Technical Report
850

Design and Performance of an On-Satellite Laser Diagnostic System for a Free Space Optical Heterodyne Frequency-Shift-Keyed Communication System

V. Jayaraman
E.S. Kintzer
J.G. Garcia
A.D. Pillsbury

11 July 1989

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

ADA211986

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Hugh L. Southall

Hugh L. Southall, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

DESIGN AND PERFORMANCE OF AN ON-SATELLITE LASER DIAGNOSTIC SYSTEM FOR A FREE SPACE OPTICAL HETERODYNE FREQUENCY-SHIFT-KEYED COMMUNICATION SYSTEM

V. JAYARAMAN
E.S. KINTZER
Group 67

J.G. GARCIA
A.D. PILLSBURY
Group 71

TECHNICAL REPORT 850

11 JULY 1989

LEXINGTON   MASSACHUSETTS

ABSTRACT

The advent of space-based coherent diode laser communications systems requires development of space-qualified laser diagnostics to make these systems robust in face of aging laser parameters. This report describes the packaging and performance of a diagnostic system which sets the wavelength, tone spacing, and optical power of a directly modulated frequency-shift-keyed GaAlAs laser transmitter.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

DESIGN AND PERFORMANCE OF AN ON-SATELLITE LASER DIAGNOSTIC SYSTEM FOR A FREE SPACE OPTICAL HETERODYNE FREQUENCY-SHIFT-KEYED COMMUNICATION SYSTEM

1. INTRODUCTION

MIT Lincoln Laboratory is developing a heterodyne 4-ary frequency-shift-keyed satellite communication system at 220 Mb/s using directly modulated GaAlAs laser diodes at 8630 to 8660 Å.* An important part of this system is a diagnostic module, which periodically measures transmitter wavelength, spacing between transmitted FSK tones and laser power, and directs a laser controller to hold these values constant by adjusting laser bias current, temperature, and modulation current. Two facts motivate building a diagnostic module: (1) the design of the communication and tracking systems imposes strict requirements on laser diode power and spectral properties and (2) laser diodes are known to age. In order to build a robust system which can operate for several years in the presence of changes in laser diode characteristics, a diagnostic system[†] must detect those changes and compensate for them. More specifically, the communication and tracking systems require the following:

(a) *Laser wavelength must be within 100 MHz of a known reference.* This is necessary to ensure that the intermediate frequency (IF) signal after mixing with the local oscillator lies within the receiver bandwidth.

(b) *FSK tone spacing must be within 5 MHz of a nominal value of 220 MHz.* This is necessary to ensure that the transmitted tones lie within the centers of receiver matched filters.

(c) *Transmitted optical power must be held to 30 mW (full laser power) ± 1 mW.* This is necessary to maintain the link margin.

These requirements are met using a neon glow lamp, an interference filter and detectors for wavelength and power, and a static Fabry-Perot interferometer and detector for tone spacing, as shown in the system block diagram of Figure 1. The rest of this report will describe in detail these components, their functions and performance, and how they are packaged for launch and space operation.

---

* V.W.S. Chan, "Space Coherent Optical Communication Systems — An Introduction." IEEE J. Lightwave Technol. **LT-5,** 633 (1987), DTIC AD-A189959.

