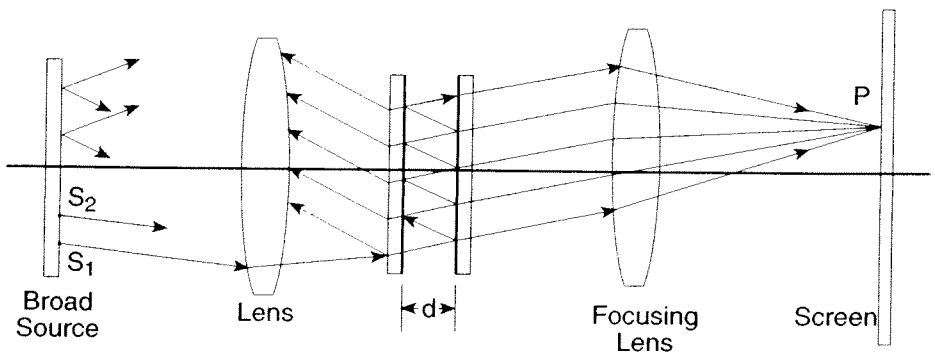


Figure 2-1. Typical plane-mirror cavity Fabry-Perot interferometer.

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The coefficient of finesse is not the same as the finesse, which will be defined shortly. The second definition is that of the Airy function, which is given by

$$A(\delta) = \{1+F\sin^2(\delta/2)\}^{-1}. \tag{2-3}$$

The transmitted intensity from Equation 2-1 may now be written as

$$I_t/I_i = [T/(1-R)]^2 A(\delta). \tag{2-4}$$

The transmitted intensity is a maximum when $A(\delta)=1$. Therefore, the peak transmission is given by

$$(I_t/I_i)_{max} = [T/(1-R)]^2. \tag{2-5}$$

The relative irradiance, $I_t/(I_t)_{max}$, is given then by the Airy function.

A measure of the sharpness of the fringes is given by the **full-width half-maximum**, γ. As shown in Figure 2.2, γ is the width of the peak, in radians, when $I_t/(I_t)_{max}=1/2$, since the relative intensity is given by the Airy function. Thus, γ satisfies the relation

$$[1+F\sin^2(\gamma/2)]^{-1} = 1/2, \tag{2-6}$$

so that

$$\lambda = 4\sin^{-1}(1/\sqrt{F}). \tag{2-7}$$

When F is large, as is the case with the SuperCavity, $\sin^{-1}(1/\sqrt{F})$ can be closely approximated by $1/\sqrt{F}$, so

$$\gamma = 4/\sqrt{F}. \tag{2-8}$$

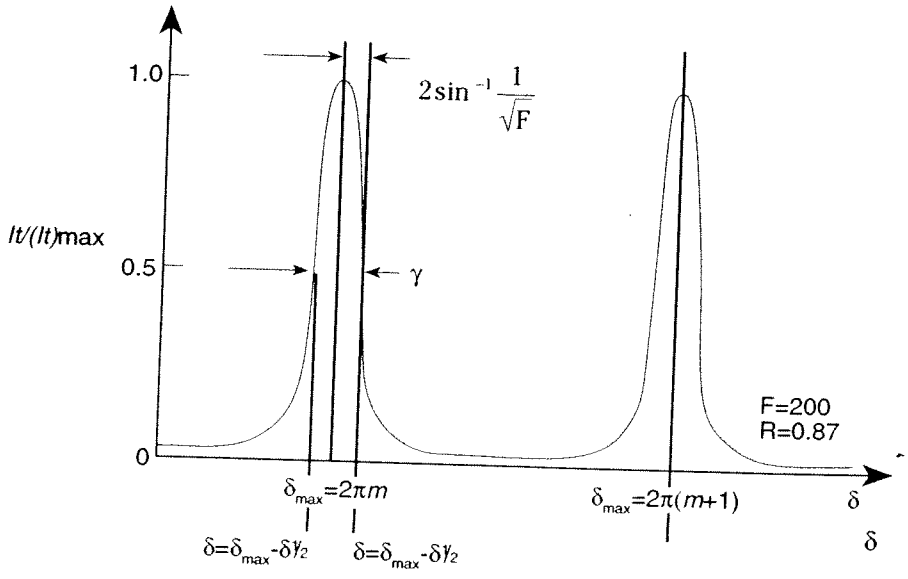


Figure 2-2. Peaks from mth and (m+1)th order of a typical Fabry-Perot interferometer, showing the full-width half-maximum, γ, of the peak.

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A parameter of particular importance is the finesse of the cavity. The **finesse**, $\mathcal{F}$, is defined as the ratio of the separation of adjacent maxima to the full-width-half-maximum, which is using Equations 2-8 and 2-2,

$$\mathcal{F} = 2\pi / \gamma = \frac{\pi\sqrt{F}}{2} = \frac{\pi\sqrt{R}}{1-R} \quad . \tag{2-9}$$

Over the visible spectrum, the finesse of ordinary plano Fabry-Perot cavities is on the order of 30. The physical limitation on $\mathcal{F}$ is due to losses of the mirrors and the fact that after many passes the beam will "walk" off of the plane mirrors. Mirror losses include scattering from the substrate surface and coating, and absorption by the the coating. Conventional mirrors rarely exceed 99.7% reflectivity. SuperCavity mirrors exceed 99.99% reflectivity for the original High Finesse series and 99.94% for the High Transmission series. SuperCavity mirrors have typical losses which are less than 50 ppm per pass at band center.

The Fabry-Perot interferometer is often used to analyze the details of the structure of spectral lines. If a monochromatic source such as that shown in Fig. 2-2 was, instead, composed of two monochromatic components, two superimposed systems of fringes would result, as shown in Fig. 2-3. The phase difference, δ, between the components is a function of the wavelength.

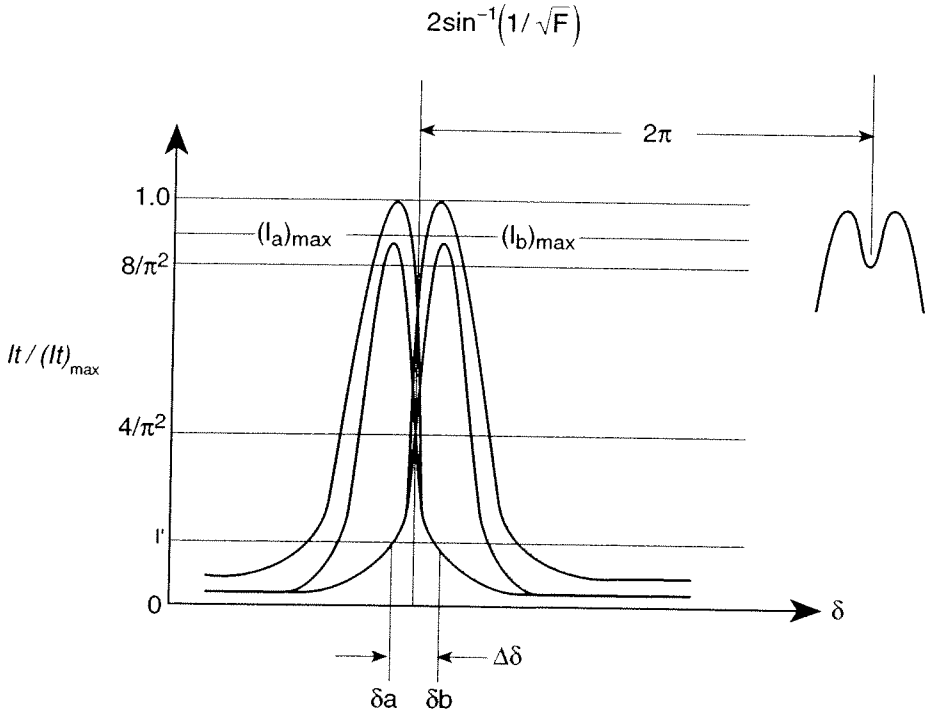


Figure 2-3. Resolution of two lines by a Fabry-Perot interferometer.

When the two fringes are individually discernible, they are said to be resolved. For large values of $\mathcal{F}$, the smallest phase difference which can be resolved can be shown to be (see Hecht, op. cit.)

$$(\Delta\delta) = 4.2 / \sqrt{F} = 2.1\pi / \mathcal{F} \tag{2-10}$$

This minimum resolvable phase difference can be related to minimum increments in wavelength ($\Delta\lambda = \lambda_o^2 / 2\mathcal{F}L$), frequency ($\Delta\upsilon = c/2\mathcal{F}L$), and wave number ($\Delta k = / \mathcal{F}L$), which define the resolving power of the interferometer.

