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OPERATING MANUAL

OPCOA FP/T-1000

1.0 How It Works

1.1 Introduction To Fiber-Optic Sensors

Present sensor technology has not kept pace with the data accumulation and reduction capability of modern microelectronics. Available sensors are bulky, costly, and not readily compatable with digital microprocessing electronics. So a means of measuring temperautre, pressure, flow rate, and similar parameters would greatly enhance the performance of many systems. Yet such sensors will need to withstand hostile environments, including electromagnetic interference. With the recent rapid acceleration in the growth of fiber optic transmission systems, it seems natural that all-optical sensors would be the logical next step.

Fiber-optic sensor systems to be most useful should have a digital transmission format and be independent of intensity variation. Thus, the number of light wave transmission parameters which can be utilizerd is limited (although these constraints do not limit the number of parameters that can be used for sensing). If single mode fibers were used, five characteristics of light could be applied to digital transmission: amplitude, intensity, wavelength, phase, and polarization. However, multimoide fibers are currently practical. These restrict transmission schemes to digital intensity modulation (binary, pulse width, frequency, etc.), wavelength (or color) modulation, and color multiplexing.

It's desirable that transducers produce digital signals directly, rather than requyire the analog-to-digital converters used with conventional sensors. Further, transducers should require only optical input power.

With these criteria, a "digital-compatible" sensor can be any sensor which is not affected directly by amplitude variations (such as changes in fiber or connector attenuation). The possibilities for sensor construction are as extensive as the potential applications. Opcoa has developed under NASA Contract NAS-3-23522 one such promising sensor (FP/T-1000), as discussed in this operations manual.

Fabry-Perot sensors involve a multiplicity of reflections and splitting of a beam of light such that interference and support of the components of a single light ray can occur many times. Such sensors have the desirable characteristic that the change in output can be very sharp function of the wavelength.

The sensor system shown in Figure 1.1 consists of a broadband light source coupled into a fiber which transmits this broadband spectrum to the remote sensor element. The sensor element is a variable gap Fabry-Perot cavity which modulates the reflected spectrum according to gap dimension. The reflected spectrum is fiber transmitted back to a microprocessor-based, color demodulation system. This color demodulation is accomplished by prism dispersion over a charge-integrating line-scanning device (CLD). The microprocessor analyses the spectral data and converts it to temperature

This manual presents a discussion of the FP/T-1000 hardward, softward, operation and performance.

2.0 Hardware Description of the OPCOA FP/T-1000

2.1 Sensor

The sensor which was delivered under Contract NAS 3-23522 is as shown in Figure 2.1. This sensor does not differ in ways which would be apparent in this drawing, from planned subsequent sensors. There are, however, details concerning the particular unit delivered, which are important. These details will be discussed in the following description.

The body (1) of the sensor, Figure 2.1, and the two end caps (2) and (3), are constructed of 304 stainless steel. This steel has a melting point of 1427-1510 deg-C (2600-2750 F) and an annealing point of 1037-1093 deg-C (1900-2000 F). The scaling temperature for continuous service is 899 deg-C (1650 F). These values are expected to be satisfactory for moderate duration low-stress application at the design maximum temperature of 1000 deg-C. For extended use of the sensor at higher temperatures, an alloy such as 330 stainless may be preferred for these body parts, in order to give better strength, as well as improved resistance to carburization, oxidation and thermal shock.

The spring (4) provides a compressive force to hold the components in place. The compliance of the spring allows this force to be maintained during the differential expansion encountered during use of the sensor. This spring in the delvered sensor is an ordinary room-temperature-steel spring. The spring is in the outer part of the sensor and is thus not subjected to the intensive heat of the actual sensing element. However, it is recognized that temperatures will be quite high here as well. Before a final design of this spring can be made, it will be necessary to determine just how high the

