WL-TR-96-4006

REAL-TIME, SELF-DIRECTED MBE FLUX CONTROL INCORPORATING IN SITU ELLIPSOMETRY

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DECEMBER 1995

FINAL REPORT FOR 04/01/93-06/30/95

MATERIALS DIRECTORATE
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE DEC 1995

3. REPORT TYPE AND DATES COVERED FINAL 04/01/93--06/30/95

4. TITLE AND SUBTITLE REAL-TIME, SELF-DIRECTED MBE FLUX CONTROL INCORPORATING IN SITU ELLIPSOMETRY

5. FUNDING NUMBERS
C F33615-93-C-5329
PE 65502
PR 3005
TA 05
WU 53

6. AUTHOR(S) DAVID PALAITH

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
MATERIALS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7734

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TR-96-4006

11. SUPPLEMENTARY NOTES THIS IS A SMALL BUSINESS INNOVATION RESEARCH, PHASE 2 REPORT.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this program was to develop a process control technology that would be generally applicable for advanced materials processing and to transfer that technology to end users in industry and government. The specific goal was to apply the control concepts to fabrication of electronic and opto-electronic devices by thin film deposition using molecular beam epitaxy (MBE). MBE was chosen because it is the favored technique and yet suffers from long deposition times and relatively high device rejection rates.

The key results of this effort are detailed in this report. They include the development of a data logger, PID temperature control module with feedforward temperature compensation development, data logger and control module testing at the Materials Directorate and the Laboratory for Physical Sciences (LPS), along with future testing plans.

14. SUBJECT TERMS
Molecular Beam Epitaxy, MBE, Intelligent Process Control, Sel-Directed Control, In-Situ Ellipsometry

15. NUMBER OF PAGES ~~132~~

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The purpose of this program was to develop a process control technology that would be generally applicable for advanced materials processing and to transfer that technology to end users in industry and government. The specific goal was to apply the control concepts to fabrication of electronic and opto-electronic devices by thin film deposition using molecular beam epitaxy (MBE). This deposition method was chosen as the appropriate test bed for validation of the control methodology because MBE is the favored technique and yet suffers from long deposition times and relatively high device rejection rates.

During the Phase I effort, the control principles were confirmed and initial trials using ellipsometry as the in situ sensor showed considerable promise for improved process control. It was proposed that the three basic control elements, cell temperature, shutter status including compensation for transient flux response, and in situ ellipsometry be completed and incorporated into the two MBE machines in the Materials Directorate and beta test sites in other government or industrial laboratories.

The key results of this Phase II effort were:

- A data logger was developed and copyrighted by MLIM;
- PID temperature control module with feedforward temperature compensation, and digital control module were completed;
- Controls were installed on the MBE machine in the Materials Directorate;
- A data logger was installed on an MBE machine at the Laboratory For Physical Sciences (LPS) of the National Security Agency;
- Control modules will be installed at the LPS site in the near future;
- A data logger currently is being installed at a thin film magnetron sputtering facility.

Additional work is continuing as a Phase III program in which TA&T is working closely with MLIM to beta test, adapt and market all of the software modules under terms of a CRDA.

1. INTRODUCTION The leading edge of advanced materials development and commercialization activities requires continuous, rapid improvements in materials processing technologies. Repeatable processes that can be tailored to new material requirements and opportunities as they arise, and can be fine-tuned along the materials development learning curve are essential if economic advantages are to be realized. Thus, both research and development, and market penetration of new materials and products depend critically on progress in new processing technologies.

Current processing technologies are, in general, process specific. This creates an impediment to materials development and especially to dissemination of manufacturing technology. For example, details of the control methodology used in a rolling aluminum sheet mill are different than those used in a molecular beam epitaxy chamber for fabricating semiconducting wafers to atomic layer accuracy. The difference is not only one of scale, but more importantly, is one of different process parameter interrelationships. The process models are different and lessons learned from developing controls for one process do not necessarily aid in developing controls for a different process. It is clear that development of control schemes for new processes could greatly benefit from a uniform, generic process control approach that is isolated from process model specifics.

For the generic approach to succeed it is necessary to have flexible process control hardware and software architectures in place. Such an architecture then provides not only the backbone for development of advanced, *hierarchical process control* schemes, but also can serve, without further development, as a high quality conventional process control capability that can run with or without in situ sensors and/or ex situ, post-processing materials evaluation feedback, and also. In order to validate the usefulness of a particular control approach, the architectures initially should be developed and applied to specific materials fabrication technologies for which the economic payoff is measurable. For this development program, molecular beam epitaxy (MBE) growth of electronic and opto-electronic devices was chosen for the test bed.

Many of the performance driven demands of future Air Force weapon systems are dependent on the availability of advanced solid state devices and components fabricated from new semiconducting materials and processes. Examples of potential devices and associated defense applications include:

- ***active electronically-scanned arrays (AESA), like those being developed for the Air Force's Smart Skins program, which rely on wafer-scale integrated T/R modules consisting of an amplifier, attenuator and a phase shifter capable of shifting phase in less than 50 nanoseconds;***

- ***radars capable of operating above 10^{12} Hz;***

- ***opto-electronics modules for ultra-high-speed fiber optic communications and photo-detectors for high-speed thermal imaging in the F-16's low altitude navigation and targeting infrared for night (LANTIRN) system;***

- ***millimeter-wave monolithic integrated circuits (MIMIC), currently an integral part of the planned upgrade to the AN/ALQ-136 jammer for the AH-1 Cobra and***

AH-64 Apache (the Longbow radar/missile system) attack helicopters, and to the AN/ALQ-165 airborne self-protection jammer (ASPJ).

In all cases, the basic materials for these devices are the group (III-V) semiconductors based on aluminum-gallium-arsenide (AlGaAs) and indium-gallium-arsenide (InGaAs) using gallium-arsenide (GaAs) and indium-phosphide (InP) substrates, respectively. Although MBE is well-established as the preferable method for producing these solid state devices, the relatively low production yield that results from sensitivity to deposition parameters has kept the cost of devices high and productivity low. Process automation and control has been identified as one of the major challenges to MBE device processing, and remains the major obstacle to low cost commercialization.

This challenge could be met by achieving complete control over the MBE deposition process; specifically, real-time control of beam fluxes. Controlled alloy composition and film thickness with high product repeatability would result; process agility would be facilitated; technology transfer with wide dissemination would be accelerated. The specific payoffs include:

- improved device performance through tight control of deposition parameters and concomitantly close tolerances in materials properties;
- increased production throughput because
  1) wafers would contain fewer processing defects,
  2) when fatal defects do occur, it would be possible to abort the deposition before additional manufacturing resources are expended;
- a real-time process control system that would serve as a valuable development tool for engineering new semiconducting materials, and minimizing product development cycles and research expenditures.

These ideals could be realized by development of a state-driven and a goal-driven feedback control loop, and the demonstration of their autonomous control capabilities. The paramount purpose of these two loops, operating in concert, would be to control the molecular beam fluxes by a temperature set point shutter compensation system and ellipsometry feedback system that directly determines the composition and thickness of the growing film.

An additional control capability would oversee and integrate these two control loops into a supra-supervisory, self-directed control system, called the "Qualitative Process Automation" (QPA) system that was designed and developed at the WL/MLIM*. The goal of this system was to establish and maintain control boundaries, and effect control decisions not amenable to the strict logic of the first set of autonomous control loops. Thus, QPA would permeate all software modules of the MBE control system, and would be integrated into this system.

* Materials Process Design Branch, Integration and Operations Division, Materials Directorate, Wright Laboratory, Wright-Patterson AFB, OH.

2. PHASE I RESULTS During the Phase I effort, considerable progress was made toward establishing the potential of this process control methodology. Specific achievements include the following:

- A means for selecting optimum process conditions for the proportional/integral/derivative (PID) cell temperature controllers was demonstrated, and appropriate control modules were installed on the two MBE machines in the Materials Directorate at the Air Force Materials Laboratory.

- Bench testing of the Process Discovery Autotuner was successfully completed -- ahead of schedule. This software module is required for automation of the PID optimization process. Successful Phase II implementation was virtually assured by these Phase I results.

- A Shutter Opening Transient Compensator was tested in a concept design version. Bench testing resulted in a preliminary compensation function, demonstrating the viability of this approach for MBE flux control.

- An ellipsometer was installed on the Vacuum Generators MBE machine in the Materials Directorate and *in situ, real-time* measurements of Low Temperature-GaAs film growth were successfully made.

- Modular design of the overall MBE control system was completed.

3. PHASE II GOALS Based on these results, the overall objectives of the Phase II work performed under this contract can be itemized as follows:

- Achievement of fully automated first generation Qualitative Process Automation (QPA) process control over semiconductor devices grown by molecular beam epitaxy;
- Beta testing of first generation WL/MLIM-developed QPA control system, and development of a plan for commercialization;
- Identification and development of additional applications of QPA.

An overview of the process control loops for MBE is shown in Figure 1 where it can be seen that the individual software modules exchange information, receive data from sensors, and communicate with system actuators via a common communication line developed expressly for this system. It is called the Inter-Application Communication (IAC). A more detailed description of this same process control approach is shown in Figure 2.

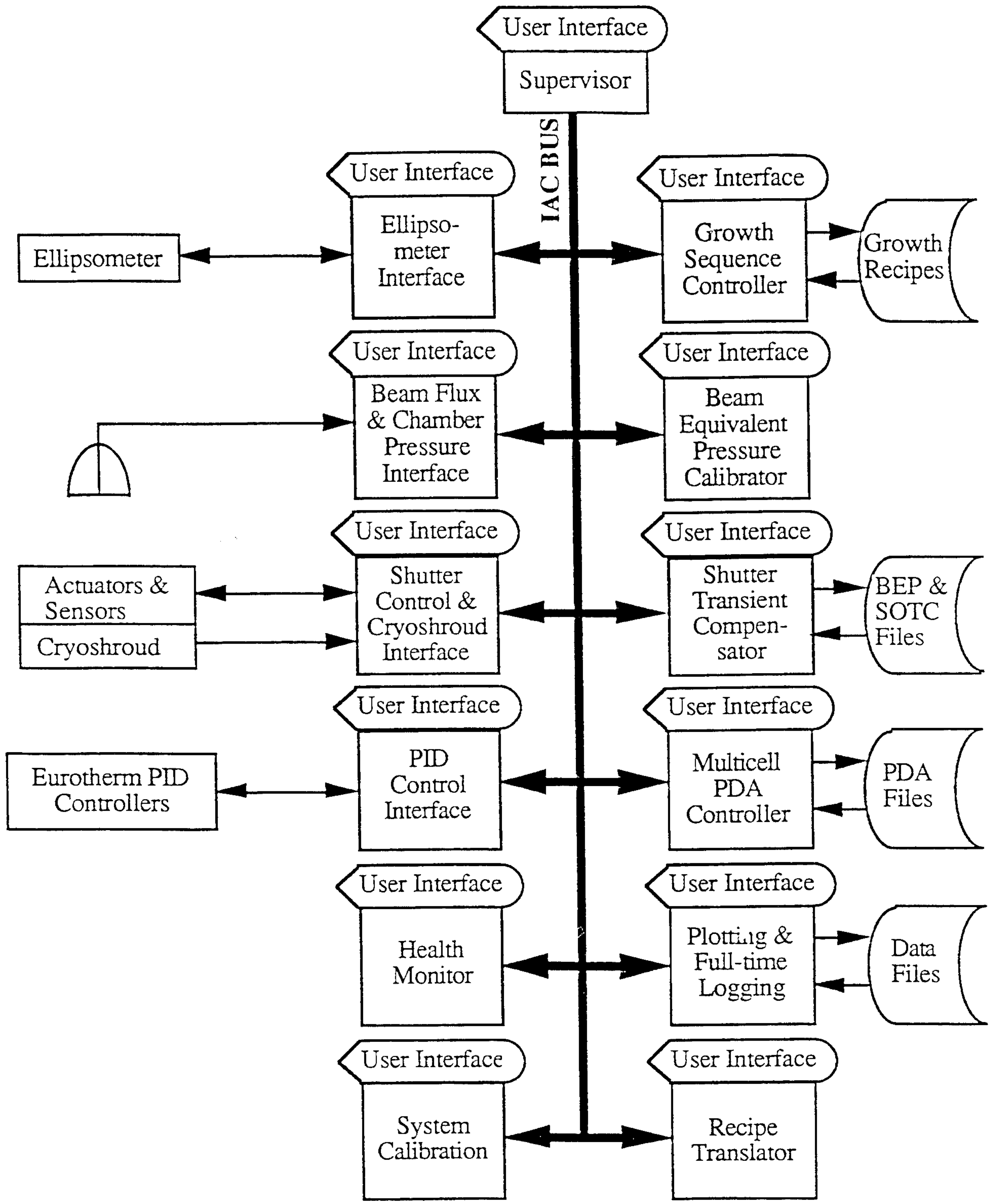


FIGURE 1 PROCESS CONTROL ELEMENTS

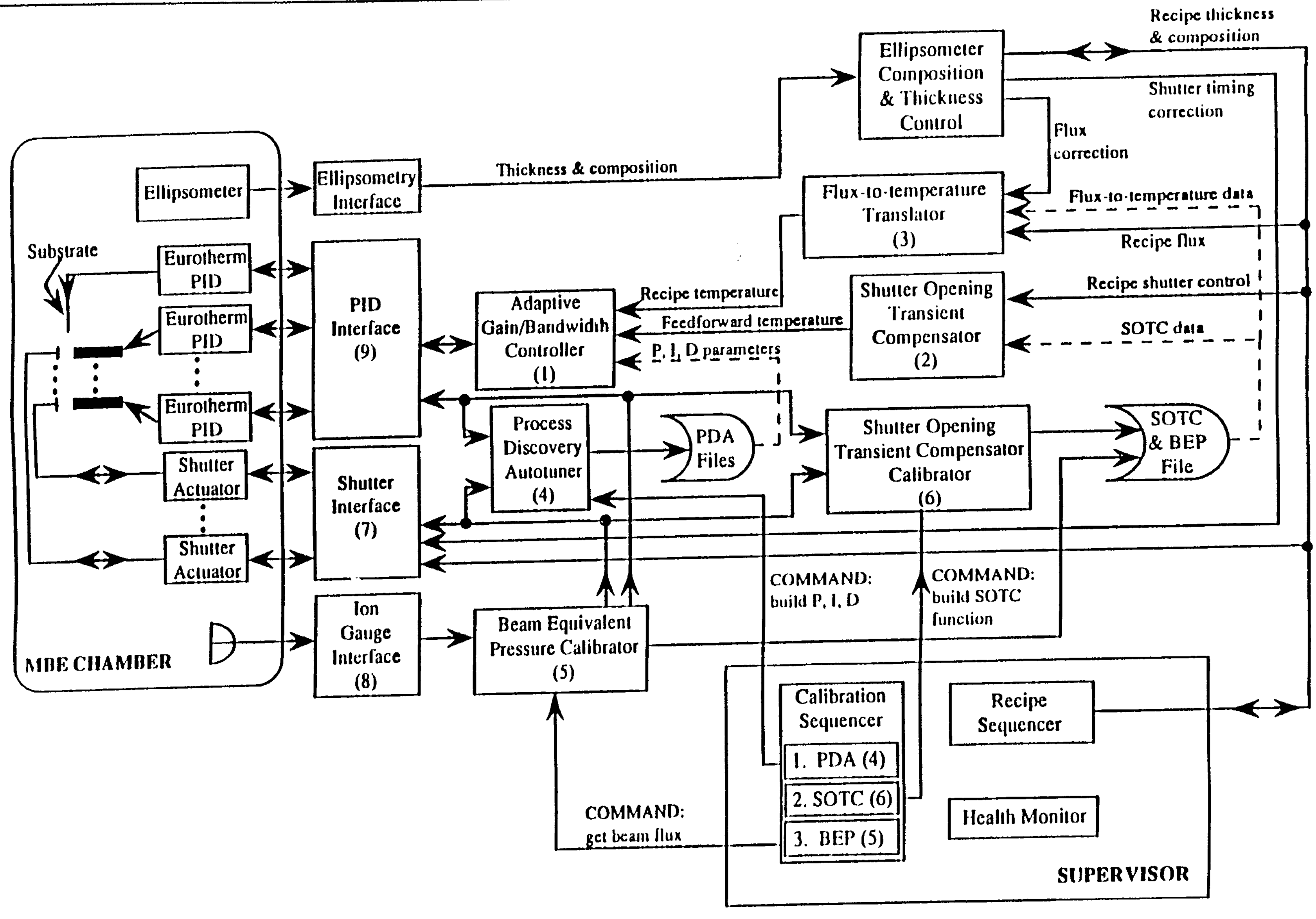


FIGURE 2 DETAILED PROCESS CONTROL BLOCK DIAGRAM

4. PHASE II TECHNICAL RESULTS -- DATA LOGGER The first requirement of the MBE process control scheme was the development of a data logger. Critical data to be recorded are cell temperature set point, actual cell temperature, shutter status, substrate temperature and substrate rotation rate. A cell label was associated with each cell temperature and shutter status so that the complete data word had to be large with the concomitant risk that the data set for a run could become unwieldy. This potential problem was avoided in the following manner. Since the data stream was synchronized to a clock, only changes in a parameter value needed to be logged in order to reconstruct the entire data set. This also eliminated the need to preestablish the time interval between data points. These comprise the critical data. Additional data needed for health monitoring but not recorded includes chamber pressure and cryo-shroud temperature.

A flow chart of the entire data logger that handles the data stream and creates the corresponding data files is shown on Figures B1 - B10 of Appendix B. This was developed in cooperation with MLIM and was patented by MLIM under the trade name, InfoScribe™. The user's manual for InfoScribe™ is included with this report as Appendix C. As discussed below under the section, "Technology Transfer," InfoScribe™ currently is under beta test at multiple sites that include materials processing techniques other than and in addition to MBE. ***Thus, the data logger not only has fulfilled the basic requirements of this program, but it already has reached wider applicability and is being tested in non-MBE process control environments.***

5. PHASE II TECHNICAL RESULTS -- PROCESS CONTROL Although the successful development, copy protection and marketing of InfoScribe™ is a major achievement of this program, it represents only part of the total effort. Materials by process design is the long-range goal and practical implementation is underway. A more immediate goal is control over molecular beam epitaxy deposition of thin films. This provides a concrete test bed for the much more general control concepts embodied in Qualitative Process Automation (QPA). As applied to MBE, the basic QPA block diagram is shown in Figure 2. The nine numbers in the blocks representing the software modules correspond to simplified flow charts shown in Figures 3 - 11. More detailed flow charts are presented in Appendix B.

The key control elements are those affecting PID temperature control and shutter control. PID control incorporates two key control modules. The *first* is a Process Discovery Autotuner (PDA) (item 4 and Figure 6) that determines individual cell responses to changes in the power input to each cell's heater. This information is obtained by having the PDA perform a series of experiments to determine the cell's temperature response to step set point changes around a series of ambient conditions, and to then determine the three PID feedback parameters that will optimize the temperature response. The flow charts for this software module are shown in Figures B11 - B20 of Appendix B. The *second* PID control module is an Adaptive Gain-Bandwidth Controller (item 1 and Figure 3) that utilizes PDA information to adjust the PID tuning parameters for each temperature change that is demanded by the growth recipe. The flow charts for this software module are shown in Figures B39 - B51 of Appendix B. A small module that interfaces the Adaptive Gain-Bandwidth Controller with the PID controllers and ensures no conflict in the data flow, is the PID interface (item 9 and Figure 11). The growth recipe does not, by itself, create demands for a cell temperature, but rather a demand for a beam flux of a particular growth species. Thus, it is necessary to convert beam flux into cell temperature for each cell. This conversion is accomplished by the Flux-to-temperature Translator (item 3 and Figure 5) using data acquired during beam flux calibration (item 5 and Figure 7). The flow chart for this module is shown in Figures B27 - B32 of Appendix B. In addition, beam flux data is acquired via an Ion Gauge Interface (item 8 and Figure 10). The operator's manual for PID software module developed jointly by TA&T and MLIM is included with this report as Appendix D.

The shutter control shown in Figure 2 also comprises two key control modules. Both work together to provide a means of compensating for flux transients that result when a shutter is opened in response to a growth recipe demand. This transient occurs because the heat load on a cell changes suddenly when a shutter is opened so that the instantaneous beam flux does not correspond to the anticipated flux for a given cell temperature measured immediately prior to the shutter opening. This calibration is called the, "shutter opening transient compensation." The *first* is the Shutter Opening Transient Compensator Calibrator (item 6 and Figure 8). An ion gauge is inteposed between the sample substrate and the cells. A series of experiments is performed in which shutters are opened after being closed for prescribed periods of time with the corresponding cell having been maintained at a prescribed temperature. This information is used to compute the parameters of a compensation function and these parameter values are stored in the SOTC & BEP Data File. Upon demand from the recipe, the *second* module, the Shutter Opening Transient Compensator (item 2 and Figure 4) uses the SOTC data to determine how far in advance and by what amount the cell temperature should be adjusted in order to anticipate the upcoming transient. Thus, the output of the SOTC provides input to Adaptive Gain-Bandwidth Controller (item 1). The flow charts for this module are shown in Figures B21 - B26 of Appendix B. Commands to the shutter actuators are coupled via a Shutter Interface (item 7 and Figure 9). The operator's manual for the corresponding digital I/O module is included as Appendix E.

Finally, all sensor data must be read whether it is to be stored by the data logger or used as part of the controls. The flow charts of the software module that accomplishes this are shown in Figures B33 -B38 of Appendix B.