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The individual fringes due to a single monochromatic component each represent different orders of the interference pattern. When the phase difference changes by 2 , the or der m changes by 1, implying the relationship

$$2\pi(\Delta m) = (\Delta\delta). \tag{2-11}$$

As the wavelength difference between the two monochromatic components in the source increases, the peaks shown in Figure 2-3 separate. As this wavelength difference increases, the mth-order fringe of one wavelength approaches the (m-1)th-order fringe of the second wavelength. The wavelength difference at which these two fringes overlap is defined as the free spectral range (FSR) of the interferometer. In an interferometer with an air gap between the two mirrors, a change of 2 in δ corresponds to a difference in wavelength of a free spectral range,

$$FSR = \lambda_0^2 / 2L , \tag{2-12}$$

where λ_0 is to first order the wavelength of the monochromatic component of the source. In terms of frequency, the free spectral range is given by

$$FSR = c/2L , \tag{2-13}$$

where c is the speed of light in vacuum.

If an attempt is made to increase the resolving power by increasing the gap, L, between the mirrors, Equation 2-13 predicts the free spectral range will decrease, resulting ultimately in a confusion of overlapping lines from different orders. However, using Equation 2-12 and the original definition given above for the resolving power of the interferometer, $\Delta\lambda = \lambda_0^2/2\mathcal{F}L$, then

$$\mathcal{F} = FSR/(\Delta\lambda). \tag{2-14}$$

What is actually required, therefore, to increase the resolving power of the interferometer, is that λ be as small as possible and that the FSR be as large as possible. Also, Equation 2-14 implies that for a cavity with a fixed finesse, an increase in the free spectral range will result in a commensurate loss of resolution, and an increase in resolution (decrease in $\Delta\lambda$) will result in a decrease in the free spectral range.

Scanning techniques are used for spectroscopic applications of Fabry-Perot cavities. Scanning is accomplished by varying the cavity length L. In the SuperCavity, this is accomplished by a scanned piezo-electric transducer (PZT) which expands or contracts the length of the cavity in response to an input voltage from the controller.

2.1.2 Spherical-Mirror Non-Confocal Cavity Interferometer

In the discussion of finesse which was given in the previous section, it was stated that plane-mirror (10mm diameter window or more) Fabry-Perot interferometers typically have a finesse of about 30. A significant contribution to this low finesse comes from the fact that after a relatively small number of reflections within the cavity, the beam will "walk" off of the mirrors and be lost. This problem can be resolved by using a spherical mirror cavity. SuperCavity is a **spherical-mirror non-confocal cavity**. A non-confocal cavity (Fig 2b.) is one in which the mirror separation is not equal to the radius of curvature of the mirrors (L ≠r).

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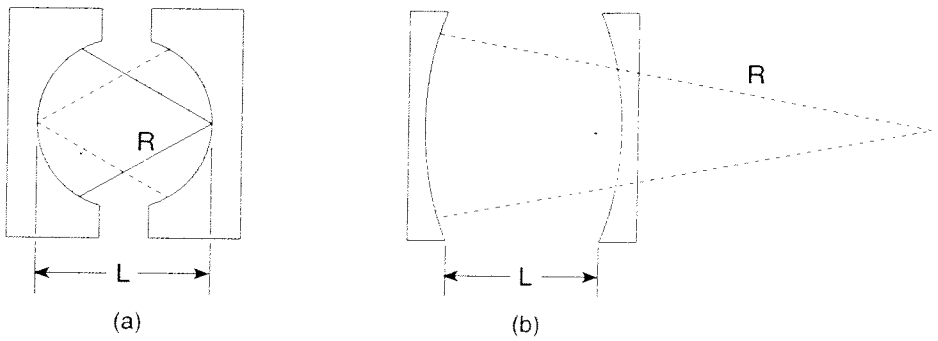


Figure 2-4. Spherical mirror cavities. (a) Confocal Cavity, (b) non-confocal cavity.

A non-confocal Fabry-Perot cavity will have resonant modes which have the same form as those which are present in a laser resonator with spherical mirrors. In the steady state, (after multiple-reflections) the beam will form a stabilized energy distribution within the cavity characterized by a beam waist and a beam contour. The beam waist is located midway between the mirrors, as shown in Fig. 2-5. (See H. Kogelnik and T. Li, "Laser Beams and Resonators," Applied Optics 5, 1550 (1966).)

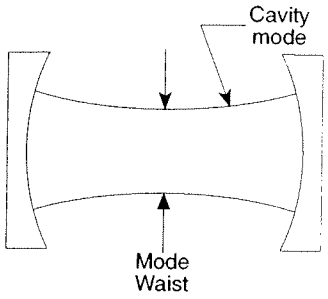


Figure 2-5. Beam profile of the fundamental mode of a spherical-mirror non-confocal cavity, such as the SuperCavity.

Frequency Distribution of Resonant Cavity Modes:

The cavity mode structure is composed of both longitudinal and transverse modes that are usually separated (non-degenerate) in frequency space. The mode distribution for both confocal and non-confocal cavities is given by

$$f_{qmn} = \frac{c}{2L}\left[q + (m+n+1)\frac{\cos^{-1}\left(\pm\sqrt{g_1 g_2}\right)}{\pi}\right] \qquad (2\text{-}15)$$

where c/2L is the longitudinal mode spacing,
c = the speed of light,
L = the cavity length,
m,n = transverse mode order = 0, ±1, ±2, ...,
q = longitudinal mode number,
$g_i = 1 - L/R_i$, i=1,2
R_i = radius of curvature of the ith mirror.

For the Newport SuperCavity, both the front and rear mirrors have radii of 300 mm, and a nominal length of either one inch or 20 microns. This makes it a non-confocal cavity. The cavity mode structure, represented by Eq. (2-15) is shown in Fig. 2-6.

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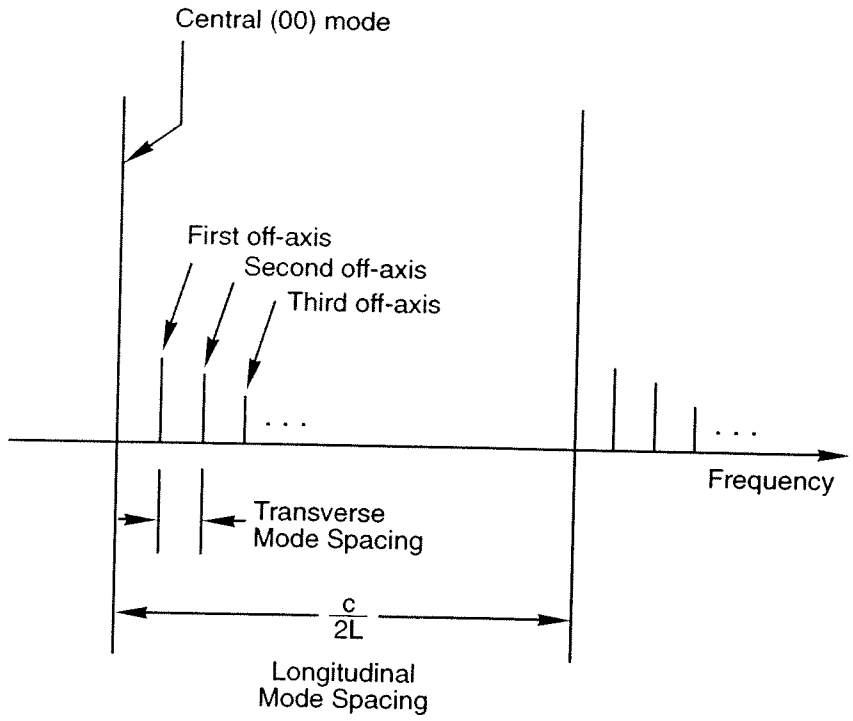


Fig. 2-6 SuperCavity mode structure in frequency space.

For $g_1=g_2=g$, the longitudinal mode spacing is c/2L while the transverse mode spacing is $(c/2L)\frac{\cos^{-1}g}{\pi}$.