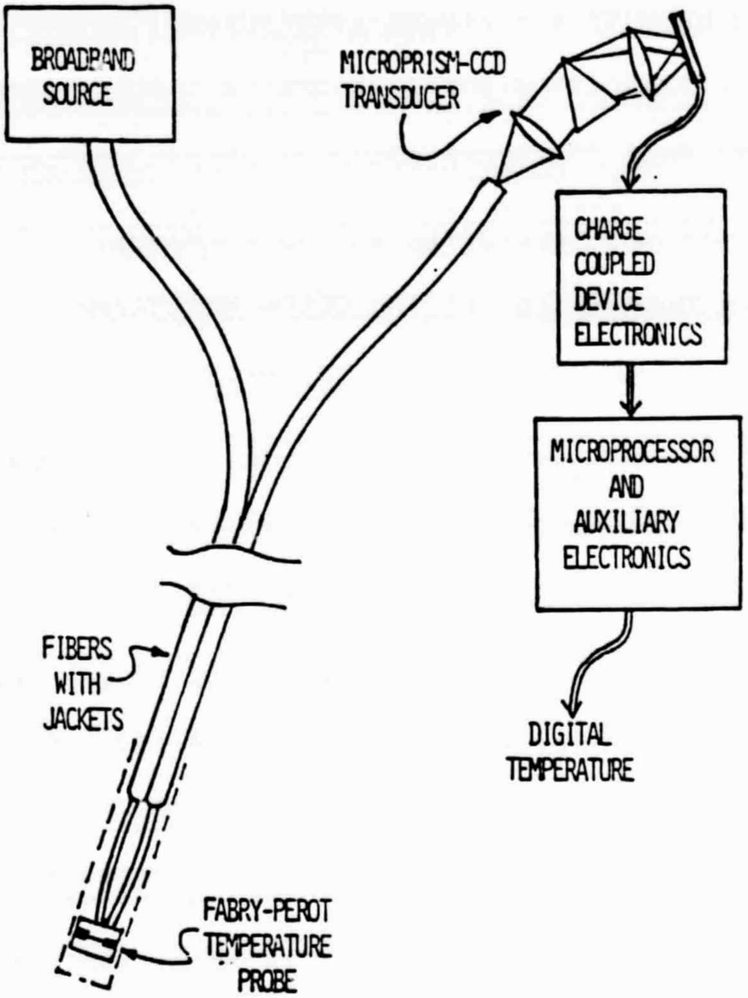

Figure 1.1--FP/T-1000 System Overview

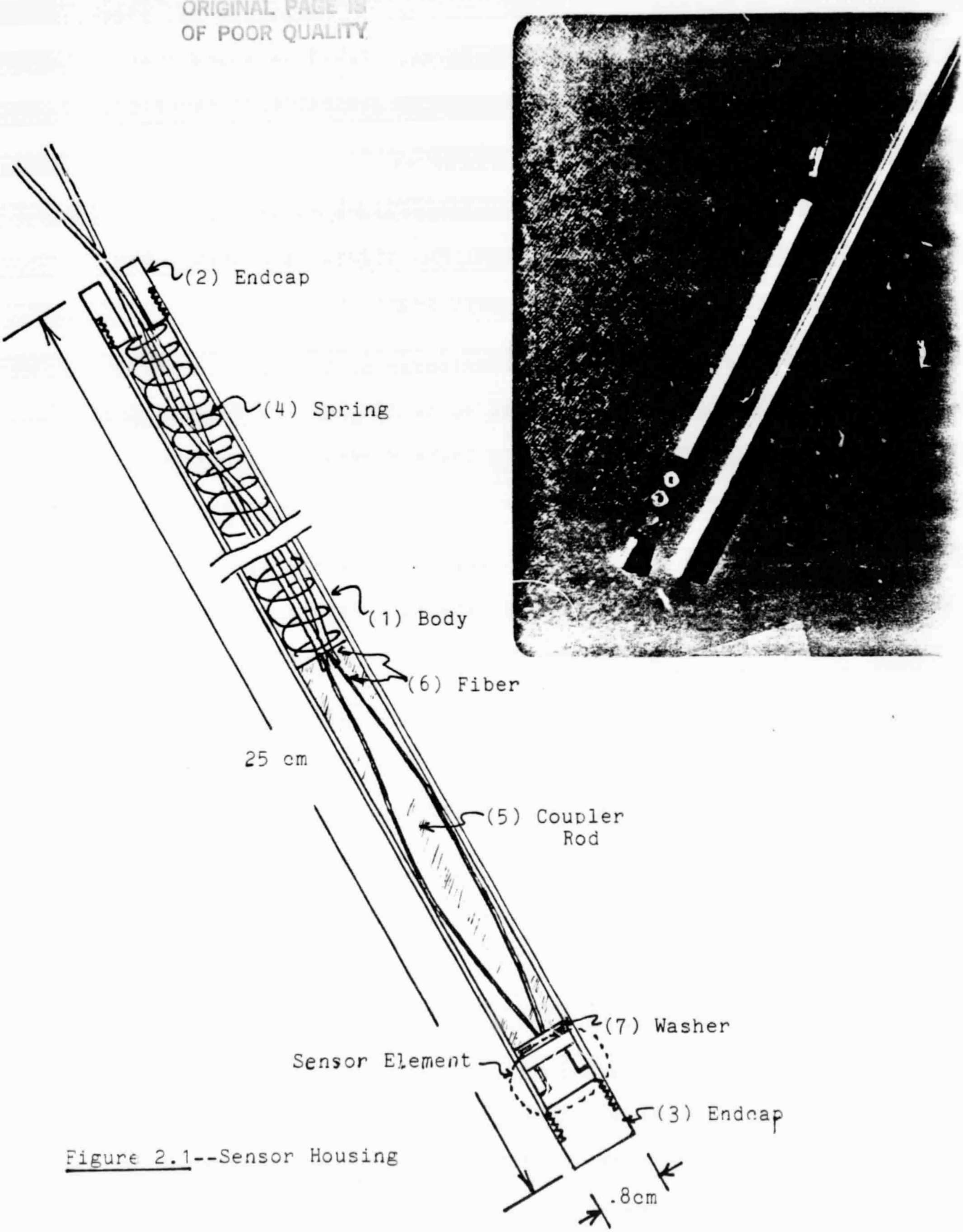

Figure 2.1--Sensor Housing

temperature will be in this region. If it is found that the temperature is so high that a suitable spring design is excessively difficult, it may be desirable to redesign the housing so that a spring force can be provided from a location of somewhat lower temperature.

The Coupling Rod (5) is integral with the fibers (6). This rod is cast of the high-temperature material, Sauereisen No. 12. This material, made by the Sauereisen Cements Company of Pittsburgh, PA, 15238, is a chemically setting inorganic cement with a maximum service temperature of 1204 deg-C (2200 deg-F).

The fibers are QSF-300-AS fibers, made by Fibres Optiques Industries, and distributed by Quartz Products Corporation of Plainfield, NJ, 07061. These fibers are specified by Quartz Products to be "All-Silica Fibers" and are made by combining "axial plasma deposition and lateral plasma deposition methods." These fibers contain a pure fused silica core, optical cladding, surounded with a silica coating.

In the coupling rod (5), the plastic coating of the fiber has been removed from the fibers except for a short portion near the spring end of the coupler. As with the spring, it is not known what the temperature will be at this location. Thus it is anticipated that the heat at this location may be excessive for the jacketed fiber. If this is the case, the fiber will require Sauereisen coating farther out (longer coupling rod), and/or replacing the fiber with a fiber of higher temperature resistance.

Steel washer-shaped shims (7) are used between the coupling rod and the sensor assembly. In the delivered assembly three shims are used here with a total thickness of 0.25 mm (.010"). These shims are made of standard steel (magnetic) "shim stock" which has an undetermined temperature resistance. Clearly it will be necessary to either verify the temperature resistance of the material used, or to use a higher temperature steel in future used for very high temperature.

The purpose of these shims is twofold. First, they distribute the pressure from the coupling rod to the sensor assembly. It is important that this holding pressure be applied around the circumferential periphery of the sensor. This is true because, although the top of the sensor is relatively rigid, the high sensitivity of the Fabry-Perot gap makes it respond to moderate pressure applied at the center of the top (10). Second, the shims allow spacing of the coupling rod for maximum optical coupling efficiency.

The sensor assembly itself, the sensor "button" (8,

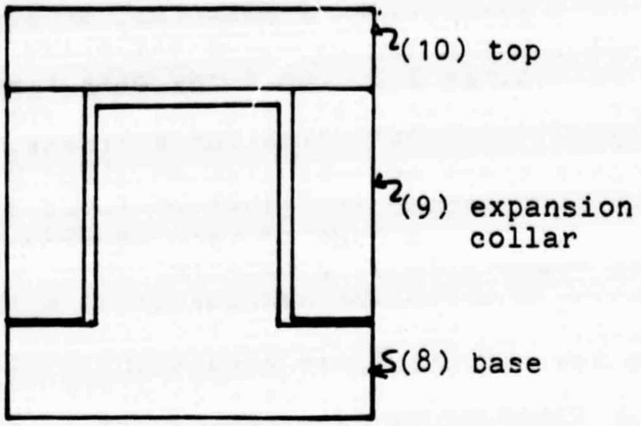

Figure 2.2--Sensor Element

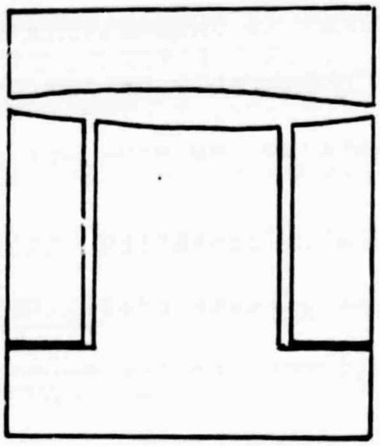

Figure 2.3--Confocal Fabry-Perot Sensor Element Components Before Optical Bonding