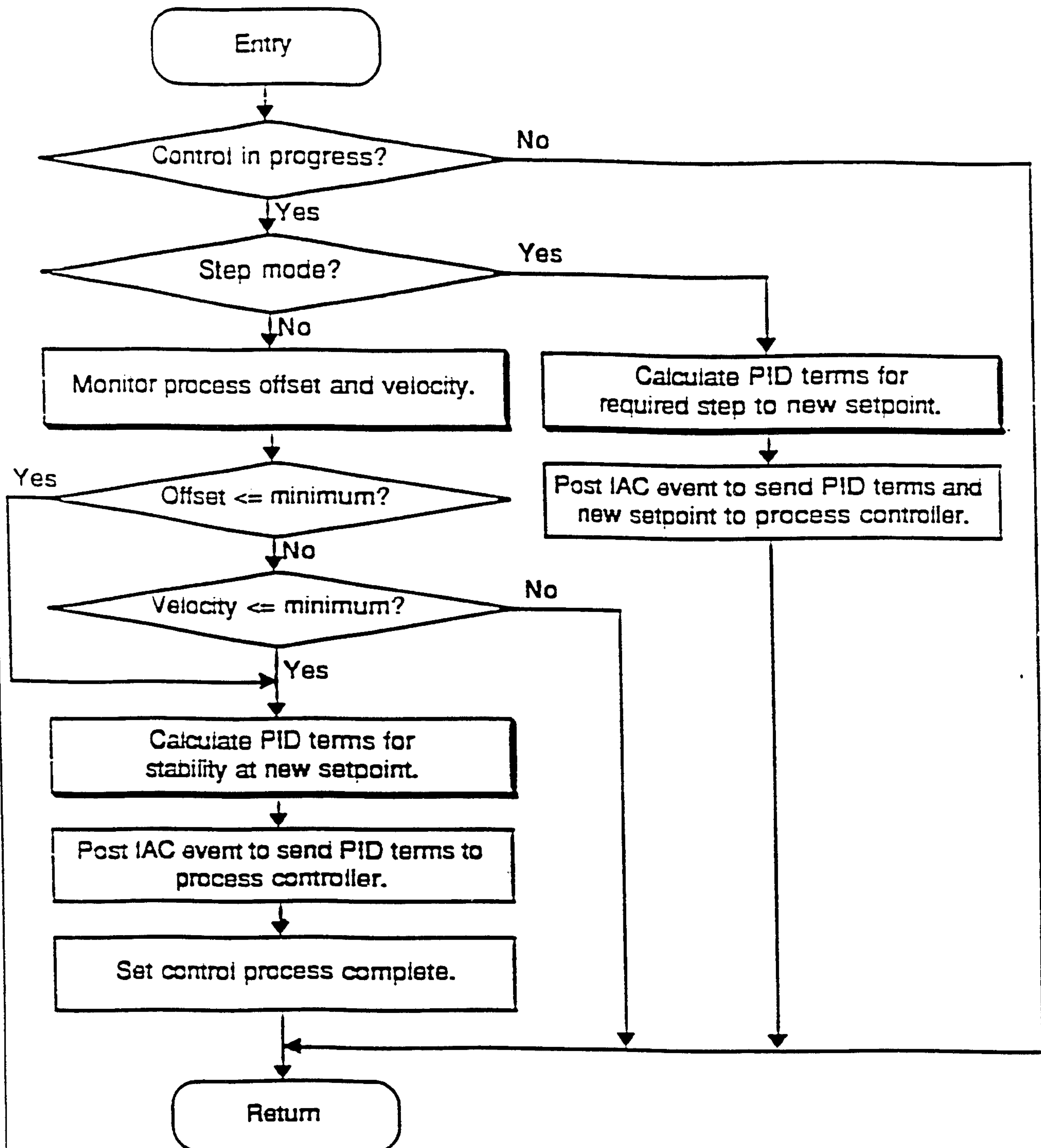


FIGURE 3 ADAPTIVE GAIN BANDWIDTH CONTROLLER

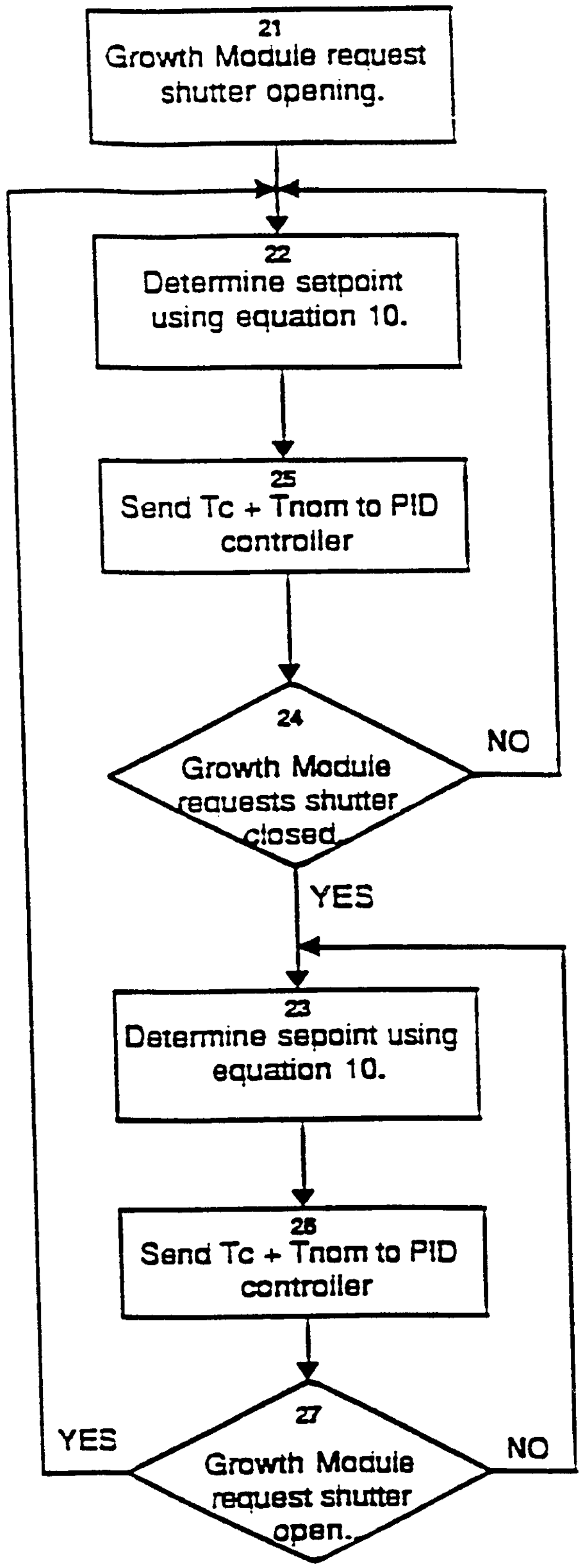


FIGURE 4 SHUTTER OPENING TRANSIENT COMPENSATOR

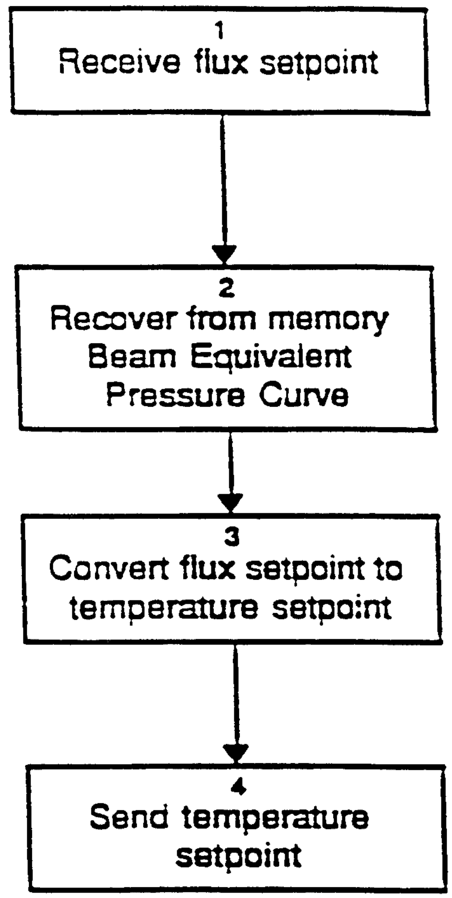


FIGURE 5 FLUX-TO-TEMPERATURE TRANSLATOR

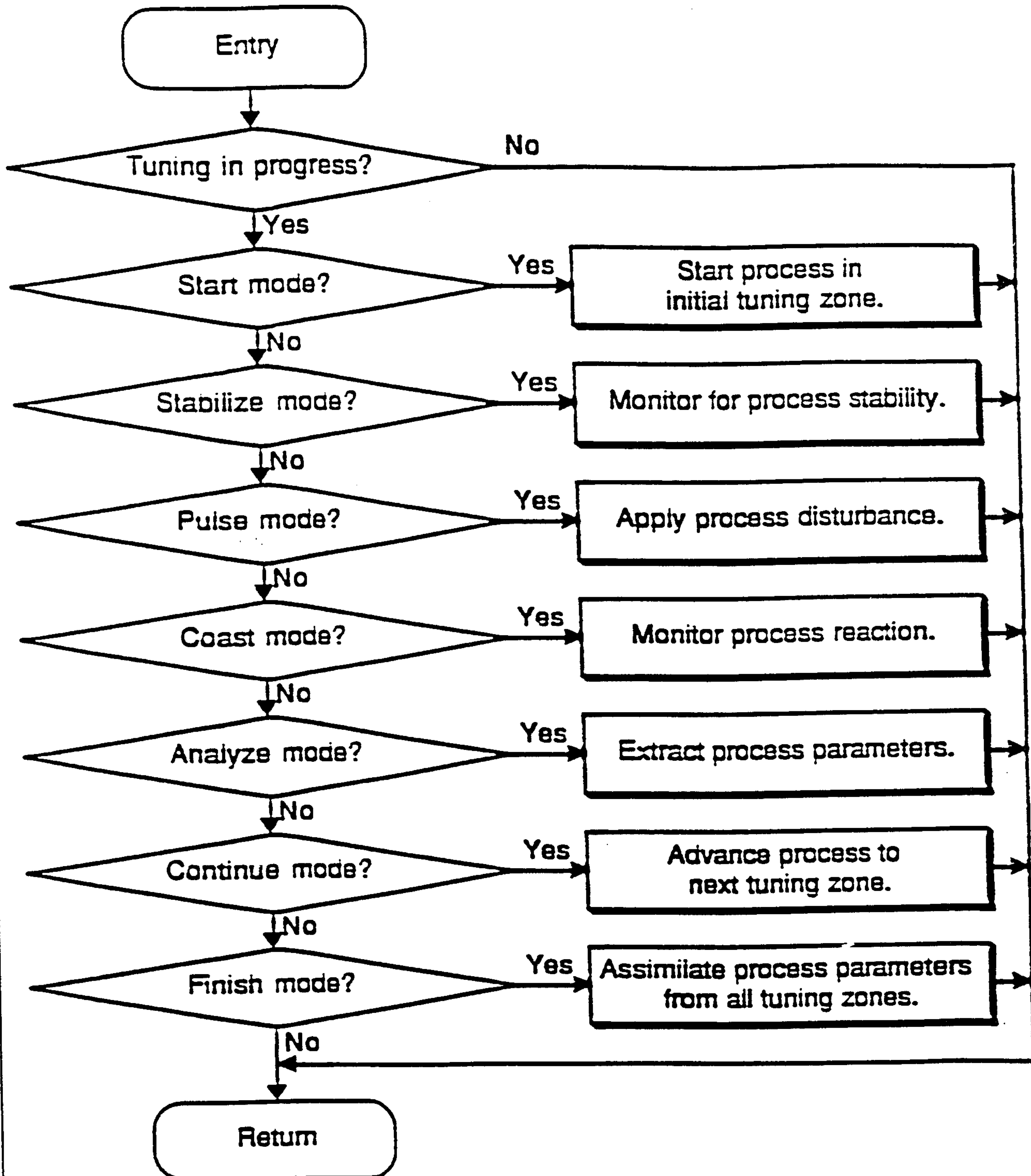


FIGURE 6 PROCESS DISCOVER AUTOTUNER

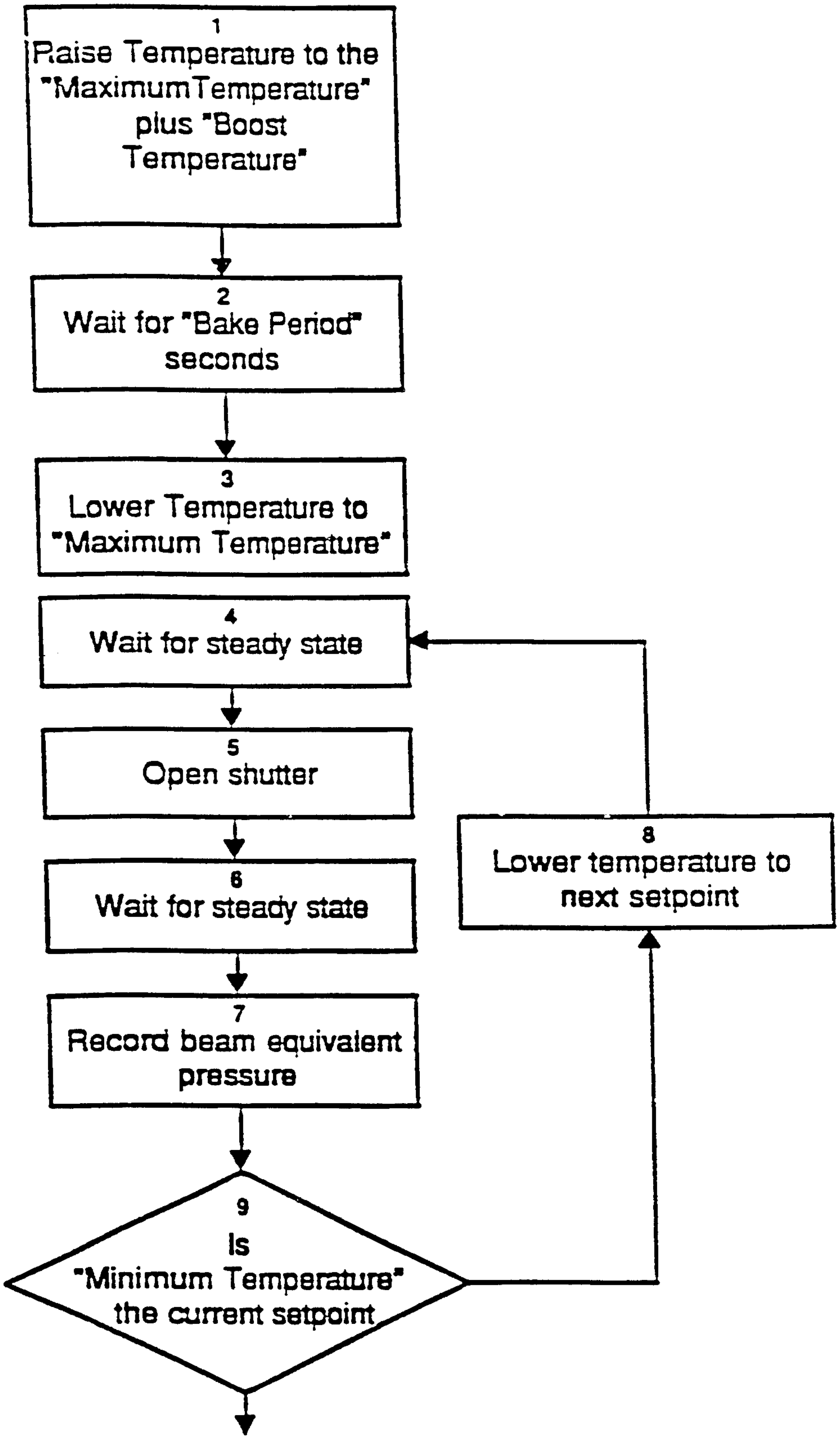


FIGURE 7 BEAM EQUIVALENT PRESSURE CALIBRATOR

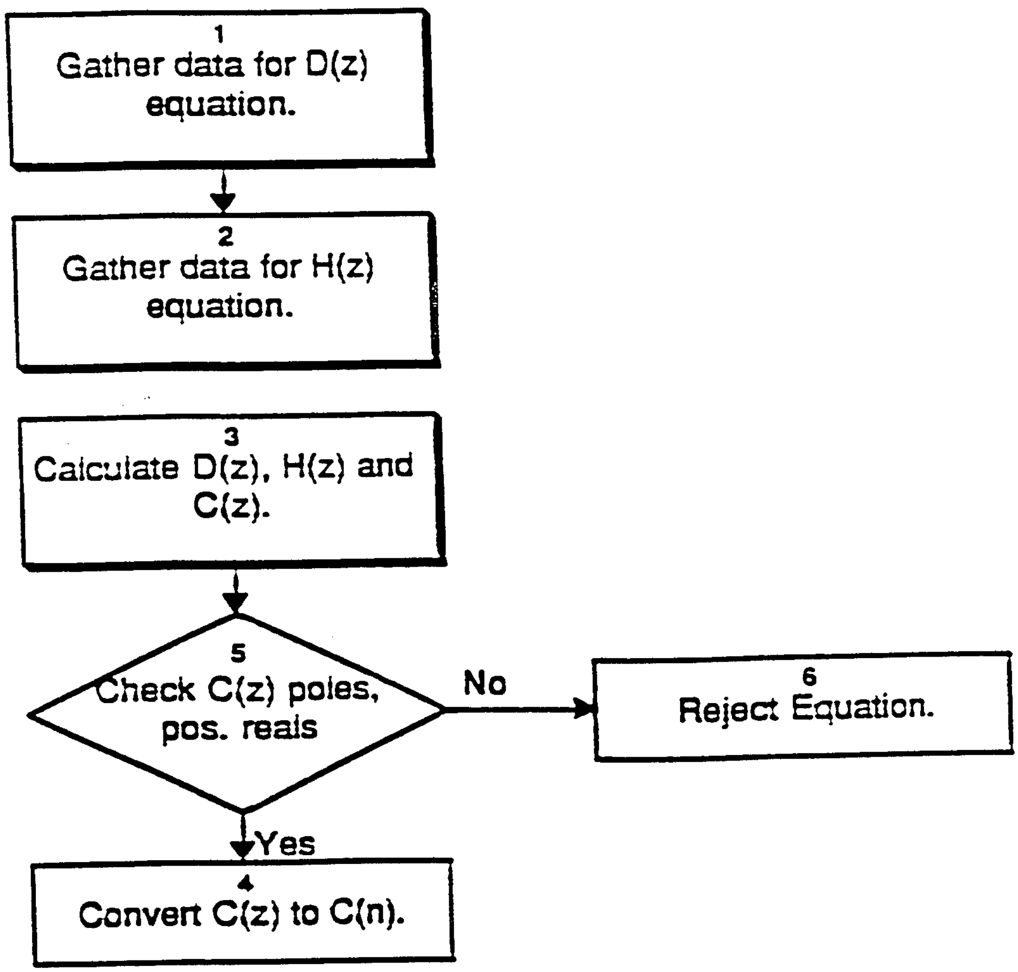


FIGURE 8 SHUTTER OPENING TRANSIENT COMPENSATOR CALIBRATOR

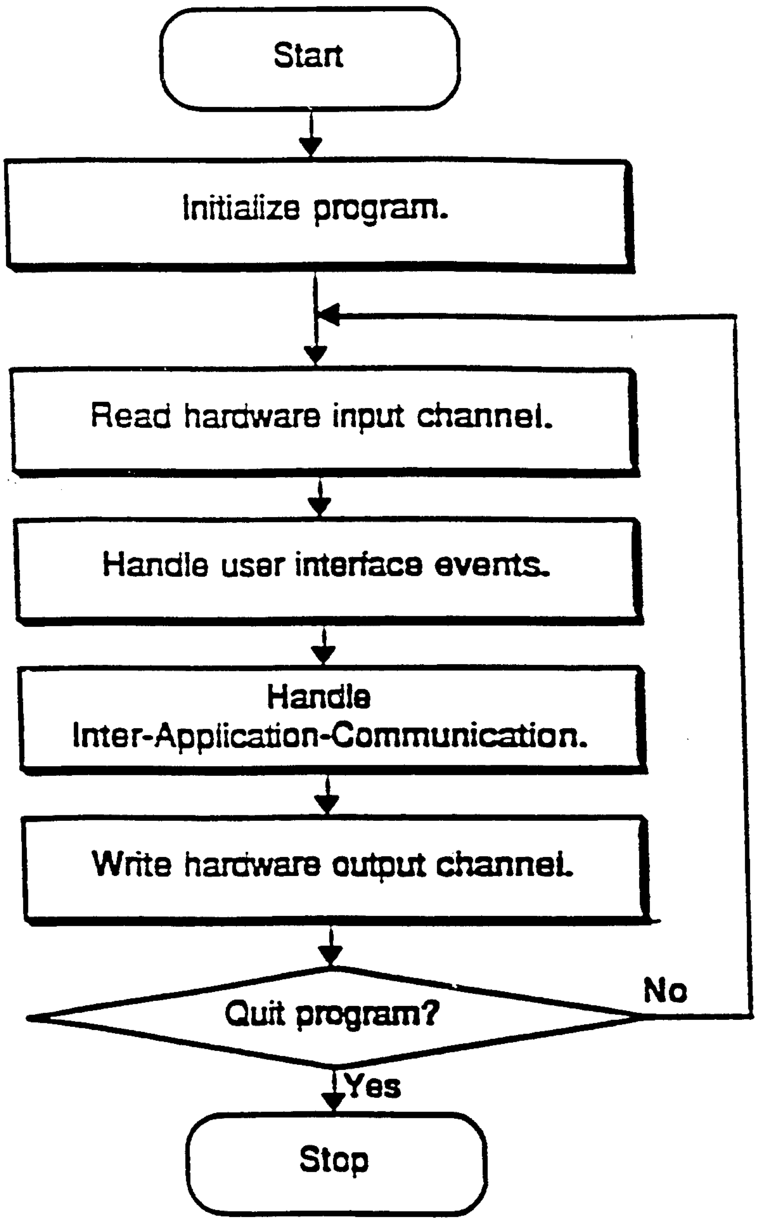


FIGURE 9 SHUTTERS INTERFACE

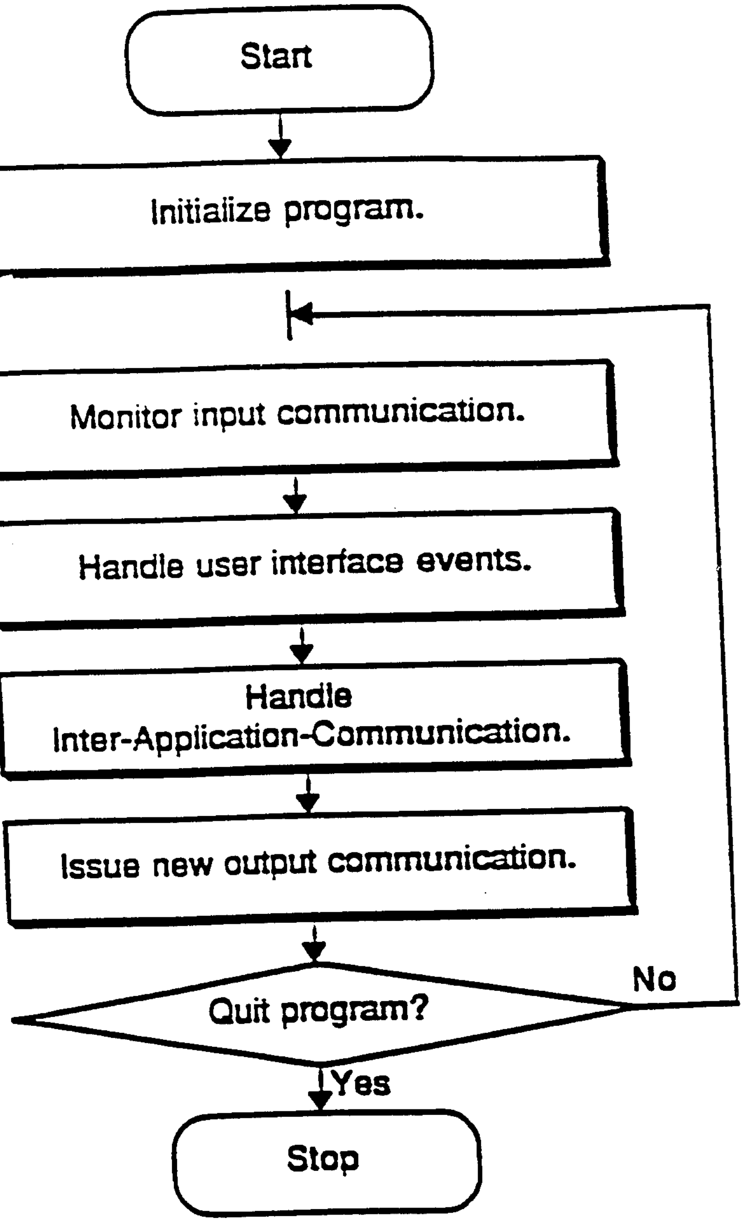


FIGURE 10 ION GAUGES INTERFACE

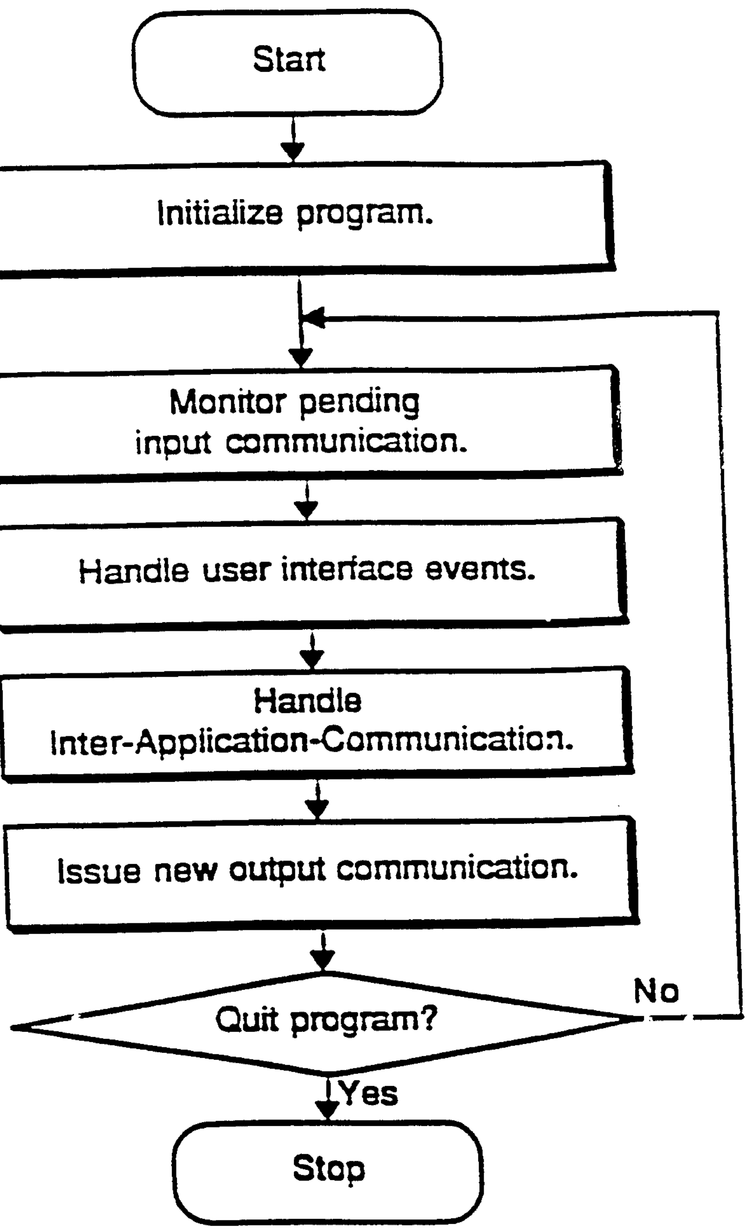


FIGURE 11 PID CONTROLLERS INTERFACE

The ellipsometer was to be used as an in situ sensor to provide alloy composition and film thickness during growth. This information then was to be used to change PID set points and to override or pre-empt shutter opening and closing commands. In order to reach this objective, two goals had to be achieved: reliable MBE machine control as described in the preceding paragraphs, and reliable codes that could separate alloy composition from thickness effects. In the first case, many versions of each of the control modules described above were very extensively tested on one of the MBE machines in the Materials Directorate. It was felt that none of these provided sufficient robustness for unattended operation. For example, both the PID tuning equation and the shutter transient equation went through numerous revisions in search of the optimum control function. The original trapezoidal tuning was found to be too slow for some growth conditions, and a shutter transient compensation function that accurately reproduced the observed transients under all conditions was very difficult to develop. In the second case, difficulties in reducing ellipsometry data would have made interfacing the ellipsometer with the MBE machine difficult.

The ellipsometer output is sensitive to three pieces of materials information: real part of the dielectric constant, imaginary part of the dielectric constant and the film thickness. But the ellipsometer provides only two pieces of information: amplitude and phase of the reflected light. But with information regarding the film extracted from ex situ measurements, it is possible to improve the probability of extracting all three growth parameters. Two methods were tried during this work. The first used a method of least squares fitting the measured data to expected behavior. The second employed an artificial neural network to perform the data inversion. The neural network approach appeared superior until it was realized that the parameter space had been truncated as if the range of parameter values were known in advance -- which, in general, they are. This truncation procedure was never applied to the least squares method so no fair comparison was possible.

A final impediment to implementing in situ ellipsometry control was that the interface was not completed. Since the beginning of this work, the ellipsometer manufacturer, Woolam, has produced a multispectral ellipsometer that should greatly reduce the complexity of separating thickness and alloy composition. The Woolam software provides these parameters directly so that coupling an ellipsometer interface to a reliable PID and shutter controller would provide the neede MBE process control. This work is continuing under a Phase III effort.

6. TECHNOLOGY TRANSFER A major aspect of the Phase II program was joint WL/MLIM-TA&T effort to transfer the control system to two 'beta' (operational test) sites for evaluation and refinement in actual manufacturing environments. The transfer of the technology is not always straight forward, and often requires considerable support and interaction with the installation site. This premise certainly held true throughout the Phase II effort. This effort is continuing under the terms of a Cooperative Research and Development Agreement (CRDA) between TA&T and MLIM.

- One site is the Laboratory for Physical Sciences (LPS) at the University of Maryland. This laboratory is operated for the National Security Agency with a charter to explore the frontiers of a broad spectrum of advanced electron and electro-optic devices grown by molecular beam epitaxy.

- The second site is TA&T's precision thin films and coatings group located at Millersville, MD. The immediate application is for data logging the more than 16 process parameters each of which is critical to magnetron sputtered thin film performance and product reproducibility.

These technology transfer successes are discussed in detail in the following sections and summarized along with the current and future technology needs in Table 1.

7. TECHNOLOGY TRANSFER LPS INSTALLATION Currently, the Vacuum Generator (VG) MBE machine at LPS is controlled by a Eurotherm PC3000 slave computer which, in turn, is directed by a host computer. Instructions are written to the host computer where VG software is used to convert them to low level commands that are sent to the PC3000 controller. Prior to the MLIM/TA&T installation, there was no data logger running with the LPS MBE. Furthermore, installation of a data logger was considered to be a necessary first step in the development of process control. To proceed with this plan, an Apple Computer, Quadra 950 computer with a 17" monitor and several data I/O boards was installed adjacent to VG MBE machine in the MBE clean room at LPS. The long term plan is, of course, to replace the host computer with the Quadra and use it to run InfoScribe™ as well as future control software developed by MLIM. In the interim it was necessary to implement data logging using the Quadra *with the host computer in place*. The data logging requirements are shown in Table 2.

TABLE 1 SUMMARY OF JOINT WL/TA&T TECHNOLOGY TRANSFERS

SITE	PRODUCT DESCRIPTION & PRODUCTION METHODOLOGY	CURRENT TRANSFERRED TECHNOLOGY	FUTURE TECHNOLOGY REQUIREMENTS
LPS	Advanced electronics, semiconducting thin film devices by molecular beam epitaxy.	InfoScribe™ (MLIM's advanced data logger)	Full process automation including recipe generator
MAGNETRON THIN FILM SPUTTERING FACILITY	Advanced thin films for wear, erosion and corrosion reduction, and thermal barrier applications.	InfoScribe™ (MLIM's advanced data logger)	Full process automation including recipe generator

TABLE 2 LPS MBE DATA LOGGING REQUIREMENTS

PROCESSING PARAMETER NAME	NUMBER OF PARAMETERS
Cell temperature	8
Shutter state	8
Substrate temperature and sample rotation	2

Interfacing between the Quadra and the MBE machine was not straight forward. In order to log data, it appeared necessary to know the structure of the data stream sent and received by the host computer. However, VG claimed that the structure of this data was proprietary information and would not divulge it in spite of numerous discussions both with their representative here in the States and with their headquarters in the UK. They claimed they were developing their own data logger. Thus there were two problems that had to be solved:

- hardware interfacing with the VG's host computer remaining in place,
- communication through this hardware interface with the PC3000.

Progress in solving the first problem came when TA&T was successful in acquiring schematics of the cabling for both the shutters and the Eurotherm PID controllers. Yet, even with these schematics, two secondary problems were encountered. First, unconventional shutter connectors had been used by VG. After additional conversations with VG, TA&T learned that these were made by a British company, AERCO, with no U.S. distributor. TA&T pursued this and purchased eight connectors and prepared the necessary cables. Second, each available shutter signal was directed to the shutter control module and provided a 12 volt actuation signal rather than the standard 5 volt TTL level. MLIM contracted to have an adapter made outside the base. It was incorrectly wired so TA&T redesigned it and built it inside of a connector. MLIM then made the first of several trips to LPS to evaluate and implement technical aspects of shutter logging interface. The mechanical interface of the PID temperature controllers to the Quadra 950 was considerably easier than the shutter control interface.

With regard the second problem, implementing PID temperature logging presented a major challenge. On other MBE machines running in the Materials Directorate, PID parameter data is acquired by a command-reply sequence. A command is sent to the PID and the reply is received. Timing of the reply is, therefore, synchronized with the command. After another visit by MLIM to LPS, MLIM determined that in the LPS system, this timing is controlled by a host computer that controls the Eurotherm PC3000. In order to implement data logging and, subsequently, process control, this host computer had to be paralleled by the Quadra 950. Thus, this critical data synchronization was not available to the Quadra 950 and a polled data scan revealed considerable timing disorder. Essentially, a command was sent from the host computer to the Eurotherm PC3000 and this was followed by a reply, but there was no instrument identification. LPS would not allow MLIM or TA&T to implement a command-reply approach through the Quadra 950 because they wanted command protocols to remain in their host and did not want machine processing commands to be sent by the data logger. Therefore, data logging had to be implemented in a monitor-only mode.

An indirect approach to reestablishing data synchronism was developed by MLIM. The code was written by MLIM, sent to TA&T, TA&T went to LPS and ran the experiment in the clean room and then sent the data disk back to MLIM. Two routines were run. In the first, a control monitor protocol test, the serial port was polled, data stored in a buffer, and an attempt made to decipher the data structure. ***Already knowing the Eurotherm protocols, a data pattern was surmised and it was assumed that this would be readable if a fixed time synchronization could be established.*** The second, an interrupt-driven routine, detected the character of a command and used it to initiate storage of the entire command in a buffer before the reply was sent. Immediately following this, the reply also was received and stored. The command contained the instrument identification, and the reply contained the parameter identification and value.

Once this data had been analyzed by MLIM, InfoScribe™ interface programs were modified for use with the VG MBE machine at LPS. MLIM then made a final installation/support visit to LPS and completed installation as far as possible at that time. MLIM made additional revisions to the software and sent the completed version to TA&T who returned to the clean room and installed it on the Quadra 950. As often happens with new software, it did not run smoothly at first, but with TA&T working by phone from the clean room with support from MLIM the data logging system was made fully operational.

Perhaps an even more impressive achievement was the fact that in order to obtain a complete data set it was necessary to run six of these interrupt-driven routines simultaneously. The original routine was copied and installed. ***All three banks of Eurotherm PID controllers were monitored seamlessly with no cross interference. This is a clear indication of the high quality code produced by MLIM.***

Finally, the logos of Wright Laboratory, TA&T and LPS were added to the data logger display in time for display at the North American MBE Conference hosted in September by the University of Maryland.

8. TECHNOLOGY TRANSFER THIN FILM DEPOSITION INSTALLATION

A second Apple Computer, Quadra 950 computer with a 17" monitor and several National Instrument data I/O boards were installed adjacent to a thin film, magnetron sputtering system in the thin film deposition clean room at the thin film sputtering facility. The sensors and logging requirements are given in Table 3 on the following page.

TA&T designed and fabricated a sensor interface hardware module in which sensor lines could be reconfigured to be compatible with the data I/O board requirements, and in which the data levels could be filtered, shifted and/or windowed. Thus, all sensor lines now are input to a common hardware module the output of which connects directly to the computer. There are several advantages to this approach.

- First, the magnetron sputtering system generates sufficient extraneous RF radiation to interfere with other sensor signals. For example, in one earlier arrangement the outputs of the gas mass flow controller's flow sensors were connected directly through a ribbon cable to one of the computer I/O boards through the interface module. However, RF interference was so severe that when the magnetrons were energized no gas flow control was possible. Since the flow data passed through the interface module, it was easy to eliminate this problem by reverting to the RS232 port available on the flow controllers own control module.

TABLE 3. LOGGING REQUIREMENTS OF THIN FILM DEPOSITION SYSTEM

PROCESS PARAMETER	SIGNAL CHARACTERISTIC	NUMBER OF SIGNAL CHANNELS REQUIRED
Gas mass flow	digital (available on RS232)	2
System partial pressure	analog	1
DC power voltage	digital	1
current	digital	1
power	digital	1
RF power supplies forward power	analog wattmeter	2 x 3 = 6
reflected power	analog wattmeter	2 x 3 = 6
DC bias voltage	analog	1
current	analog	1
Rotation speed	analog	1
Diffusion pump valve aperture	analog	1
Targets shutters status	analog	1
Film deposition rate	analog	1

- Second, many sensors provide output levels that are out of range of the requirements of the computer I/O boards because the manufacturer never intended the sensor levels to be read by any computer interface. A good example of this is the RF levels -- key data for the logger.
- Third, many sensors provide signal levels that are always within ranges when the system is operating correctly. Signal levels outside these ranges are indicative of some system malfunction, and levels within these ranges must be accurately recorded. An example of this is the chamber pressure which provides output from atmospheric pressure to below 10^{-6} Torr but the operating is 10^{-3} to 10^{-4} Torr. Thus, bracketing the corresponding sensor output level and then expanding it to match the full ADC range would provide maximum pressure accuracy.
- Fourth, background signals as well as spurious RF radiation still can effect sensor signals and, therefore, their recorded values. For example, it was discovered that the temperature recorded by an unshielded thermocouple wire was sensitive both to 60 Hz radiation from nearby transformers and low-level magnetron radiation. Filters on the interface module can eliminate these sources of error.

Every data logging environment is different. This is due not so much to the different signal levels since the hardware interface module described above can smooth out many of these differences. The differing nature of the data streams is the key reason. Therefore, it was necessary at this development stage that MLIM visit the thin film sputtering facility and collect sample data from the sputtering system. This data comprised gas mass flow sensor levels. In this case, these data must be polled using a specific protocol, and the actual flow rates calculated by applying a special algorithm to the return value. In some respects this is similar to having to know the Eurotherm PID protocols. Each sensor will have its own special interface and interpretation problems. TA&T and MLIM will continue to work together to ensure that InfoScribe™ is successfully integrated with the magnetron sputtering system at the thin film sputtering facility.

9. TECHNOLOGY TRANSFER -- FUTURE PLANS The future of the joint MLIM-TA&T technology transfer will take three directions -- completion of the LPS installation and the thin film sputtering facility installation, establishment of new beta test programs for other fabrication methods, i.e. chemical vapor deposition and chemical vapor infiltration and licensing and transferring control software to individual users. EPI, the only U.S. manufacturer of MBE systems is interested in the calibration and shutter transient compensation modules.. This work is being performed under the terms of a joint CRDA.

Six tasks have been defined for the LPS installations. These are

Task 1	Installation of automatic data logger
Task 2	Automated growth rate calibration
Task 3	Automated doping concentration calibration
Task 4	Thermal transient compensation calibration
Task 5	Alloy composition definition
Task 6	Intelligent prediction (recipe) growth.

Task 1 was completed with the installation of InfoScribe™ at LPS. Operating manuals are completed and will be provided in the near future. Installation of the process control modules, including the PID and digital modules, will begin by the end of the year. Currently, they are under final test in the Materials Directorate.

At the thin film sputtering facility, InfoScribe™ will be installed first. This is an ideal site at which to test the flexibility of the data logger because TA&T has unrestricted access and will be readily able to communicate data to MLIM and receive via Modem software designs and modifications that MLIM develops. This should occur in two stages. First, on the basis of the gas mass flow signal data captured by MLIM, logging this data should begin in the near future. Second, this will require installation of InfoScribe™ which then will permit TA&T and MLIM to work together to begin recording other sensor values. TA&T is eager to receive and experiment with InfoScribe™ at its thin film magnetron sputtering facility because its thin film deposition technology requires detailed knowledge of the processing parameter values in order to achieve high reproducibility for production "toll coating" services and to accelerate the development of new multilayer films.

There are several additional opportunities for both InfoScribe™ and the control modules. One is the EPI MBE at LPS. This is a new MBE installation and incorporates Woolam's 44-wavelength ellipsometer for in situ process control. Control of the EPI machine is accomplished via a scripting language known as, MOLLY. Some dissatisfaction over the use and flexibility of MOLLY has been received from LPS. This dissatisfaction is related to the ellipsometer, not because any known weaknesses in the ellipsometer itself, but because the interface with the MBE machine is not as seamless as Woolam had promised. Woolam has software that provides thickness and composition rapidly and accurately. But if the interface is flawed or if MOLLY can not meet its control obligations, MLIM may be able to enter the breech. In this case there will be no competition because the EPI machine is in the same clean room at LPS as the VG machine that is currently running with InfoScribe™. Thus, MLIM might wish to increase the priority of installing the control modules on the VG machine as this is a rare marketing opportunity.

Two more opportunities exist at Ceramic Composite Incorporated. Both are for data logging and process control of chemical vapor infiltration (CVI) and chemical vapor deposition (CVD). One set of CVD furnaces uses conventional induction heating, and the other two use microwave heating. Temperature and gas flow, mixture and pressure are the key processing parameters in both systems. Currently, these are logged separately by hand so that correlations among the data are very difficult to detect and, due to this difficulty, seldom are sought. Yet the product depends very critically on the processing details so that a data logger would be a major improvement. Furthermore, substantial processing improvements can be made if the temperatures and gas flows and mixtures can be made time dependent in some prescribed manner. Without process controls, this is nearly impossible. With regard to microwave CVI processing, CCI already has an acute need to fix magnetron power levels automatically. Also, it is planned that data logging and control of both systems use PC platforms, dependent on the functionality of real-time dynamic data exchange (DDE). Since TA&T has unrestricted access to these facilities, TA&T will work closely with MLIM to support this cross platform migration of InfoScribe™ and the control modules.

Finally, TA&T has recently completed a Phase I STTR with the University of Cincinnati to develop process control methods for CVI. During this work it was demonstrated how artificial neural networks could be used in conjunction with physics-oriented models of the process to create process control models. In the Phase II submission it is proposed that X-ray radiometry measurements of material density be used as the direct in situ sensor for process control. If awarded, a portable version of this sensor concept will be fabricated and used with both microwave and conventional CVI processing at CCI. This will provide additional facilities for InfoScribe™ and especially the control modules, that ultimately will lead to Materials By Design processing and Intelligent Materials Process Control. Once these full up control systems are refined for the MBE, magnetron sputtering and CVD/CVI deposition methods, TA&T will undertake a concerted effort to sell these tailored control systems to equipment manufacturers and end users. In addition to a broadbased relationship with EPI, TA&T already has developed good contacts with magnetron sputtering equipment manufacturers such as Denton Vacuum Equipment Co., Integrated Vacuum Technology, TEER Coatings, Inc., CEME-CON, and Hauszer Techno-Coating. The same is true for CVD equipment manufacturers. Potential end users will be accessed through Trade Show, Internet, direct mailing and salesman follow ups and manufacturer representative.

APPENDIX B

SOFTWARE MODULES -- FLOW CHARTS

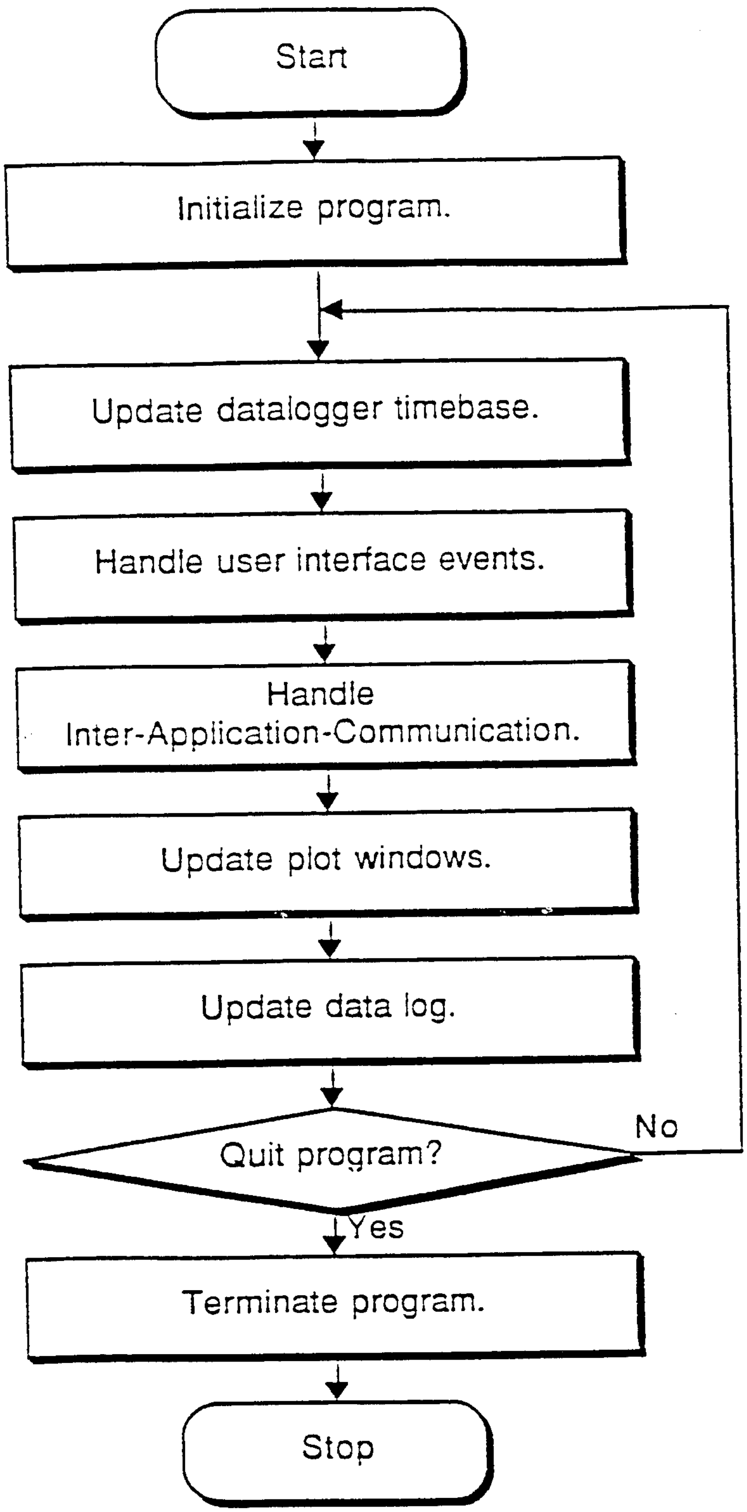


Figure B1. Data Logger Main Program Loop.

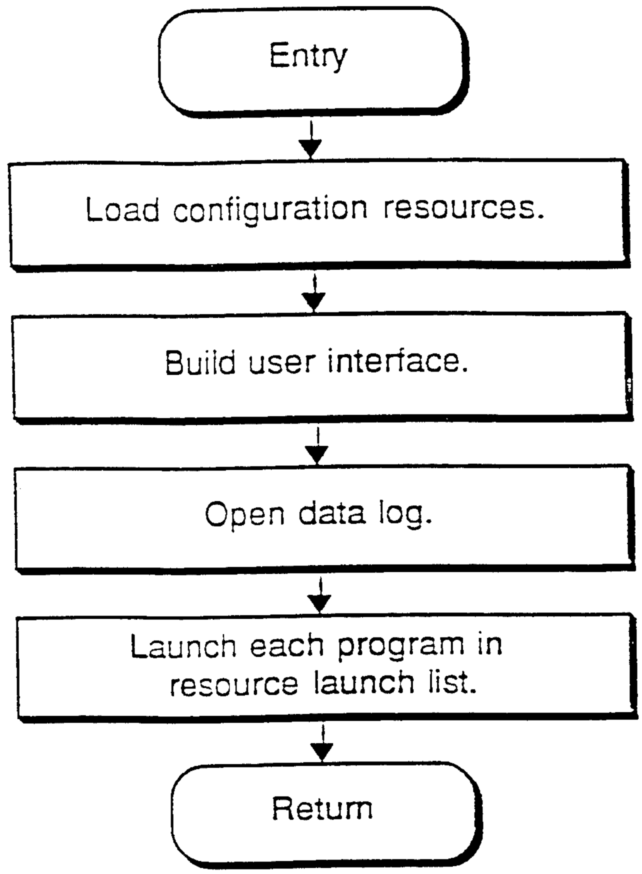


Figure B2. Initialize Program.