† V. Jayaraman, "Autonomous Laser Diagnostics System for Optical Heterodyne Communication Systems," in Technical Digest, Optical Fiber Communications Conference, Reno, Nevada, 1987, paper THG1.
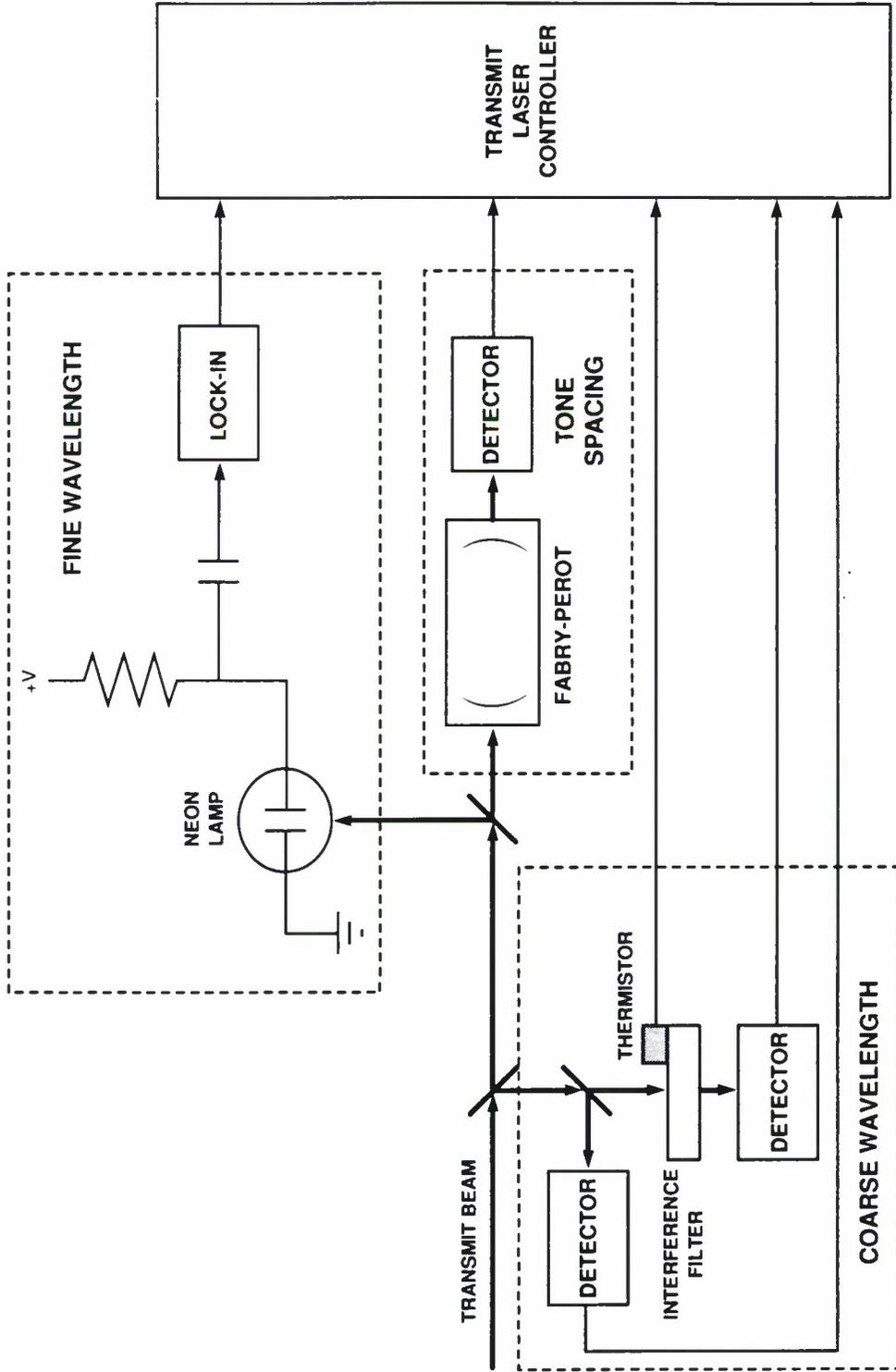
Figure 1. Block diagram of the diagnostic system.

TRANSMIT LASER CONTROLLER

FINE WAVELENGTH

LOCK-IN

+V

NEON LAMP

TONE SPACING

DETECTOR

FABRY-PEROT

TRANSMIT BEAM

THERMISTOR

DETECTOR

INTERFERENCE FILTER

DETECTOR

COARSE WAVELENGTH

2. SETTING WAVELENGTH

A. INTERFERENCE FILTER

The first step in setting wavelength is the coarse wavelength determination using a narrowband dielectric interference filter with a FWHM ~ 30 Å spanning the diode laser operating region. The transmission through the filter at the unknown wavelength is measured and the transmitted power is normalized to the power in a reference detector. The interference filter transmission curve is stored in a lookup table which is used to determine the wavelength. An example of such a curve is shown in Figure 2. The reference detector also serves as an absolute power monitor for power-correction purposes.
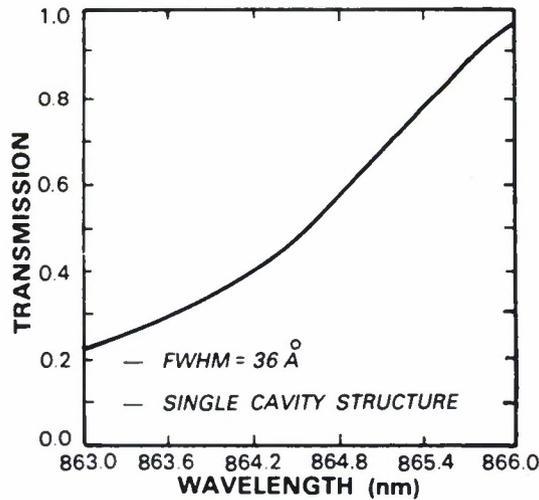

Figure 2. Interference filter transmission.

The transmission curve of the filter shifts with temperature by an amount ~0.25 Å/°C. This is compensated for by monitoring the temperature of the filter mount with a thermistor and including a temperature-correction factor in the lookup table. The filter curve also can be shifted by changes in angle of incidence, but holding the angle of incidence within ±5 mrad of normal incidence limits the shift to <0.05 Å.

An important limit on the accuracy of the filter curve as a measure of the diode laser wavelength is set by the side-mode ratio. The longitudinal modes of the transmitter laser are spaced 3 Å apart so that typically 10 or more modes will fall within the transmission curve. The ratio of power in the main mode to power in any side mode is specified to be ≥25 dB . This can add as much as 0.5 percent to the transmission in some regions of the curve which, in turn, can lead to an error of as much as ~0.3 Å depending on the slope of the curve at that point. Mode ratio varies with the operating point, as well as with age, making this source of error difficult to remove. Overall, a resolution of ~1 Å can be achieved for coarse tuning and detection of mode hops.