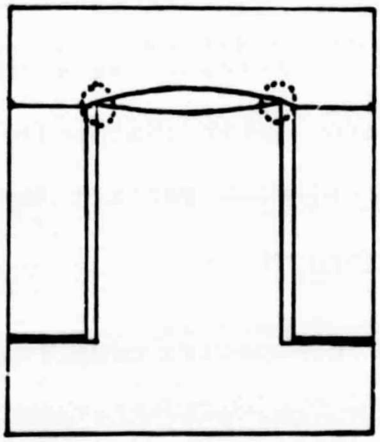

Figure 2.4--Low Temperature "toughing" effect in confocal resonator

9, and 10), consists of a base (8), an expansion collar or sleeve (9), and a top (10). These parts are shown in more detail in Figures 2.2. Both the base piece, which includes the center post, and the top are made of Corning Glass Works "ULE" 7971 titanium silicate, a material which has a coefficient of expansion of about 0.05E-6/deg-C, a value which is about 1/10 that of fused silica. The expansion collar is made of Corning 7940 fused silica. Thus the fused silica, a material which often finds engineering application because of it's low expansion coefficient, is here used as the expansion element, working against the lower expansion titanium silicate. This choice of two low expansion materials is dictated by the high temperature requirements of this particular sensor. Other members of the OPCOA FP/T family will work with materials suitable to their respective temperature range.

The expansion collar is fusion bonded to the base. Although a lower-than-optimum pressure was applied to this base-collar bond during assembly of the delivered sensor, this bond has been temperature cycled to 1000 deg-C, has held up with no problems during many tests, and is expected to perform well.

The top is "optically contacted" to the expansion collar; that is, the optical polish, cleanliness and assembly techniques are of such precision that the parts in the assembled state are sufficiently close together for molecular attraction to provide the holding force. No other bond is either required or desired here.

The sensor "button" delivered under this contract incorporates an experimental grinding (and polishing) technique which was intended to reduce the cost of producing the "initial" gap, i.e., the gap at room temperature. This technique was only partly successful. The technoue and the problem which it produced will now be described. First the technique is to grind the surfaces (or one surface) slightly concave, as shown in Figure 2.3. The concavity is of the order of an eighth to a quarter of a visible wave length. When the parts are then optically contacted, there is sufficient elasticity in them to allow the top to fully contact the sleeve. (The existance of "optical" contact can be seen by the absense of reflection at this boundry.)

This technique for producing a room-temperature gap worked as planned. An unexpected problem, however, was encountered. At and slightly above room temperature, there appears to be a touching of the post (center of base 8) to the sensor top. Presumably the geometry of what is happening is approximately as is shown in Figure 2.4. The existence of this probable touching is indicated by a lowering of the sensor sensitivity (optically measured gap change for a given temperature change), as lower temperatures are approached. The result is nonlinearity and reduced accuracy of temperature measurement from room temperature to about 140 deg-C.

This effect can be seen in Figure 2.5, which is a plot of temperature vs "X3", a measure of the Fabry-Perot gap determined by analysis of the spectrum. The units of X3 are scaled for computational speed and convenience. The actual indicated Fabry-Perot gap in micrometers (um) can be obtained by dividing X3 by 12.14. Thus it can be seen in Figure 2.5 that the gap at room temperature is indicated to be about 1.8/12.14 = 0.148 um, or 148 nm, or 1480 A. The gap at the point where the curve begins to deviate from linearity is measured to be 3/12.14 = .247 um, or 247 nm, or 2470 A. It can be seen that the gap changes by only 0.1 um, or 1000 A over the nonlinear region.

Referring to Figure 2.4, it would be assumed that touching begins when the center gap is about 2500 A, and that compression of the touching corners occurs from about 140 deg-C, down to room temperature at about 20 deg-C. It seems clear that during this compression, micro chips may form, and that these chips, as well as any other debris that may have not been removed in the cleaning, may during different temperature cycles seat in different ways and thereby cause a certain amount of randomness in the indicated temperature in this region of measurement.

Emphasizing this problem is the fact that curvature introduced into the calibration curve, below 140 deg-C, increases the temperature difference reported for a given variation in actual gap. No claims therefore are made for operation below 140 deg-C.

2.2 Electro-Optic Converter

The Electro-Optic Converter is shown in Figures 2.6 and 2.7. The only connections to this converter are via the two fiber-optic connectors and the single 25-pin electrical connector, seen in the figure on the near end of the enclosure. A single multiconductor cable from this connector to the Signal Processor (Section 2.3) provides the Electro-Optic Converter with electrical power and signals from the processor, and returns signals from the Electro-Optic Converter to the processor.

The FP/T-1000 sensor itself has only two connections made to it, and these two are the two fiber-optic cables which attach to the two fiber-optic connectors mentioned in the paragraph above. One of these optical cables provides a source of illumination to the sensor, and the