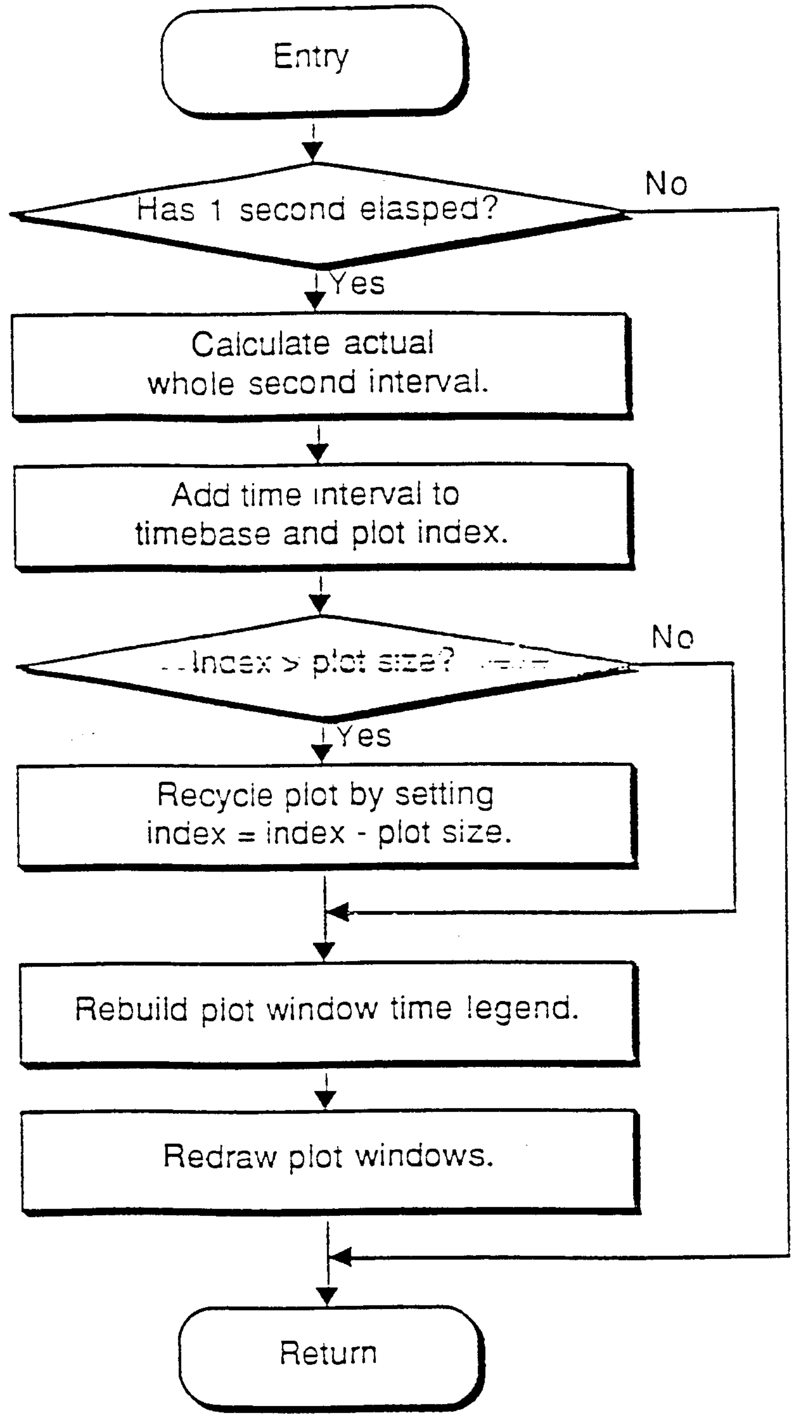


Figure B3. Update plotter-recorder timebase

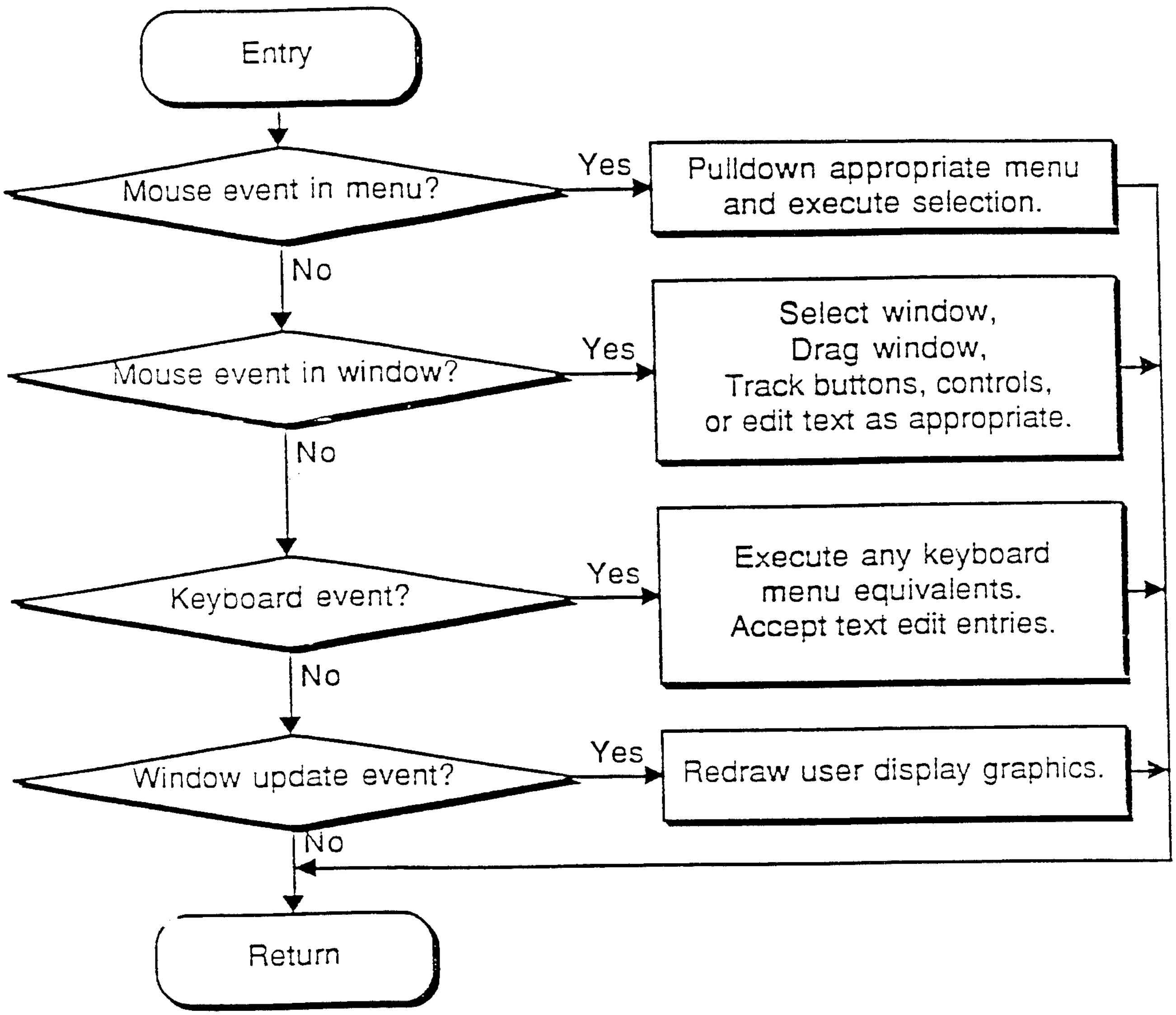


Figure B4. Handle user interface events.

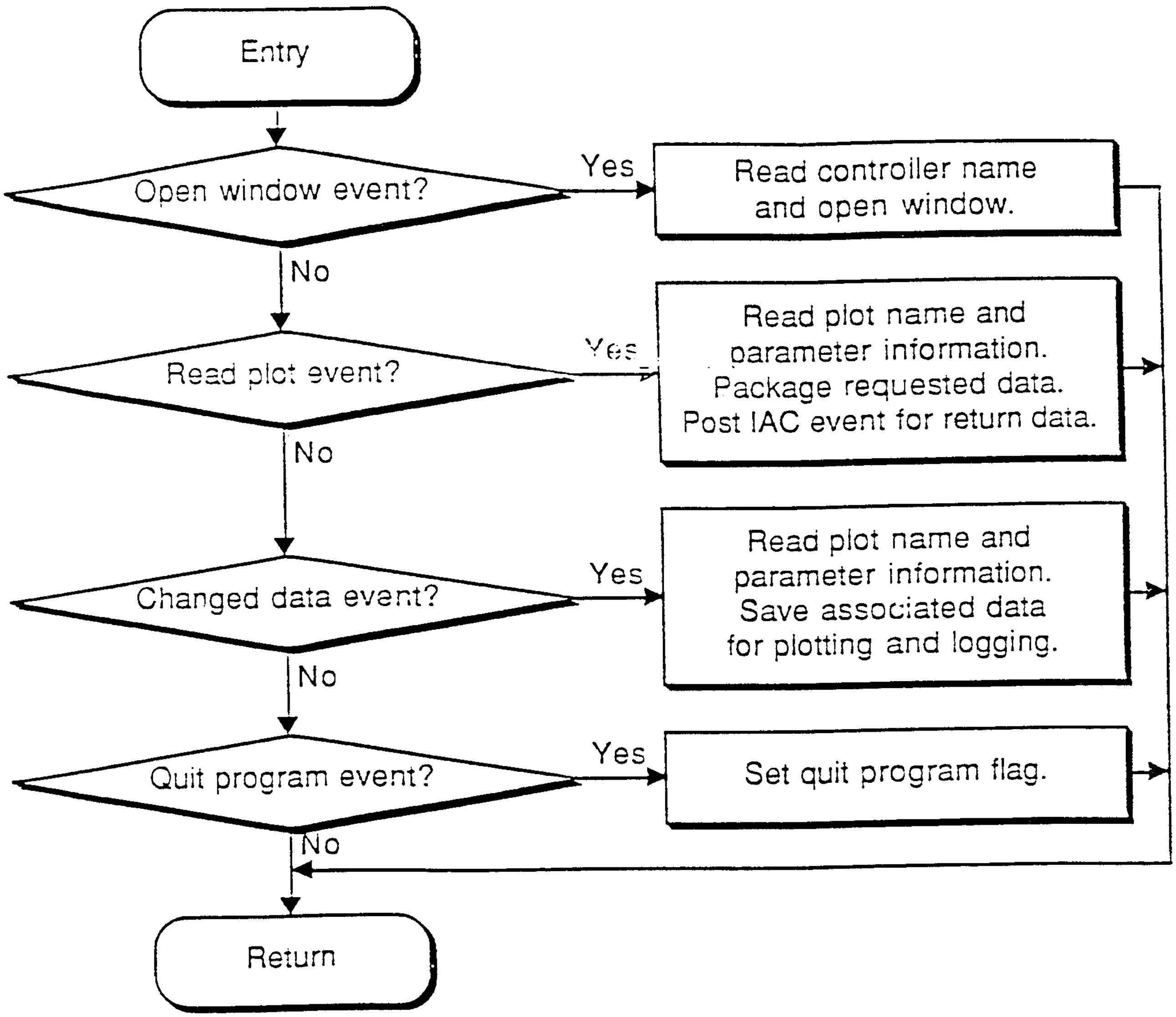


Figure B5. Handle Inter-Application-Communication.

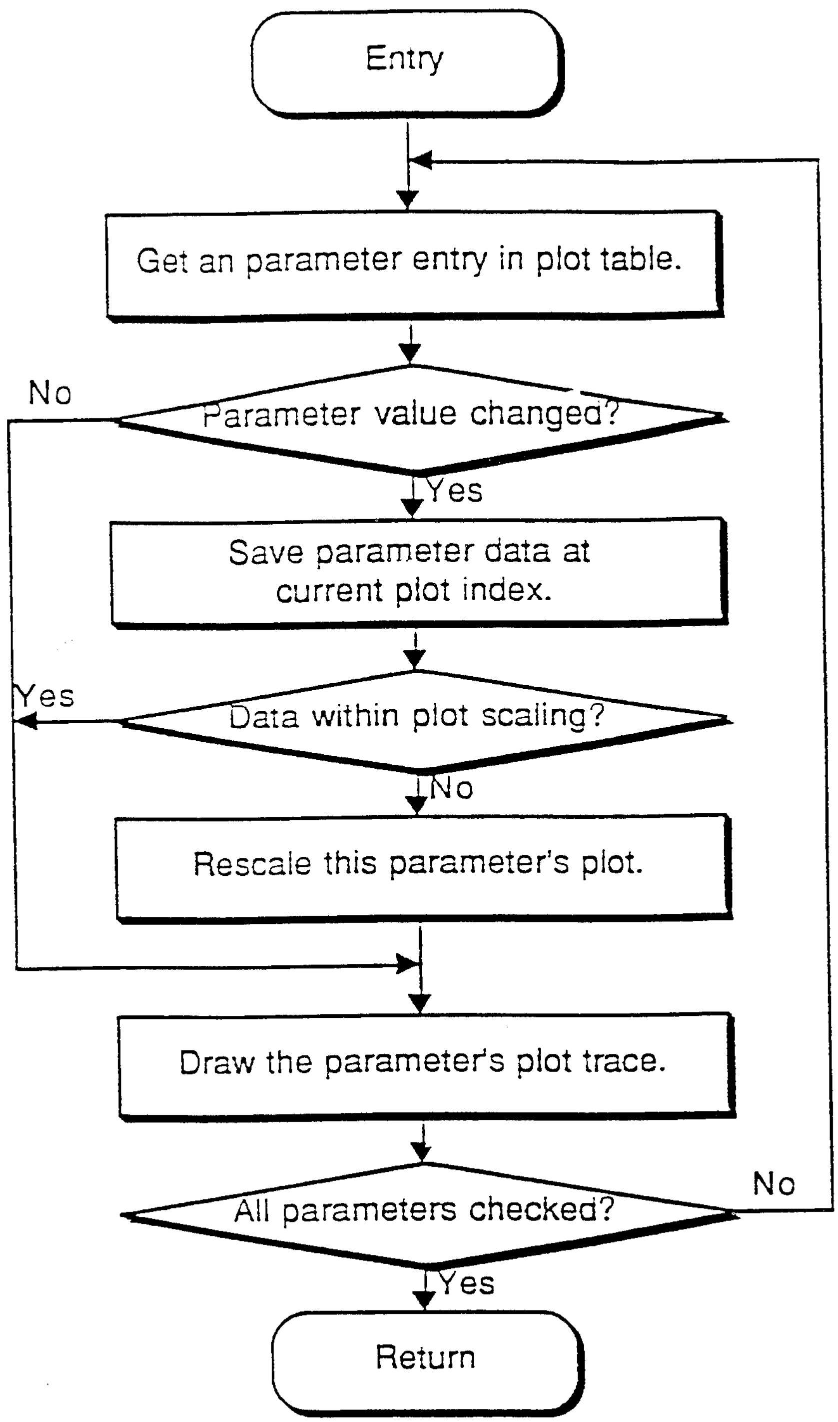


Figure B6. Update plot windows

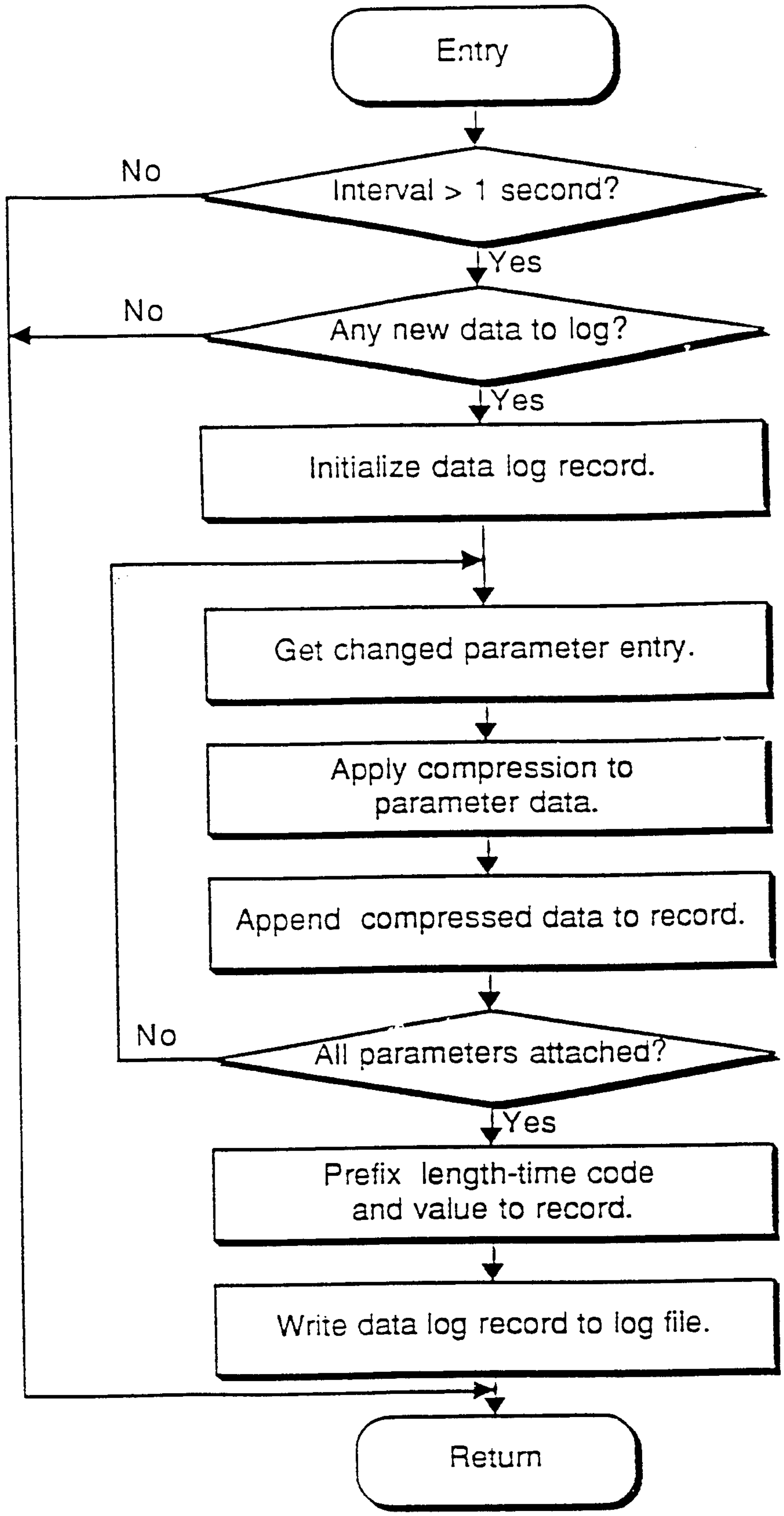


Figure B7. Update data log.

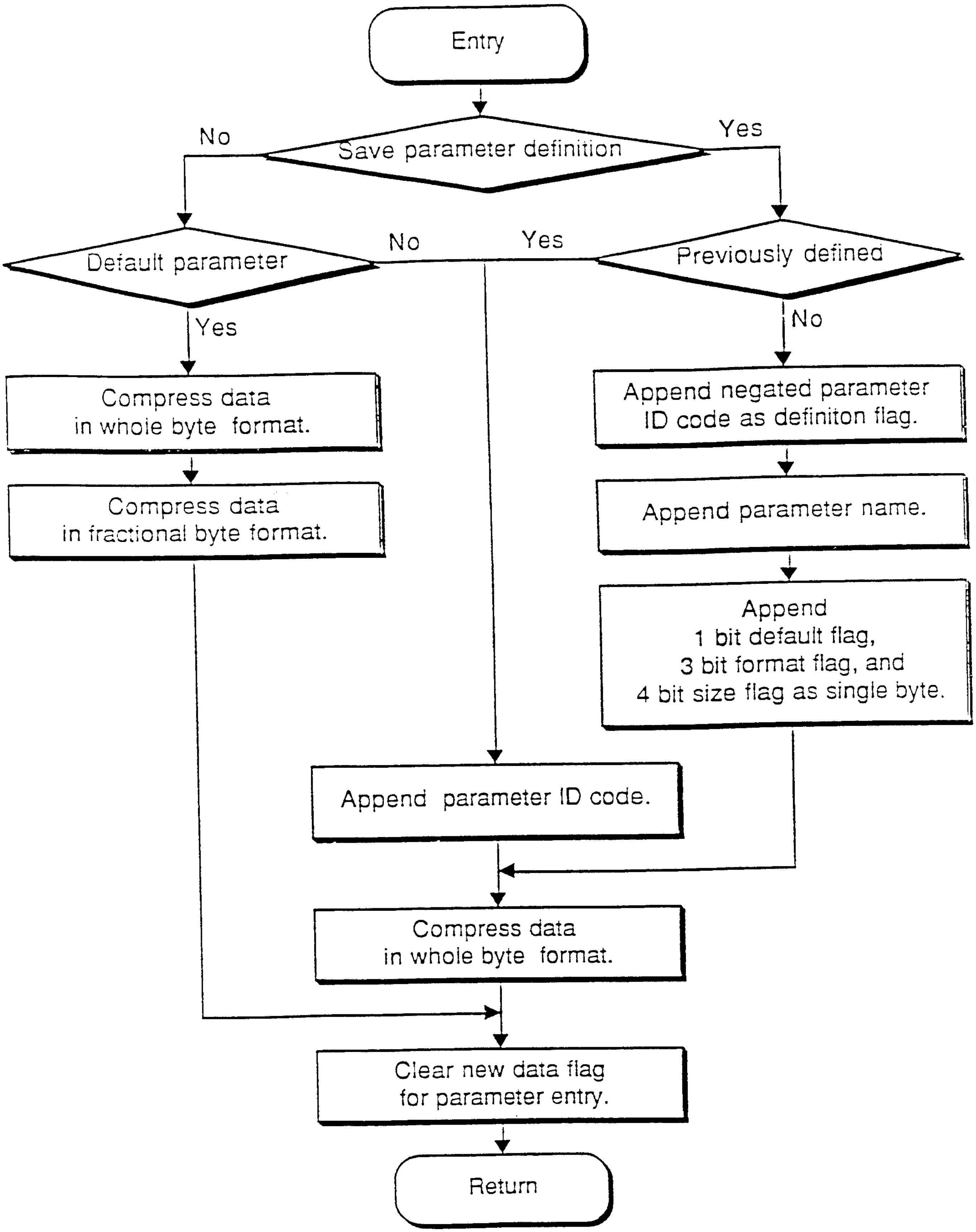


Figure B8. Apply compression to data value.

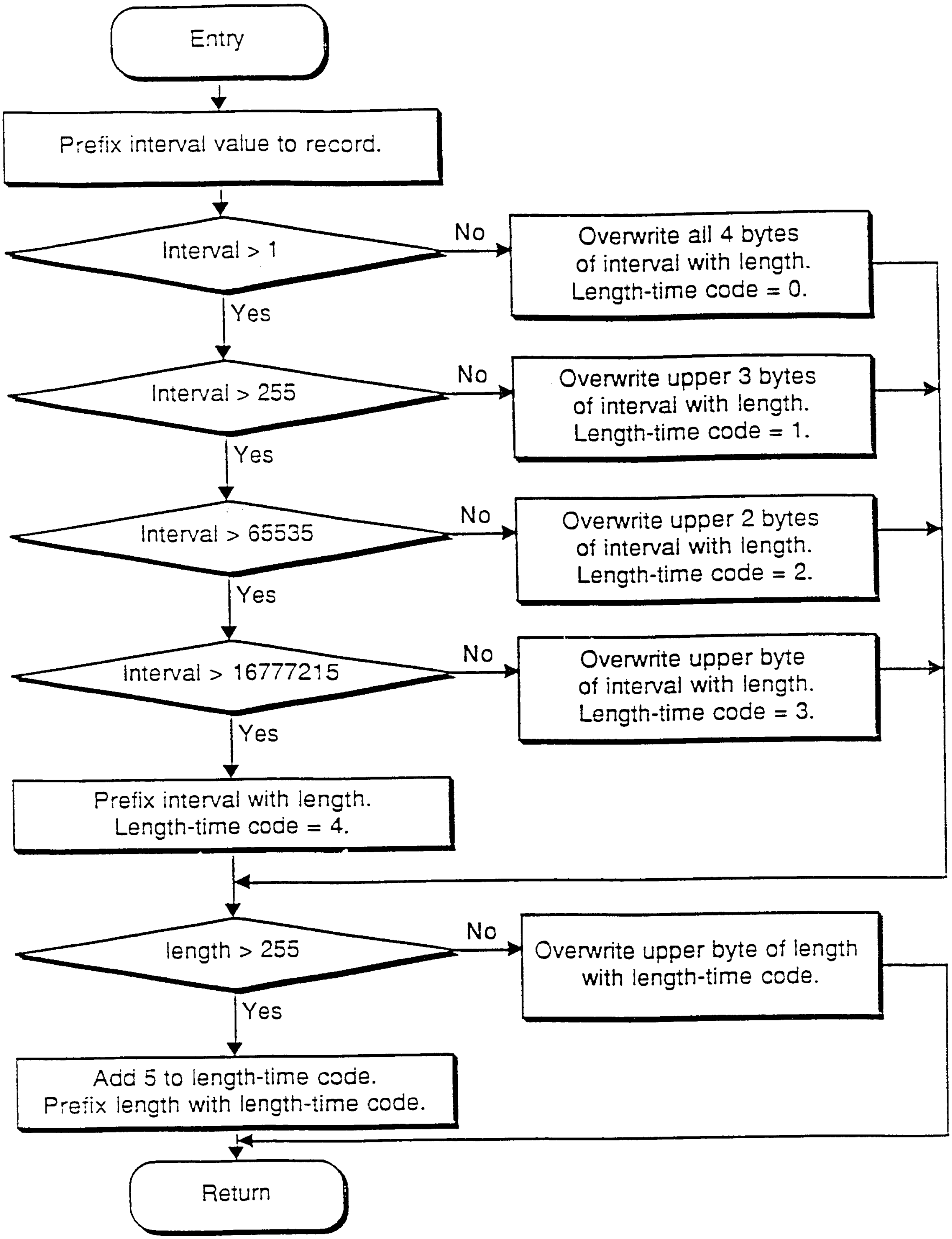


Figure B9. Prefix length-time & value to record.

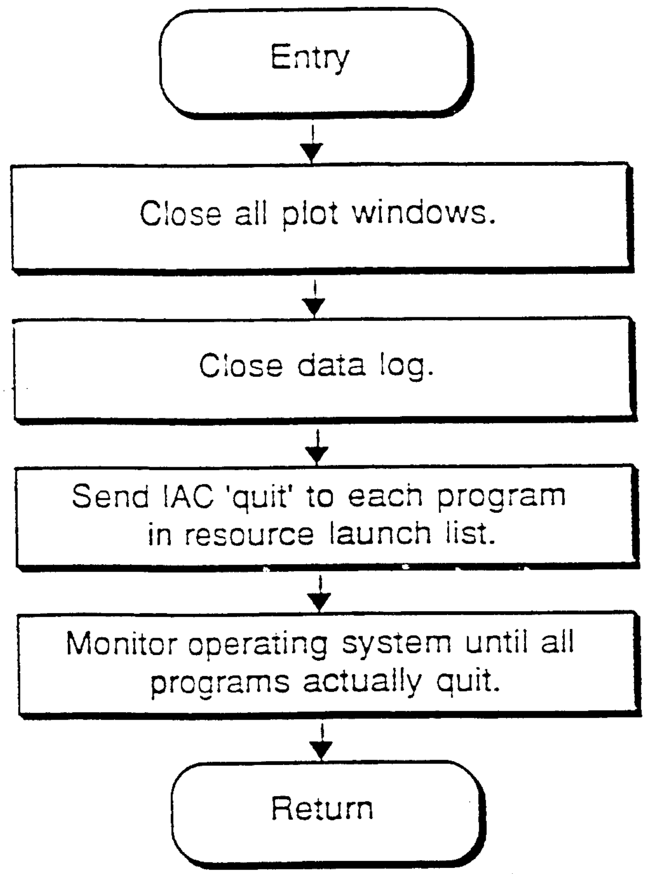


Figure B10. Terminate program.

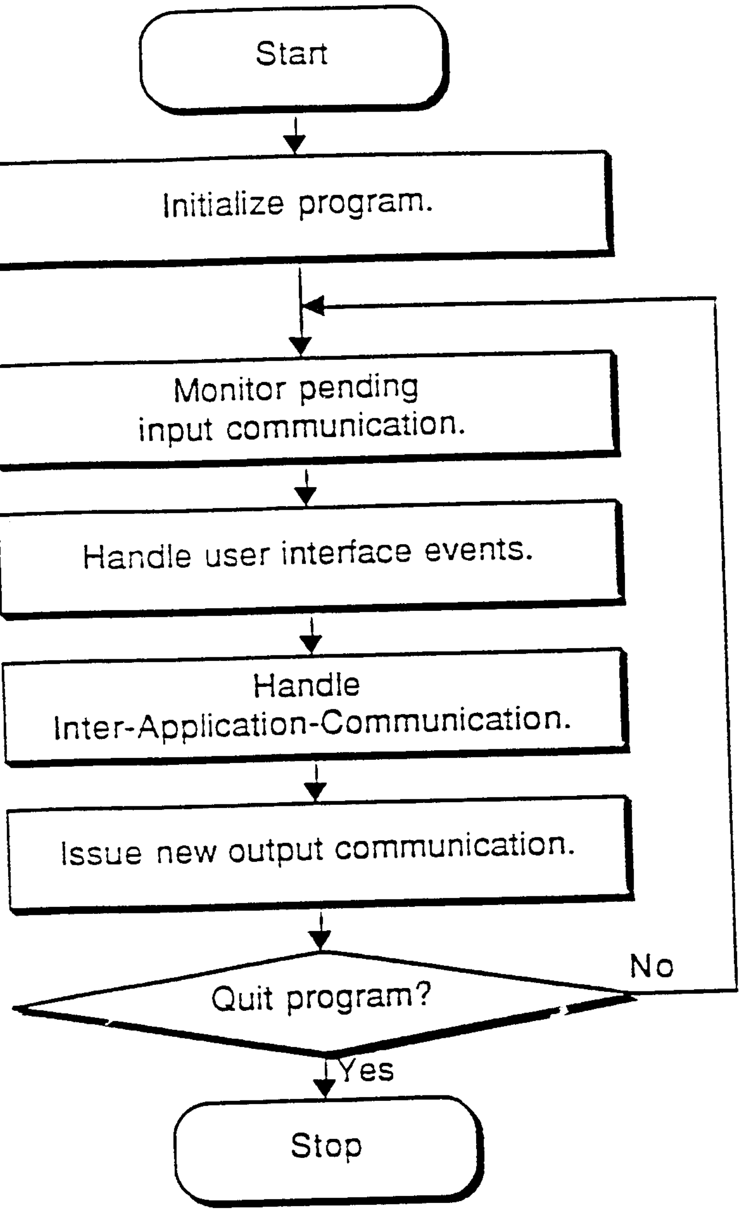


Figure B11. Eurotherm Main Program Loop.

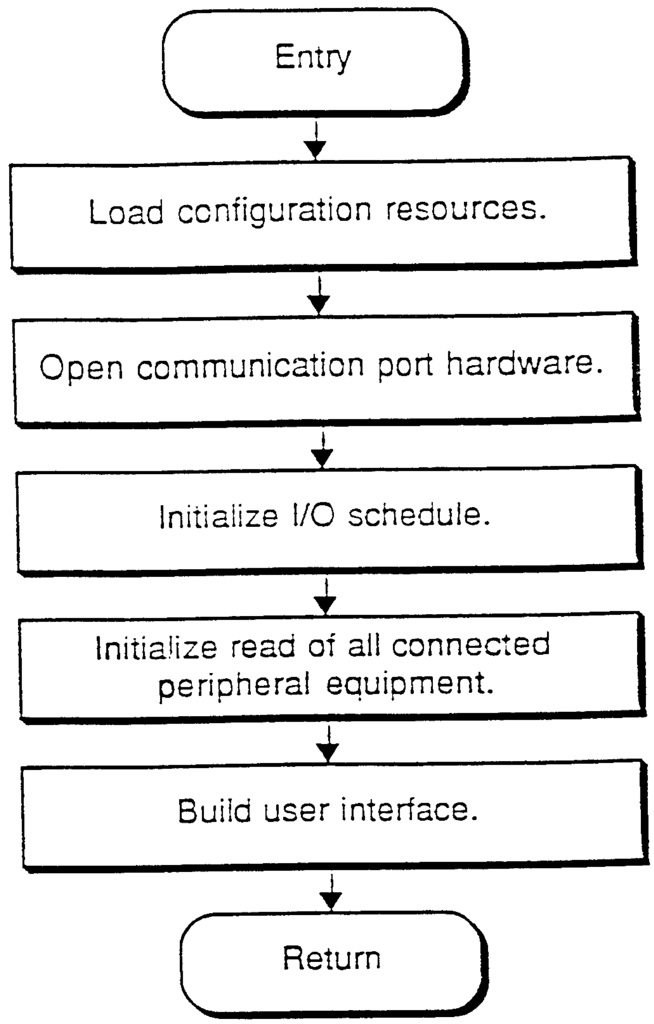


Figure B12. Initialize program.

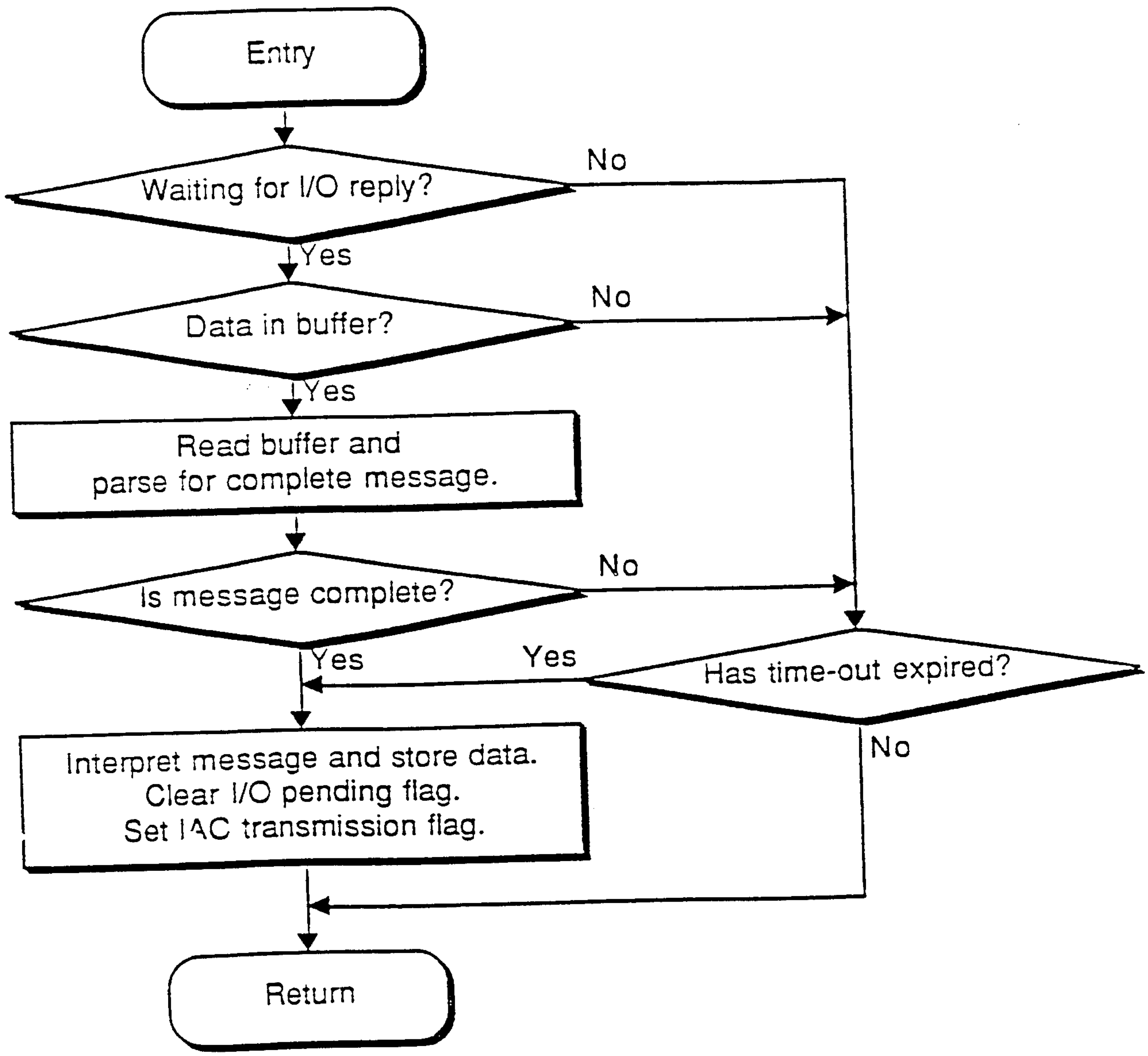


Figure B13. Monitor pending input communication.