3

B. NEON REFERENCE

Fine tuning of the laser wavelength is achieved using optogalvanic detection* of transitions of neon in a discharge cell . The transitions of interest in our system lie at 8634.6, 8647.0, 8654.4, and 8655.5 Å. In optogalvanic detection, the absorption of resonant light is observed as a change in the impedance across the discharge. The laser light is frequency modulated with a frequency deviation of several hundred megahertz and tuned across the 1.0- to 1.4-GHz-wide Doppler broadened transition. The ac-coupled discharge voltage is monitored with a lock-in amplifier and the derivative of the transition line shape is detected, as shown in Figure 3. An algorithm stored in the on-board microprocessor fine adjusts the laser bias current and searches for the zero-crossing in the dispersive line shape which corresponds to the position of the center of the transition.
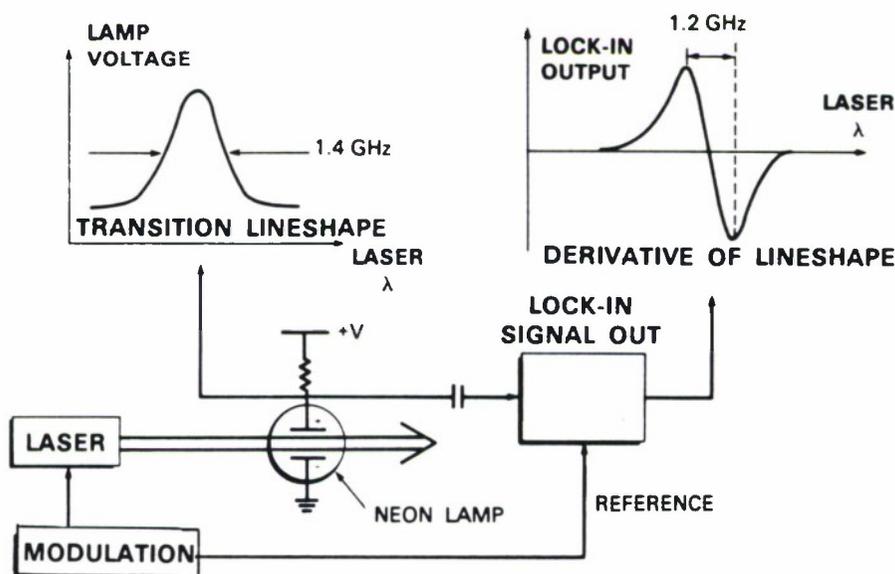

Figure 3. Schematic of optogalvanic detection.

The gas discharge cell used in the diagnostics module is a commercial high-brightness neon glow lamp of the type often used as instrument panel lights. It has the advantage of being both compact and rugged. Figure 4 shows the SNR measured in the glow lamp for the four neon lines and the accuracy that can be achieved as a function of SNR. These numbers are based on 20 mW of optical power in a 5-mm-diam. beam, 3-kHz modulation frequency, 600-MHz modulation deviation, 2-mA dc lamp current, and a 1-Hz detection bandwidth. We estimate a worst-case SNR of 25 dB based on detection of the weakest transition and end-of-life performance, which implies a fine tuning accuracy of better than 50 MHz rms.

---

* S. Yamaguchi and M. Suzuki, "Simultaneous Stabilization of the Frequency and Power of an AlGaAs Semiconductor Laser by Use of the Optogalvanic Effect of Krypton," IEEE J. Quantum Electron. **QE-19**, 1514 (1983).
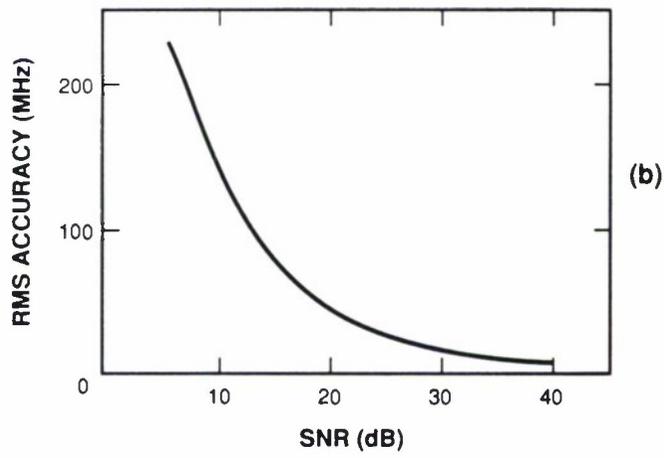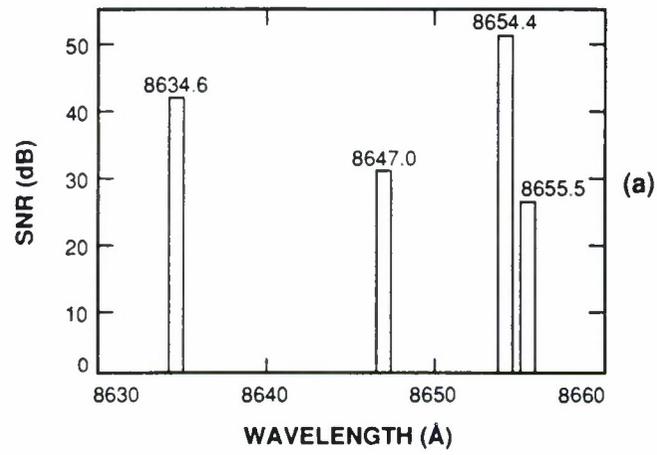
Figure 4. (a) Signal-to-noise ratio in a neon lamp; (b) wavelength setting accuracy vs SNR.