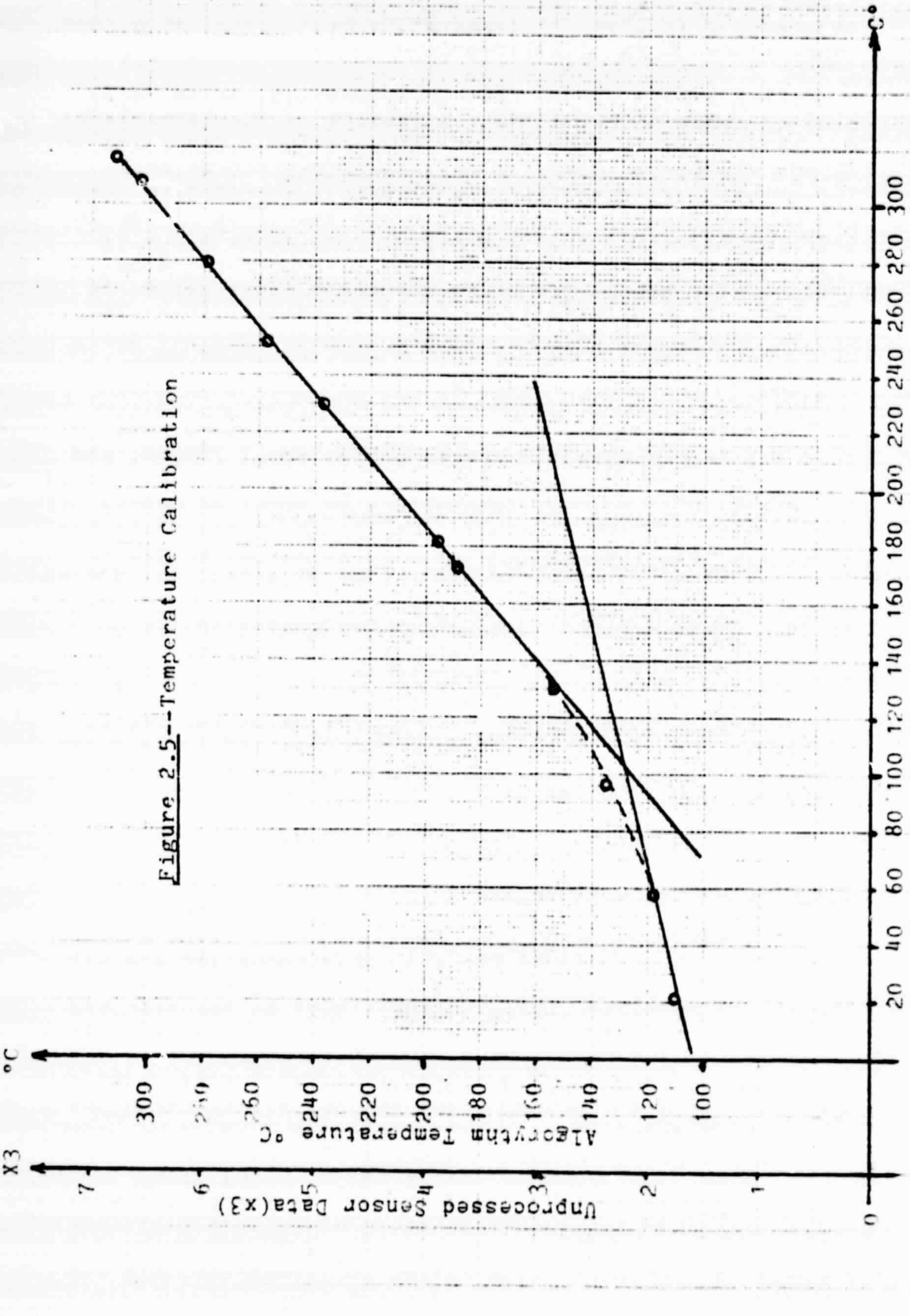

Figure 2.5--Temperature Calibration

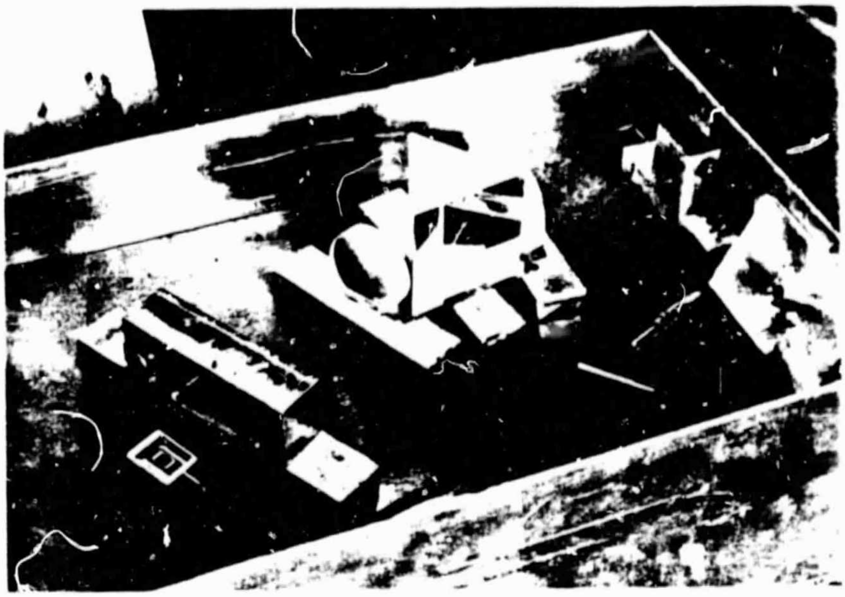

Figure 2.6--Electro-optic Demodulator(optics)

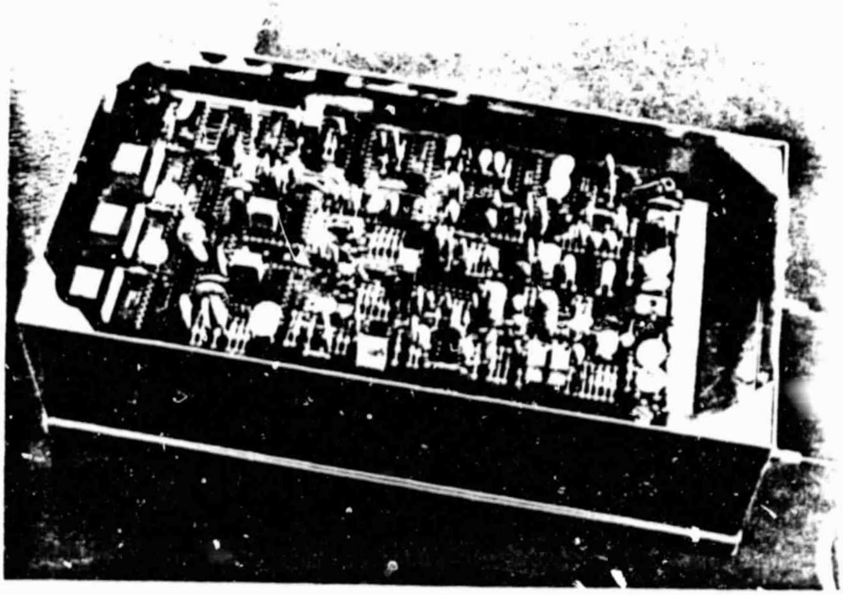

Figure 2.7--Electro-optic Demodulator(electronics)

other cable returns the signal from the sensor to the Electro-Optic Converter.

Figure 2.6 shows the Electro-Optic Converter with the cover removed from the optical side of the enclosure. The optical components are mounted on what might be termed a miniature optical bench. This consists of a 6.35 mm (1/4") thick aluminum plate which can been seen as the bottom of the open space visible in the figure. This plate has successfully provided the temperature and physical stability necessary to maintain the required long- and short-term stability of the optical parts.

These optical parts, as seen in Figure 2.6, are as follows: On the near left is the illumination source and the connector for attaching the illuminating fiber. The lamp in the enclosure is a Welsh-Allyn 00200 miniature lamp. The lamp base inself is inscribed "WA2". Because this lamp is commonly used in medical instruments, it is fairly readily available, for example from medical supply houses. In application here, the lamp has been derated to about 3000 hours average life, based on manufacturer's specifications. The electronic parts seen farthest from the viewer comprise a solid-state switch which gives the processor on-off control over the lamp.

The temperature-encoded light signal which returns from the sensor enters the Electro-Optical Converter through the fiber-optic connector seen to the right, foreground. Immediately beyond this connector structure is an adjustable optical slit, the top of which can be seen in the figure. This slit has been set to about 50 um (0.002") in the unit delivered.

After the slit, away and to the left in the figure, are two lenses and a dispersing prism. Both lenses are achromats of about 50 mm focal length and 20 mm dia (f/2.5). The prism is equilateral, 30 mm on a side and 20 mm high.