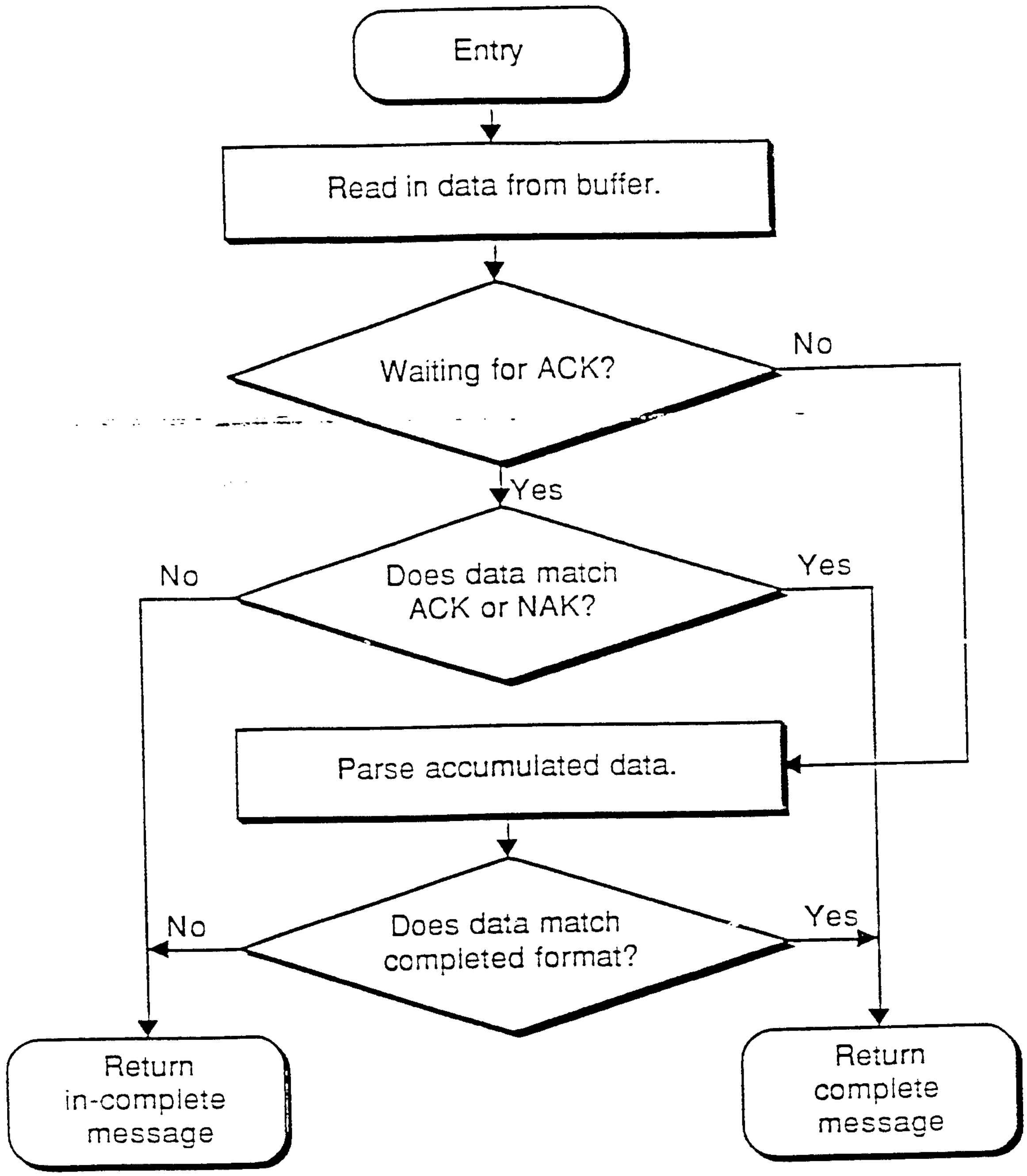


Figure B14. Read data and parse for complete message.

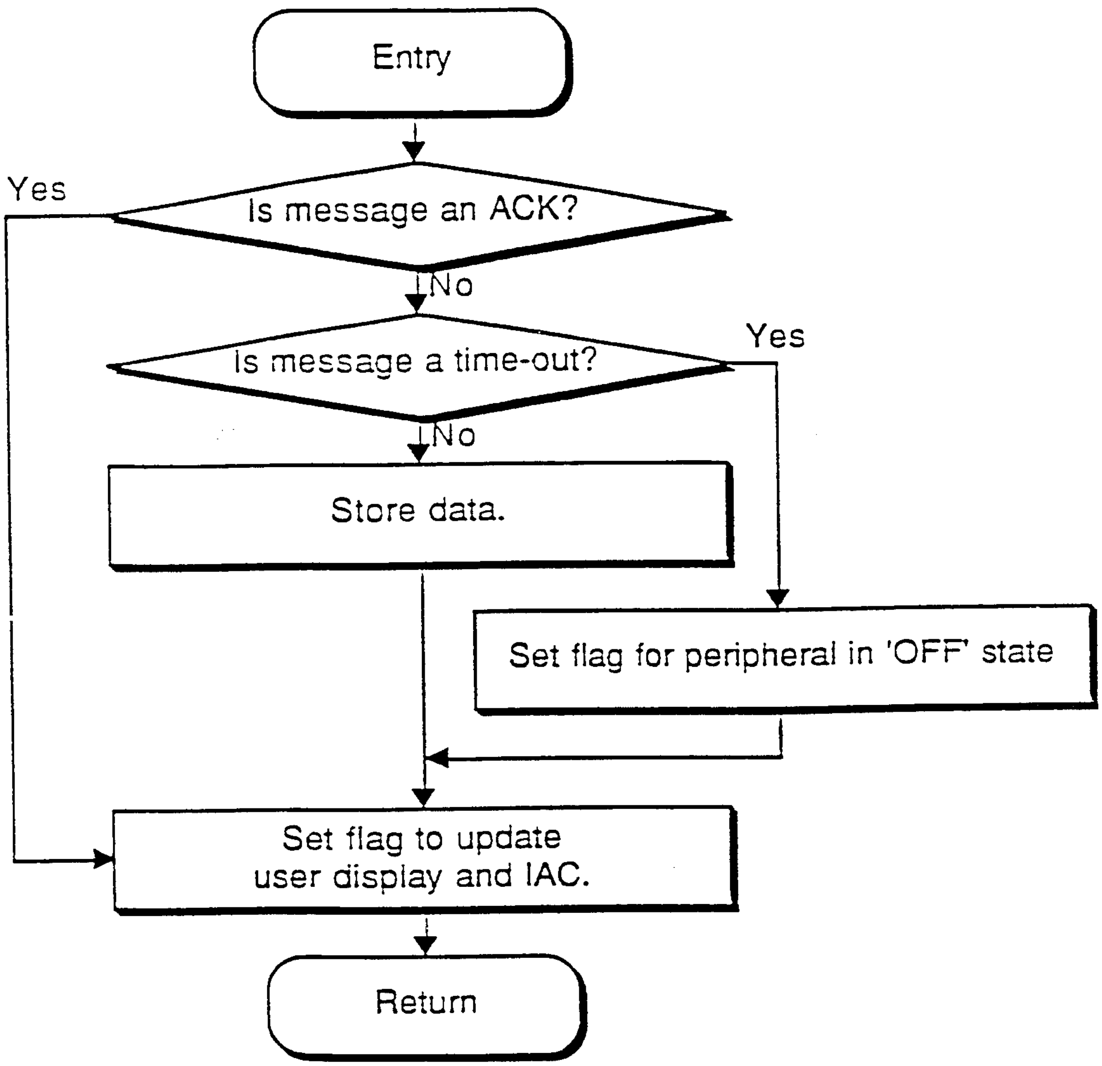


Figure B15. Interpret message, store data and clear I/O pending flag.

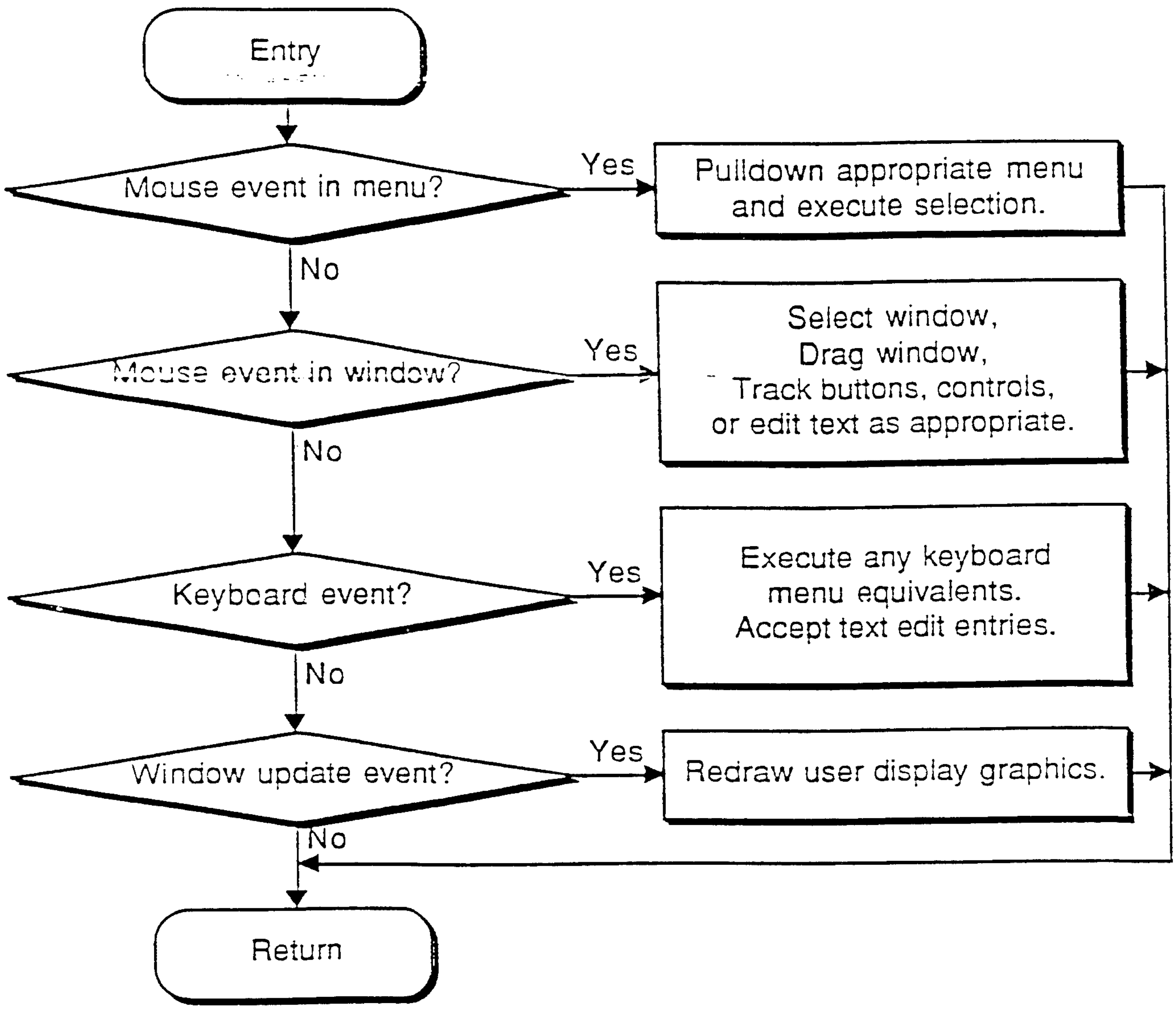


Figure B16. Handle user interface events.

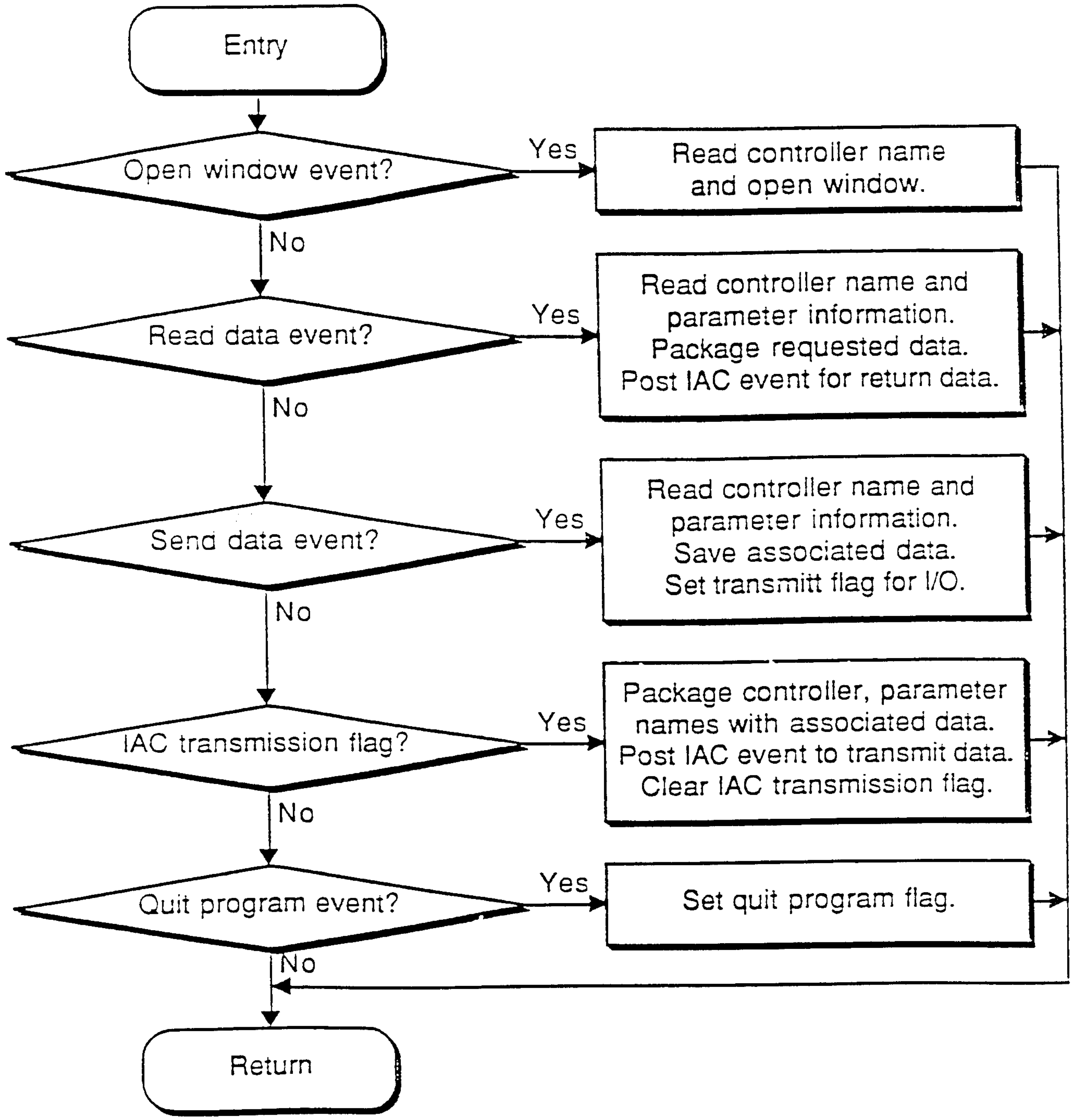


Figure B17. Handle Inter-Application-Communication.

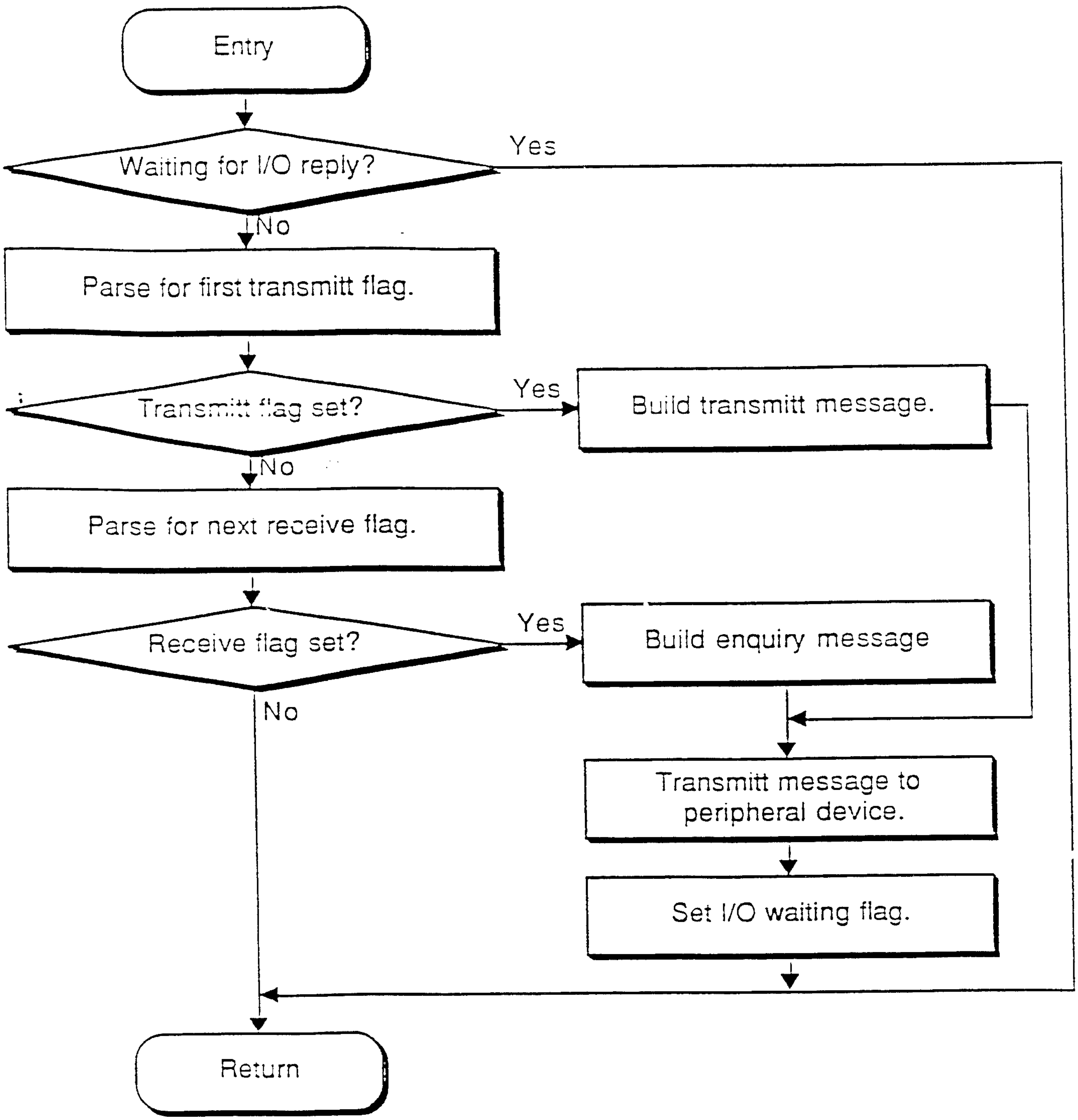


Figure B18. Issue new output communication.

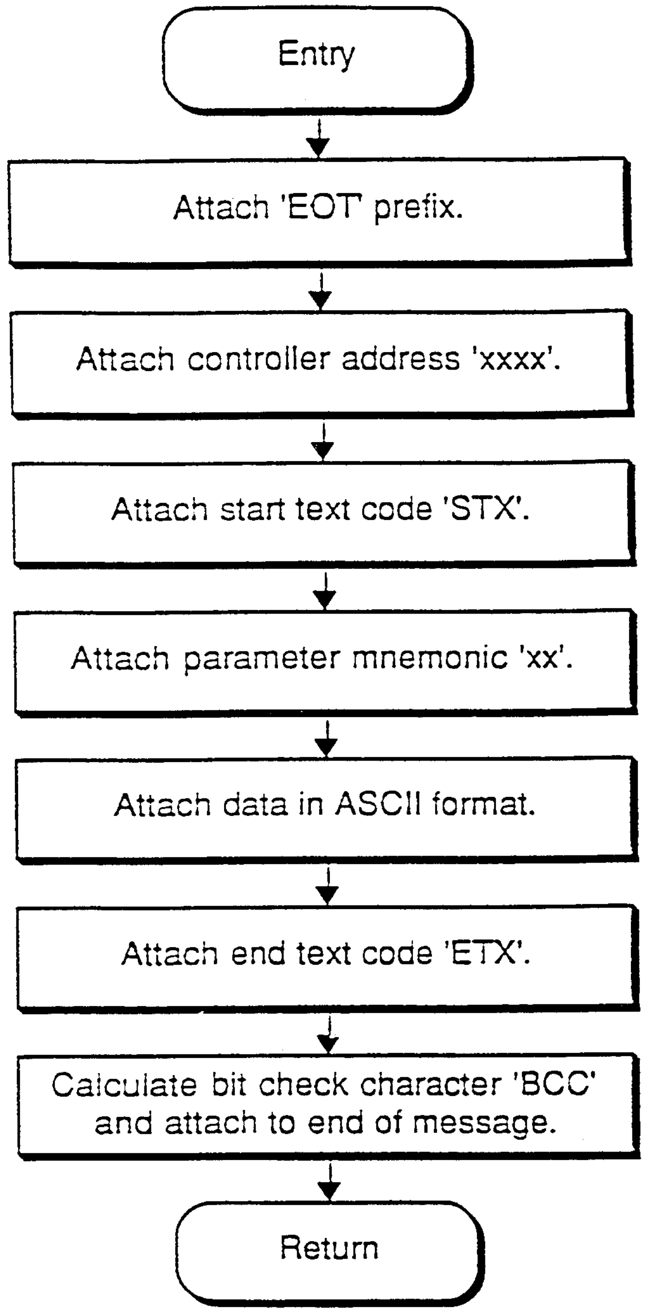


Figure B19. Build transmitt message.

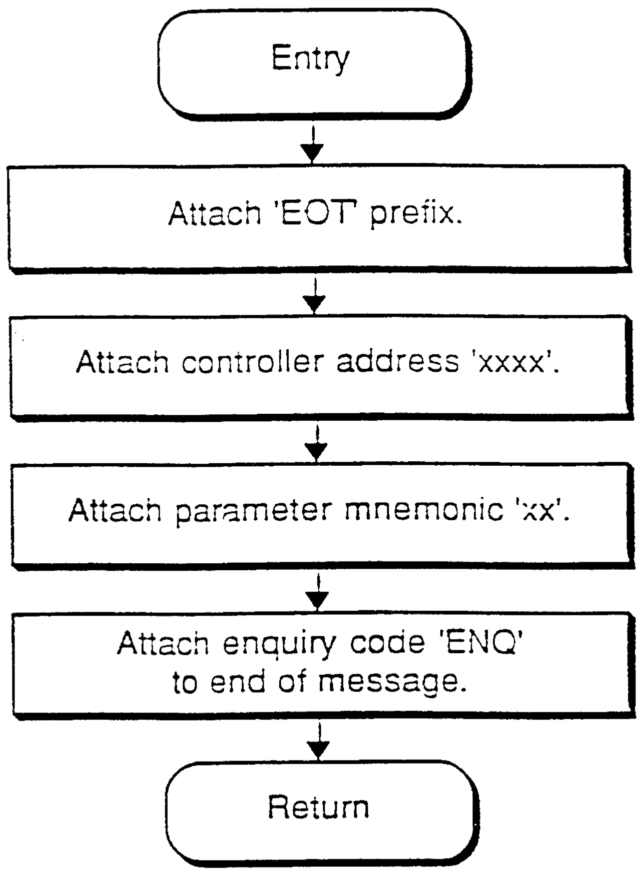


Figure B20. Build enquiry message.

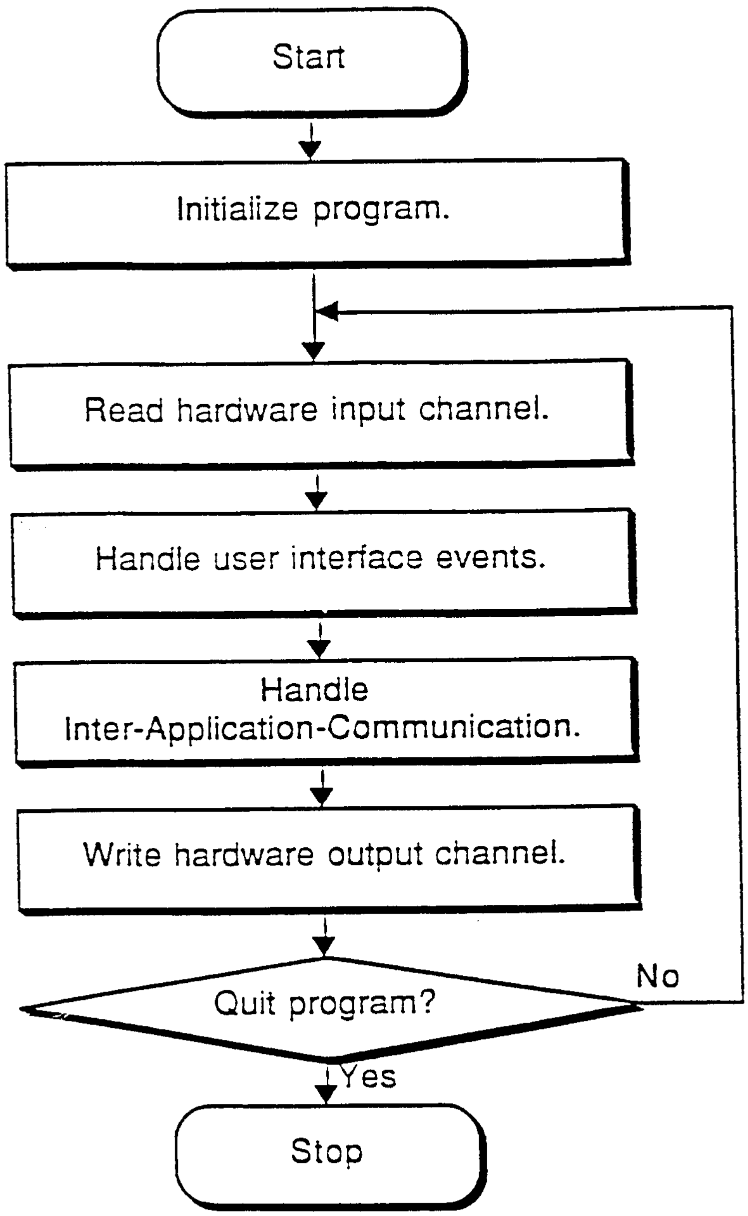


Figure B21. ShutterControl Main Program Loop.

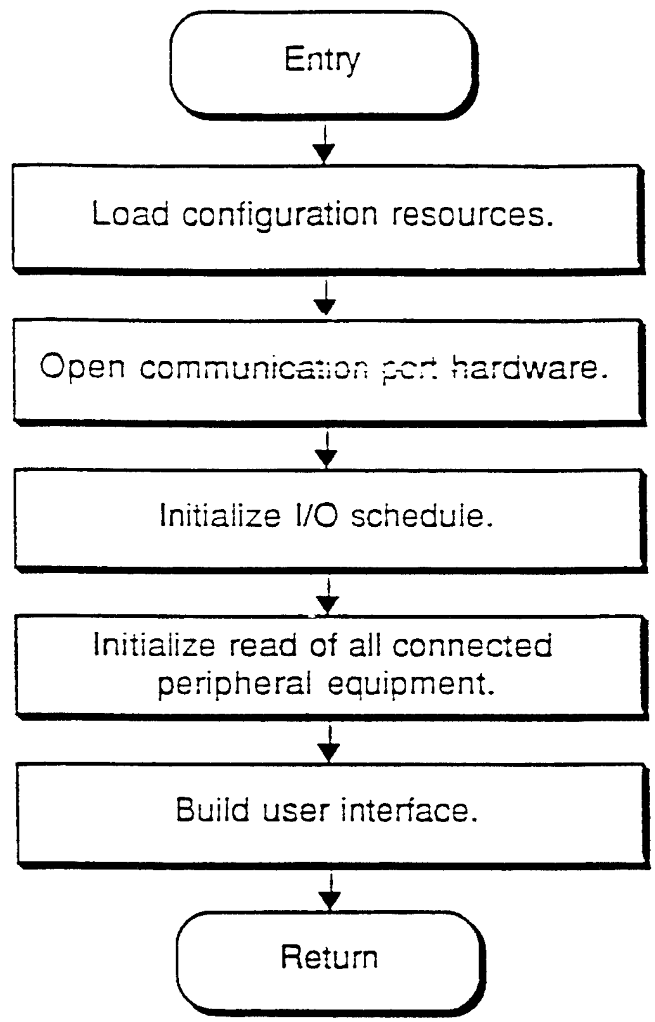


Figure B22. Initialize program.

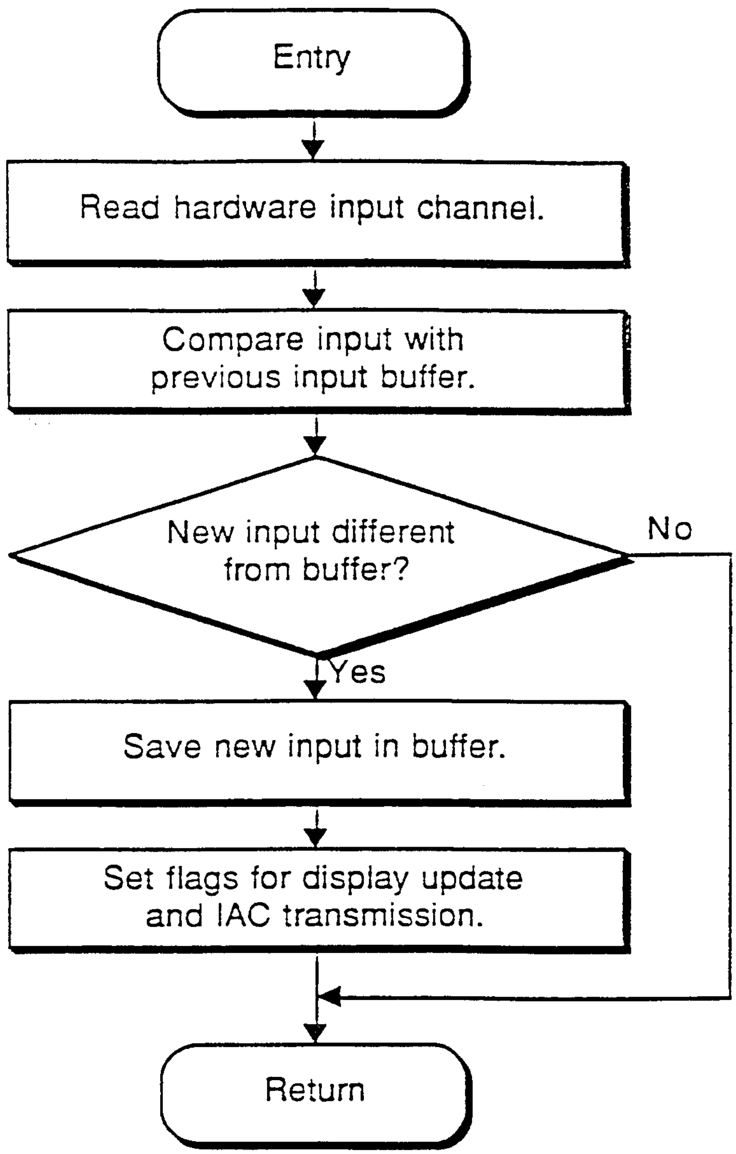


Figure B23. Read hardware input channel.

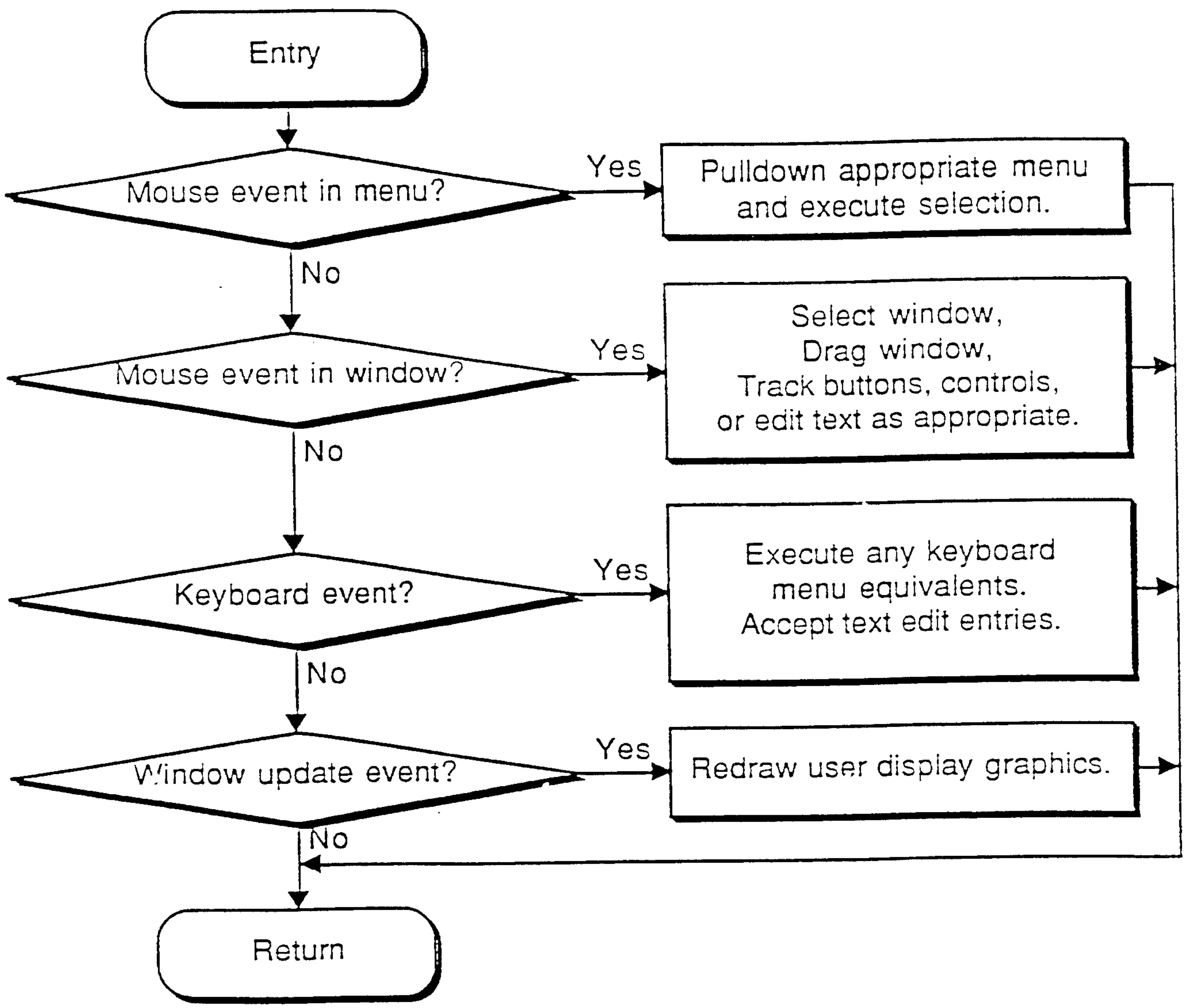


Figure B24. Handle user interface events.

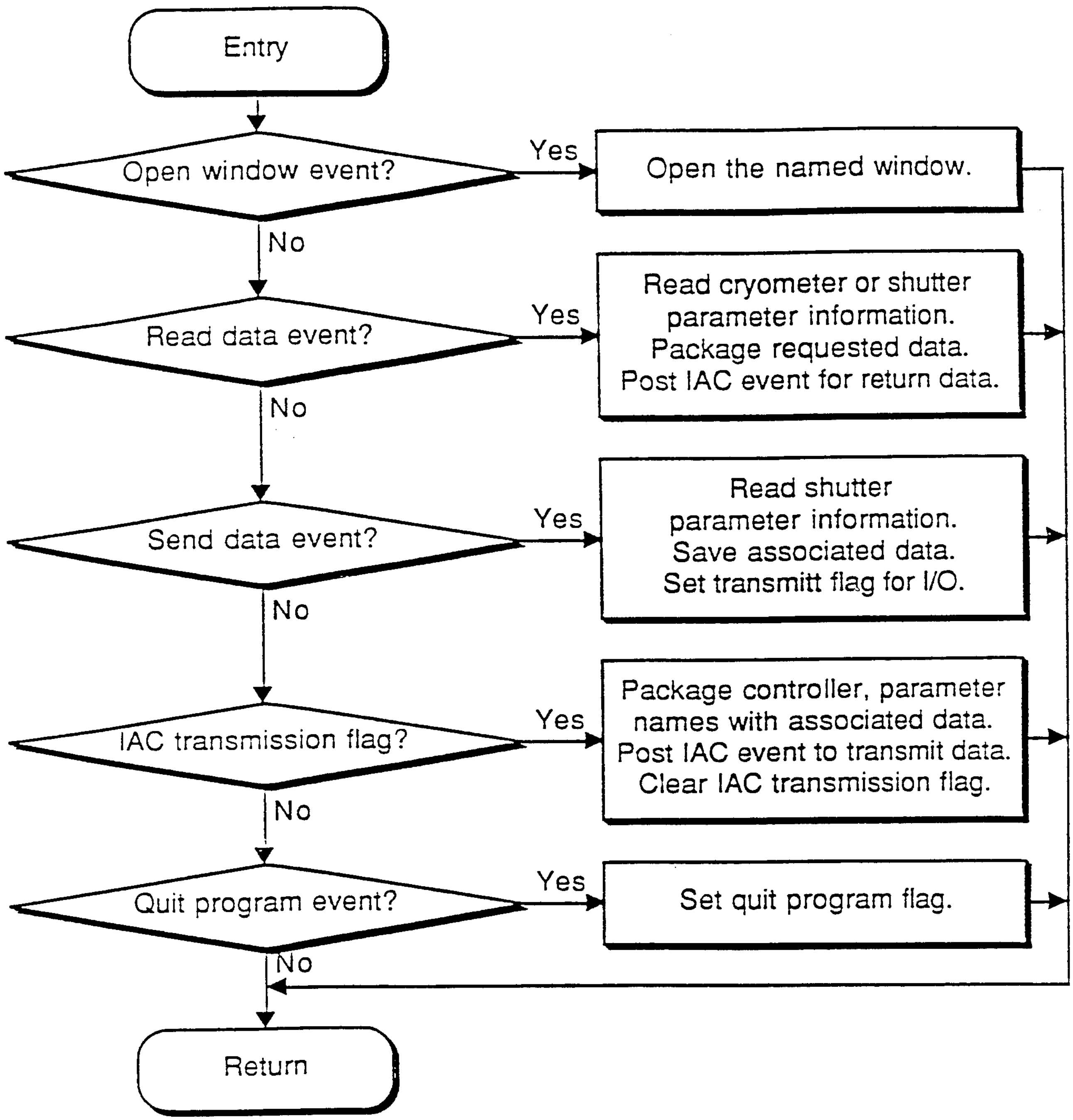


Figure B25. Handle Inter-Application-Communication.