5

The neon glow lamps have a rated lifetime of 15,000 h at 2 mA dc. We have performed accelerated life testing at 5 mA dc and have observed survival to the equivalent of 25,000 h at 2 mA dc with <2-dB loss in SNR. Beyond this length of use, the lamps begin to fail in a catastrophic fashion.

C. ALGORITHM

In the normal mode of diagnostics operation, the transmitter laser is started up at the current and temperature at which it is expected to access a neon line (usually the operating point from the last communications session). If the optogalvanic signal is not present, then the interference filter transmission is checked and the laser is tuned in current or temperature until the wavelength is in the vicinity of the desired reference line within the accuracy of the filter. The laser frequency is then tuned via the bias current until the center of the neon line is found. If the laser power is altered beyond the operating specifications by the changes in current and temperature, then a power correction routine at approximately constant wavelength is activated after which the wavelength is rechecked. Wavelength search and power correction routines can be iterated, if necessary, until they converge to the reference wavelength and specified optical power.

3. SETTING TONE SPACING

As stated in Section 1, tone spacing must be set to within 5 MHz of 220 MHz to prevent significant energy loss from misalignment of the transmitted spectrum with respect to the receiver filters. Figure 5 shows more precisely how tone-spacing error affects energy detected at the receiver. A 5-MHz error in spacing between adjacent tones leads to an energy loss in the outer demodulating filters in a 4-ary system that approaches 0.1 dB. Since this loss is only in the outer tones, the corresponding communication system power penalty is <0.1 dB. In other words, setting tone spacing to 5 MHz is sufficient to guarantee communication with insignificant system power penalty.

The method for setting tone spacing to 220 ± 5 MHz consists of two steps:

    (a) Frequency modulate the laser at the system symbol rate with an alternating sequence of ones and zeros.

    (b) Monitor the optical spectrum with a static confocal Fabry-Perot during modulation. The tone spacing can be deduced from the optical spectrum.
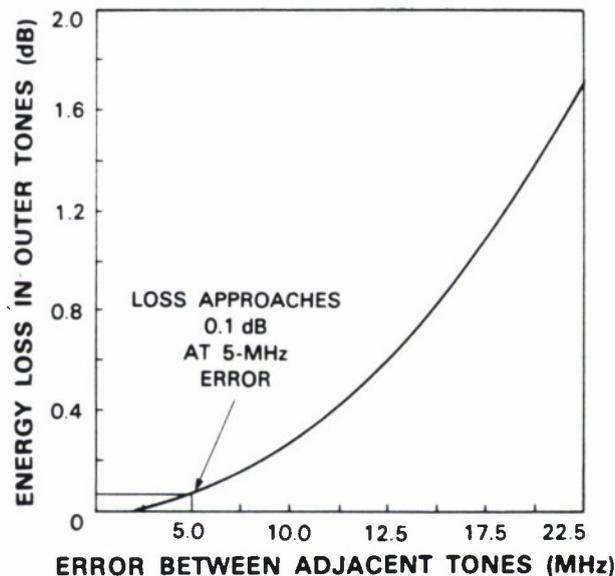
Figure 5.   4-ary outer tone loss vs tone-spacing error.

Figure 6 shows a typical Fabry-Perot measurement of the optical spectrum with square-wave modulation. In this system, the source spectrum is mapped out by holding the Fabry-Perot mirror spacing fixed while scanning the source spectrum. The Fabry-Perot has a free spectral range of 1.5 GHz and a finesse of 200, giving enough range to scan the whole optical spectrum and enough resolution to see individual sidebands.