The first lens (nearest the viewer) is mounted one focal length from the slit, so that the rays leaving it are essentially parallel. A round target on the far inside wall of the housing has the same diameter as the lens and is used for aligning the first lens (with the prism temporarily removed). With proper alignment, light from the fiber will produce a spot on the target the same size as the target. If the lens is too near or far from the slit, the spot will be correspondingly too large or small. If the lens is improperly positioned, the spot will not superpose the target. If the slit is not properly positioned relative to the end of the fiber, the illumination of the spot will not be uniform. Once the slit and first lens are aligned, the prism is replaced and the second lens is positioned near the prism. The angles for these are based on the expected refraction of the prism. Finally, the mounting block for the Charge-integrating Line-Scanning Photodiode Array is positioned one focal length from the second lens. It is to be noted that all mountings have designed into them the adjustability needed to fine tune the alignment and focus of the system.

The Charge-integrating Line-Scanning Device (CLD) sensor is a 128-element electro-optic device made by EG&G Reticon, Sunnyvale, CA 94086, type RL128S. The 128 elements in this light sensor have 0.025 mm (1 mil) spacing for an array length of 3.25 mm (about 1/8"). The elements are charged at the beginning of a cycle, and during the light-sensing interval, these small diode capacitors discharge in proportion to the light falling on them, thus giving a reading proportional to the time-integral of the illumination falling on them during that period. During the read sequence, the charges are transferred out in time sequence by solid-state multiplex switches driven by two internal shift registers.

The face of this CLD sensor is mounted directly to the CLD mounting block, so that the alignment of the sensing-element array is not dependent on the seating of the electrical connector. The "DIP" socket for the CLD is attached to the flat cable which can be seen extending from behind the CLD mounting block through the "optical bench" plate toward the space below the "bench".

Figure 2.7 shows the Electro-Optic Converter housing turned over, and with the cover on the other side removed. The space below this side reveals the specialized CLD electronics. This board is a standard Reticon PC circuit which they have designated RC-1024SA. The extra wires seen on the board are modifications made for the application here. In particular, these connections provide synchronizing signals for the microprocessor, and also allow the microprocessor to modify the integration time, thus giving it a means of maintaining optimal gain. The CLD-to-circuit board cable attaches to the underside of this board and is not visible in this figure. A 44-pin edge connector for the RC-1024SA circuit board is wired to the 25-pin connector on the front of the Electo-Optic Converter housing. The only connections to this 25-pin connector, beyond these to the 44-pin edge connector, are the power and signal to the lamp and lamp solid-state switch mentioned above.

2.3 Processor

The Processor works with the Electro-Optical Subsystem to analyse optical data from the OPCOA FP/T-1000 sensor to obtain the desired temperature data. This processor is an "AIM-65" standard micro-computer built by

Rockwell, International, combined with a second IC known as the "VIDEO-1" expansion board. (The power supply was also expanded to include requirements of the CLD Charge-integrating Line-scanning Device circuits discussed above.) The two are mounted in a single case. As Part of OPCOA's continuing upgrading program, it is planned in future systems to use the smaller "Commodore 64" instead of the AIM-65 micro-computer, along with a more specialized replacement for the VIDEO-1. Advantages of the Commodore 64 include improved reliability, smaller size, increased internal memory for reduced requirements on the expansion board, lower cost, easier availability of service and/or replacement. The AIM-65 had advantages of flexibility in this earlier development. The fact that both of the microcomputers use 6500-series microprocessors, and thus have the same machine-language instruction set, will ease software transition.

The Processor requires only two connections to make the FP/T-1000 system operative. These consist of applying standard 110-volt ac power, and of connecting the 25-pin connector on the cable from the Electro-Optic Subsystem.

An optional connection is from the Processor to a standard television (75-ohm cable with RCA audio jack at Processor end) to provide a monitor display of the raw optical spectrum of the sensor signal, and a cleaned-up version. (As a secondary feature, this display will present the spectrum of any optical signal provided by the user to the input fiber.) At present this signal is modulated for channel 3, 4, or 5, depending on tuning of a coil next to the 75-ohm cable connection on the processor. It is planned for future units to be available for monitor connection also.

In operation, the Processor sends on/off signals to the Optic lamp, and digital sample-time signals to the CLD board. The sample-time signals determines the free running speed of the CLD board when then sends data ready signals to the processor.

The AIM-65 board is a standard piece of hardware. All special functions are performed on the VIDEO-1 board. Principally this board provides analog/digital conversion for the CLD signals. In addition it supports the EPROMS which store the specialized programs which save and analyse the spectral optical data and convert this information to sensor temperature. It also provides additional RAM at more convenient memory locations. In addition, although not fundamental to the temperature conversion function, it makes the video screen spectral display opton possible by providing the permanent software, the needed additional video RAM and the hardware necessary for the video display. The AIM-65 and other standard boards are shown in Figure 2.8, as well as the