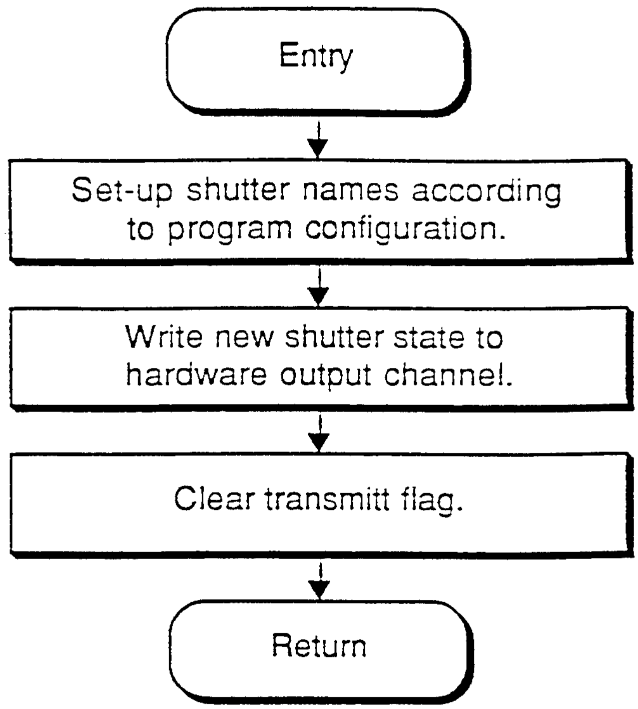


Figure B26. Write hardware output channel.

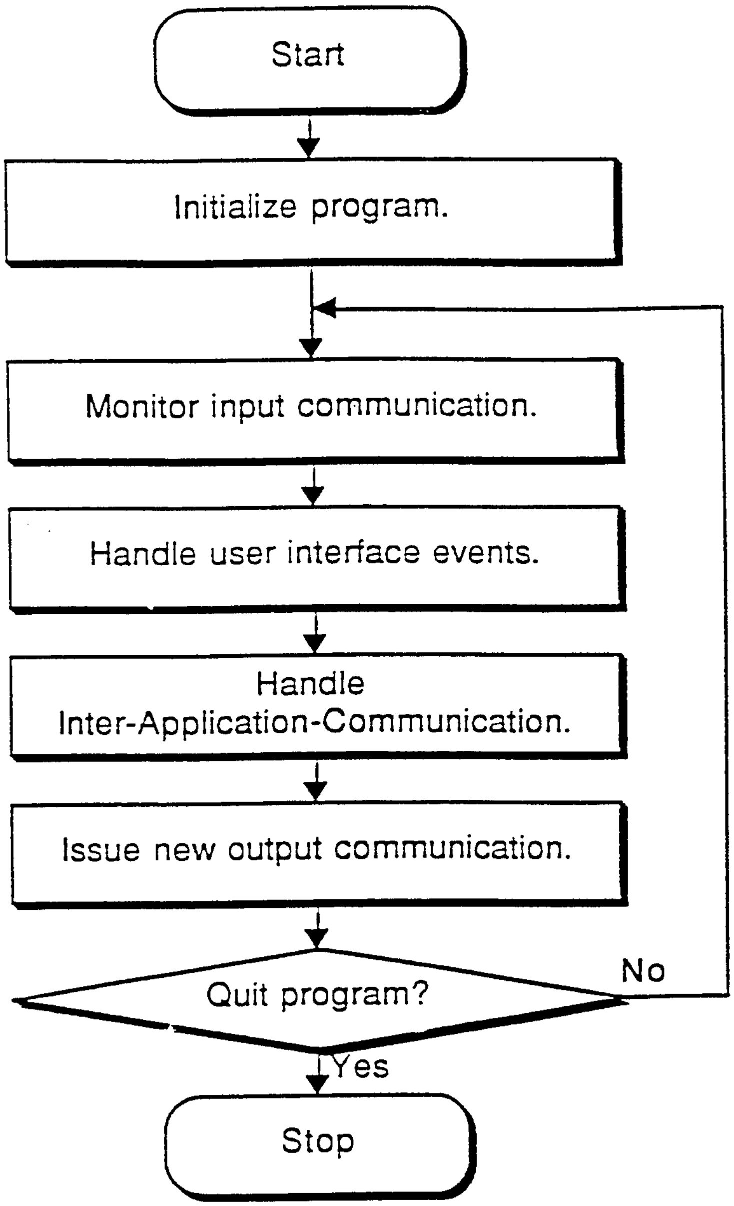


Figure B27. Ion Gauge Main Program Loop.

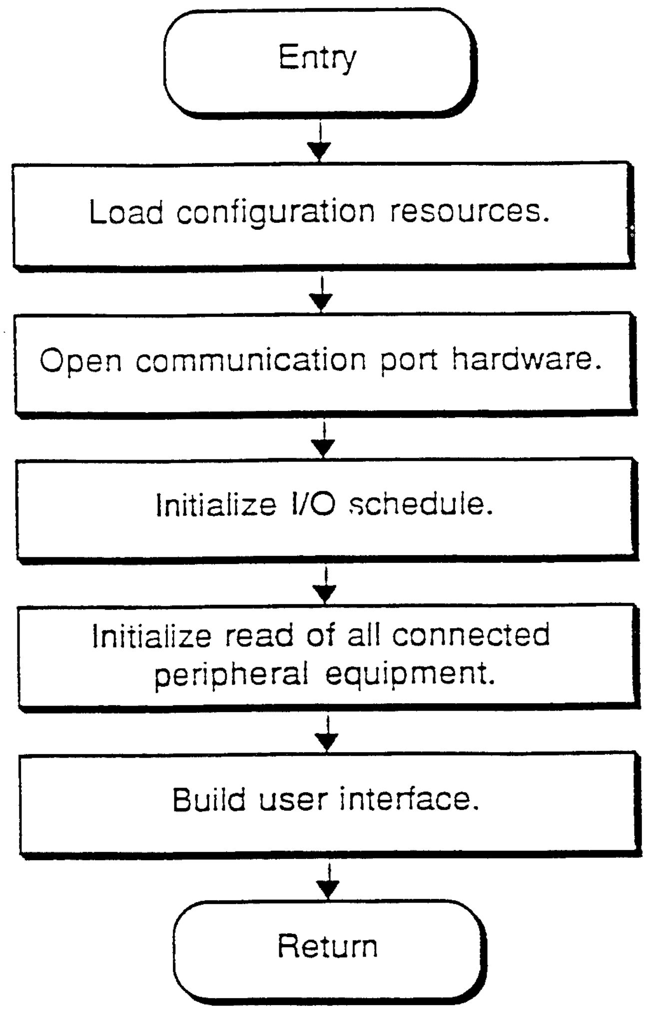


Figure B28. Initialize program.

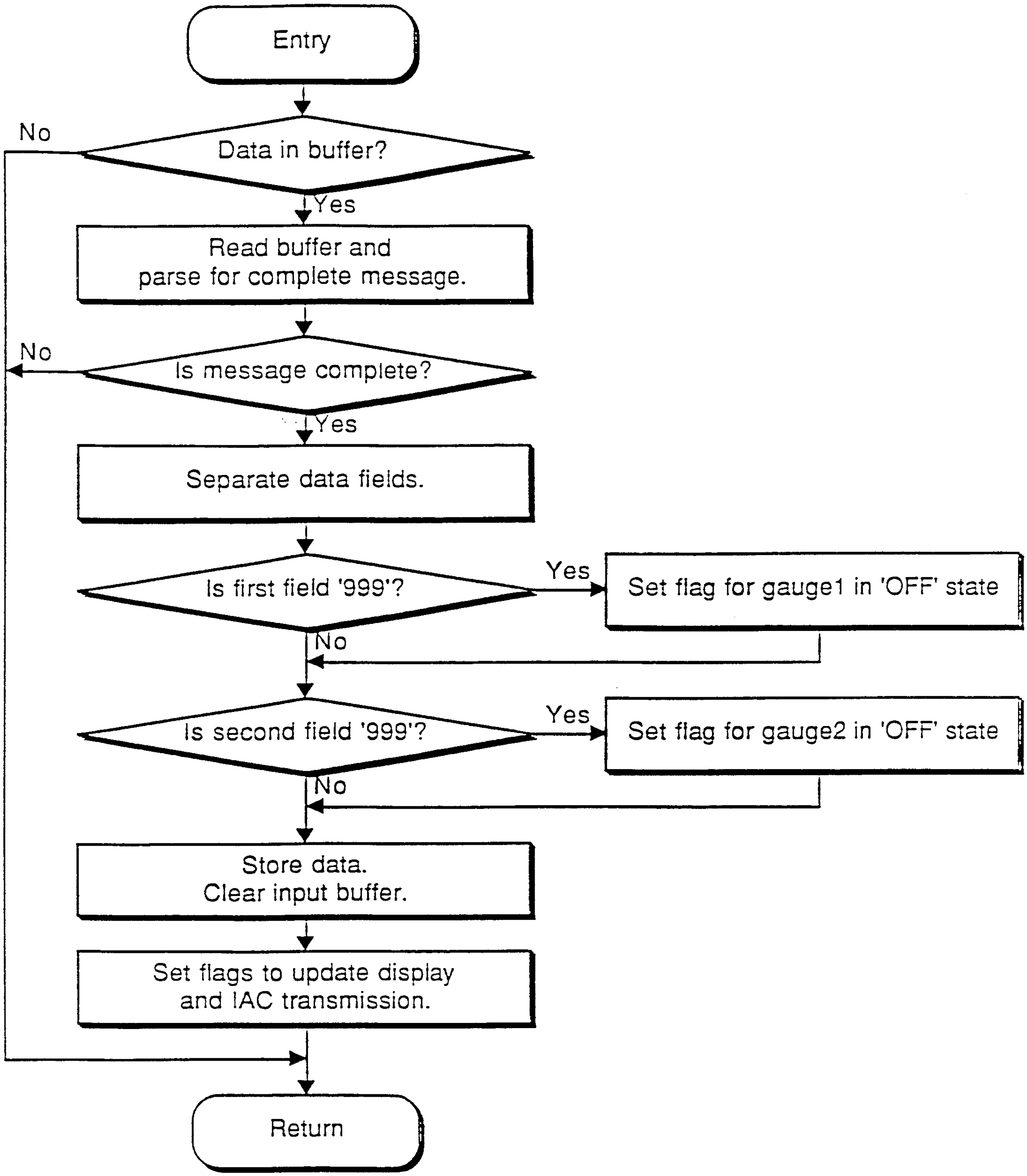


Figure B29. Monitor input communication.

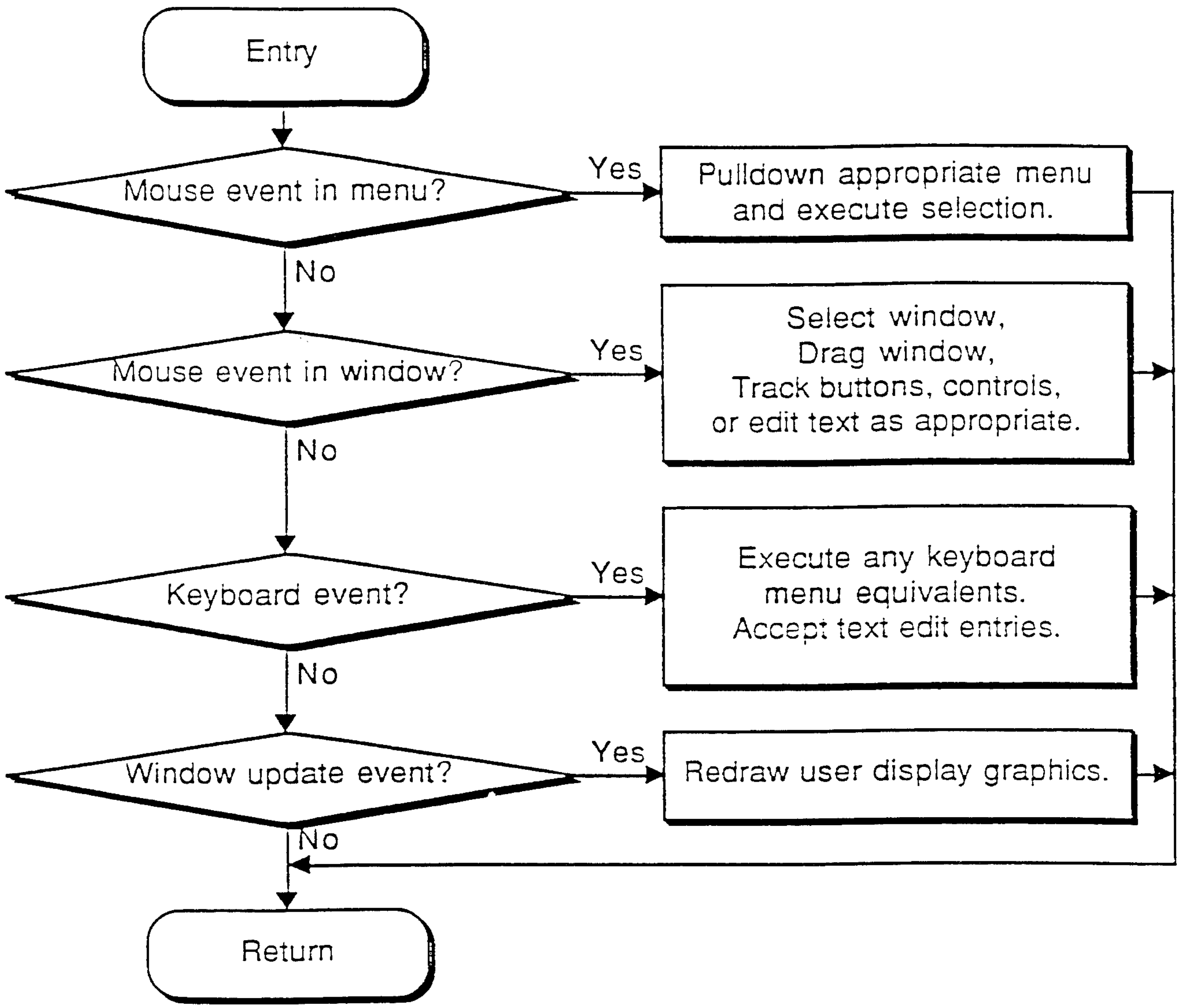


Figure B30. Handle user interface events.

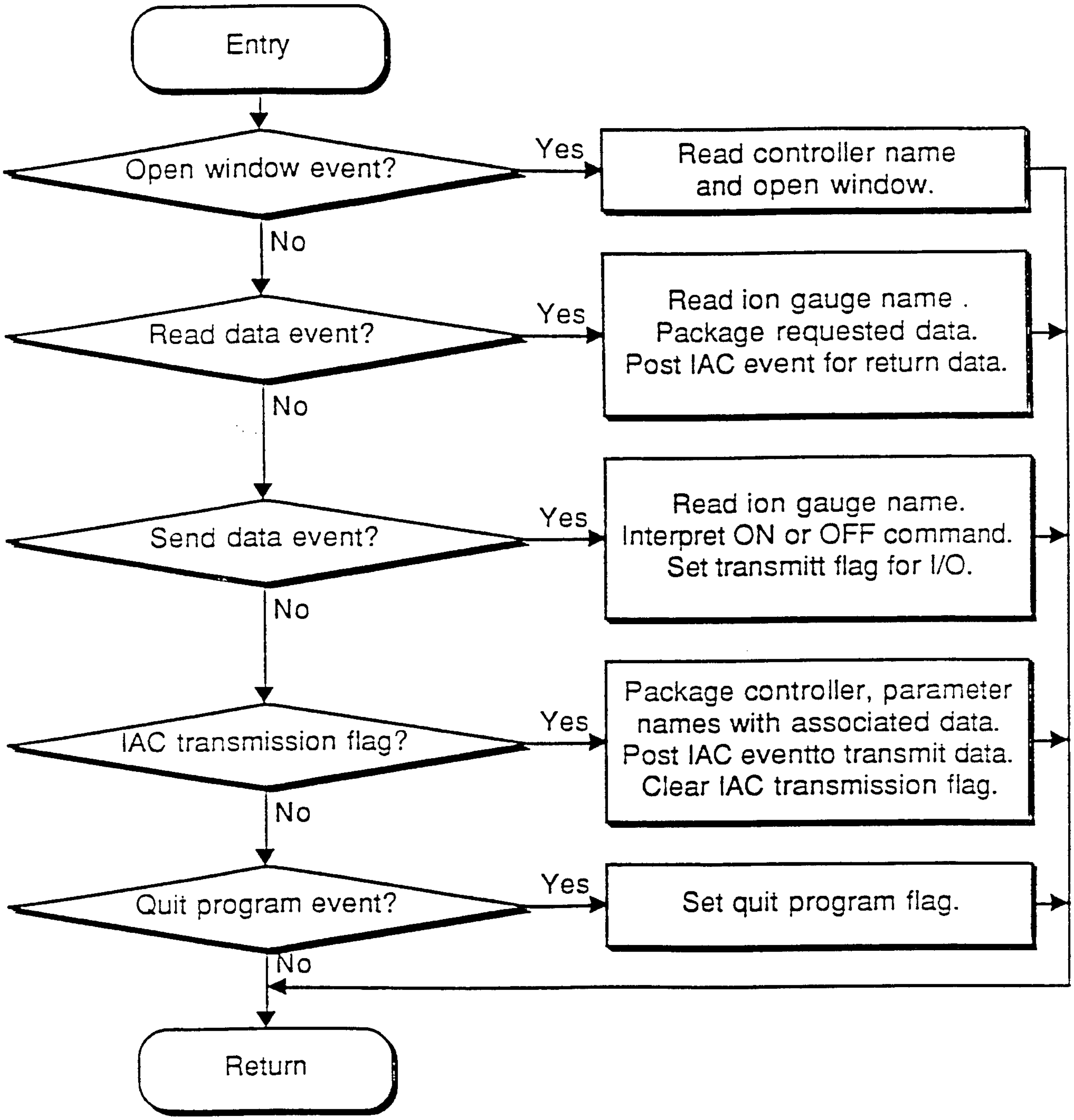


Figure B31. Handle Inter-Application-Communication.

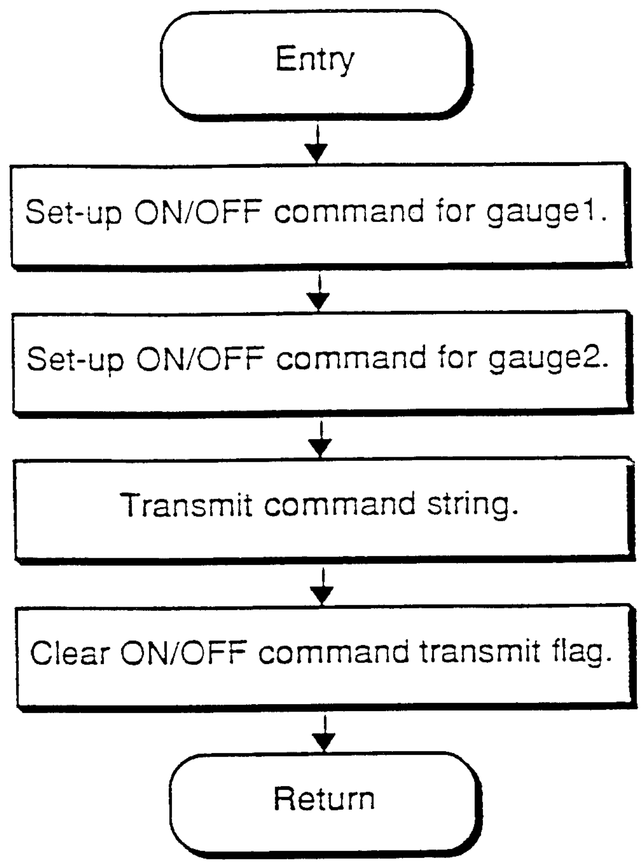


Figure B32. Issue new output communication.

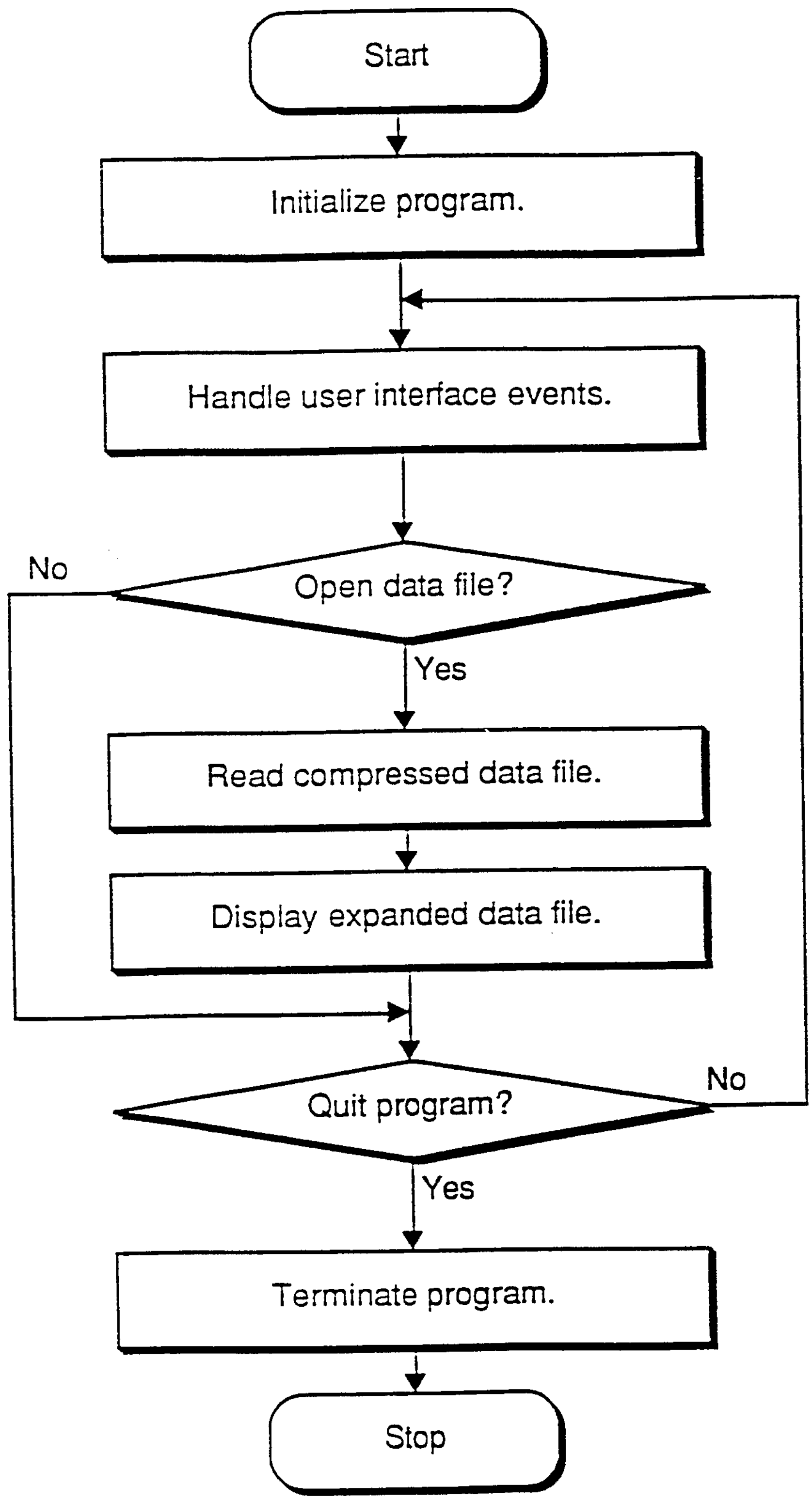


Figure B33. Data Reader Main Program Loop.

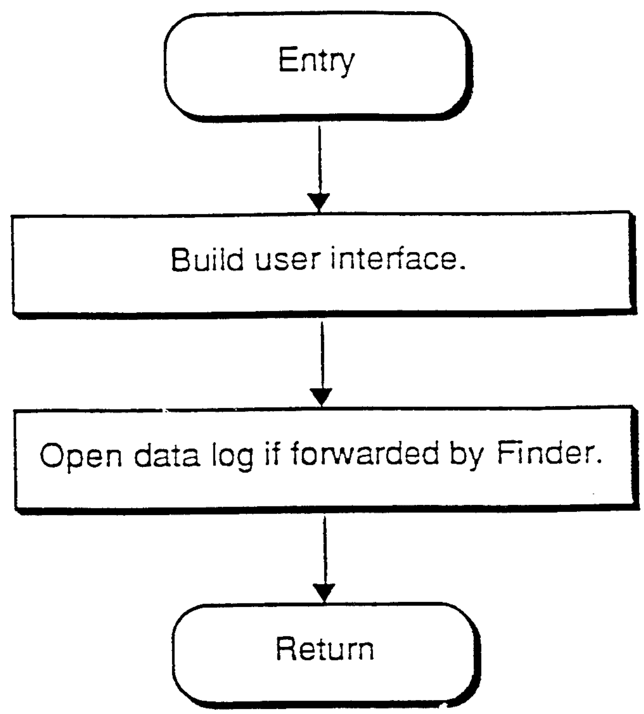


Figure B34. Initialize program.

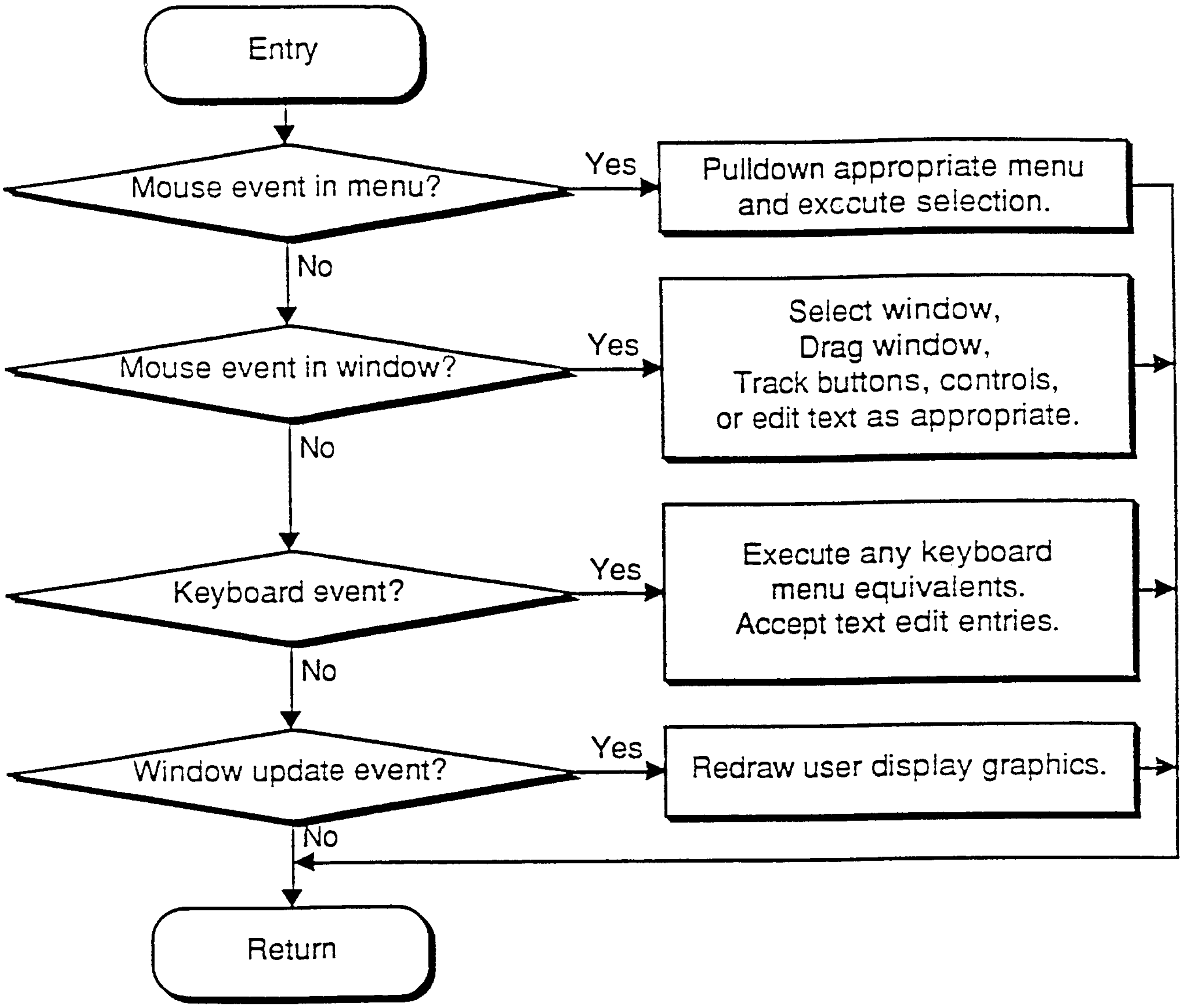


Figure B35. Handle user interface events.

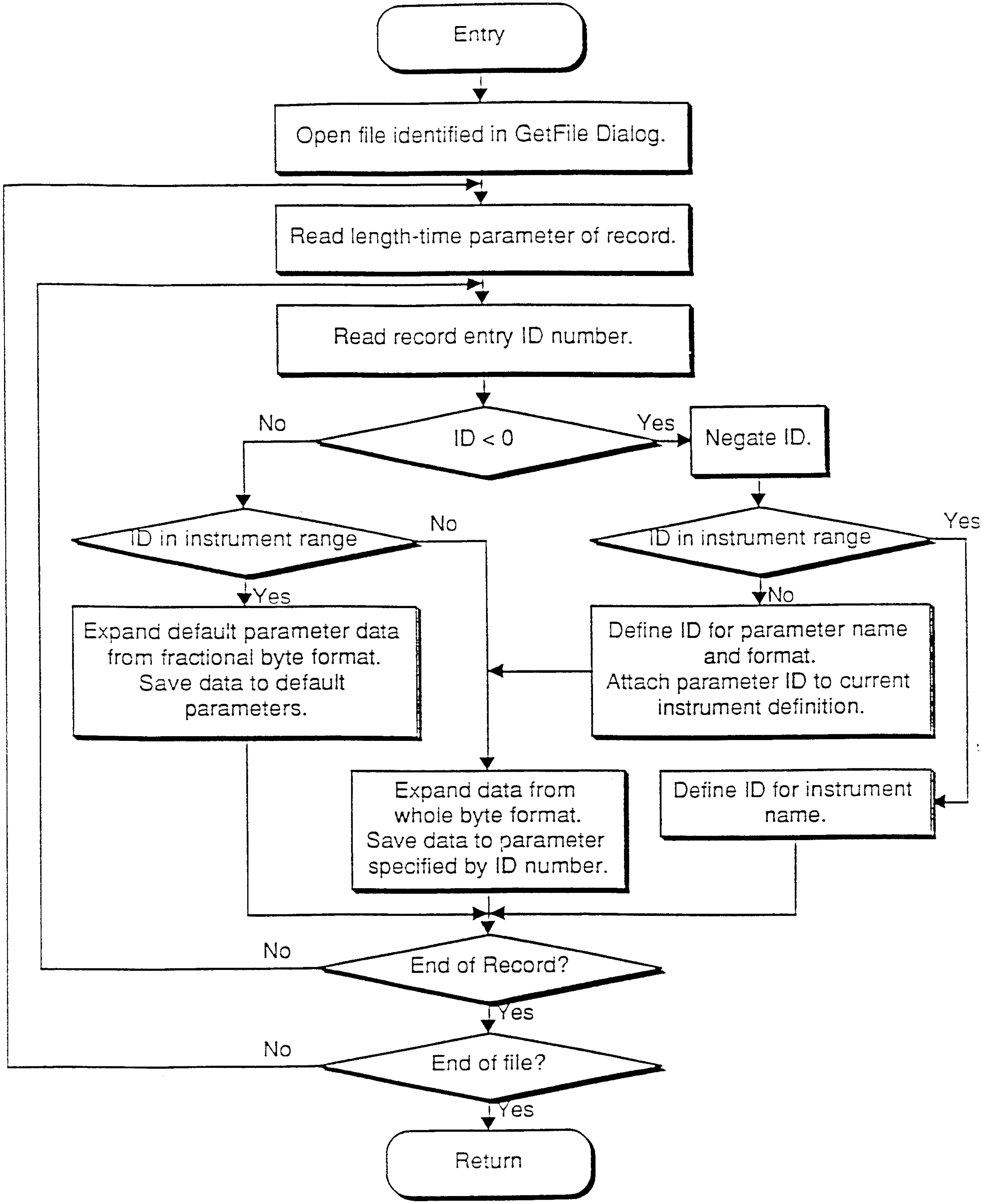


Figure B36. Read compressed data file.

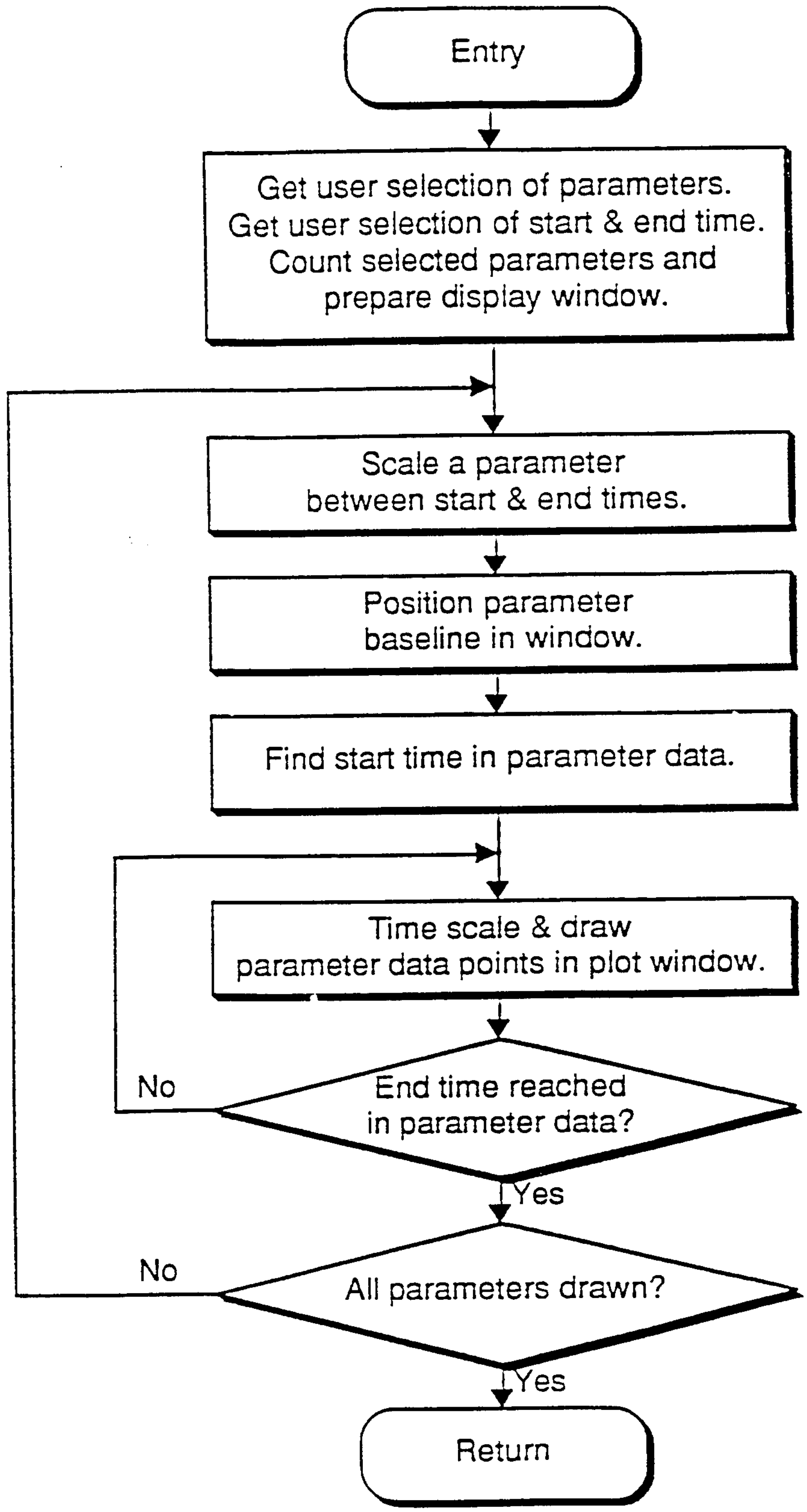


Figure B37. Display expanded data file.