The ratio of the transverse to the longitudinal mode spacing is referred to as the fractional mode splitting (FMS). The FMS for the Newport standard FSR SuperCavities is

$$\begin{aligned} \text{FMS} &= 0.131 \text{ for SR-100 series cavities} \\ &= 0.00365 \text{ for SR-200 series cavities} \end{aligned} \qquad (2\text{-}16)$$

Note that the FMS for SR-200 series is very small. This indicates that compared to the longitudinal mode spacing, the transverse modes are very close to each other. Hence the shorter the cavity the closer are the transverse modes as compared to the longitudinal mode spacing. Conversely, the further the two mirrors are from each other the larger is the FMS.

The confocal cavity geometry represents a special point of interest where the FMS=0.5, i.e. the first order transverse mode is midway between the longitudinal modes. The second order modes overlaps in frequency onto the adjacent longitudinal mode, i.e. the mode frequencies are degenerate. This is why the modes for confocal cavities are designated as c/4L modes since the overall mode separation appears half that of regular laser cavity. The transition of mode structure from that of a non-confocal to confocal cavity is shown in Fig. 2-7.

2.1.3 Transverse Mode Distribution for Resonant Cavities

Figure 2-4 shows typical spherical cavities. These cavities have characteristic eigenmodes whose resonant frequencies are shown in Equation (2-15) and Fig. 2-6.

These cavity modes form a complete set of orthogonal modes that may also be

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referred to as the Fourier series decomposition of the intracavity field. The first element of this series is the one of interest to us. It is the zeroth order axial or longitudinal mode, and its spatial intensity distribution is Gaussian in shape. Any input energy that does not have the spatial distribution that matches that of the longitudinal mode is either reflected or is coupled to higher order transverse modes. Hence, to improve the coupling efficiency into that mode, it is important for us to characterize the Gaussian intensity distribution of this mode.

Gaussian waves are completely defined by the location and size to their waist, which in turn are well defined for spherical mirror cavities by the length of the cavity and by the radius of curvature of the mirrors. Spherically symmetric cavities, such as Newport's SuperCavity, have two identical mirrors. The location of the waist of the Gausian mode is therefore at the middle of the cavity. The waist diameter (do) is related to the cavity geometry as follows:

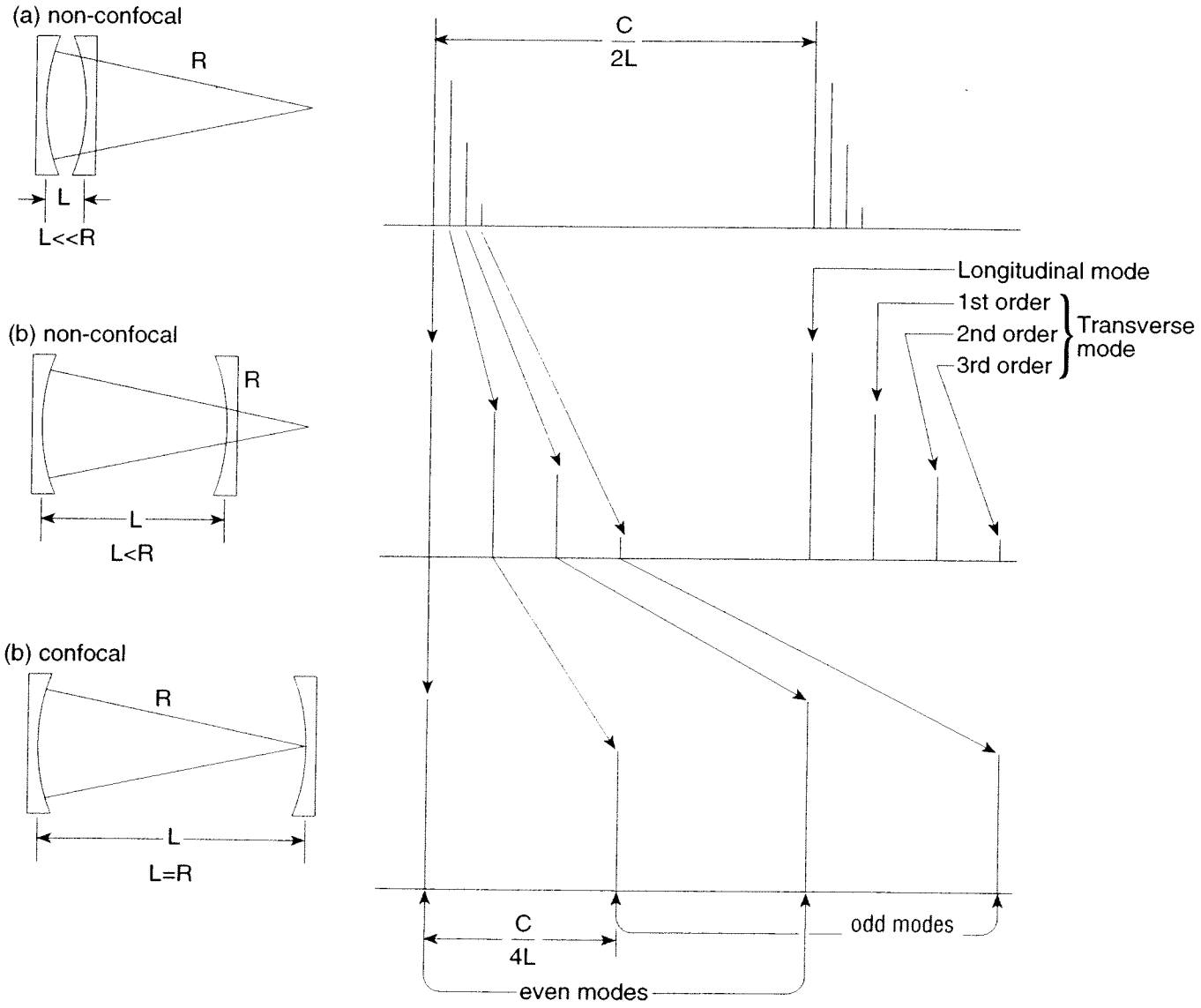


Fig. 2-7. Mode structure for confocal and non-confocal cavities. The arrows indicate the change of the resonance frequency of the modes as the cavity length is increased from (a) L<<R, (b) L<R, to (c) L=R. Note that for graphical representation we have kept c/2L = constant.

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$$d_0 = 2\sqrt{\frac{L\lambda}{2\pi}} \cdot \left(\frac{1+g}{1-g}\right)^{\frac{1}{4}} \qquad (2\text{-}17)$$

where g = 1 - L/R, L is cavity length and R is radius of curvature of the mirrors. SuperCavity uses mirrors that have R=300mm. Following is Table 2.1 which gives waist sizes for the various SuperCavity models as calculated from Equation (2-17).

Also included in Table 2.1 is the Raleigh range for each SuperCavity. The Rayleigh range is defined as the distance from the beam waist to the point where the diameter has increased to $\sqrt{2}d_0$, where d_0 is the diameter of the waist. It is equal to

$$Z_R = \frac{\pi d_0^2}{4\lambda}. \qquad (2\text{-}18)$$

In other descriptions of Gaussian beams, the Rayleigh range is sometimes characterized by the confocal beam parameter and is equal to twice the Rayleigh range.

Model no.	λ(nm)	cavity length	waist dia	Rayleigh range
SR-110	495	1 inch	195μm	60.4 mm
SR-120	550	1 inch	205.7 μm	60.4 mm
SR-130, 135	620	1 inch	218.4 μm	60.4 mm
SR-140, 145	810	1 inch	249.6 μm	60.4 mm
SR-150, 155	1060	1 inch	285.5 μm	60.4 mm
SR-160	1320	1 inch	318.6 μm	60.4 mm
SR-170	1550	1 inch	345.3 μm	60.4 mm
SR-210	495	20 μm	33 μm	1.73 mm
SR-220	550	20 μm	34.8 μm	1.73 mm
SR-230, 235	620	20 μm	37 μm	1.73 mm
SR-240, 245	810	20 μm	42 μm	1.73 mm
SR-250, 255	1060	20 μm	48.4 μm	1.73 mm
SR-260	1320	20 μm	54 μm	1.73 mm
SR-270	1550	20 μm	58.47 μm	1.73 mm

Table 2.1 SuperCavity waist diameters and Rayleigh ranges. Note that the Rayleigh range depends purely on cavity geometry, such as cavity length and mirror curvatures.

2.1.4 Mode Matching To SuperCavity

The key in using the SuperCavity is to match the mode of the input beam to the Gaussian mode of the cavity. To do this the input beam should be (1) as close to a Gaussian beam as possible, and (2) is focused into the cavity so that its waist matches the beam waist of the fundamental cavity mode, both in diameter and position, as shown in Fig. 2-5.