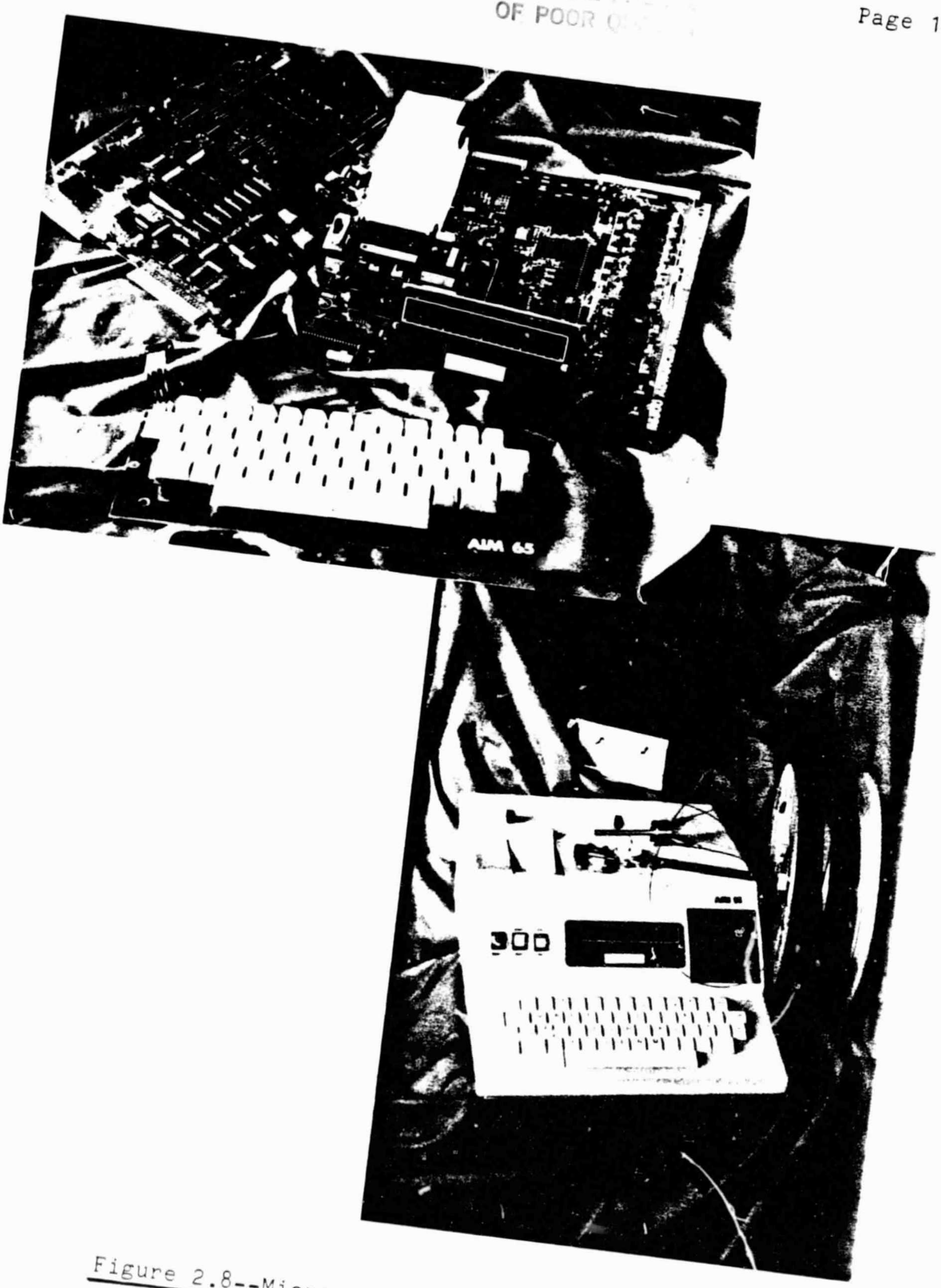

Figure 2.8--Microprocessor System and Completed FP/T-1000

completed FP/T-1000.

3.0 Operating Instructions

3.1 Hookup and Initialization

3.1.1 Electrical. The electrical hookup requires only:

1. Plug cord on Processor to standard 110 v, 60 Hz ac power

2. Connect the 25-pin connectors on the ribbon cable to the Processor on one end and the Electro-Optic Subsystem on the other end. The connector on the Processor is female and located on the back panel. The 25-pin connector on the Electro-Optic Subsystem is male and located near the two fiber optic connectors.

3.1.2 Software Initialization. It is convenient to initialize the software before attaching the fiber-optic cables. This is done as follows.

1. Turn on Processor ac power at the switch on the back panel.

2. Enter the following ("Rtn" refers to the single key labeled "RETURN", Use shift as required, e.g., for "*")

KEYS TYPED	APPEARS ON DISPLAY
(Power On)	<
* 9 8 0 0	<*>=9800^
Rtn	<
G	<G>/^
Space	^
(Ctrl-Print)	(OFF)

Cntl-Print (Print Key depressed while Control Key is held down) is optional. Cntl-Print toggles printer off/on. Use here if it is desired not to print out temperature values during normal operation.

R U N	RUN^
Rtn	NEW REF?(Y/)

3.1.3 Optical Hookup. At this point in the initialization it is necessary to decide if a new reference is to be used, or if the default reference will be used. At low sensor temperatures, a variation in the voltage of the lamp produces a spectral shift similar to that produced by a change in sensor temperature. The system delivered under contract NAS 3-23522 has the lamp voltage set to a slightly different value than that at which the default spectrum was recorded, resulting in an offset at these lower temperatures. In later versions of the FP/T-1000 it is planned to use a larger initial Fabry-Perot gap dimension to largely elliminate this effect. For this, and other reasons discussed below, it may be desirable to take a new reference.

In answer to the question "NEW REF?" above, any key except "Y" ("Space" is convenient.) will cause the new reference sequence to be skipped, and a default set of reference data to be used. In this case the sequence jumps directly to the request for "SENSOR SIG, ANY KEY" (see below). (If a key defined in Section 4.1 is entered instead of space or another undefined key, the requested operation will occur before the program proceeds. See Section 4.1) If the key "Y" is hit, then:

```
     Y                          REF SIGNAL...ANYKEY
```

The program now waits for the reference signal to be connected at the Electro-Optic Subsystem. If the Screen Display option is being used, the signal spectrum will be displayed on the TV screen in a real-time mode, so that the reference signal can be seen as the optical cable is being attached.

This connection is made by connecting the short fiber-optic cable directly from the input to the output. When connecting this in the unit delivered, it is necessary to put one or both of the connectors only part way into the connector socket(s) to avoid saturation of the signal.

Once the reference signal is established, hit any key ("space" is convenient) to indicate "ready." The program will now go through an optimizing sequence involving gains, offset, and dark signal. If the display is being used, it will display spectra used during this optimization procedure.

If the signal used for reference is too strong, you will be asked to "REDUCE SIGNAL, KEY". In this case, pull one connector part way out of the socket and hit a key (i.e., space) to indicate "ready."

When the optimization of the reference signal is complete, the display will read

SENSOR SIG, ANY KEY

Attach the two FP/T-1000 fiber-optic cables to the two connectors on the Electro-Optic Subsystem. If the TV option is being used, the screen will be displaying the resultant signal, real time, to verify that the connection is correct.

When a key is now pressed, the sensor will go through an initialization similar to that described for the reference, in this case optimizing the parameters for the sensor signal. When this procedure is completed, the normal temperature measuring mode will be entered automatically.

3.2 Normal Operation of the FP/T-1000

The display will now read three values, separated by ">" On the left is the rms error of the fit. In the middle is the value of the maximum data point (255 maximum). On the right is "T=" the temperature in Deg-C. If the printer was left on during initialization (power-up default), these values will also print out about once every 6 seconds.

During normal operation the processor is constantly performing tests relating to performance. When parameters are discovered which would cause excessive errors, re-optimization proceedures are called. More monitoring techniques such as these are planned for future systems. One of the two routines which will be noticed during normal operation at present are the "NEW ZERO" routine which is entered when the CLD (Charge-integrating Line Scanning Device) system has been determined to have drifted beyond set limits. This will occur most often soon after a previously cold system has begun operation, and will occur very little if ever after the system is thorouly warmed up. The other automatic routine which will be observed to occur occasionally resets the gain and offset parameters. This routine is entered (automatically) most often when the temperature is changing, resulting in changing sensor signal levels which are best handled with changed gains.

4.0 Operating Options Available

Figure 3.1 is a simplified map of the modes of operation, ways of going from one mode to another, and principal commands available in each of the modes.

Referring to Figure 3.1, it will be seen that the initialization entries listed in Section 3.1.2, above, took us through the monitor, through BASIC, and to the FP Program. Within the FP Program there are a number of commands which can be used. These are described in the next section.