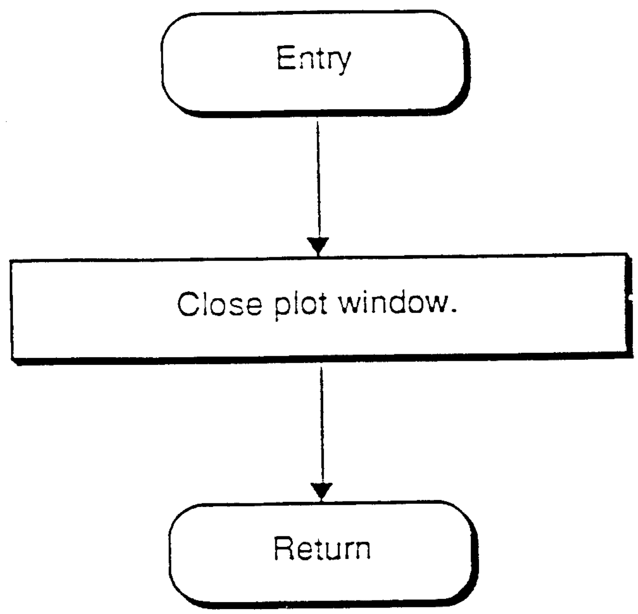


Figure B38. Terminate program.

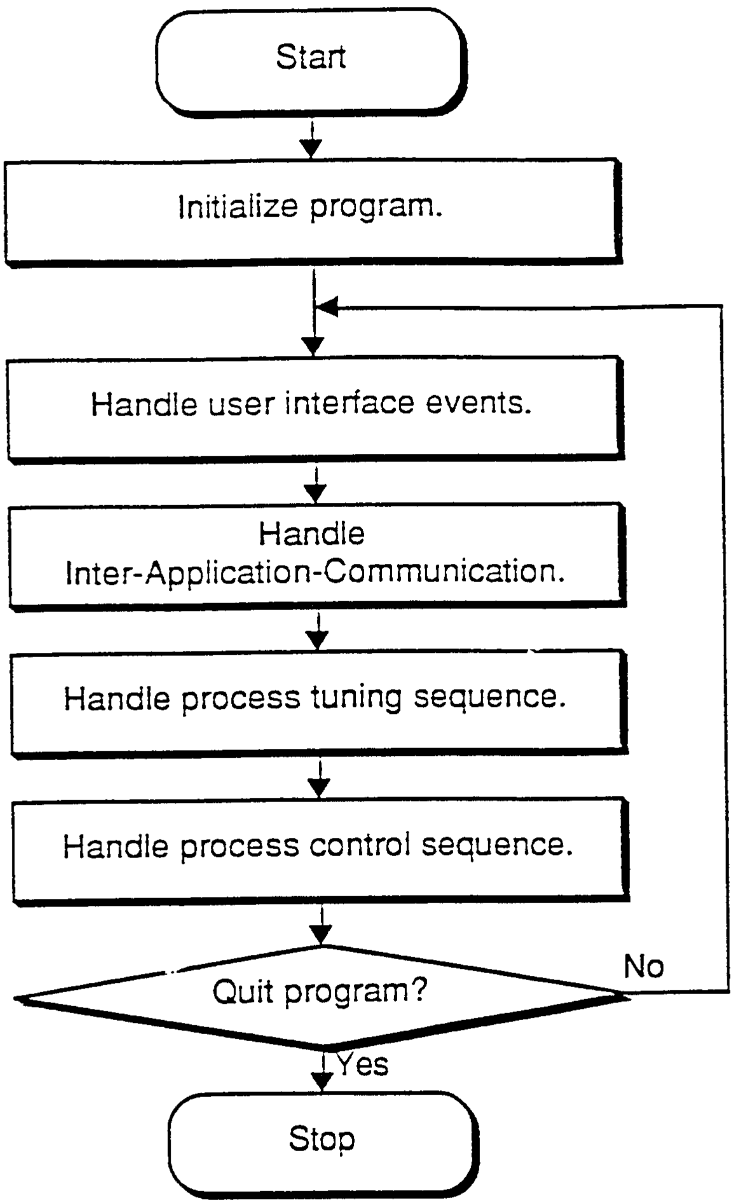


Figure B39. Adaptive Gain Bandwidth Controller Main Program Loop.

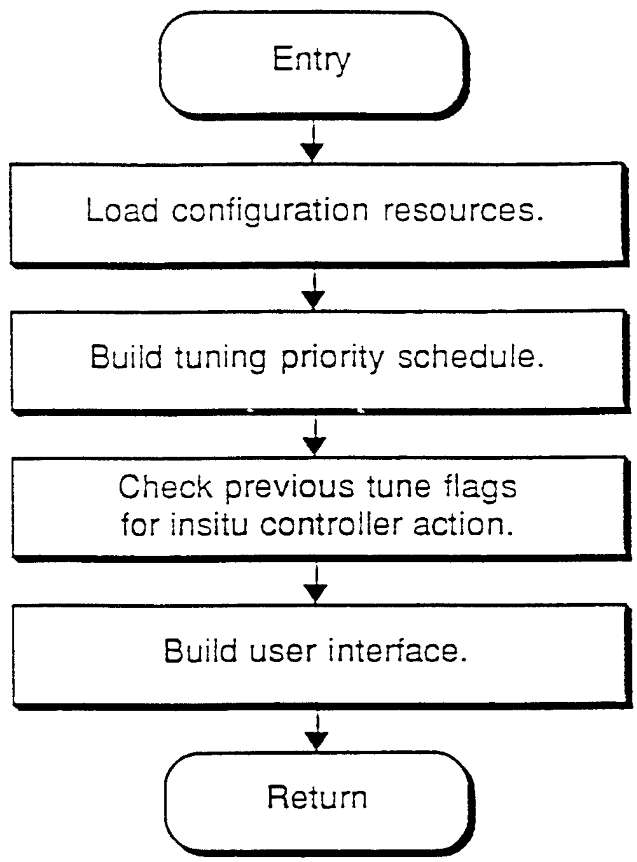


Figure B40. Initialize program.

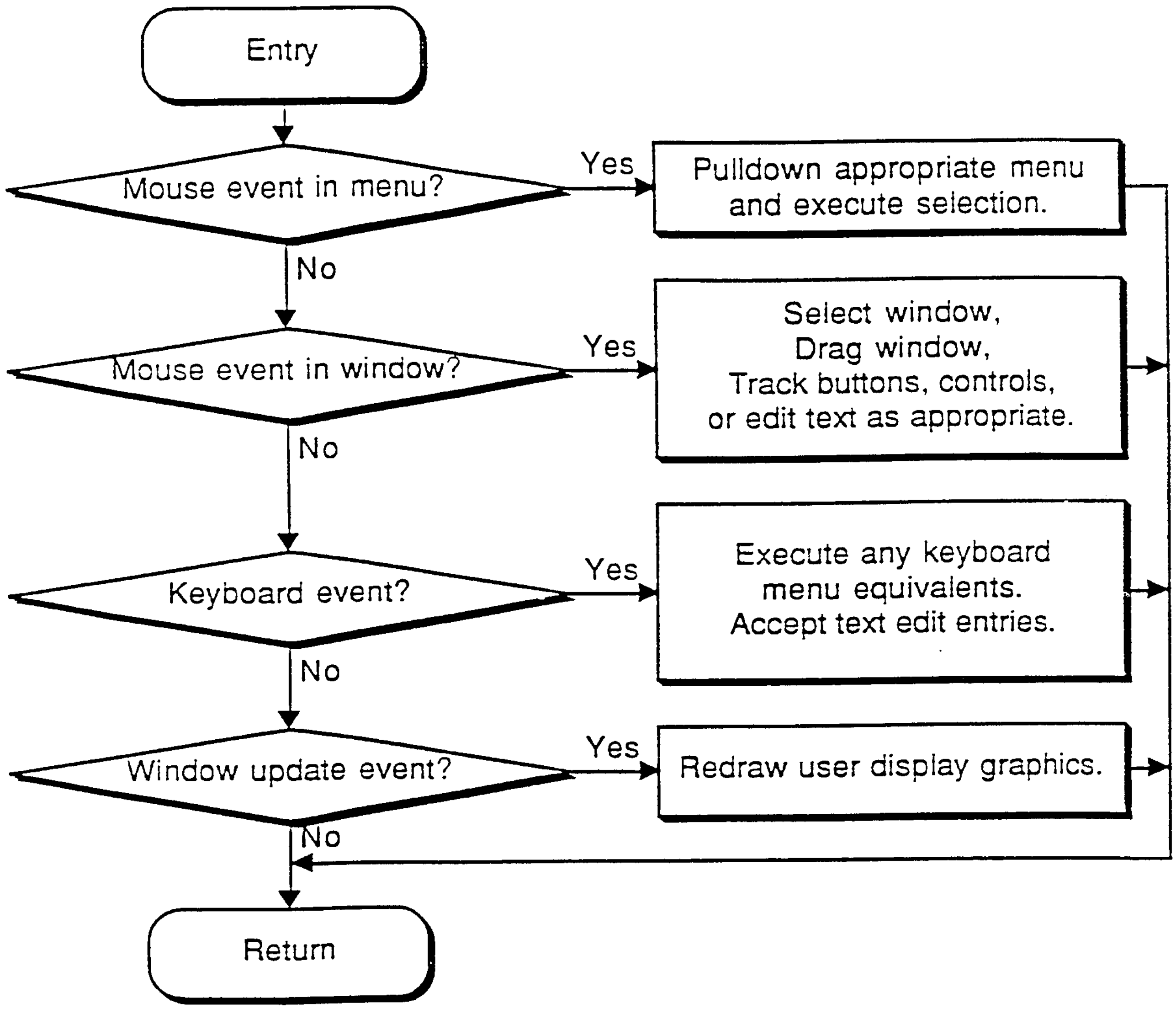


Figure B41. Handle user interface events.

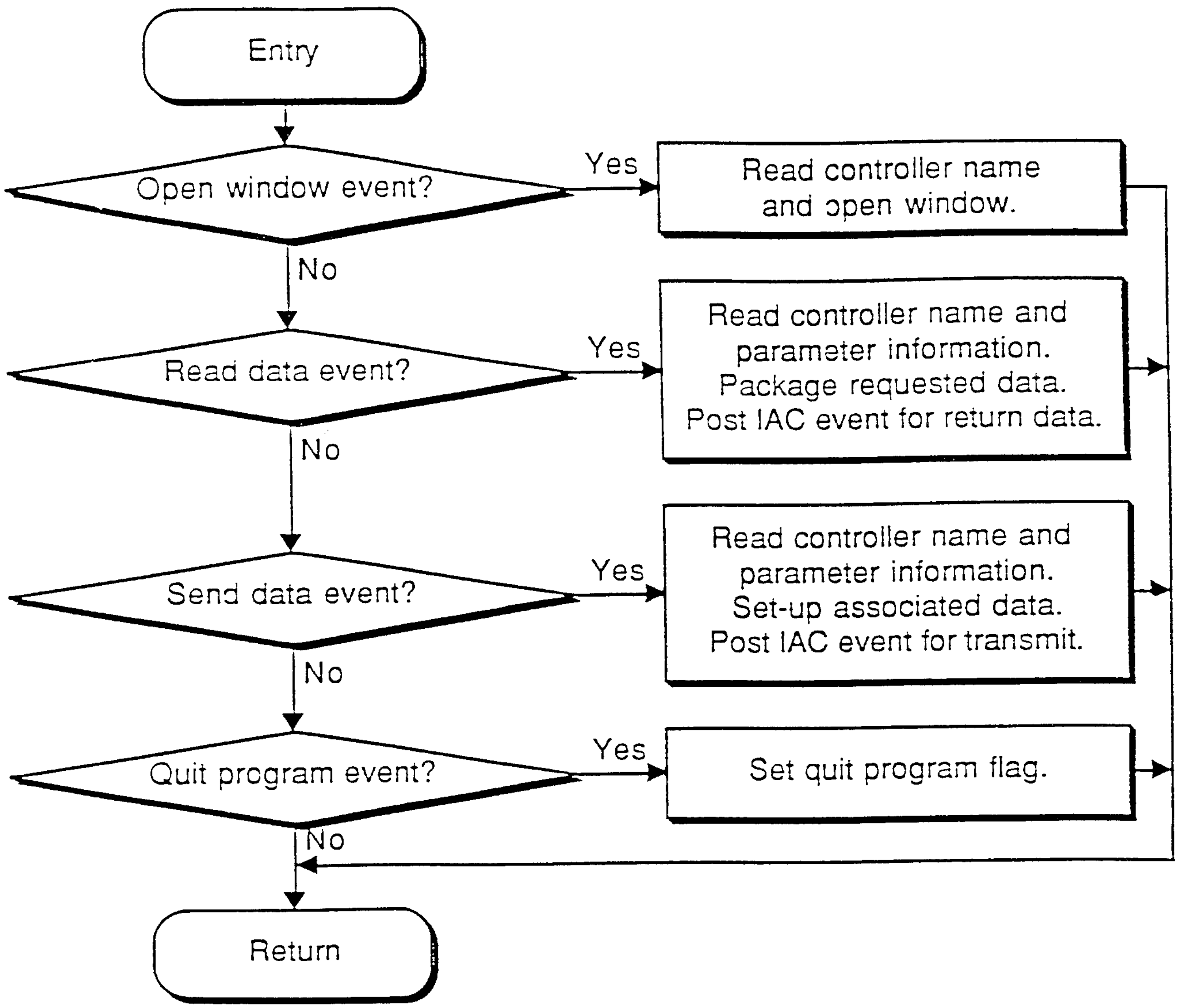


Figure B42. Handle Inter-Application-Communication.

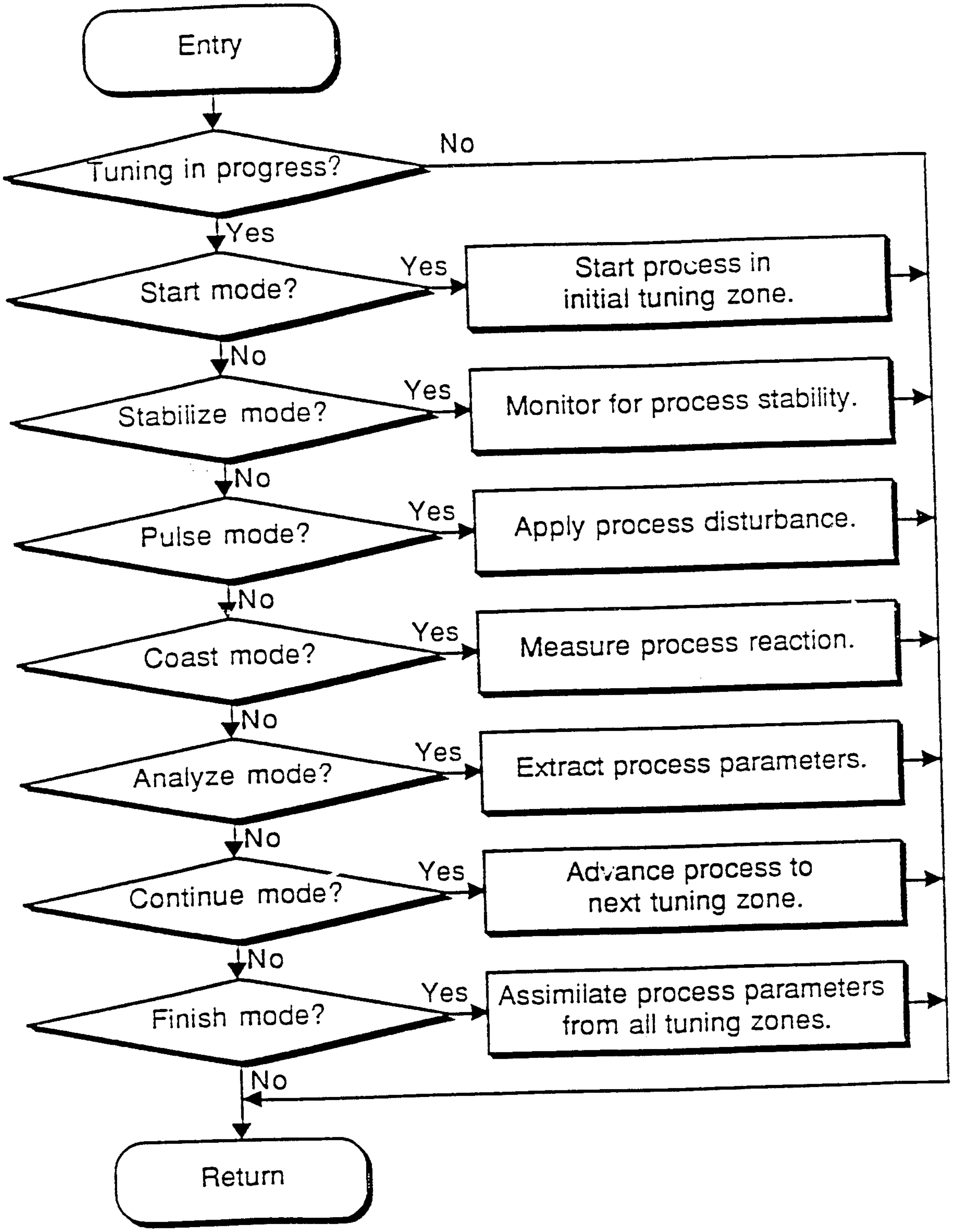


Figure B43. Handle process tuning sequence.

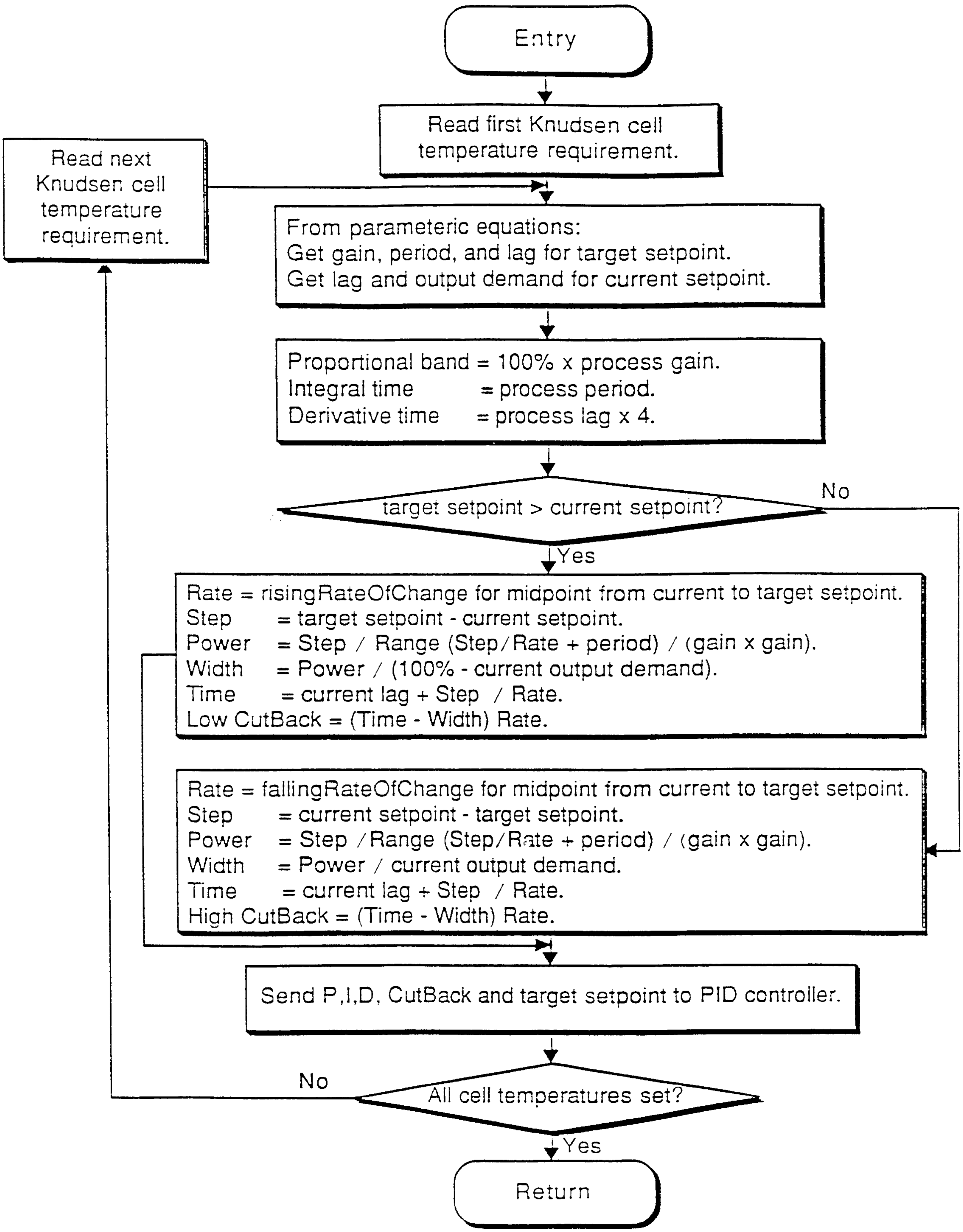


Figure B44. Handle process control sequence.

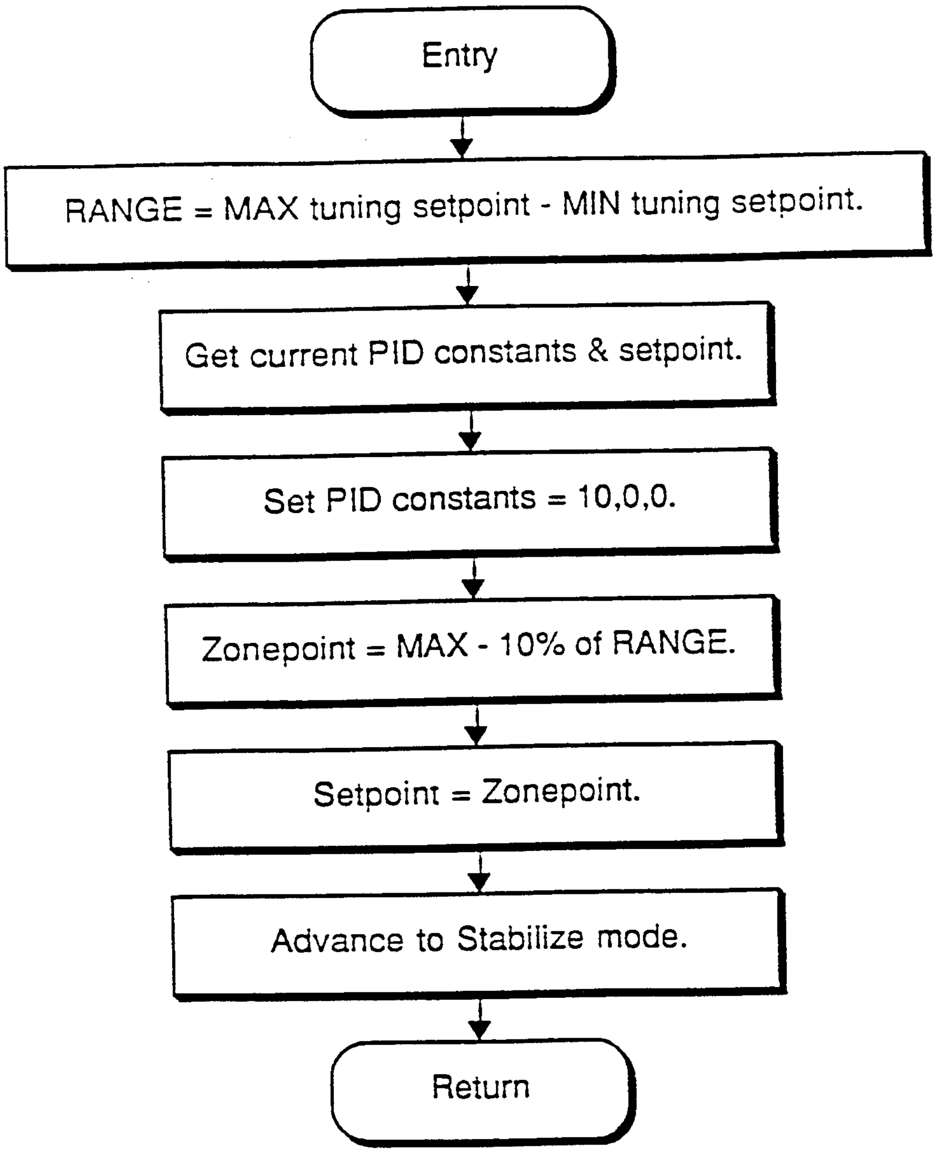


Figure B45. Start process in initial tuning zone.

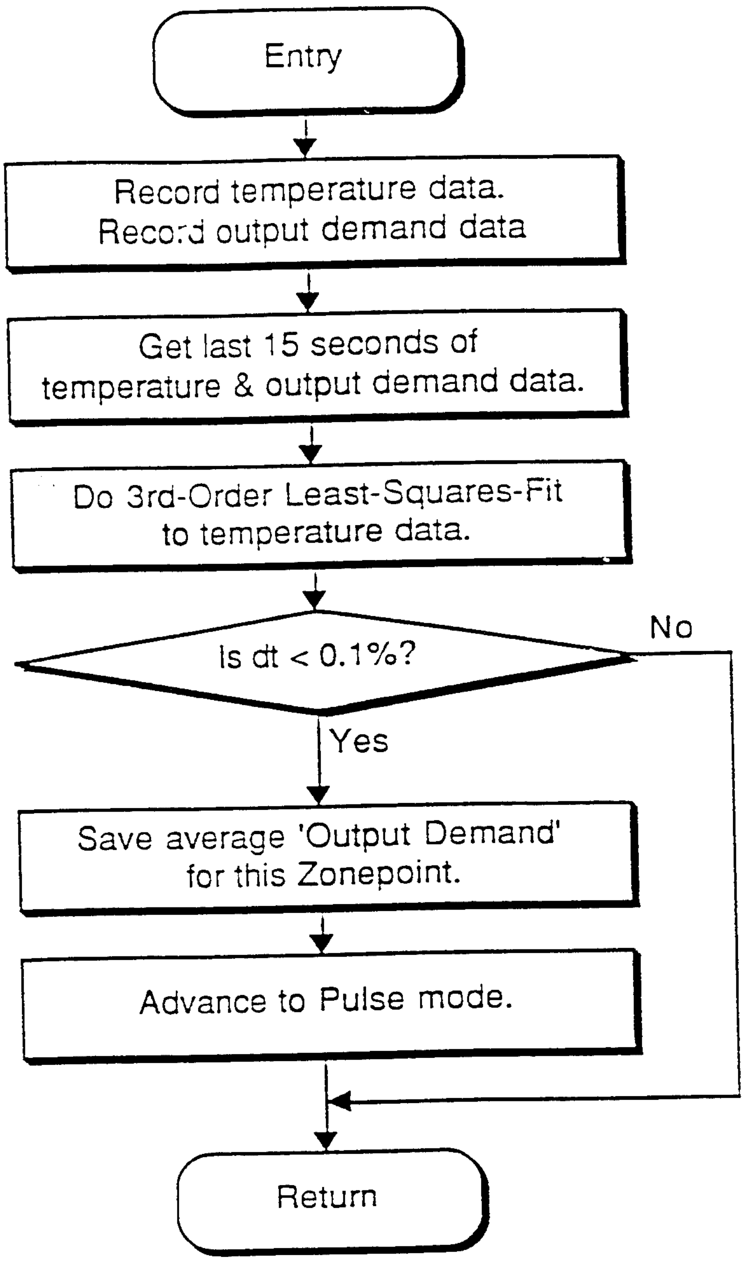


Figure B46. Monitor for process stability.

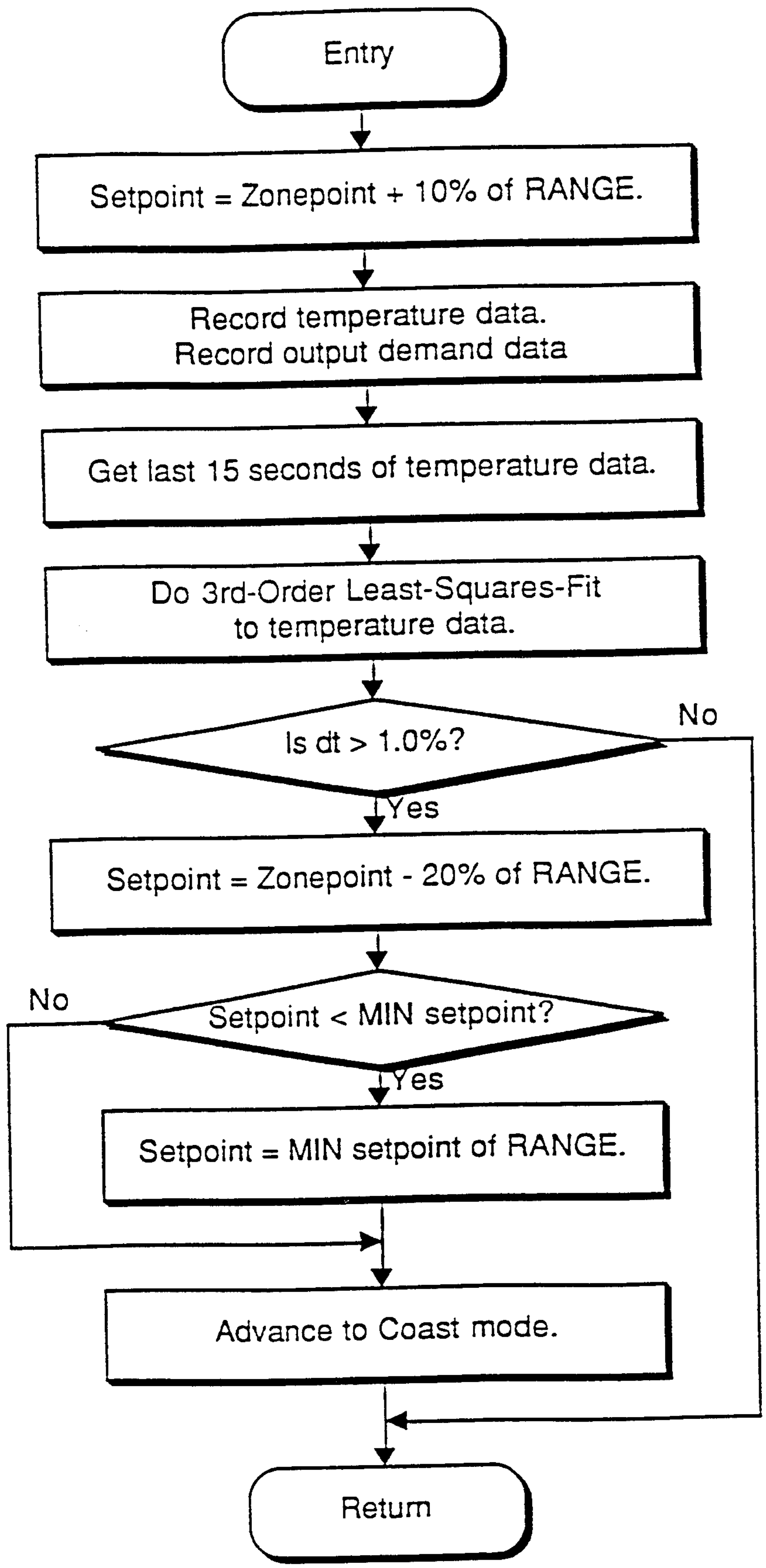


Figure B47. Apply process disturbance.

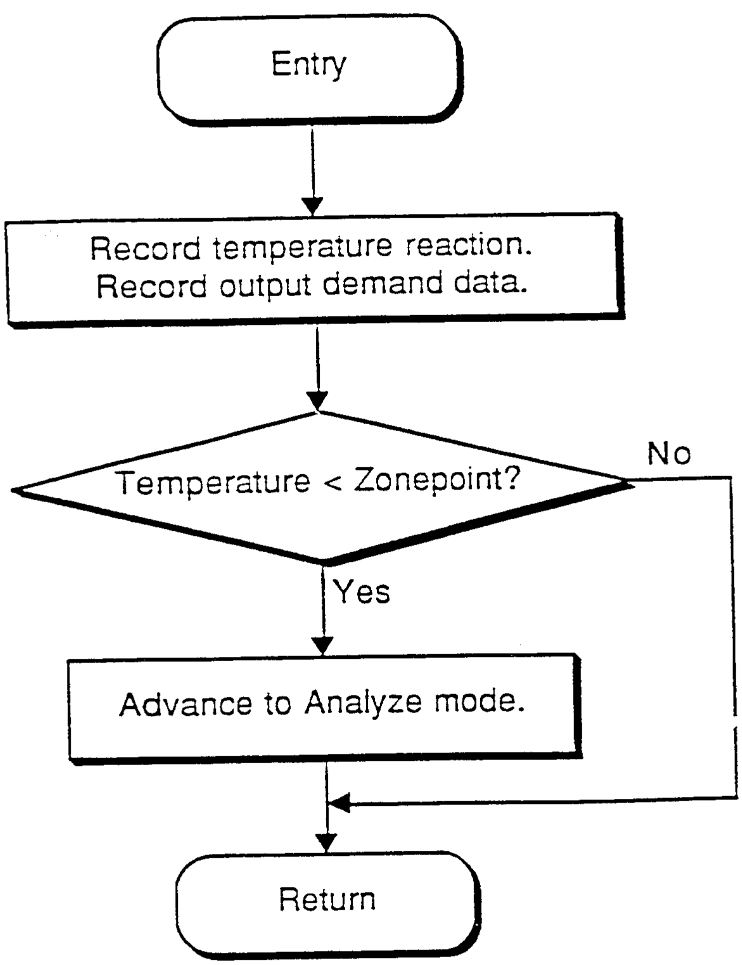


Figure B48. Measure process reaction.