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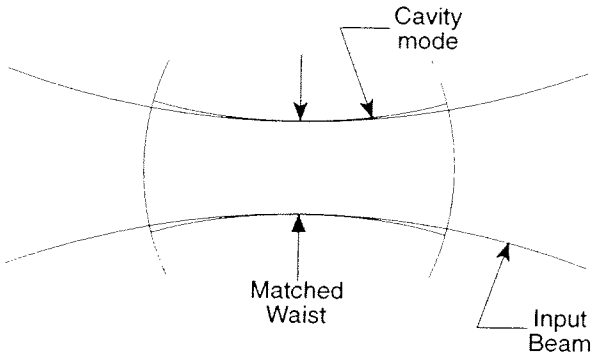


Figure 2-8. Matching the waist of the input beam to the fundamental mode of the SuperCavity.

Basic Equations

The Cavity mode-matching conditions are based on the propagation and focusing properties of Gaussian beams. In the paraxial approximation, Gaussian beam waists are imaged by lenses in a manner quite similar to that of geometrical optics. In general, the law describing the change of waveform curvature by a lens is given by:

$$\frac{1}{q_2} = \frac{1}{q_1} - \frac{1}{f} \tag{2-19}$$

where the complex radius of waveform curvature is defined as:

$$q_n(z) = z_n + i\left(\frac{\pi\omega_n^2}{\lambda}\right), \quad \text{or} \tag{2-20}$$

$$q_n(z) = z_n + ia_n, \quad n = 1,2 \tag{2-21}$$

and where ω_n is the waist of the beam, $= 3.14159$, and $a_n = (\omega_n^2/\lambda)$. z is the distance from the point of interest, i.e. the lens, to the waist, as shown in Figure 2-9.

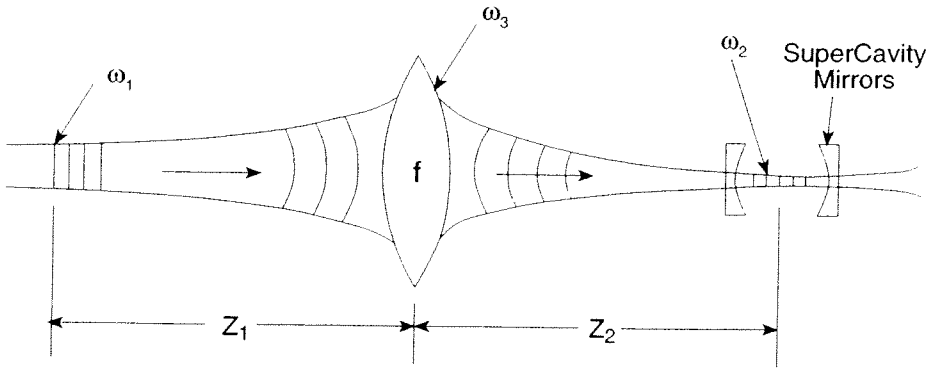


Fig. 2-9. Mode Matching Schematic, ω_1, ω_2 and ω_3 are the waist locations. Mode diameter is twice the waist.

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Inserting Equation (2-21) into Equation (2-19), and separating the real and imaginary parts, the following two cavity matching conditions are derived:

$$a_2 = \frac{f^2 a_1}{(z_1 - f)^2 + a_1^2} \tag{2-22}$$

$$z_2 = -f\left\{\frac{a_1^2 + z_1(z_1 - f)}{a_1^2 + (z_1 - f)^2}\right\} \tag{2-23}$$

The first condition establishes the required focal length, f, of the coupling lens, while the second condition gives its location, Z_2 with respect to the SuperCavity and to the input beam.

Using Equations (2-22, 2-23) and appropriate values for the 1" and 20 micron SuperCavities yields a_2 = 61 mm and 1.7 mm, respectively. a_1 depends on the source laser waist ω_1. In most cases a_1 varies between 50 mm for ω_1 = .1 mm and 1000 mm for ω_1 = .5 mm.

Special Cases

A. Numerical Analysis, an example:

In this example Equations (2-22 and 2-23) are used in a short computer program to calculate various values for mode matching parameters, such as focal lengths and distances. The inputs to the program are wavelengths, cavity length and the divergence of the laser. The output of the program are suggested lens focal lengths together with the distances from the laser to the lens and lens to SuperCavity.

Provided here is a listing of the code, written in BASIC and a sample of its output. This enables the user to make whatever modifications necessary to customize the code to any application.

```
10    INPUT "printout (y/n) "; PRIYN$
15    IF PRIYN$ = "y"    THEN LPRINT TAB(20); "SuperCavity
      Modematch Calculation"
16    IF PRIYN$ = "y" THEN LPRINT
20    INPUT "Please input laser output wavelength in nm";
      L:LAMBDA=L*1E-09
30    IF INPUT$ = "y" THEN LPRINT "wavelength = ";L;" nm"
40    INPUT "Please input laser output beam divergence in
      mrad";T:THETA=T*.001
50    IF PRIYN$ = "y" THEN LPRINT "Divergence = ";T;" mrad"
60    PRINT  "pick one:"
70    PRINT  "1: one inch SuperCavity (Series 100)"
80    PRINT  "2: 20 um SuperCavity (Series 200)"
90    PRINT  "3: Custom FSR"
100   INPUT "your choice:       ";C
110   IF C=1 THEN L = 0.0254
```