Some commands available in other modes are discussed in subsequent sections. Commands relating to changing modes are generally discussed under the mode being left, but some are considered self explanatory in Figure 3.1.

The screen display (optional) has a slight problem in the system delivered. (This will be corrected in later units.) When a new ZERO is taken, the screen display is switched to displaying the zero data during this routine. Due to a programing oversight, the display is not switched back at the end of this routine. There are two ways this can be done manually without changing the values of the variables in the program. These are mentioned in Section 4.1 under "Key, S" and in Section 4.2 under "SP=DP".

4.1 FP Program Options Available

During operation, several options can be instigated by pressing suitable keys. The keyboard is checked once every temperature cycle; hence, the key much be held down until the end of the current cycle. Also, anytime the processor asks for "ANY KEY" the use of one of the defined keys will cause that operation to be performed. The keys which are defined are as in the following paragraphs. An undefined key will simply be printed and operation will continue. After the operation of a defined key is completed, the system will ask for another key, and <u>wait</u> until a key is pressed. If simple program continuation is desired, press "Space" or any undefined key. If another defined key is pressed, that operation will be performed and the system will ask for still another key, etc.

Key, Z. This key will cause the system to read a new zero, i.e., the optical dark signal.

Key, S. Sensor gains and offset parameters will be automatically optimized.

Key, 2. This key will cause the next optimizing operation to optimize only the two variables amplitude and offset. Because these variables are by themselves linear, they will converge rapidly and aid in system convergence in cases where the current approximation is far off. This operation normally happens automatically, however, and the key entry is not needed except perhaps for testing. A two-variable iteration can be observed in normal operation by the fact that the same <u>identical</u> temperature is printed out for two sequential iterations. This is common when the system is first powered up

Key, T. This key allows the operator to insert a different value for X3 in the estimation vector (X3 is the system temperature parameter). This has two uses. First, it makes it possible to observe the dynamics of the convergence by upsetting it temporarily. Second, if the estimated temperature is far from the correct value, there are, in the delivered system, situations in which an erroneous stable point can be found by the temperature-estimating algorithm. By using the T entry, the operator can bring the system to a region in which it will convergence correctly. Software systems are being designed which will automatically detect this problem and locate the correct stable point. These will be incorporated into future systems, but for the present, the T entry gives a method of recovering if there should be a problem of this nature.

Key, A. Enter Alternative start and end values of n. The default values here are 18 and 81. This means that, although 128 elements of CLD (Charge-integrating Line-scanning Device) spectrum are taken and converted to digital data, only those over an (81-18+1=64) range are used in the analysis. This was done in the interests of speeding up the operation and also because the illumination outside this range is rather low and does not contribute a great deal to the operation. Use of this key enables the operator to determine the effect of including this extra data.

Key, I. Interval of data used in analysis. Default value is 4. This means that only data points 18, 22, 26, etc., are used in the analysis. This using every 4th point is purely in the interests of speed. When more sections of the software are converted to machine language, the speed here will not be a problem, and every point will be used. In the delivered unit, this key entry permits operation at different values of I to be evaluated.

Key, Q. Quit the program and return to BASIC.

Key, F1. Transfers operation from Program to Direct-Entry BASIC by causing a "BREAK" in operation. If the printer is not on at the time of a break, it is good practice to hit the "Print" key immediately after "F1" in order to make a record of the line number in which the break occurred. After this break direct commands can be entered. After completing direct commanos, operation can be resumed where it left off by typing "GOTO xxxx, Return" where xxxx is the line number displayed upon the break.

4.2 "BASIC" Options Available

Once Command Level BASIC has been entered with Key F1, many of the usual BASIC direct commands can be used. However, because the program is stored on EPROM, no entries which attempt to change the program will work. Some of the most useful entries are those that print out values of the variables, or which change these variables. Examples are listed below.

4.2.1 General BASIC Direct Commands

Cntl-Print. Toggle printer off and on.

PRINT ZP;DP;SP. (or: ?ZP;DP;SP) Values of different variables can be obtained.

SP=DP. Change SP (Screen Page) to DP (Data Page). This is an optional way of restoring the screen display after the ZERO routine, during which, the screen page (SP) is changed from normal data to zero page (ZP). As mentioned above, due to a programing oversight in the delivered system, it is not changed back at the end of that routine.

RUN 40000. This is a short, experimental BASIC routine that allows the operator to enter values for GN (Gain Number), AO (Analog Offset), and CG (Gain of the CLD, the Charge-integrating, Line-scanning Device) while the screen display continues. The Gain Numbers are not monotonic with gain.

4.2.2 Temperature Scale-Factor Modification. The FP Program makes no provision within the program for modifying or calibrating the temperature-output scale factor. In future versions it is planned to include routines for calibrating the instrument. Although the routines will be rather elaborate, involving Kalman filtering, their operation will involve simply entering known temperatures when desired. Upon entering a calibrate symbol, the routines will ask for estimated probable error of the entered data, and then combine this data with previous calibrations to obtain an overall best estimate of the calibration.

At present, however, in the delivered system, if it is desired to change the calibration, it must be done manually, as follows. First, the calibration equations are of the form,

```
T = (X3) * (T5) - T6                 ,for X3 > 3

T = (X3-T0) * (T1 - (X3-T0) * T2) ,for X3 =< 3
```

The default calibration constants which are initialized into the system immediately upon entering with a RUN command are

T0 = 1.62
T1 = 166.67
T2 = 47.25

T5 = 47.22
T6 = 1.66

Figure 2.5 shows a calibration run on the sensor from room temperature to about 350 deg-C. It is seen that the parabolic calibration below X3 = 3 (T = 140 deg-C) is introduced to compensate for the touching shown in Figure 2.4 and described in Section 2.1. As mentioned, solutions for this problem appear to be clear and are planned.

Recalibration of the sensor can be made by recalculating these constants and introducing them at <u>any</u> time <u>after</u> the system is started with a RUN command. This could be done, for example, with the following sequence.

R U N	RUN^
Rtn	NEW REF?(Y/)
F1	^BREAK IN 8606
T5=...	T5=...^
Rtn	^5=...
T6=..., etc.	
GOTO 8606	GOTO 8606^
Rtn	Note that "NEW REF?(Y/)" will not reappear at this point, but the program is still waiting for the answyer to that question, so, for example:
Y	REF SIG...ANY KEY

And so forth. The line number 8606 is an example and happens to be the line number which occurs when the system is waiting for a key input. If F1-break is made at any other time, when ready to reenter the program simply GOTO the line number at which the break occurred. The program cannot be reentered with a RUN command in this case because that would cause the reinitialization of all variables to the default values. The GOTO reentry preserves all values entered manually, as well as the values which were in the program at the break.