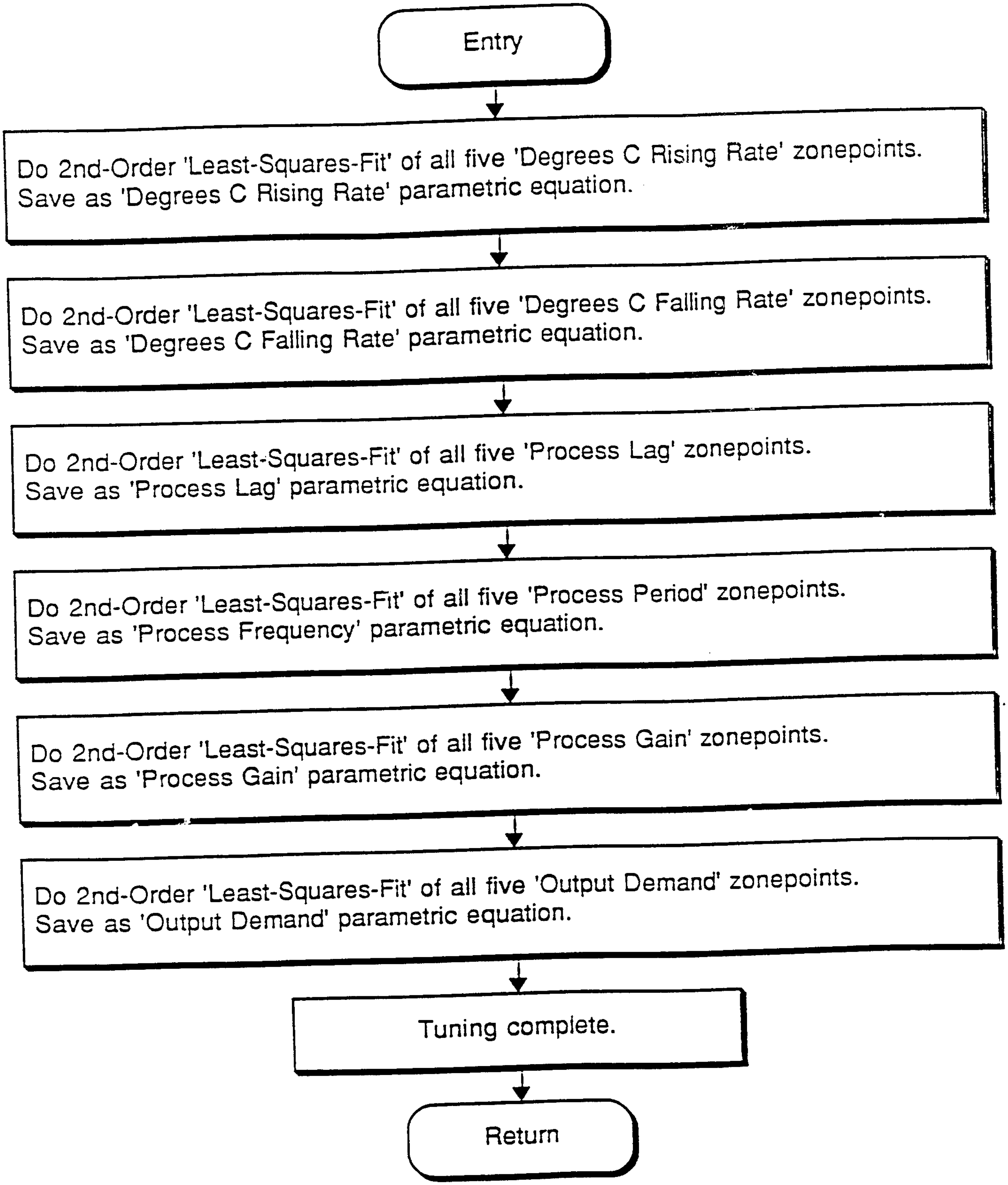


Figure B49. Assimilate process parameters from all tuning zones.

APPENDIX C

InfoScribe™ MODULE USER'S MANUAL

A description of software and hardware modules
currently under development
by Wright Laboratory MLIM

InfoScribe™

Submitted to:

and:

Wright Laboratory, Materials Directorate
WL/MLIM

Technical Manager:
Steven R. LeClair

Authors:
Sam Laube
Jeff Heyob
Steve Adams
David Liptak
Brian Guilfoos

DISCLAIMER : This software is being used at user's own risk: Neither the Government Agency nor its contractors assure software's accuracy or its appropriate use.

Version 1.0 8/01/95

Outline

I. Introduction

The InfoScribe™ system was developed at Wright-Patterson Air Force Base in the Material Process Design group. The InfoScribe™ system provides an integrated information management system for almost any type of process which is limited by the computer and peripheral hardware. The InfoScribe™ system was designed on a Macintosh IIfx and is Power Macintosh accelerated.

InfoScribe™ was developed to provide an integrated method of collecting and displaying data from a variety of material processes. The InfoScribe™ system provides a research or manufacturing facility with a uniform file format that all data can be stored to and recalled from. The flexibility of the InfoScribe™ system allows it to adapt to any type of process where data is collected. The InfoScribe™ system has been installed on a Molecular Beam Epitaxy process, on a Chemical Vapor Deposition process and at a hospital to monitor patient's oxygen and carbon dioxide levels.

II. InfoScribe™ Features

- Large data file capacity limited by installed system memory. (256MB)
- Formal parameter description for each data stream.
- Extensible through Apple Events to LabView™, Microsoft Word, etc.
- Low overhead for fast execution.
- Data file integrity maintained.
- User defined environment (environment stored in preferences).
- Reliable TimeTag™ on data.
- User friendly graphical interface.
- Chronological logging of data.

InfoScribe™ features during data collection

- Data storage types (Boolean, Integer, Real, Text, Pictures)
- Multiple data parameters added on demand. (i.e., a "temperature" parameter can be added to the data file while data collection in running.)
- Each data parameter is maintained as an independent data stream. (If one instrument fails, the remaining instruments can continue sending data to the file unimpeded.)
- Asynchronous data entry for any parameter at any time.
- Real-Time data interaction with instrument interface.
  - Push buttons to control actuators.
  - Edit fields for sending data to devices.
  - User definable display precision.
- Millisecond time resolution for each data entry via TimeTag™.
- Scaleable parameter window widths.
- Define user preferences for display data and machine information.
- Most recent data value displayed.
- Current range of display.
- Data units displayed for each parameter.
- Parameter name displayed for each input.

- Operator note entry.

- Ability to open multiple windows of data.

- Window management utilities:
  - Tile windows.
  - Stack windows.
  - Fit window to page.

- Data presentation utilities:
  - Adjust height of display entry.
  - Move plot.
  - Delete plot.
  - Mark data points.
  - Display value of data points.
  - Display average value.

- Time Management Utilities:
  - Adjustable time viewing frame.
  - Direct input of display range.
  - Mouse adjustable display range.
  - Selectable time resolution of current plot.

InfoScribe™ features during data retrieval

- Time Management Utilities:
  - Direct input of display range.
  - Mouse adjustable display range.
  - Graphical selection of display range (i.e. zoom).
  - Selectable time resolution of current plot.

- Selectable data for export.

- Data Export Utilities (Multiple storage formats driven by data requirements):
  - Microsoft Excel 4.0.
  - Microsoft Word 5.0.
  - MatLab 3.1.
  - Mathematica 3.0.
  - Delta Graph 3.1.
  - Text.
  - User defined (e.g., tab delimited, etc.).

- Selectable display data fields.

- Multiple file display.

- Multiple window display.

- Data presentation utilities:
  - Adjust height of display entry.
  - Move plot.
  - Delete plot.

- Mark data points.
    - Display value of data points.
    - Display average value.

- Window management utilities:
    - Tile windows.
    - Stack windows.
    - Fit window to page.

- Print capabilities. The current active window is printed as seen. The program sizes the window to fit on a sheet of paper.

- User defined preferences.

III. The Structure of InfoScribe

The InfoScribe™ system (figure 1) is designed as a modular combination of programs, i.e., InfoScribe™ and various support programs, which are adaptable to any process.

Although InfoScribe™ is the main program responsible for displaying and storing data, it does not interface directly to the hardware. Support programs provide the interface between InfoScribe™ and system hardware. Each support program is responsible for a robust interface between the sensor, actuator and InfoScribe™. The number and types of support programs are based on the requirements of the process and the amount of control required. The type of interface, unidirectional or bi-directional, is dependent on the requirements of the process hardware. Each support program is a separate program running on the Macintosh. If one program has a problem all other programs continue to process their data.

In addition to interface modules, InfoScribe™ may also use control modules. These modules are designed to improve the control of a process by integrating information from the sensors.

The cooperative multi-tasking Macintosh environment supports many programs working interactively to handle the process data. A supervisory program, InfoSupervisor™, monitors the function of related programs and provides intervention response when appropriate.

A diagram of the InfoScribe™ system is shown in figure 1.

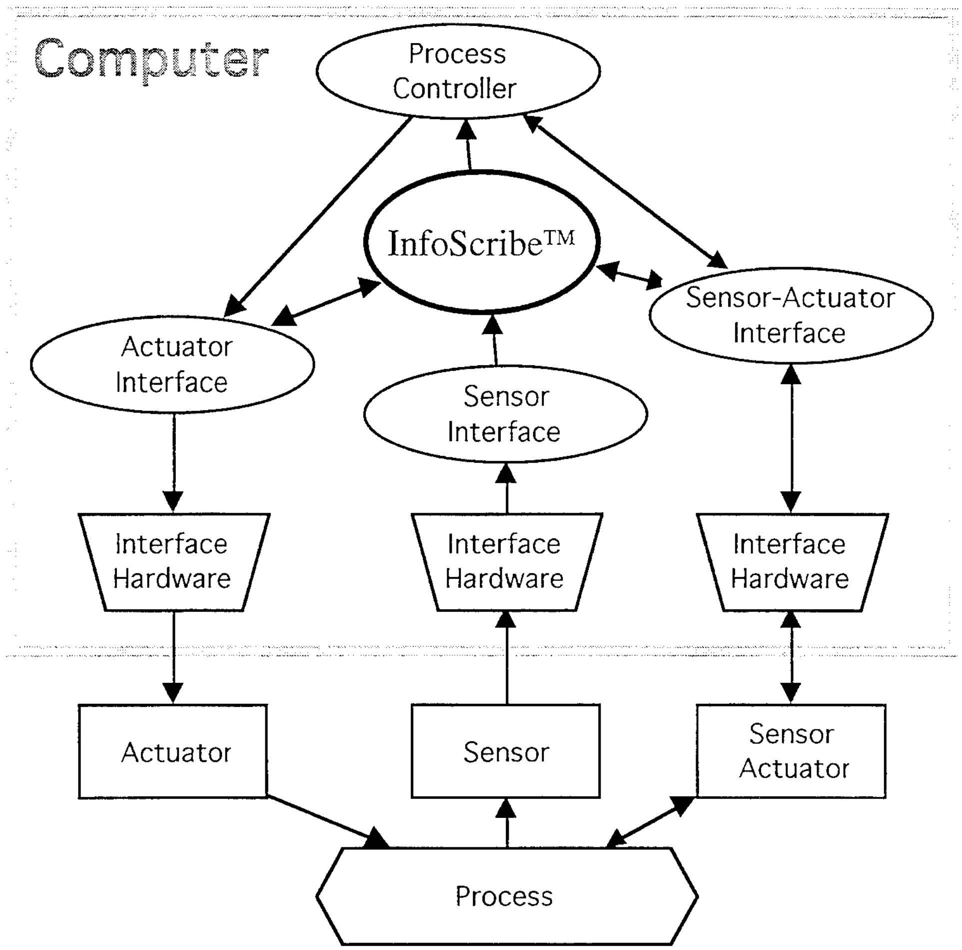


Figure 1

IV. Data Preservation

One of the key features of the InfoScribe™ data logging application is its ability to preserve data if the program terminates abnormally. Since typical applications for InfoScribe™ involve acquiring data over extended periods of time, say several days or even weeks, data preservation is essential. Most other data logging packages do not have this capability. When these programs crash, all data is lost. Not so with InfoScribe™! InfoScribe™ protects your data by using a temporary file to store data during data collection. If the program crashes, at most only ten seconds of data is lost. The remaining data is still available, stored safely on your hard disk.

V. Getting Started

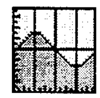
System requirements

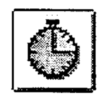
The minimum system requirements for the InfoScribe™ application are a Macintosh II and at least 8 Mbytes of RAM. The system version must be at least 7.0.1.

Required files

To run InfoScribe™ the following three files are required. They are contained on the InfoScribe™ installation disk.

InfoScribe™ 

InfoSupervisor™ 

InfoScribeTimeTag™ 

InfoScribe™ -----------------	Program that creates and displays information files for data acquisition programs in the Advanced Process Module Environment.
InfoSupervisor™ ---------	Program that interfaces InfoScribe™ to associated support programs.
InfoScribeTimeTag™ --	Program that manages the InfoScribe™ time base.

Installing the application

Use the following procedure to install InfoScribe™ onto your hard drive.

1. Insert the InfoScribe™ installation disk into disk drive.
2. Create a new folder. Name it InfoScribe.
3. Copy the InfoScribe™ and InfoSupervisor™ files from the installation disk to the InfoScribe folder that you have just created.
4. Copy the InfoScribeTimeTag™ file from the installation disk to the Startup Items folder that is located in the System folder.
5. Eject the InfoScribe™ installation disk and store in a safe place.

***If InfoScribe™ is to be run on a MacII or older system, you must place a copy of Mode32 in the Extensions folder.

You are now ready to run the InfoScribe™ program.

VI. Launching the InfoScribe Program

To start the InfoScribe™ application, click on the InfoSupervisor™ icon.

VII. The InfoScribe Window

Central to the InfoScribe™ integrated information management system is the InfoScribe™ window (figure 2). This is the command center from which you monitor and make adjustments to your process. The focus of this section is to introduce the different regions of this window (the legend, the plot region and the time scale) and the three icons that are available (the Note Book, Parameter List and Tool icons).

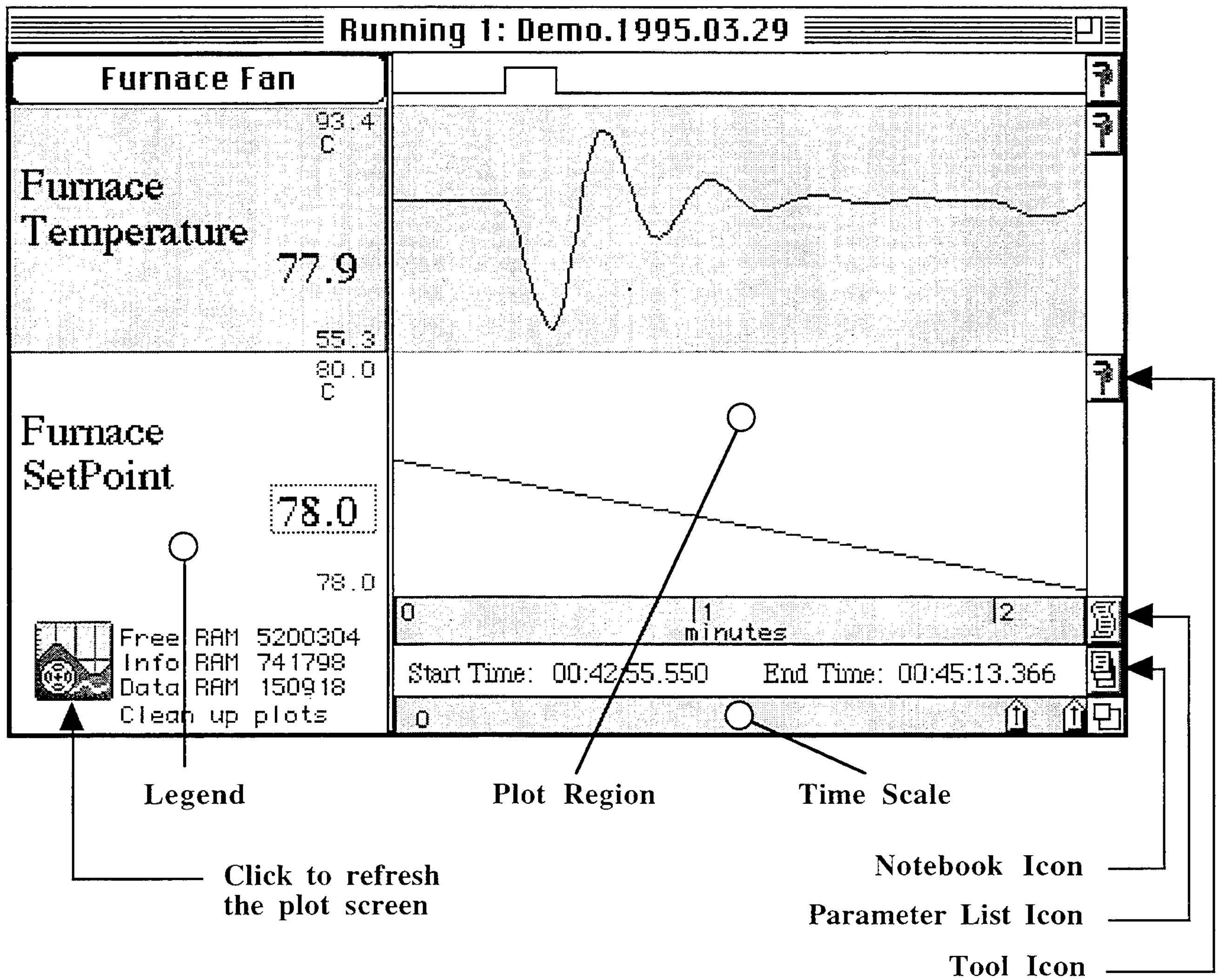


Figure 2

Legend -------------- Provides information on the attached plot region.
Plot Region ------- Graphical representation of the data.
Time Scale --------- Time display tools.
Note Book ---------- Open Notebook for user information.
Parameter List --- Open the Parameter List for this window.
Tool ------------------ Open Tool menu.

The plot region

The **plot region**, located in the upper right side of the window, is the display area for the data that your instruments collect and send to the InfoScribe™ application. Multiple plots can be displayed simultaneously.

The legend

To the left of the plot region lies the **legend**, which contains for each plot a title, the value of the most recent data point and the Y-axis scale. With certain modules the **legend** will also contain control buttons and data entry fields.

Do not be surprised if your **legend** looks different that the one shown in figure 3. The appearance of the **legend** varies depending on the type of support module being used, the names defined for the parameters and the choice of plots selected for display. The 'typical' **legend** in figure 3 contains examples of fields and instrument that you may encounter.

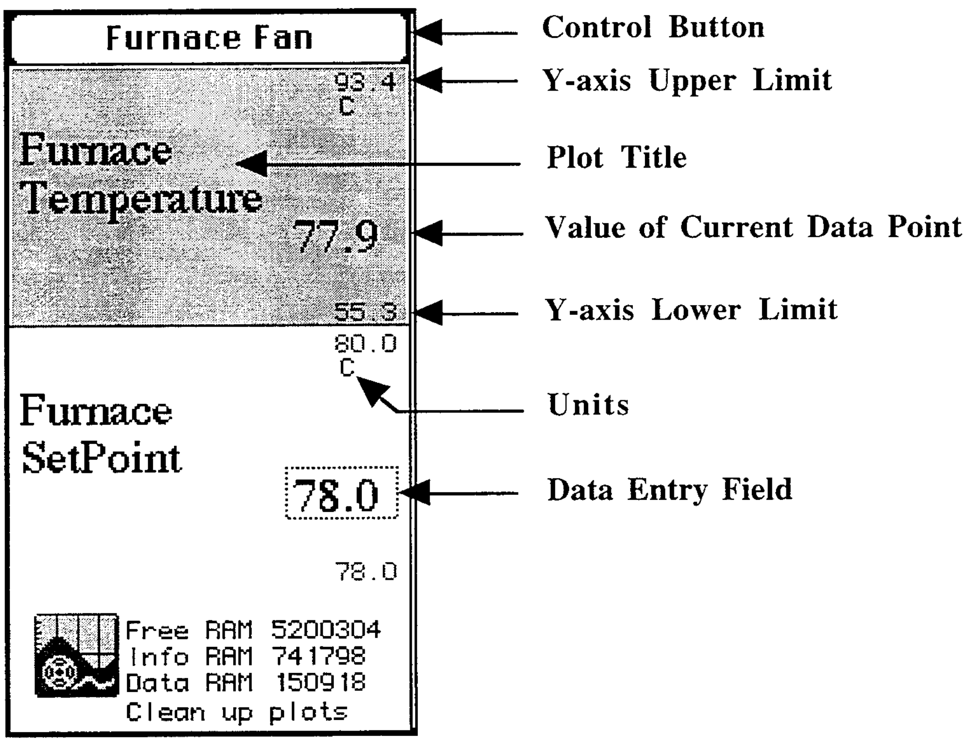


Figure 3

Control Button ------------------------ Turns an actuator on or off.
Y-axis Upper Limit ----------------- Current maximum value of the Y-axis.
Y-axis Lower Limit ----------------- Current minimum value of the Y-axis.
Plot Title --------------------------------- Descriptive name of the plot.
Value of Current Data Point --- Value of the most recent data point acquired.
Units --------------------------------------- Y-axis units defined by support modules.
Data Entry Field --------------------- Used to set a control parameter to a particular value.

A convenient feature of the InfoScribe™ program is that the Y-axis upper and lower limits are automatically scaled. These values will change periodically as InfoScribe™ updates the Y-axis scale to accommodate the entire set of data points in the display range.

The time scale region

The last region that needs to be introduced is the **time scale** region, which is located directly below the plot region. The **time scale** that you see on your screen will look similar to the one in figure 4.

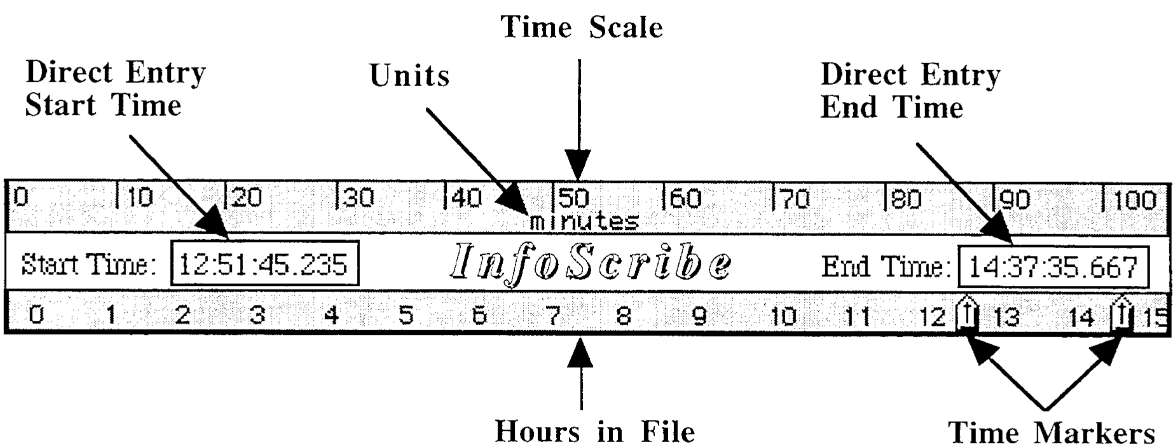


Figure 4.

Hours in File ---------------------- Represents the time, in hours, starting at midnight (zero hours) and ending on the first whole hour following the time that the latest data point was acquired.

Time Scale -------------------------- Indicates the current time scale and width of the display region. Starts from the left at zero and increases toward the right to a maximum value representing the time width of the display region.

Units ---------------------------------- Selectable from the Time Scale option on the menu bar.

Time Markers --------------------- Tools used to change the display range.

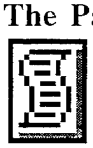
Direct Entry Start Time ----- Data entry field used to change the display range.

Direct Entry End Time ------- Data entry field used to change the display range.

The Notebook icon

The **Notebook** icon opens the **Notebook** window. Refer to 'Using the Notebook', in section VIII of this manual, for and explanation of how to use the **Notebook** to insert notes into your data files.

The Parameter List icon



The **Parameter List** icon opens the **Parameter List** window shown in figure 6. Use the **Parameter List** window to select parameters for display in the plot region.

The Tool icon

There will be a separate **Tool** icon associated with each plot. The **Tool** icon opens the **Tool** menu shown in Menu 4. From this menu a plot may be resized, moved or deleted. In addition, the **Parameter List** window is accessible through the **Tool** menu. The tool menu is automatically adjusted to provide tools for different parameter types of data.

VIII. <u>Using InfoScribe</u>

Naming data files

One of the first things that you need to do before attempting any data collection is to tell InfoScribe™ where to store the data that is collected. On startup, InfoScribe™ will display a **Setup File Defaults** window that allows you to uniquely identify the data logging session. (This window is also available via the Edit/Setup File Defaults option on the menu bar.)

Figure 5 is an example of the **Setup File Defaults** window.

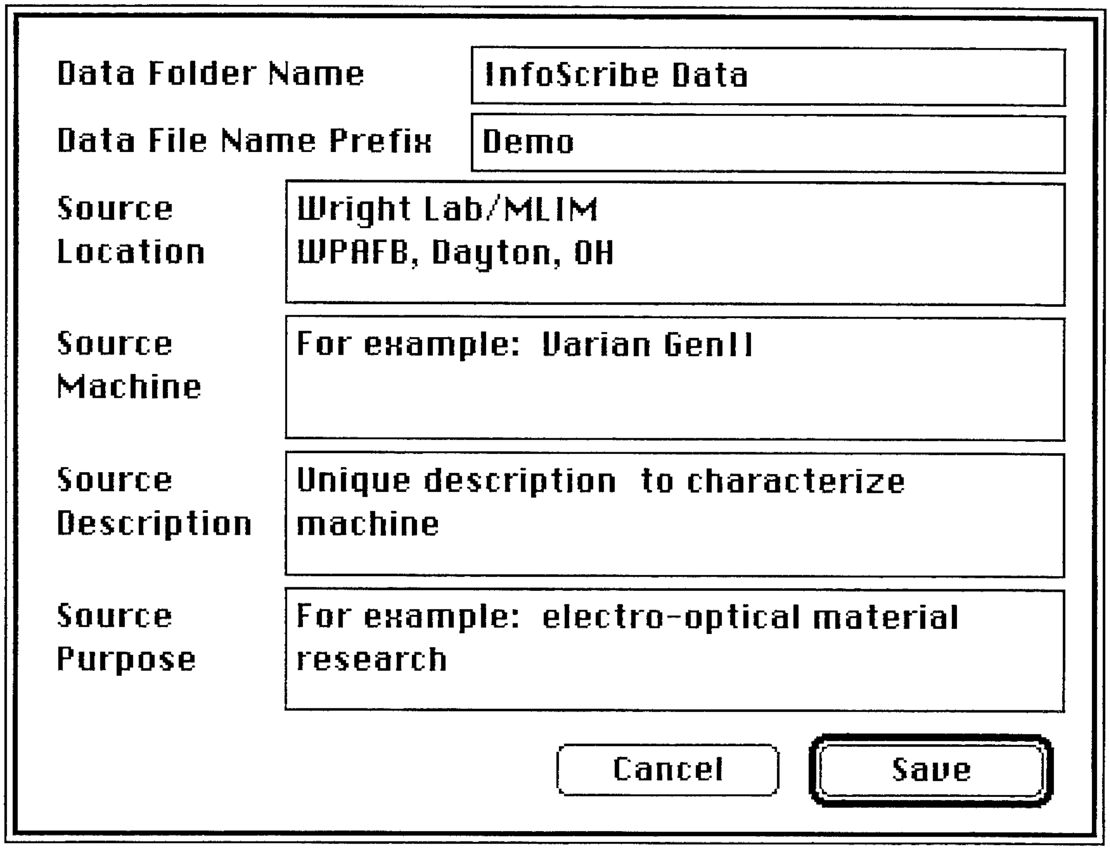


Figure 5

Data Folder Name ----------- Folder where current data file will be stored.
Data File Name Prefix --- Prefix for current data file.
Source Location ------------- Place where the InfoScribe™ system is located.
Source Machine -------------- Name of the machine used.
Source Description -------- Unique description that characterizes the machine.
Source Purpose -------------- Brief description of the purpose of the source.

Use the following procedure to identify the data logging session.

1. Enter the name of the folder where you want to store your data file into the **Data Folder Name** field. If the folder does not already exist, InfoScribe™ will automatically create it on the desktop of the boot volume.
2. Enter a meaningful name for the current data file into the **Data File Name Prefix** field. InfoScribe™ automatically combines this prefix with the current date to create the filename. To illustrate how this works lets assume that today is January 21, 1995. We want the filename of our InfoScribe™ session to reflect that this is a demonstration run, so we choose 'Demo' as the **Data File Name Prefix**. All data taken today with these file parameters will then be stored in the InfoScribe Data folder in a file named Demo.1995.01.21.
3. Place additional information concerning the InfoScribe™ session in the remaining four fields.
4. Click on **Save** to close the window and save the file defaults.

Selecting parameters to view
To select the parameters that you wish to display in the plot region click on the **Parameter List** icon located on the right side of the InfoScribe™ window. The **Parameter List** window will appear (figure 6).

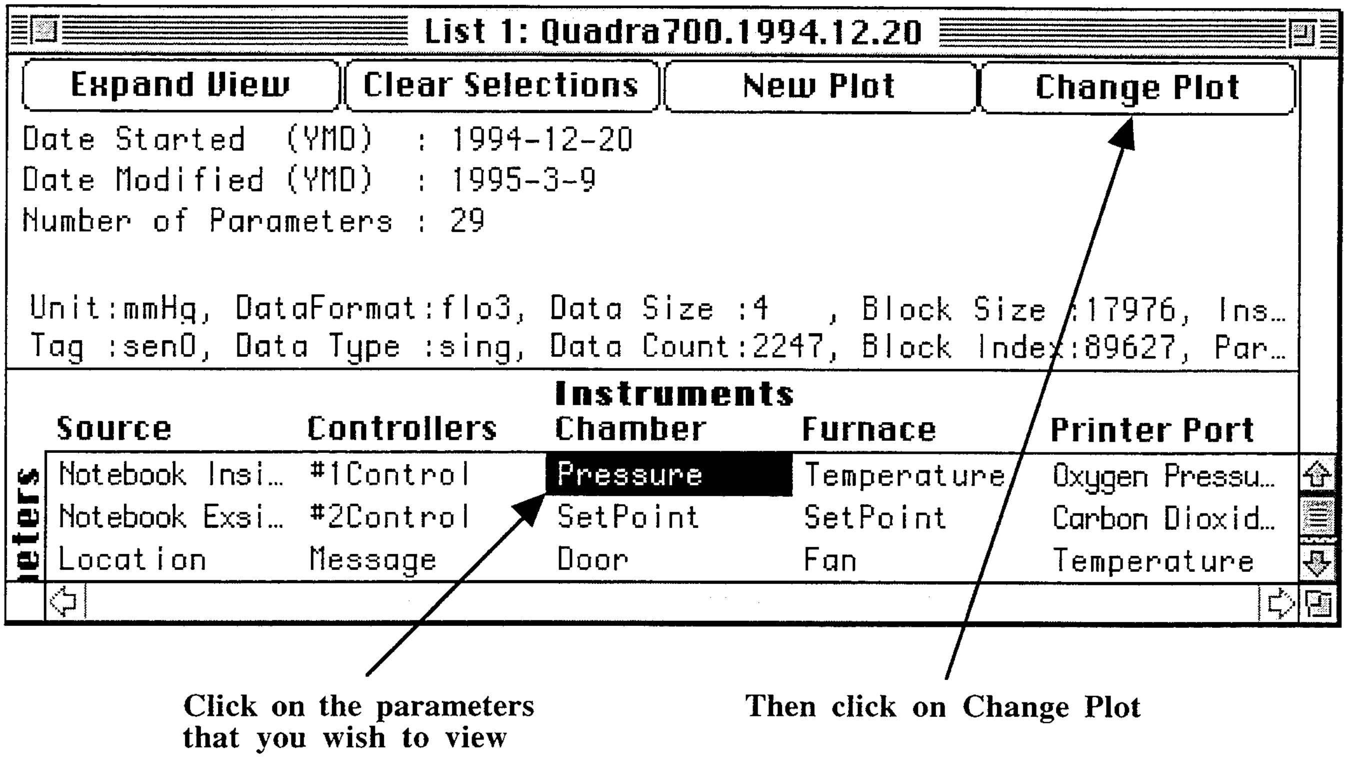


Figure 6

Expand View ------ Will display the entire parameter name without ellipses.
Clear Selection -- Unselect all selected parameters in parameter list
New Plot ----------- Open a new plot window using selected parameters.
Change Plot ------- Change current window using selected parameters.

Select the parameters that you want to display (e.g., Pressure, Temperature, Carbon Dioxide Pressure) by clicking on them in the order that you want them arranged on the plot screen. The plot for the first parameter selected will appear at the top. Each following selection will appear immediately below the previous, with the last selection at the bottom. Once selected, the parameters appear highlighted. To deselect a parameter, click on it a second time. The highlight will disappear, indicating that the parameter is no longer selected. Once the desired parameters have been highlighted, click on **Change Plot** to close the window. The original InfoScribe™ window will now display a plot for each parameter chosen.

Choose **New Plot**, instead of **Change Plot**, to plot these parameters in a new window. During active data logging the new plot is a freeze frame of the data for that time.

If some of the selected plots are not visible, or are not tall enough to see clearly, then use the zoom box to resize the InfoScribe™ window so that they are easier to view. Clicking on the zoom box will cause InfoScribe™ to expand the window and accommodate all of the selected plots. A second click on the zoom box will return the window to its previous size.

Using control buttons

Control buttons are located in the **legend**. Figure 7 is an example **legend** containing a **control button**.

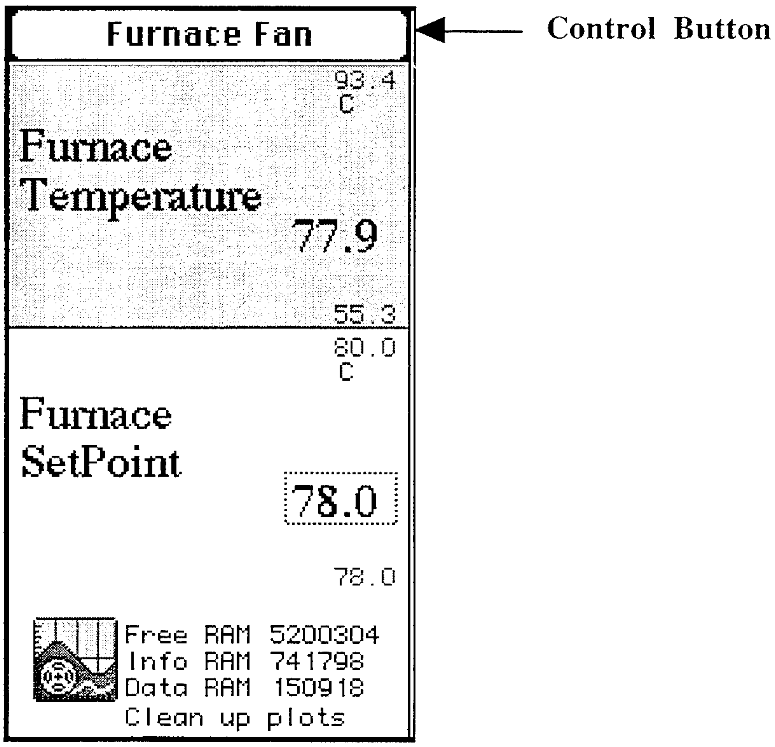


Figure 7

A **control button** functions as a Boolean actuator to turns some process on or off. The button in figure 7 has the name "Furnace Fan" and is currently in the OFF state. When the button is in the ON state the word "ON" appears following the button name. For this example the button will read "Furnace Fan ON" when in the ON condition. Clicking on a control button will cause it to change state.

The color scheme of a control button may be changed by the following procedure.

1. In the 'Tool' menu choose 'Set Button Color'.

A window similar to figure 8 will appear. Notice the text in the upper left corner of the window, i.e., 'Button: Furnace Fan ON'. The word 'Button' indicates that this window affects the background color of the control button. If the word 'Text' appears instead of 'Button', then the window affects the color of the text in the control button. 'Furnace Fan' is the name of the control button whose color is being changed. The last word, 'ON', indicates that the selected color will be applied to the control button when the button is in the ON state. If the word 'ON' is not present then the selected color will be applied to the control button when in the OFF state. This feature makes it easy to tell when the button has been activated.