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```
120   IF C=2 THEN L = 0.00002
130   IF C=3 THEN INPUT "cavity length in mm? ";X:L=X/1000
140   IF PRIYN$ = "y" THEN LPRINT "cavity length = ";L*1000;
      " mm"
150   A1 = 4*LAMBDA/(3.14159265*THETA*THETA)
160   A2 = SQR(.15*L*(1-L/.6))
170   MINF = SQR(A1*A2)
180   STARTF = INT(100*MINF+1)/100
190   PRINT "Focal length(mm)";TAB(20);Laser-lens
      dist(mm)";TAB(40);"Lens-SuperCavity dist(mm)"
200   IF PRIYN$ = "y" THEN LPRINT"Focal length(mm)";TAB(20);"
      Laser-lens dist(mm);TAB(40);"Lens-SuperCavity dist(mm)"
210   FOR F = STARTF TO 1 STEP .01
220   Z1 = SQR(F*F*A1/A2-A1*A1)+F
230   Z2 = F*((A1*A1+Z1*(Z1-F))/(A1*A1+(Z1-F)*(Z1-F)))
240   PRINT CINT(1000*F);TAB(20);CINT(1000*Z1);
      TAB(40);CINT(1000*Z2)
250   IF PRIYN$= "y" THEN LPRINT CINT(1000*F);TAB(20);
      CINT(1000*Z1);TAB(40);CINT(1000*Z2)
260   NEXT F
```

Example printout:

wavelength = 633 nm

Divergence = 1.5 mrad

Cavity length= 25.4 mm

Focal length (mm)	Laser-lens dist (mm)	Lens-SuperCavity dist (mm)
150	222	162
160	313	186
170	378	205
180	433	223
190	483	239
200	530	256
210	575	272
.	.	.
.	.	.
.	.	.

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B. z_1 >> f, Quasi-Far-Field Approximation:

This case describes the situation where the coupling lens (or mode matching lens) is located far from the laser. With such conditions we can make certain approximations that allow us to estimate lens focal length needed for proper mode matching. From Equations (2-22) and (2-23), and assuming $Z_1 >> f$ and $z^2_1 >> a^2_1$, then:

$$f = \frac{\omega_2 z_1}{\omega_1} \tag{2-24}$$

$$z_2 = -f \tag{2-25}$$

For large z_1, $\omega_3 = (\lambda z_1)/(\omega_1)$, where ω_3 is half the mode diameter at the lens, as in Figure 2-9. Using this in Equation (2-24), then:

$$f = \frac{\pi \omega_2}{\lambda} \omega_3 \tag{2-26}$$

The cavity matching conditions are given by Equations (2-25) and (2-26). These conditions dictate that the SuperCavity is located at the focal point of the coupling lens, and that the focal length of the coupling lens is given by (2.26).

Condition (2-26) is plotted in Figure 2-10 for both the 25.4 mm (1") and the 20 micron cavities. The horizontal axis is the operating wavelength, while the vertical axis is the focal length (in mm) of the coupling lens for an input beam of mode diameter = 1 mm. For mode diameters other than 1 mm, the focal length of the coupling lens f_D is simply $f_D = Df_{(D=1)}$, where D is the mode diameter of the input beam in mm.

For example, consider a laser source of wavelength 620 nm and a spot size of 1.5 mm at the lens. The required focal length for the coupling lens is 415 mm and 70 mm for SR-100 and SR-200 Series SuperCavities, respectively. The corresponding distance from the laser to the lens should be at least 2 m and 0.4 m, respectively.

As the wavelength increases, the divergence angle of the source also increases (ω_1 = constant). Hence, for a constant z_1 and ω_1, the spot size at the mirror becomes larger; therefore, a shorter focal length coupling lens is needed for efficient coupling. This trend is also shown in Figure 2-7.

C. z1 << f, Near-Field Approximation:

In this second case, the Fabry-Perot interferometer is located very close to the laser under examination. From Equations (2-18) and (2-19) we get:

$$f = \frac{\pi \omega_2}{\lambda} \left\{ \frac{\omega_1}{\sqrt{1 - (\omega_2 / \omega_1)^2}} \right\} \tag{2-27}$$

$$z_2 = -f \left\{ \frac{a_1^2 - f z_1}{a_1^2 + f_2} \right\} \tag{2-28}$$

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D. Special Case; $z_1 = f$, Intermediate-Field Approximation:

This is a special intermediate point. From Equations (2-22) and (2-23), and using $z_1 = f$ then:

$$f = \frac{\pi \omega_2 \omega_1}{\lambda} \tag{2-29}$$

$$z_2 = -f \tag{2-30}$$