4.3 Machine-Language Routines.

Once the system has been initialized (with *9800,Rtn,G,Space), and the Monitor reentered (Esc from BASIC), then the Key, F2, will enter operation to the machine language, real time display. This routine (which uses no BASIC commands) will display the spectrum once across the screen. It is useful for simply observing the operation of the spectrum. Several commands are available during operation of this routine. Some of these are:

A, Set Analog Offset applied to the analog serial signal from the CLD board.

G, Set Analog Gain on the CLD signal.

C, Set CLD Gain. This is a digital control and it operates by changing the integration time (count) used by the CLD.

0, Turn Lamp off.

1, Turn lamp on.

P, Print display if print buffer full or nearly full.

Z, Read new zero data. This will not turn lamp off. If lamp is not turned off manually before reading new zero data, the "zero" data will be some spectrum, and subsequent displays will have this subtracted from the current spectrum.

4.4 Independent BASIC Facility.

If BASIC is entered using the <5> entry command, it will function as a normal BASIC, with the OPCOA FP Program never available. Once this entry is made, the <6> reentry will reenter this BASIC instead of the usual FP Program BASIC. Operation in this BASIC mode is independent of, and not directly connected to, the FP/T-1000 system being described in this document. In order to restore use of the FP Program, the *9800 initialization may be used again from the Monitor.

For any questions or comments on the OPCOA FP/T-1000 system, OPCOA personnel welcome and encourage contact. Because of the short duration of the program (12 months), experiments on lifetimes of the individual components could not be conducted.

All items delivered under Contract NAS 3-24322 are experimental in nature; all warrants and requirements may be found by reference to the original contract document and/ amendments. No other warranty, expressed or implied is given.

5.0 Performance

This section discusses the various parameters which determine the effectiveness of the FP/T-1000, compared to other sensor systems. Such parameters as accuracy, resolution, range, hysteresis, etc., are considered and best estimates based on experimental results are provided.

5.1 Accuracy

The accuracy of this instrument is still undergoing study. Some of the important limitations being considered are (1) physical limitations of the sensor itself, (2) limitations of the CLD opto-electric converter, (3) limitations of the analog/digital converter, and (4) limitations of the algorithm which converts the digital data to temperature.

5.1.1 Sensor Limitations. The physical limitations of the sensor itself involve chiefly those factors which affect the mechanical stability of the parts themselves and the manner in which they are joined. Qualitatively, the materials used are extremely stable. Fused silica and Dow Corning ULE are both used where extreme stability are the primary concern, for example in primary mirrors for large reflecting telescopes. However, as the sensing technique is capable of detecting very small displacements, this qualitative stability cannot be used to draw any positive conclusions concerning overall stability. It is thought that any definitive conclusions will have to await long-term testing of a complete instrument.

The methods used to make the joints between parts can likewise be said to be extremely stable. The expansion collar is attached to the base by glass fusion welding (using a glass frit designed for use with these materials). This fusion layer is both thin and stable. The sensor top is joined to the expansion collar by "optical contacting," a technique which involves getting the surfaces so clean and smooth that they come into such intimate contact that they are held together by molecular forces. Like the glass-frit fusion, this method is also, qualitatively, very stable. However, as with the parts materials, this known high stability cannot be used to draw positive conclusions on overall stability, and it is expected therefore that overall sensor stability must await suitable long term testing.

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OF POOR QUALITY

<u>5.1.2 Opto-Electric Converter Limitations.</u> The opto-electric converter introduces random fluctuations to the individual data points at the different wavelengths being measured. How these propogate through the system has not yet been studied.
in detail. However, additional software could be used to average such fluctuations over sufficient times as to minimize these effects.

<u>5.1.3 Analog/Digital Converter Limitations.</u> Like the opto-electric converter, the A/D converter introduces random fluctuations to the individual data points, and that effect can be treated in the same way as the random effects due to the opto-electric converter. The A/D converter, in addition introduces digitizing errors which can be treated in a somewhat similar fashion.

<u>5.1.4 Algorith Limitations.</u> The algorithm which is used to convert the raw data to temperature introduces limitations on the system accuracy. One set of tests which was performed on this limitation was conducted as follows: First a set of digital data was obtained from the D/A converter, and stored in microprocessor memory. Then this data was analyzed to determine the indicated temperature. Next, one element (representing one wavelength in the spectrum) was changed by the least significant amount. For example, there are 128 data points, and each can vary from 0 to 255. One of these was taken, and for example, if it had a value of 177, that value was changed in memory to 178, while the 127 other data points were left unchanged. The algorithm was again run, and a new indicated temperature was obtained. The algorithm was rerun before and after to insure that the results were repeatable, which they were. The resulting indicated difference in temperature was 0.000006 deg-C, or 6 micro-degrees-C. Out of a range of 1000 deg-c, this represents 1 part in 166 million. This represents the least change in temperature which can be detected by the algorithm. (The repeatability from run to run, using the <u>same</u> digital data, was better than this.)

In addition to the above, the nature of the algorithm contributes to the manner in which other errors are propogated. However contributions made by the algorithm itself to accuracy limitations appear to be totally negligible.

<u>5.1.5 Test Results.</u> The test results to date have shown the accuracy to be limited by random noise effects, which have values in the 1 deg-C range, except at the low temperature range, where, as explained elsewhere in this report, readings appear to be distorted, almost certainly, due to contact between the Fabry-Perot plates, something which will not occur in future sensors. Considering the above discussion on individual sources of accuracy limitations, better results than this should be expected. Reasons for this and system improvements which are expected to improve this noise figure are under study.

5.2 Resolution

Some of the factors affecting resolution are the same as those affecting accuracy, namely sensor limitations, opto-electric conversion, A/D conversion, etc.. For example, the limitation of the algorithm to 1 part in 166 million is a direct resolution factor. The digitizing limitation likewise is related. For example a digitizing error of 1 bit is the same 1 bit used in the above. Thus, if 128 points have a 1/2 bit average rms uncertainty, we might expect the rms error resulting to be $0.5 * (128)^{0.5} = 5.7$ parts in 166 million. Actually the weighting factor on different points is different; hence, this result will vary somewhat, but this calculation appears to indicate a proper order of magnitude.

5.3 Range

The instrument is designed for a 0 to 1000 deg-C range. However the testing done before delivery were limited to a 20 deg-C to 400 deg-C range. It is anticipated that any problems which might occur at the higher temperatures will be periferal, i.e., not inherent in the design.

5.4 Hysteresis

Accurate measurement of observable hysteresis will require more accurate testing than has been done to date. Because of different time constants of the thermocouple used as a reference, and the FP/T-1000, it was difficult to determine if there was any measurable hysteresis.

Theory wise, there are no obvious sources of hysteresis. The fused silica and the Corning ULE are very pure and should be expected to be very free of any internal hysteresis. The fused joint would be expected to have negligible hysteresis, as would the optical contact. Likewise there is no apparent source of hysteresis in the electro-optic converter, the A/D converter, or the computation algorithm. Hence, it appears that any measurement of possible hysturesis will have to await test results, which to date have not been extensive enough to detect any.