7
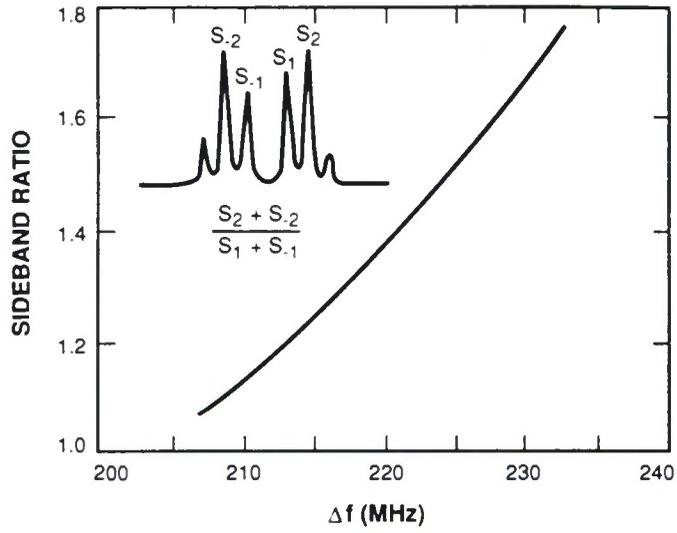
Figure 6.   Sideband ratio vs tone-spacing Δf.
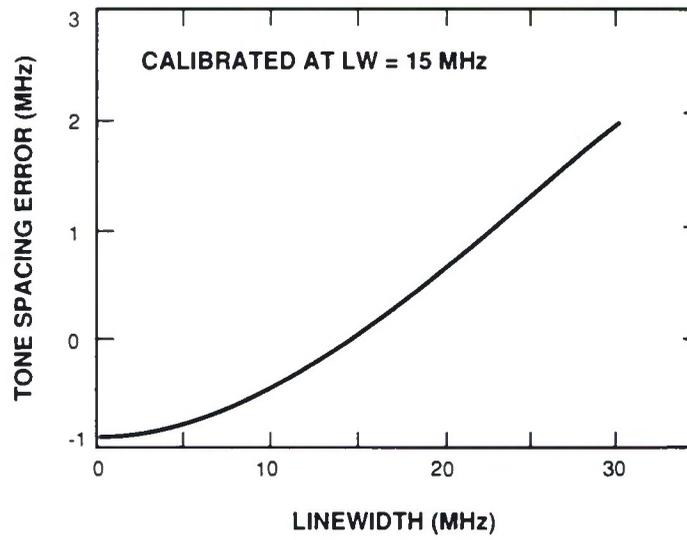
Figure 7.   Tone-spacing error vs linewidth.

8

Once the optical spectrum has been recorded, tone spacing can be deduced by measuring the ratio between the second and first sidebands (averaging positive and negative frequency values). This ratio varies steeply with tone spacing in the vicinity of 220-MHz spacing (for the given symbol rate of 110 Msymbols/s), as shown in Figure 6.   For example, a tone-spacing error of 5 MHz changes the sideband ratio from 1.35 to about 1.2. This change in ratio can be detected very easily with the SNR available. Tone spacing can thus be determined and set to much better than 5 MHz. It should be noted that nonzero laser linewidth will also influence the exact value of sideband ratio. The magnitude of this effect can be calculated by recognizing that both the laser and Fabry-Perot linewidths are approximately Lorentzian and therefore add together to form a new total Lorentzian linewidth. We can calculate the "spillover" of neighboring sidebands into a given sideband and arrive at adjusted values of sideband ratio. A typical value for laser linewidth is 7 MHz and the Fabry-Perot contributes 8 MHz, yielding a total system linewidth of 15 MHz. If one were to set sideband ratio for 220 MHz spacing assuming a linewidth of 15 MHz, then changes in the linewidth over laser lifetime would lead to errors in the tone spacing, according to the curve of Figure 7. As can be seen from this curve, substantial changes in linewidth lead to very small errors in tone spacing.

The static Fabry-Perot-based tone-spacing diagnostic described above works together with a companion microprocessor and algorithm. While the details of the algorithm are beyond the scope of this report, its main function is to allow autonomous setup of tone spacing from a "cold start." A "cold start" is one in which the relative positions in frequency of the laser spectrum and nearest Fabry-Perot transmission peak are unknown, and the "first guess" modulation current yields a tone spacing far from the nominal of 220 MHz. In short, the design of the algorithm, the sensitivity of sideband ratio to tone spacing, and the choice of a static confocal Fabry-Perot as the main measuring device all combine to make a robust autonomous tone-spacing diagnostic for space-based operation.

4. MECHANICAL AND THERMAL DESIGN

A. INTRODUCTION

One of the important features of the schemes described in Sections II and III to set wavelength and tone spacing is that the hardware associated with them can be housed in a light, space-qualifiable optomechanical module which has loose alignment tolerances, simple alignment procedures, and requires no active thermal control. This section describes the mechanical and thermal aspects of that module, which has been designed to survive $-20°$ to $+60°C$ thermal cycling, random vibration to 34 g's rms, and the severe radiation and contamination environment anticipated in launch and space operation.

B. HOUSING AND OPTICAL LAYOUT

Figure 8 shows the overall configuration which occupies a $2 \times 5.25 \times 8$-in volume and weighs 3 lb. The housing consists of separate electronics and optics cavities, allowing parallel development of the two functions, as well as preventing cross-contamination of parts. The electronics cavity has more than adequate space to house the lock-in amplifier associated with the neon reference and conditioning electronics. The optical cavity has six optical subassemblies mounted directly to its interior walls. The housing is made of aluminum and is supported by kinematic flexures which mount to a lower thermal expansion beryllium surface. These flexures, combined with the weight of the diagnostic module, create a first structural resonance of 375 Hz, well above the launch spectrum peak. The beryllium surface is temperature controlled to $25° \pm 2°C$, with slow changes expected. This benign thermal environment, combined with <2-W power dissipation internal to the diagnostic module, causes minimal structural deformations.