Equations (2-29) and (2-30) are identical to (2-25) and (2-26) except that ω_3 in Equation (2-29) is replaced by the waist ω_1. Here the waist of the source laser must be known. Because this is not in the far field region, the beam has not had a chance to expand, and the spot size at the Cavity waist (ω_2) is not much bigger than the beam waist (ω_1).

In this case, Equation (2-26) overestimates the required focal length by the ratio ω_3/ω_1, i.e. by the amount of growth of the spot size as compared to the beam waist. A more accurate estimate may be obtained by using Figure 2-7 and the same $f_D = D f_{(D=1)}$ formula except that the value used for the spot size is now twice the beam waist. Note that the variations in the lens location (i.e. z_1) may lead to appreciable variations in z_2 and in the lens focal length. For example, setting $z_1 = f + a_1$, then $z_2 = -f(1 + z_1/a_1)/2$ and $f = \sqrt{2a_1a_2}$. This leads to a change in the location of the SuperCavity waist and in the lens focal length.

Summary

1" Cavities (SR-100):

For the SR-100 series SuperCavities, the waist radius ω_2 is in the range of 0.1 to 0.17 mm. This waist might be comparable to the input laser's waist ω_1. Therefore, the required focal length for the lens as given by Equation (2-25) varies by a large margin depending on the ratio of ω_2 to ω_1.

20 micron Cavities (SR-200):

Typically, the waists for these cavities are 16 to 30 microns, and therefore, $\omega_2 << \omega_1$. Since the incoming laser beam has not diverged (especially if the output mirror of the laser is a flat coupler) then the spot size at the coupling lens is close to the laser's waist ω_1. Therefore Equation (2-27) may be reduced to the much simpler form of Equation (2-26).

Equation (2-28) may also be reduced to (2-30); however, this requires additional limits, namely, $a_1^2 >> fz_1$. This condition is not difficult to implement and check, since the lens focal length is typically in the range of 50 to 150 mm while a_1 can easily reach 1000 mm.

Conclusion

Mode matching conditions for 20 micron SuperCavities are given by Equations (2-25) and (2-26) and are shown in Figure 2-10 for both the near field and the far field limit.

Matching conditions for 1" cavities are given by Figure 2-7 for the far field limit. In the near field limit the conditions are given by Equations (2-27) and (2-28). No figure is generated for this case due to the sensitivity of the focal length to the ratio ω_2/ω_1.

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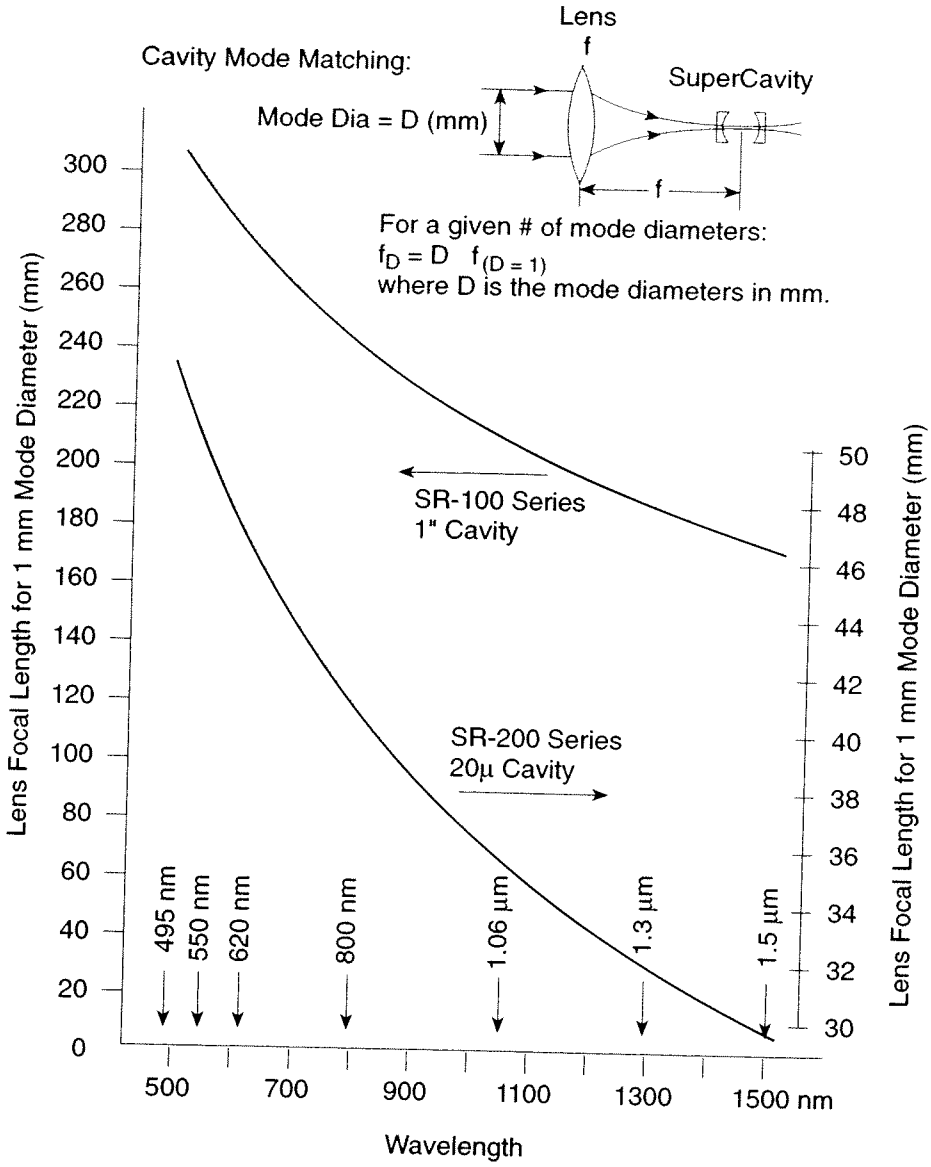


Figure 2-10. Cavity Mode Matching Chart. Example: for an SR-100 Series SuperCavity and a 633 nm laser with a beam diameter of 1.5 mm, the approximate focal length is 270 x 1.5 = 405 mm.

2.1.5 Frequency Calibration of SuperCavity

A number of methods exist by which the resolving power of the Fabry-Perot interferometer such as the SuperCavity can be calibrated. The calibration method that follows is known as Fractional Mode Splitting (FMS) and is based on the frequency separation between the transverse modes of the resonant cavity.

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Cavity Mode Resonance Frequency Structure:

The cavity mode structure is composed of both longitudinal and transverse modes that are separated in frequency space. The mode distribution is given by

$$f_{qmn} = \frac{c}{2L}\left[q = (m+n+1)\frac{\cos^{-1}(\pm\sqrt{g_1 g_2})}{\pi}\right] \qquad (2\text{-}31)$$

where c/2L is the longitudinal mode spacing,
c = the speed of light,
L = the cavity length,
m,n = transverse mode order = $0, \pm1, \pm2, \ldots$,
q = longitudinal mode number,
$g_i = 1 - L/R_i$, i = 1,2
R_i = radius of curvature of the i^{th} mirror.

For the Newport SuperCavity, both the front and rear mirrors have radii of 300 mm, and a nominal length of either one inch or 20 microns. From Eq. (2-31) and for $g_1 = g_2 = g$, the longitudinal mode spacing is c/2L while the transverse mode spacing is

$$\text{transverse mode spacing} = \frac{c}{2L}\left(\frac{\cos^{-1} g}{\pi}\right) \qquad (2\text{-}32)$$