Figures 8 and 10 show the beam path in the diagnostic module. The alignment tolerance on the beam at the entrance aperture is ~2-mrad radial angle and 0.25-mm radial position, which can be met by open loop pointing of the source. Beyond the entrance aperture the beam is directed by three beam-splitter cubes bonded to a common plate to the various subassemblies. Feedback from the beam splitters and the subassemblies back into the laser source is prevented by a variety of measures. These include tilting optics and inserting neutral density filters where possible, inserting a polarizer cube to reduce non-polarized backscatter, including light shrouds to contain and localize reflected and scattered light, and covering the inner surface of the housing with a low-reflectivity black paint.

C. SUBASSEMBLIES

Figure 9 shows some important features of the Fabry-Perot subassembly design. The lens barrel is made of Invar, allows adjustment of mirror spacing, and is supported in an aluminum mount. Invar limits thermal de-space to 0.6 μm for 10°C changes, allowing mirror spacing (and thus finesse) to be maintained over all operating temperatures. The mirrors used are ruggedized versions of commercially available units. To accommodate thermal coefficient differences between Invar and aluminum, the Invar barrel is located in an aluminum V-groove, in which it can slide while the aluminum expands. The

10

FPI
DETECTOR

x

z

ENTRANCE
APERTURE

FLEXURE FOOT

INTERFERENCE FILTER DETECTOR

POWER MONITOR

BEAM DIRECTOR

FABRY-PEROT
INTERFEROMETER

NEON GLOW LAMP

OPTICAL CAVITY
EAST SIDE

y

CONNECTOR

ELECTRONICS CAVITY
WEST SIDE

6 INCHES
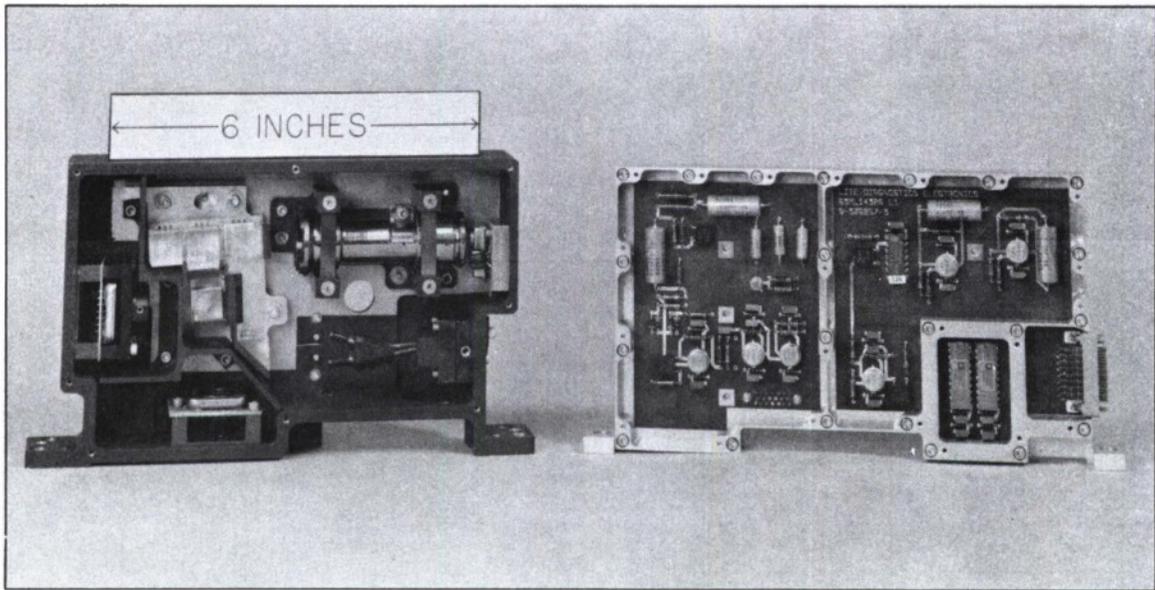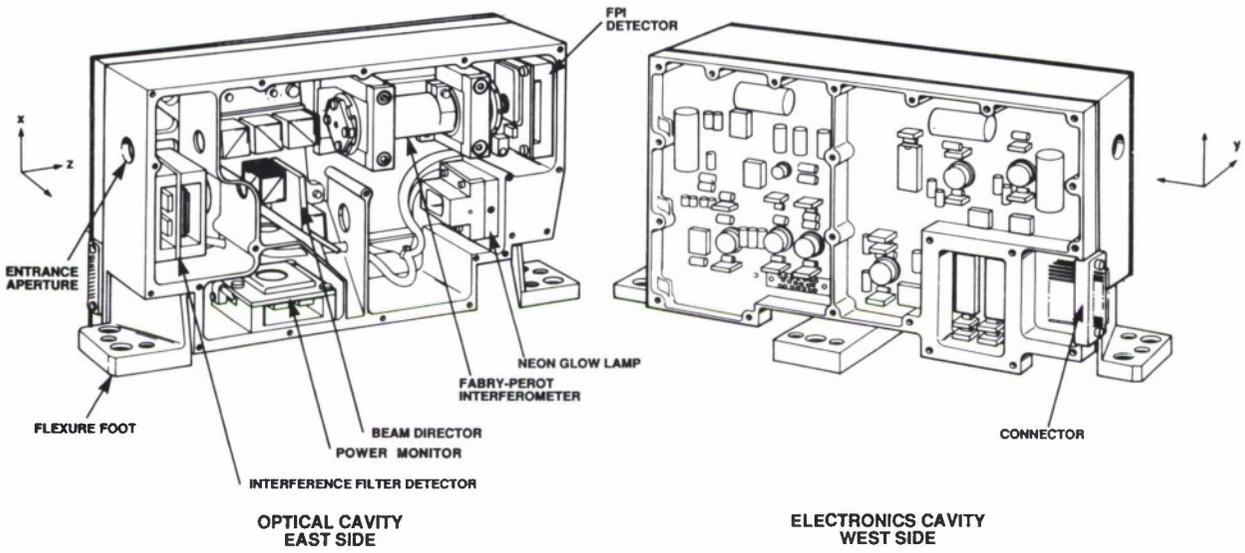
Figure 8. Diagnostic module layout and housing.
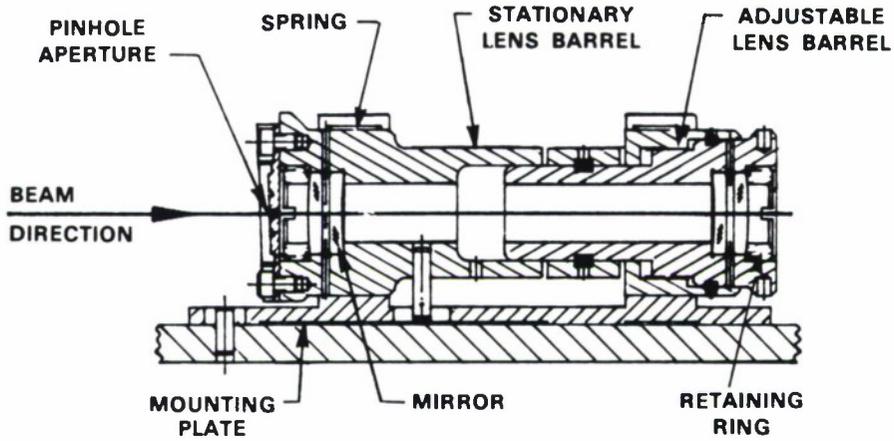
Figure 9.   Fabry-Perot interferometer.
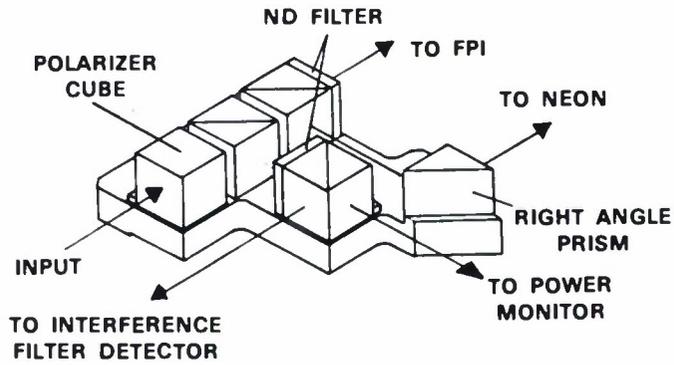
Figure 10.   Beam director assembly.

12

pinhole aperture at the front of the Fabry-Perot improves its finesse, and desensitizes the assembly to variations in input beam position. When the Fabry-Perot is mounted into the diagnostic module, it can be adjusted in elevation angle, and the whole diagnostic module housing can be adjusted in azimuth angle and position, allowing the Fabry-Perot axis to be aligned with the incoming beam.

The neon glow lamp subassembly shown in Figure 11 houses a glow lamp which is 0.25-in diameter and 0.75-in long, with a maximum power dissipation of 0.25 W. The lamp is located within its housing by a V-groove and pin, and is encapsulated with a space-qualified RTV adhesive. The neon assembly can be adjusted in azimuth and elevation position to maximize optogalvanic signal strength.
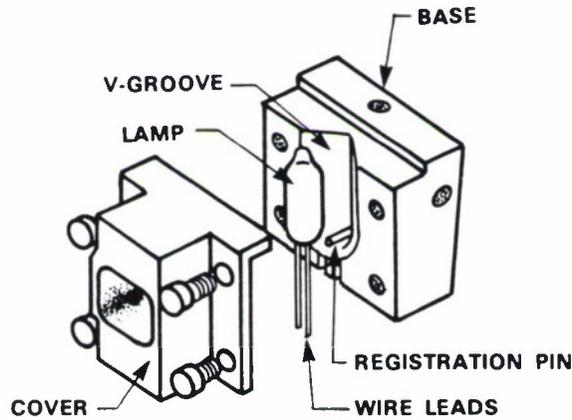
Figure 11. Neon glow lamp.

While both the neon assembly and Fabry-Perot interferometer assembly need to be aligned when placed into the larger diagnostic module housing, the detectors and interference filter shown in Figure 12 require no active alignment. All three detectors have active areas greater than twice the beam diameter, allowing simple mechanical registration against the housing. Accurate use of the interference filter requires that the beam be normal to the filter surface to within 5 mrad. This is accomplished with standard machining tolerances.
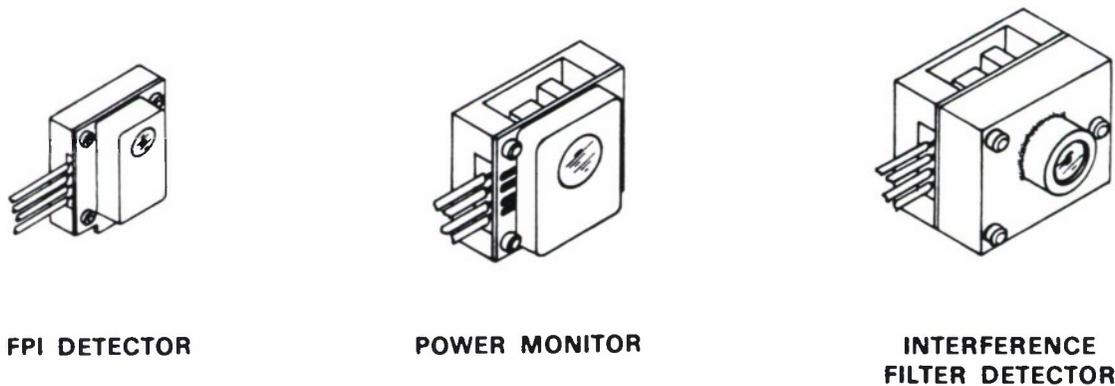
Figure 12. Interference filter and detectors.

13

5. CONCLUSION

This report has described the design and performance of a space-based diagnostic unit which is a companion to an FSK GaAlAs laser transmitter. This diagnostic unit periodically updates transmitter bias current, modulation current, and temperature to maintain constant wavelength, tone spacing, and power as the transmitter laser diode ages. Furthermore, all these functions are performed with rugged hardware that weighs 3 lb, dissipates <2 W, and has alignment tolerances on the order of milliradians and tenths of millimeters.

In addition to meeting the requirements of the 4-ary 220-Mb/s communication system described in this report, the diagnostic system can be used as a more general monitor of laser diode health over its lifetime in orbit. The interference filter, for example, can be used to measure the diode tuning curve. The known frequency spacing of the Fabry-Perot transmission peaks can be exploited in measuring diode current and frequency tuning coefficients or for offset tuning from a neon line. In summary, the combination of neon lamp, interference filter, and Fabry-Perot in this diagnostic system not only aids the successful operation of a specific communication system, but also constitutes a versatile information-gathering package for diode laser space communication.

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report 850		5. MONITORING ORGANIZATION REPORT NUMBER(S) ESD-TR-89-111		
6a. NAME OF PERFORMING ORGANIZATION Lincoln Laboratory, MIT	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Electronic Systems Division		
6c. ADDRESS (City, State, and Zip Code) P.O. Box 73 Lexington, MA 02173-0073		7b. ADDRESS (City, State, and Zip Code) Hanscom AFB, MA 01731		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION HQ AF Systems Command	8b. OFFICE SYMBOL (If applicable) AFSC/XTKT	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F19628-85-C-0002		

8c. ADDRESS (City, State, and Zip Code) Andrews AFB Washington, DC 20334-5000	10. SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO. 63789F	PROJECT NO. 270	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Design and Performance of an On-Satellite Laser Diagnostic System for a Free Space Optical Heterodyne Frequency-Shift-Keyed Communication System

12. PERSONAL AUTHOR(S)
Vijaysekhar Jayaraman, Emily S. Kintzer, James G. Garcia, and Allen D. Pillsbury

13a. TYPE OF REPORT Technical Report	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) 1989, July, 11	15. PAGE COUNT 19

16. SUPPLEMENTARY NOTATION

None

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	space communications laser diagnostics diode lasers frequency-shift-keyed

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The advent of space-based coherent diode laser communication systems requires development of space-qualified laser diagnostics to make these systems robust in face of aging laser parameters. This report describes the packaging and performance of a diagnostic system which sets the wavelength, tone spacing, and optical power of a directly modulated frequency-shift-keyed GaAlAs laser transmitter.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Lt. Col. Hugh L. Southall, USAF	22b. TELEPHONE (Include Area Code) (617) 981-2330	22c. OFFICE SYMBOL ESD/TML

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted.   UNCLASSIFIED
All other editions are obsolete.