Eq. (2-32) may be approximated for R >> L by $\left(c/\pi\sqrt{2LR}\right)$. The ratio of the transverse to the longitudinal mode spacing is referred to as the fractional mode splitting (FMS). The FMS for the Newport standard FSR SuperCavities are

$$\begin{aligned} \text{FMS} &= 0.131 \text{ for SR-100 series cavities} \\ &= 0.00365 \text{ for SR-200 series cavities} \end{aligned} \qquad (2\text{-}33)$$

From Eqs. (2-32) and (2-33), the length of the respective cavities may be found and used to calculate the longitudinal mode spacing:

$$\begin{aligned} c/2L &= 6 \pm 0.3 \text{ GHz for SR-100 series} \\ &= 7{,}600 \pm 1{,}000 \text{ GHz for SR-200 series.} \end{aligned} \qquad (2\text{-}34)$$

The inaccuracy in the above mode spacing is about 5% for 1 inch cavities and 15% for 20 micron cavities. This is due to the corresponding inaccuracy in the cavity length. In absolute frequency space, the transverse mode splitting translates to the following:

Type of Cavity	Transverse Mode Splitting
SR-100 series (1 in.)	780 ± 40 MHz
SR-200 series (20 μm)	28 ± 4 GHz

The above table refers to the frequency difference between any two transverse modes, and may be used as a means for calibrating the observed spectra. The individual SuperCavities may be calibrated by the user by measuring the FMS, as described in the next paragraph. This FMS may further be calibrated by injecting sidebands into the spectrum, for example by using an acousto-optic modulator.

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Method of Calibration:

The frequency separations between the longitudinal and transverse modes may be calculated from an experimental measurement of the FMS which is the ratio of transverse to longitudinal mode spacing.

From the spectrum as displayed on the oscilloscope (Fig.2-6), with the system operating, set the separation between the longitudinal modes to 10 volts. Measure the transverse mode spacing in volts. The FMS is the ratio of the two numbers. Using the FMS and equation (2-32) we can calculate L the distance between the two mirrors. Note that R the mirror radius of curvature is 300mm ±0.3mm. These two parameters define the frequency spectrum of the cavity, as given in equation (2-31).

2.1.6 Wavelength Dependence of Cavity Finesse

SuperCavity is a Fabry-Perot interferometer that is based on low loss, high reflectivity mirrors. These mirrors are designed using a thin film multilayer dielectric stack, which has the property that mirror reflectivity drops as the input wavelength is detuned away from the center wavelength design of the mirrors. Accordingly, a drop in mirror reflectivity translates into a drop in cavity Finesse and an increase in cavity throughput.

A typical performance curve for cavity Finesse is shown in Figure 2-11. This figure displays a typical change of cavity Finesse (vertical axis) as the input wavelength is detuned away from the center wavelength for that cavity (horizontal axis). Two curves are shown, one for High Finesse models and the other for High Transmission models.

The horizontal axis in Fig. 2-11 is the ratio of cavity center wavelength to the wavelength of the input beam. This ratio represents a normalization with respect to the measured center wavelength for that cavity, as is given in Table (1-1), for each SuperCavity design.

Superimposed on the curves in Fig. 2-11 are some experimental data for SuperCavities as tested outside their specified wavelength of operation. For example, the data point at Normalized Wavelength=1.2 corresponds to an SR-110 SuperCavity, of center wavelength=495nm, as tested at 442nm. It showed Finesse>1000. Similarly, an SR-120, of center wavelength=550nm, was tested at 633nm and showed Finesse of 230. This data point corresponds to the Normalized Wavelength of 0.87.

Figure 2-11 may be used to find the typical performance for SuperCavity as the input wavelength is changed. For example, an SR-150 with center wavelength of 1060nm is expected to have Finesse>1,000 at 980nm. Similarly, an SR-130 of center wavelength of 620nm is expected to have Finesse>1,000 at 670nm.

As mentioned above, mirror reflectivity drops and mirror transmission increases as the input wavelength is detuned away from line center. This change leads to a corresponding deviation in Finesse and Efficiency, which is clearly exhibited by the following set of equations relating cavity and mirror parameters (for high reflectivity mirrors):

$$R + T + A = 1$$

$$\mathcal{F} = \frac{\pi}{T + A}$$

$$\text{Efficiency} = \left(\frac{T}{T + A}\right)^2 \qquad (2\text{-}35)$$

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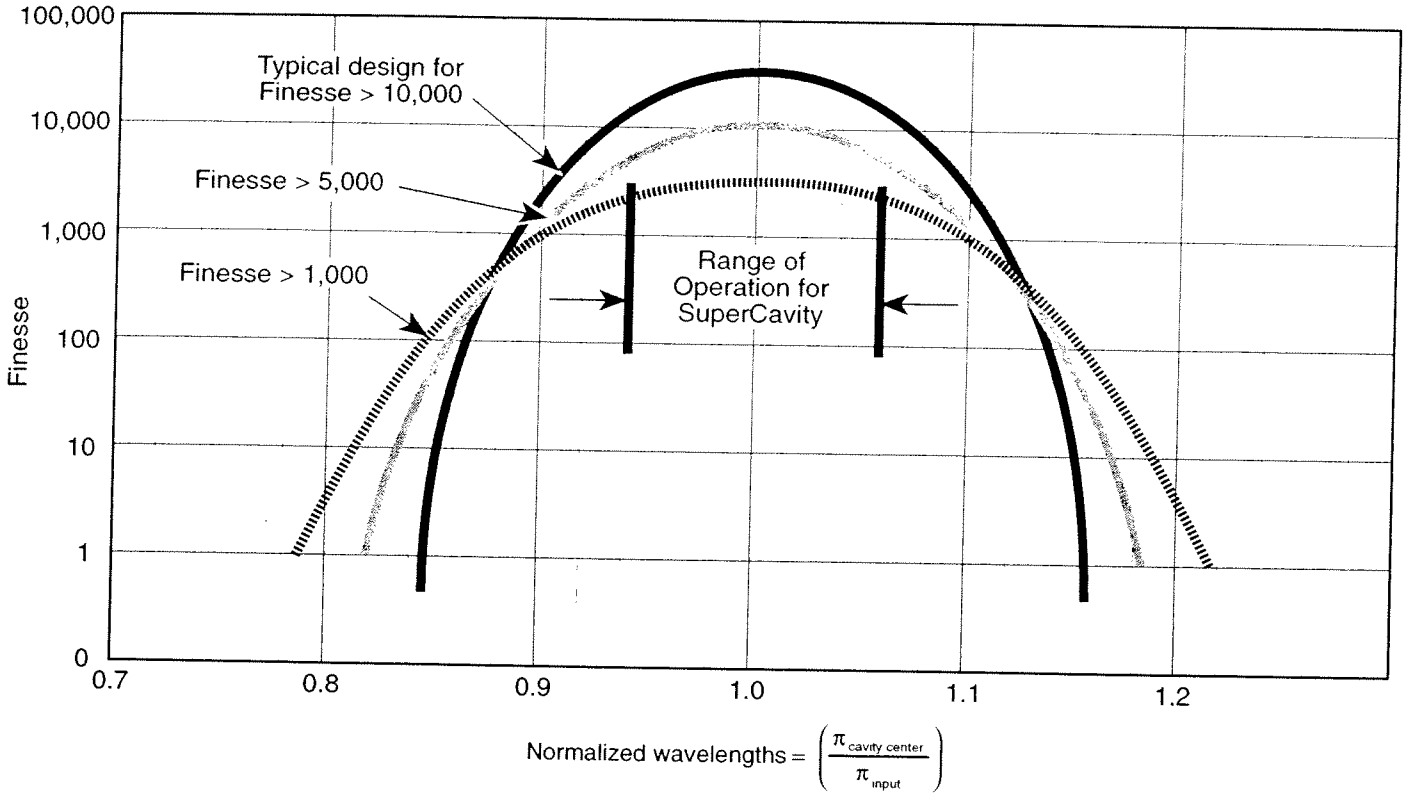


Fig. 2-11. Change of Cavity Finesse with Wavelength. The horizontal axis is the ratio of SuperCavity center wavelength to the wavelength of the input beam. The cavity center wavelength is given in Table 2-1.

where $\mathcal{F}$ is cavity Finesse, Eff. is cavity efficiency, =3.14159, R is mir ror-reflectivity, T is mirror transmission and A is mirror losses which includes scattering and absorption.

Note that Eq. (2-35) shows that as mirror reflectivity approaches 1 the Finesse increases to a high value. The Efficiency, on the other hand, exhibits a dependence on the ratio of T/A. This dependence and the trade-off between Finesse and efficiency is shown in Fig. 2-12.

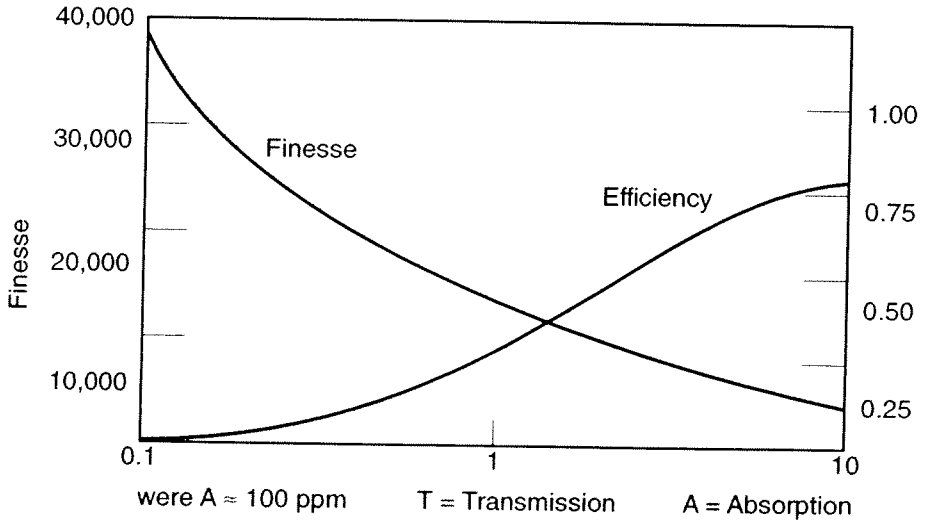


Fig. 2-12. The tradeoff between cavity Finesse and Efficiency. This tradeoff depends on the ration of T/A and on mirror reflectivity. In this figure we have assumed that mirror losses A is about 100ppm.

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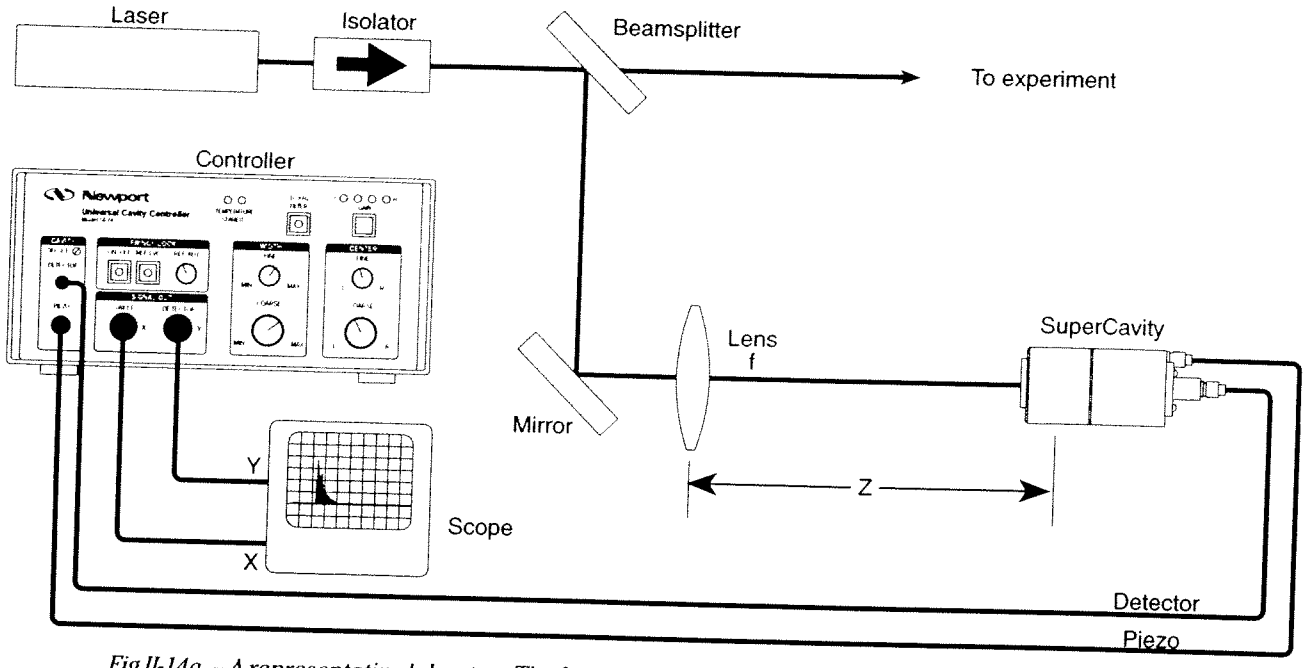
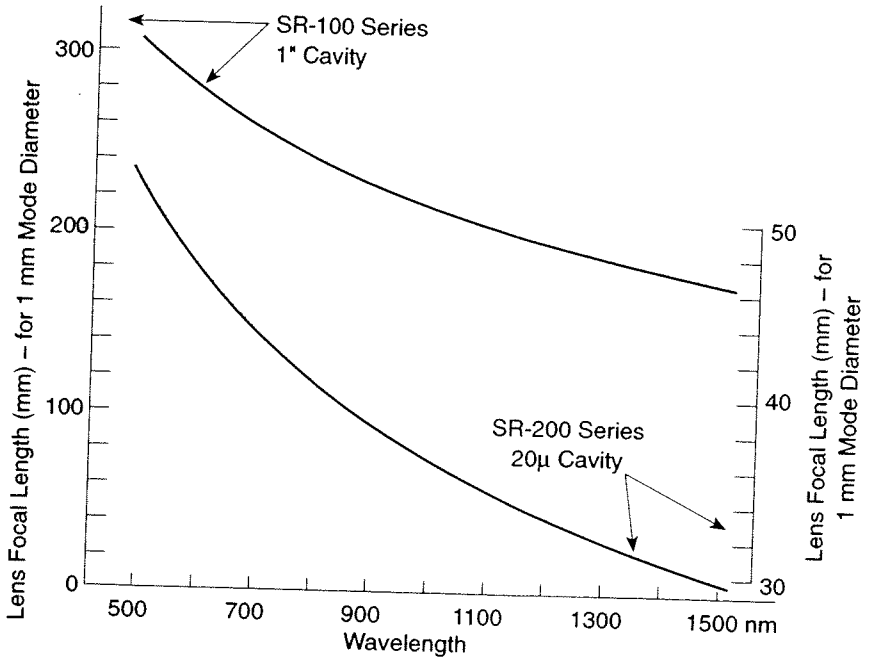
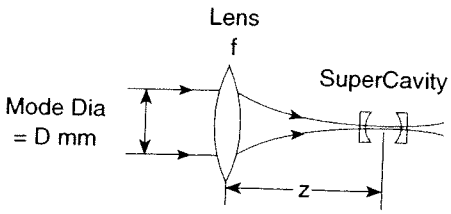


Fig II-14a. – A representative lab setup. The focal length of the lens is selected by using Fig. 14b.



Cavity Mode Matching:

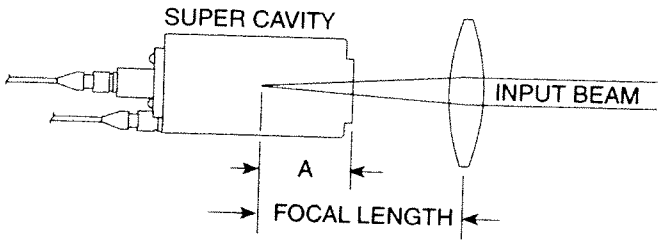


For mode diameter D mm, use focal length f_D:

$$f_D = Df_{(D=1)} \text{ where}$$

$f_{(D=1)}$ is lens focal length obtained from the chart on the left. Z is the distance from the lens to the beam waist.

Fig. II-14b. – Cavity mode matching chart



Series Model	Demension A
SR-100	1.18" (3.0mm)
SR-200	0.87" (2.2cm)

Fig. II-14c – Distance to focal waist inside cavity.

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bution.

Typical Operating Setups:

Typical operation of the SuperCavity Optical Spectrum Analyzer includes connecting the SuperCavity to the controller, which in turn is connected to an oscilloscope, as shown schematically in Figs. II-14 and II-15. Figure II-15 also shows two methods for coupling light into the fiber: by a single-mode fiber connector, or by a bare fiber coupler such as the Newport Model F-1015.

Note that it may be necessary for proper system operation to use an optical isolator such as the Newport Models ISO-7885, ISO-13FIB and ISO-15FIB. The degree of isolation needed depends upon the type of laser used. For most lasers, an acousto-optic-modulator or deflector or a 30dB isolator is sufficient to provide the necessary degree of optical isolation. However, some lasers, and in particular narrow line width laser diodes, may require more than 60dB of optical isolation for proper operation.

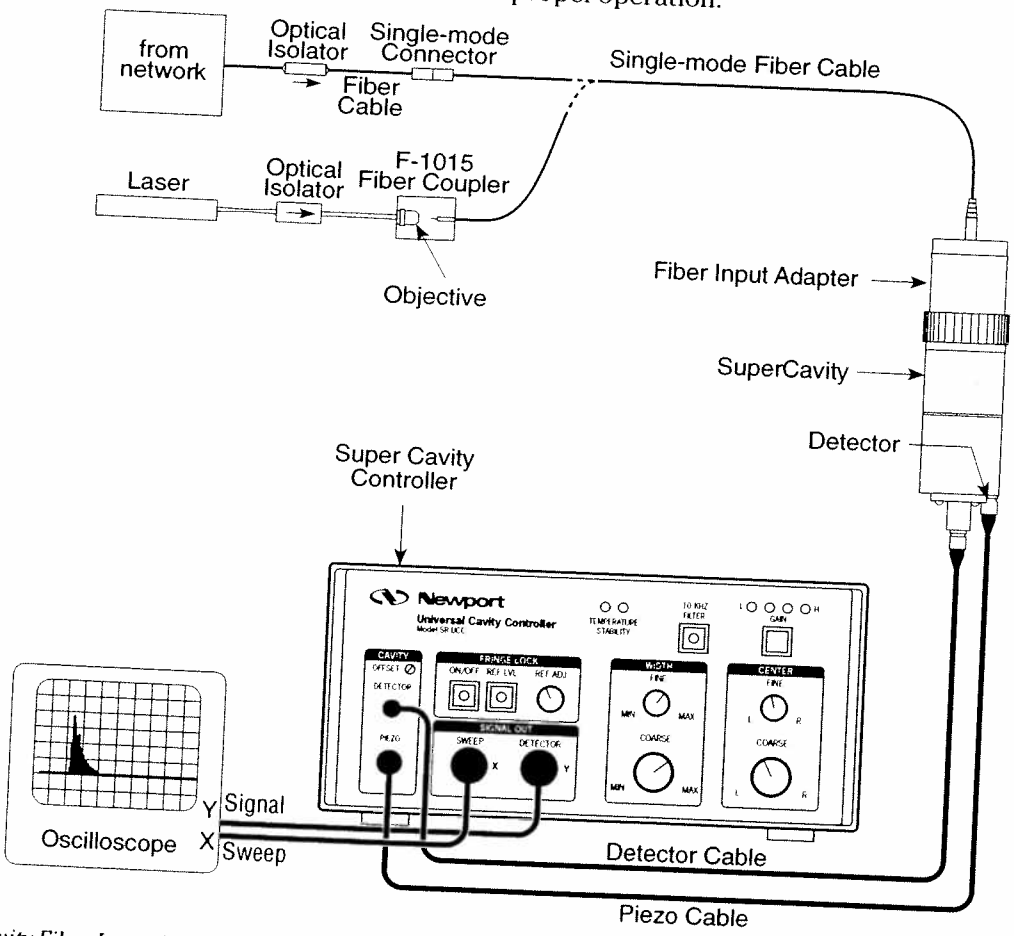


Fig. II-15 – SuperCavity Fiber Input Adapter System. Schematic for a typical setup showing the different schemes for coupling light into the single-mode fiber. For proper SuperCavity system operation an optical isolator is necessary.

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Appendix III
Reference Drawing

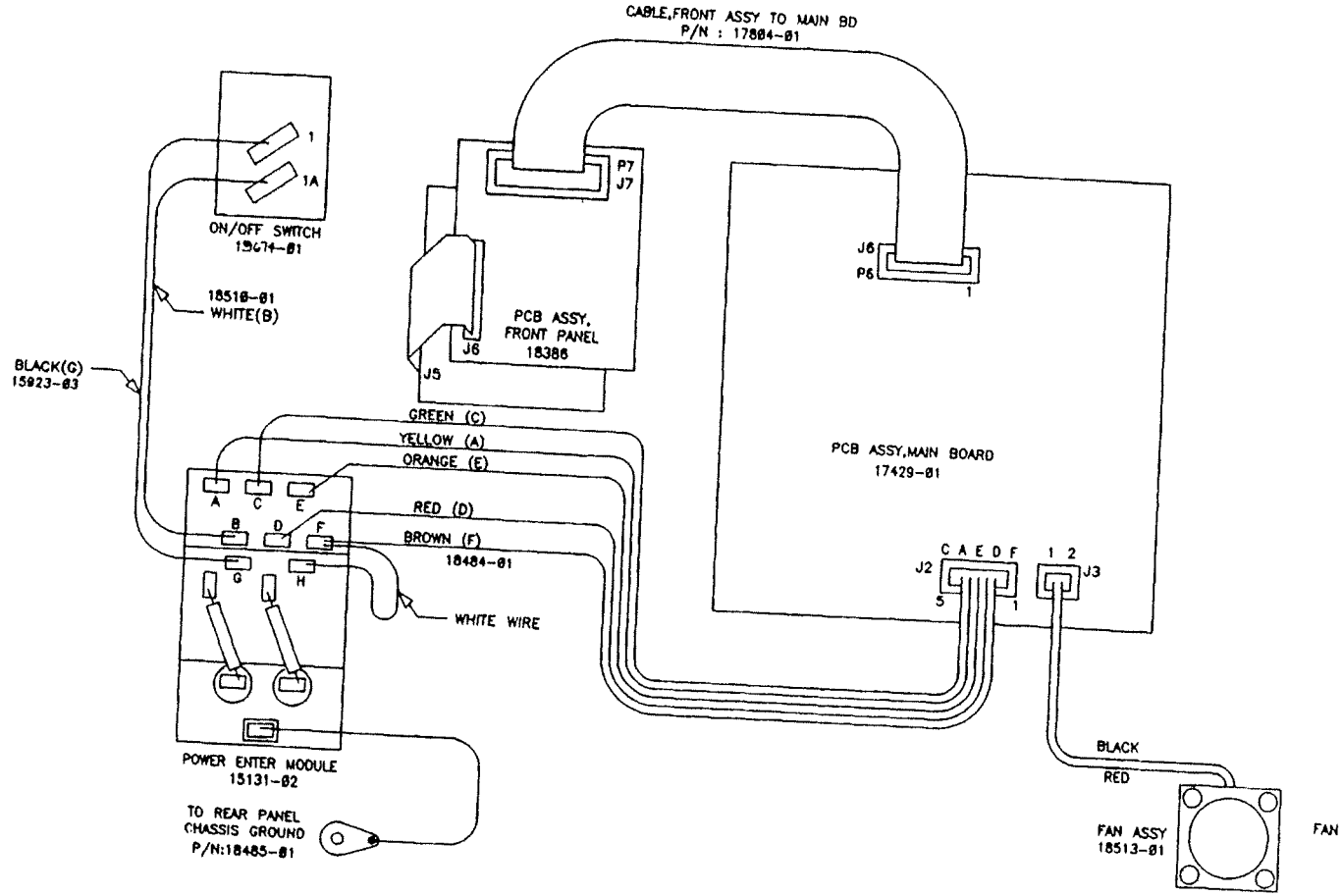
Dwg. 17805 - SuperCavity system wiring diagram, SR-UCC

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			PARTS LIST		

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