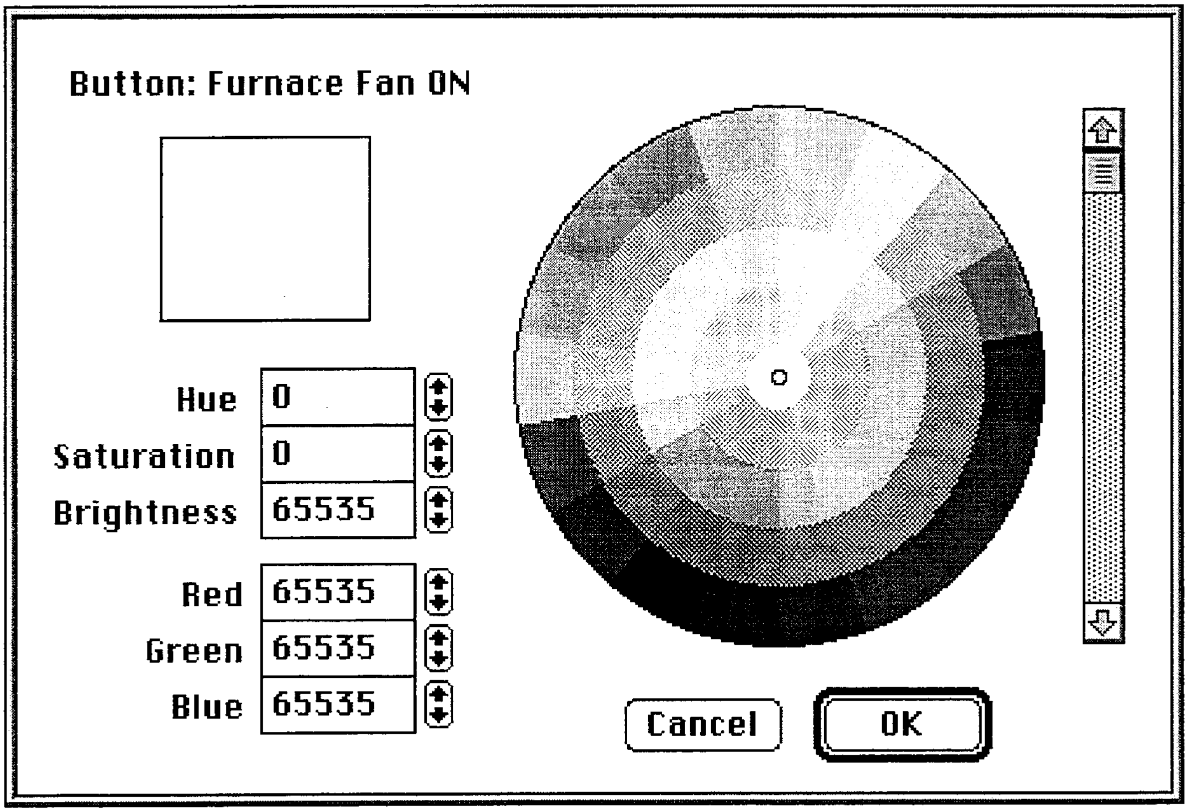


Figure 8

2. Choose the desired color from the color pallet.
3. Click on **OK** to close the window and apply the new color scheme.
4. Repeat steps 2 and 3 for each of the four color pallets that appear.

If you wish to copy the color scheme to the other buttons you can select 'Copy Button Color' from the 'Tool' menu, and then, in the 'Tool' menu of the appropriate control button select 'Paste Button Color'. All color preferences for the button will be copied.

Using data entry fields
Data entry fields are also located in the legend. Figure 9 is an example **legend** containing a **data entry field**.

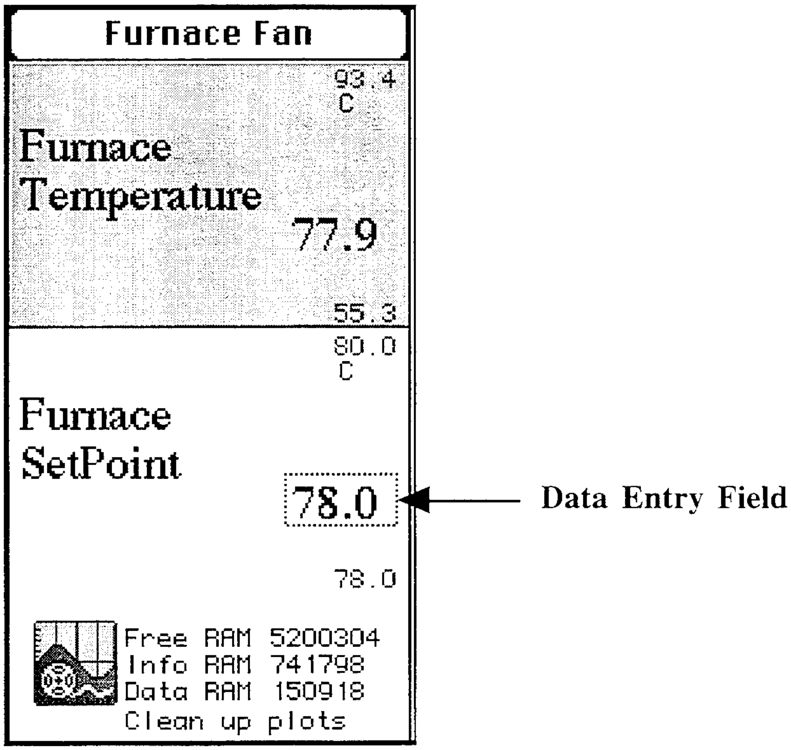


Figure 9

The **data entry field** in figure 9 is an example of a Real actuator, which is used to set a control parameter to some Real value. In this example the **data entry field** establishes a setpoint, which is the desired temperature of the furnace. Use the following procedure to set or change the value of a Real actuator:

1. Click on the actuator to select it. (The field will change color.)
2. Type in the new setting.
3. Press **Enter**.

The new value will now replace the old value.

Opening a new window
The following technique can be used to open a new InfoScribe™ window on the desktop.

1. Click in the plot region of the InfoScribe™ window.
2. While holding down the mouse button, drag the cursor to a new location inside of the plot region.
3. Hold down the **option** key.
4. Release the mouse button.
5. Release the **option** key.

This new InfoScribe™ window will contain data from the portion of the plot region that was selected by the mouse. The original InfoScribe™ window will remain unchanged on the desktop.

Changing the display range

There are three methods by which the display range can be set:

1. Positioning the time markers. (Coarse resolution)
2. Zooming in on a new window with the mouse. (Medium resolution)
3. Entering the exact time into the direct entry fields. (Fine resolution)

Positioning Time Markers**:** Use the two **Time Markers** (shown in figure 4) for coarse time scale adjustment. Click-drag the mouse on the leftmost marker to set the beginning of the time axis and on the rightmost marker to set the end of the time axis.

Hint. An easy way to scroll a window of "x" minutes through a data file is to move both time markers simultaneously by clicking between them and dragging them to a new location.

Zooming with the mouse: You may also define the time axis by click-dragging the mouse in the plot area. This method is useful for "zooming in" on a region of interest. The direct entry fields and the time markers will be automatically adjusted to reflect the new settings.

If, after "zooming in," the plots seem distorted or if several plots overlap, then click on the InfoScribe™ icon located in the lower left corner of the InfoScribe™ window. This will redraw the window and clean up the plot region.

Direct Entry: To achieve very-fine time scale resolution (i.e., millisecond resolution), use the **Direct Entry Start/End Time** fields (Also shown in figure 4.). This is the preferred method if you know the start and end times in advance. To use this method, follow these steps:

1. Click on the **Direct Entry Start Time** field.
   (A highlight indicates that the field is selected.)
2. Type in the desired start time.
3. Press the **Enter** key.
   (The **Return** key does not work in this context.)

Set the end time using the same technique, however, select the **Direct Entry End Time** field instead of the **Direct Entry Start Time** field. This option is available only when InfoScribe™ is not logging data.

When entering times into the **Direct Entry Start/End Time** fields, keep the following in mind:

1. The **Direct Entry Start Time** entry must be less than the **Direct Entry End Time** entry.
2. The InfoScribe™ time scale is based on a 24 hour clock. This means that you must enter the hours, after twelve o'clock noon, as 13:00, 14:00, etc.
3. You must enter **two** digits in each of the hours, minutes, seconds and milliseconds sections of the **Direct Entry Start/End Time** fields. Here are a few examples that illustrate this point.

Valid entries	Invalid entries
09:01:05	9:1:5
15:00	15:0
00:33	0:33
02	2

4. A colon is not required to separate the hours, minutes, seconds and milliseconds fields. Therefore...

	22:05:11	may be entered as	220511
and	01:00:01	may be entered as	010001.

Here is a useful technique for determining the starting time of the current data file.

1. Select the **Direct Entry Start Time** field.
2. Type in 00.
3. Press the **Enter** key. (Remember, the return key does not work in this context.)

The **Direct Entry Start Time** field will show the starting time of the current data file (not zero hours) and the left time marker will move to the starting time position.

Similarly, the end time can be determined by entering 24 into the **Direct Entry End Time** field. The **Direct Entry End Time** field will then show the ending time (not 24 hours) and the right time marker will reposition accordingly. The end time can be set in this manner only when InfoScribe™ is not logging data.

Moving a plot

To move a plot to a new location inside of the plot region use the following procedure.

1. Click on the tool icon located to the right of the plot that will be moved.
2. Select **move plot**. (The plot will change color and the cursor will change from a crosshair to a hand.)
3. Click the hand on the plot to be moved and drag the plot to its new location.
4. Release the mouse button.

Removing a plot

There are two ways to remove a plot from the plot region. One way is to open the parameter list window and deselect the plot parameter from the parameter list. The second way is to open the tool menu for the plot and select **delete plot**. Either method affects only the display of the data for that particular parameter. It does not stop the data from being logged.

Using the Notebook

The **Notebook** option, selected by clicking on the **Notebook** icon located on the lower right hand side of the InfoScribe™ window, allows brief comments to be inserted into the current data file. The following window, figure 10, is an example of the **Notebook** window.

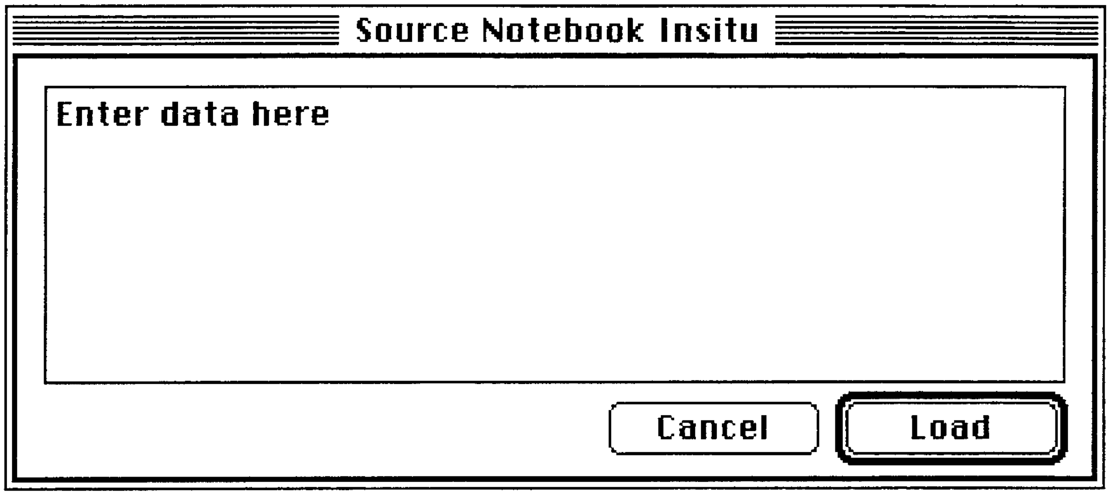


Figure 10

To 'post a note' in the current data file, enter your text into the notebook and then click on **Load**. The entry will be tagged with the current time and stored along with the data. You can view these entries by selecting **Notebook Insitu** or **Notebook Exsitu** from the **Parameter List** window.

Determining data point values

To determine the value of a particular data point do the following:

1. Position the cursor on the data point.
2. Hold down the command key as you click on the data point with the mouse.

This will print out the value of the data point nearest to the cursor.

Exporting files

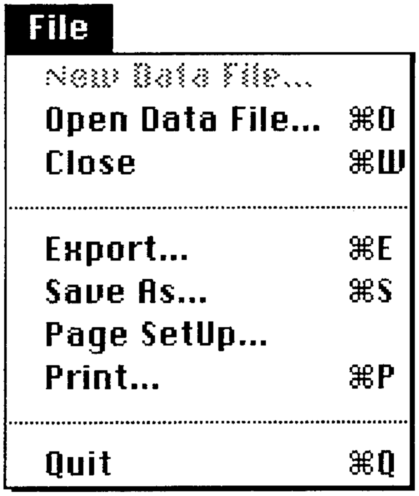
Coming soon...

IX. Shutting Down InfoScribe

From the menu bar click on **File** and then pull down **Quit** to shut down the InfoScribe™ program. All applications associated with InfoScribe™ will then terminate.

X. The InfoScribe Menus

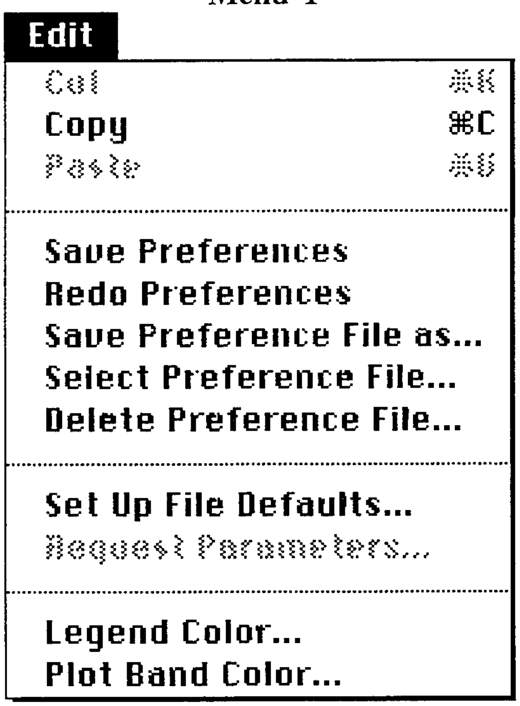
This section describes the InfoScribe™ menus available from both the menu bar and the InfoScribe™ window icons.



Menu 1

File Menu

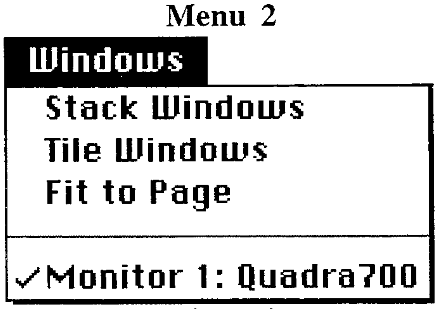
New Data File - Create a new file.
Open Data File - Open a file for viewing.
Close - Will close the current file.
Export - Convert and save the current window selection to a file.
Save As - Renames and saves the current open file
Page SetUp - Defines the printer page.
Print - Prints the current window.
Quit - Close all windows and quit InfoScribe™.



Menu 2

Edit Menu

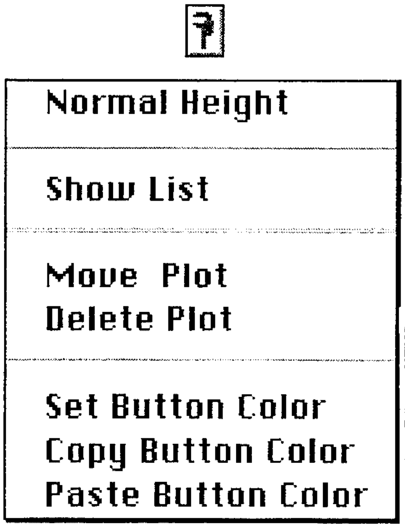
Cut - Remove a selected region of the window and store in memory.
Copy - Duplicate a selected region of the window in memory.
Paste - Copy the stored memory to the cursor location.
Save Preferences - Save active window setup, default folder name and active file name.
Redo Preferences - Reload preferences.
Save Preferences File as... - Save plot window settings.
Select Preference File... - Reload preferences.
Delete Preference File... - Choose a preference file to delete.
Set Up File Defaults - Define file information.
Request Parameters - Get a parameter list from another program.
Legend Color - Set the back ground color associated with the color band.
Plot Band Color - Set the color of the band.



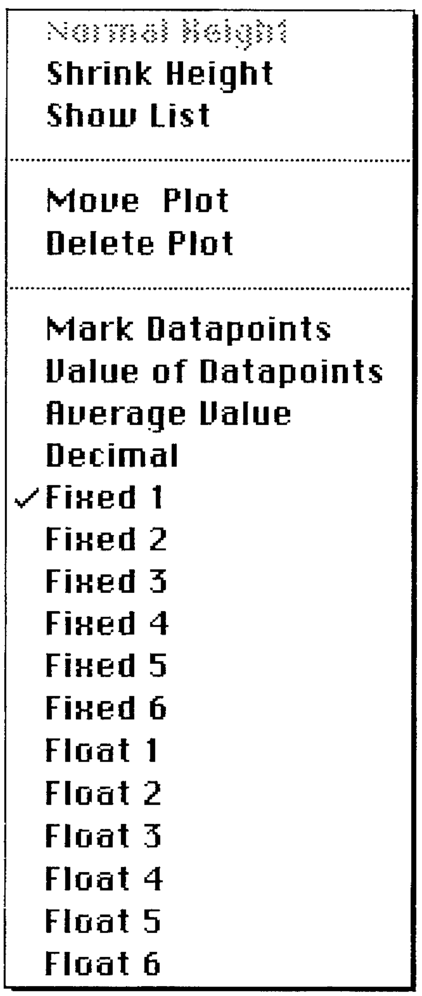
Menu 3

Windows Menu

Stack Windows - Stack the windows on top of each other showing just the title bar. (space saving)
Tile Windows - Tile the window covering the entire screen. (easy viewing)
Fit to Page - Fit the current window to the printer page size.



Menu 4a



Menu 4b

<u>Tool Menu</u>
Normal Height - Set plot height to normal.
Shrink Height - Reduce plot height.
Show List - Display current list of parameters.
Move Plot - Change the position of a plot.
Delete Plot - Remove plot from current window.

<u>4a: Boolean Switches</u>
Set Button Color - Define button backround and text colors.
Copy Button Color - Copy button colors (all four) to a clipboard.
Paste Button Color - Paste colors from clipboard to current button.

<u>4b: All Other Graphs</u>
Mark Datapoints - Mark points with a red dot.
Value of Datapoints - Display the value of datapoints on the graph.
Average Value - Draws a green line at the average value and displays the value.
Decimal - Rounds displayed values to the nearest whole number.
Fixed 1...6 - Number of displayed decimal places (eg, 4.6 ... 4.567024).
Float 1...6 - Number of displayed floating digits (eg, 7e+2 ... 7.00644e+2).

Time Scale Menu
Allow the user to select the display time scale.

Time Scale

- 1 seconds
- 2 seconds
- 5 seconds
- 10 seconds
- 20 seconds
- 50 seconds
- 100 seconds
- 200 seconds
- ✓ 1 minutes
- 2 minutes
- 5 minutes
- 10 minutes
- 20 minutes
- 50 minutes
- 100 minutes
- 200 minutes
- 1 hours
- 2 hours
- 3 hours
- 4 hours

Menu 5

APPENDIX D

PID MODULE USER'S MANUAL

A description of software and hardware modules
currently under development
by Wright Laboratory MLIM

PIDcontrol

Submitted to:

and:

Wright Laboratory, Materials Directorate
WL/MLIM

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Jeff Heyob
David Liptak

DISCLAIMER : This software is being used at user's own risk: Neither the Government Agency nor its contractors assure software's accuracy or its appropriate use.

Version 1.0 8/07/95

Outline

I. Introduction

The InfoScribe™ system was developed at Wright Patterson Air Force Base in the Material Process Design group. The InfoScribe™ system provides an integrated information management system for almost any type of process which is limited by the computer and peripheral hardware. The InfoScribe™ system was designed on a Macintosh IIfx, and is Power Macintosh accelerated.

InfoScribe™ was developed to provide an integrated method of collecting and displaying data from a variety of material processes. The InfoScribe™ system provides a research or manufacturing facility with a uniform file format that all data can be stored to and recalled from. The flexibility of the InfoScribe™ system allows it to adapt to any type of process in which data is collected. The InfoScribe™ system has been installed on a Molecular Beam Epitaxy process, on a Chemical Vapor Deposition process and in a hospital setting to monitor patient's oxygen and carbon dioxide levels.

The PIDcontrol module allows you to use proportional, integral, derivative process control data via serial ports with the InfoScribe™ program.

II. PIDcontrol Features

- Individual labeling of PID control instruments by the user.
- Short Windows are user configurable.
- Selected fields are able to be modified.

III. The Structure of PIDcontrol

The InfoScribe™ system is designed as a modular combination of programs, i.e., InfoScribe™ and various support programs, which are adaptable to any process.

Although InfoScribe™ is the main program responsible for displaying and storing data, it does not interface directly to the hardware. Support programs provide the interface between InfoScribe™ and system hardware. Each support program is responsible for a robust interface between the sensor, actuator and InfoScribe™. The number and type of support programs is based on the requirements of the process and the amount of control required. The type of interface, unidirectional or bi-directional, is dependent on the requirements of the process hardware. Each support program is a separate program running on the Macintosh. If one program has a problem all other programs continue to process their data.

PIDcontrol is a robust interfacing module between InfoScribe™ and the hardware. InfoScribe™ receives data from the PIDcontrol program, which gives the user the ability to define ports for serial data entry.

IV. Getting Started

System requirements

The minimum system requirements for the InfoScribe™ application are a Macintosh II and at least 8 Mbytes of RAM. The system version must be at least 7.0.1. In addition, in order to run PIDcontrol, you need an available serial port.

To use PIDcontrol, place the PIDcontrol program in the InfoScribe™ folder, the same location as the InfoScribe™ application.

TimeTag™ must be running prior to launching PIDcontrol or InfoScribe™. TimeTag™ should be placed in the StartUpItems folder in the Macintosh system folder so that it is always running.

You are now ready to use PIDcontrol.

V. Launching the PIDcontrol Program

Double-click on the InfoSupervisor™ icon to launch the InfoScribe™ system. InfoSupervisor™ will automatically start the appropriate programs.

VI. Using PIDcontrol: Windows

The PIDcontrol program has but one important window... the Control window. The control window gives you methods of monitoring the data being received through the serial port. There are two views for Control windows: the Full Window and the Short Window.

- **Full Window**

  The Full Window lists all available data streams coming from a PID controller. A sample portion of the Full Window is pictured below (Fig. 1).

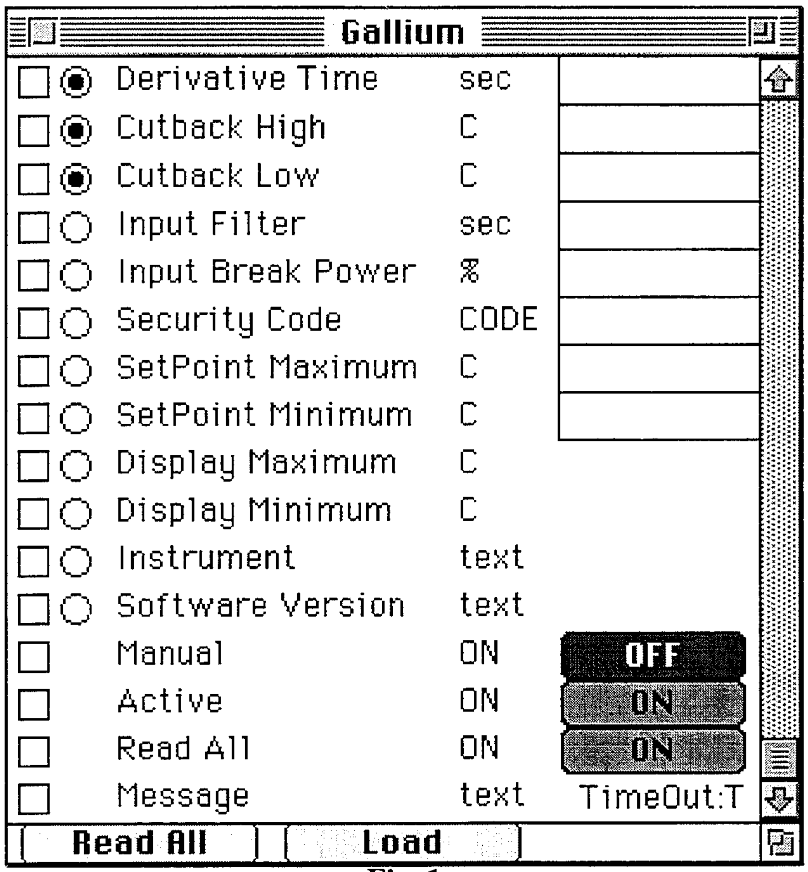


Fig. 1

There are 5 entries for each row in the window's table.

- **Checkbox**

  The checkbox allows definition of what fields appear in the Short Windows. If a box is checked, it's corresponding fields will appear in Short Windows.

- **Radio Button**

  Selects the data members that PIDcontrol will read periodically from a PID control instrument.

- **Name**

  The name of the data member is here.

- **Units**
  This column displays the units for the data.

- **Value**
  The current value of the data is here. If there is a box around the piece of data field you can click in the box and edit the field.

- **Short Window**
  The Short Window displays only the data defined as shown in the Full Windows. A sample short window is shown below (Fig. 2).

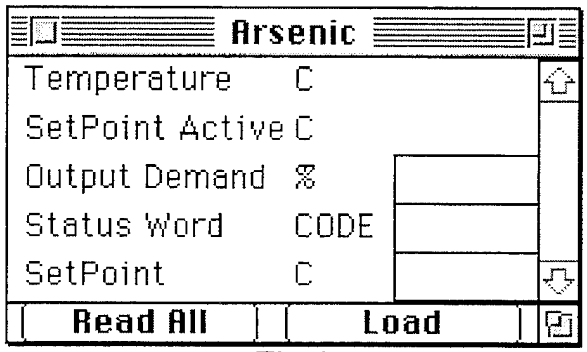


Fig. 2

The Short Window has only three entries per row in the table: Name, Units, & Value.

- **Name**
  This is the same as in the Full Windows. The name of the data member is here.

- **Units**
  The units for the data field.

- **Value**
  Again, this is also the same as in the Full Windows. The current value of the data is here. If there is a box around the data field you can click in the box and edit the field.

The PIDcontrol module has one other window, utilized in program setup.

- **Setup Ports...**
  The Setup Ports window allows you to establish the connections between the computer and the hardware through the serial ports. There are several stages to this process.

  First, the Serial Port Set Up window appears (Fig. 3). Simply choose the port(s) connected and the address search range, choose "Auto configure" and PIDcontrol will search the ports and display the address and model of each PID control instrument that it finds.

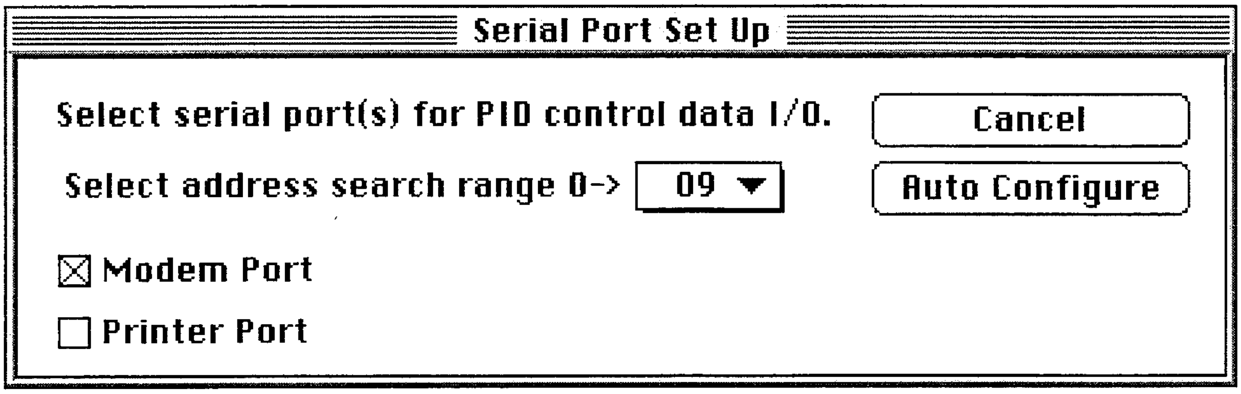


Fig. 3

The next window displays PID instruments that the program found: which port, the address, and the model (Fig. 4). You can then assign a name to each instrument (from the Family Name list), and you can send a "blink" output to the instruments external to the computer (to assist in quick recognition). Once you click the "OK" button, the program will open the Control windows for each PID instrument.

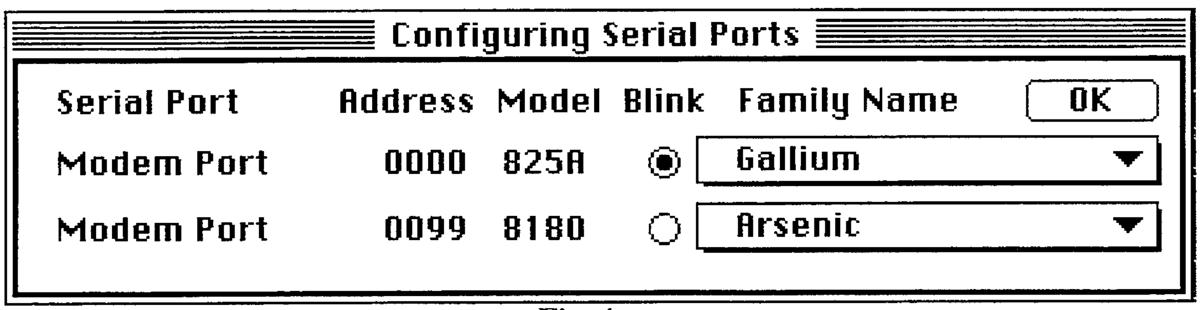
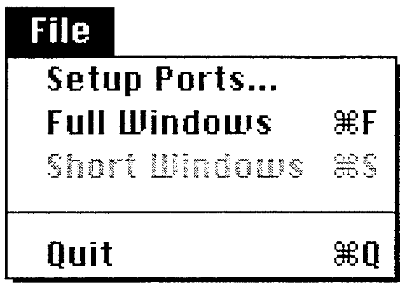


Fig. 4

VII. Using PIDcontrol: Menus

- **The Apple Menu**
  Choosing 'About PIDcontrol...' brings up the 'About' dialog.

- **File Menu**



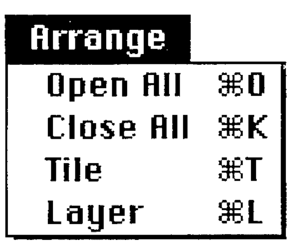
  - **Setup Ports...**
    This option displays a window that allows you to configure the serial ports.

  - **Full Windows (Command-F)**
    Displays all options in the Control windows.

  - **Short Windows (Command-S)**
    Displays the selected options in the Control windows.

  - **Quit (Command-Q)**
    This quits the program. Note that if InfoSupervisor™ is running, it will automatically restart the program.

- **Arrange Menu**



  - **Open All (Command-O)**
    Opens all Control windows.

  - **Close All (Command-K)**
    Closes all Control windows.

  - **Tile (Command-T)**
    Tiles the open Control windows.

  - **Layer (Command-L)**
    Stacks the open Control windows.

- **Controllers Menu**

This menu allows you to choose the Control window that you want to open. The names will vary depending on the names you assign in the Setup Ports process (in this case, Gallium and Arsenic).

VIII. Shutting Down PIDcontrol

Choosing the 'Quit' option from the file menu will terminate the program. Quitting InfoSupervisor™ will also terminate execution.

Note: Press the "option key" when choosing "Quit" from the PIDcontrol file menu to prevent InfoSupervisor™ form restarting the PIDcontrol program.

APPENDIX E

DIGITAL MODULE USER'S MANUAL

A description of software and hardware modules
currently under development
by Wright Laboratory MLIM

Digital I/O

Submitted to:

and:

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WL/MLIM

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Authors:
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David Liptak

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V1.0 7/31/95

Outline

I. Introduction

The InfoScribe™ system was developed at Wright Patterson Air Force Base in the Material Process Design group. The InfoScribe™ system provides an integrated information management system for almost any type of process which is limited by the computer and peripheral hardware. The InfoScribe™ system was designed on a Macintosh IIfx, and is Power Macintosh accelerated.

InfoScribe™ was developed to provide an integrated method of collecting and displaying data from a variety of material processes. This system provides a research or manufacturing facility with a uniform file format that all data can be stored to and recalled from. The flexibility of this system allows it to adapt to any type of process in which data is collected. The InfoScribe™ system has been installed on a Molecular Beam Epitaxy process, on a Chemical Vapor Deposition process and in a hospital setting to monitor patient's oxygen and carbon dioxide levels.

The Digital I/O module allows the InfoScribe™ system to monitor and modify the status of Boolean value switches using a digital I/O card.

II. Digital I/O Features

- Individual labeling of each port by the user.
- Each member bit can be individually labeled.
- The Boolean 'on' state can be defined as 1 or 0.
- A pin out chart of the digital I/O board can be displayed.
- Port direction is software configurable.
- Labels and settings are preserved from session to session.
- Status windows are color coded for easy and quick identification of the current state.
- Password protection: prevents accidental damage due to adjustment of input/output status of a port.

III. The Structure of Digital I/O

The InfoScribe™ system is designed as a modular combination of programs, i.e., InfoScribe™ and various support programs, which are adaptable to any process.

The cooperative multi-tasking Macintosh environment supports many programs working interactively to handle the process data. A supervisory program, InfoSupervisor™, monitors the function of related programs and provides intervention response when appropriate.

Digital I/O is a robust interfacing module between InfoScribe™ and a digital I/O board. InfoScribe™ receives data from the digital I/O program, which provides a control interface to a digital I/O board.

IV. Getting Started

System requirements

The minimum system requirements for the InfoScribe™ application are a Macintosh II and at least 8 Mbytes of RAM. The system version must be at least 7.0.1. In addition, in order to run Digital I/O, a digital I/O (input/output) card must be installed.

To use Digital I/O, place the Digital I/O program in the InfoScribe™ folder, the same location as the InfoScribe™ application, and install the digital I/O card.

You are now ready to use Digital I/O.

V. Launching the Digital I/O Program

Double-click on the InfoSupervisor™ icon to launch the InfoScribe™ system. InfoSupervisor™ will automatically start the appropriate programs.

VI. Using Digital I/O: Windows

Digital I/O has two window types: the Configure window and the Status window.

- **The Configure Window**

The Configure windows allows you to control the definitions of the ports on the I/O card. The window consists of four parts: Member Name field, Pin Out button, the Direction switch, and the individual Bit name & On State. Figure 1 shows a Configuration window setup for input, after the password enabled edit mode has been entered (the active Direction switch).

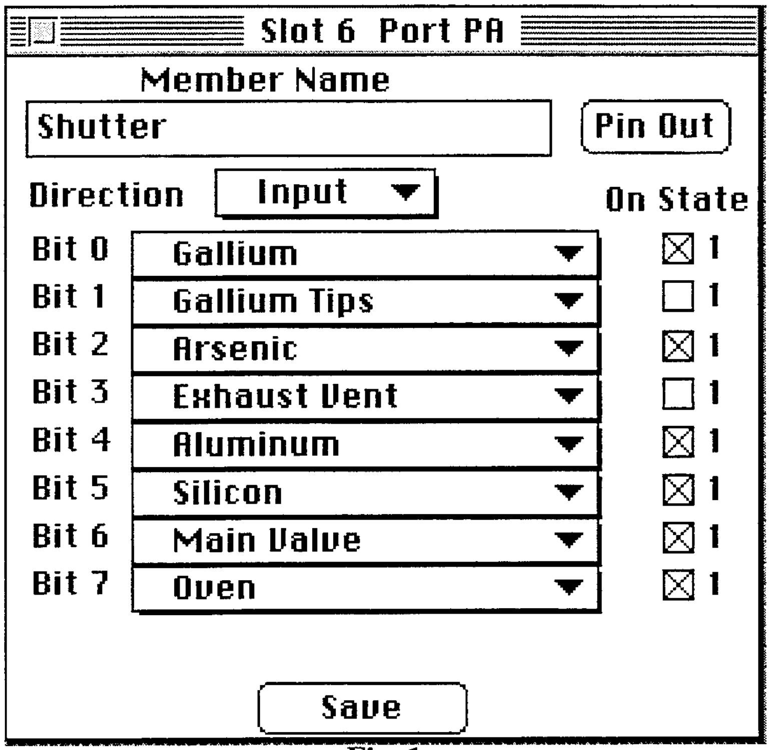


Fig. 1

- **Member Name**
  The Member Name is a label for the port, allowing you to give it a more meaningful name than 'Port 6a', for example.

- **Pin Out**
  The Pin Out button displays the pin out chart of the digital I/O card connector.

- **Direction**
  Defines the direction of the port. If the port is for data input, choose 'Input'. Please note that this option is normally inactive to protect the system hardware. To edit the Direction definitions for the operating session choose 'About DIO Control...' in the Apple Menu, and then click the 'Config' button to call up the password dialog. After you enter the password, the system will allow you to change the Direction definition

until you terminate the program. When you restart the program the Direction option is inactive again.

- **Bit Name & On State**

  All eight bits (0-7) have their own Family name list and On State check boxes. The Family name list has names you can use to describe each bit. This provides a means of easy identification of each individual bit. The On State check box lets you define the state that is considered 'On' for the bit. For example, if the box is checked, then 1 is the 'On State'. If the box is unchecked, then 0 is the 'On State'.

- **Save**

  This will save current window configuration settings.

When you close the Configure Window the program will ask if you want to save the changes, if you did not choose the 'Save' button.

- **The Status Window**

The Status window shows the current state of the eight bits in each port, and if the port is output, allows you to toggle the states. Figure 2 shows a Status window set up for input (note the grayed buttons).

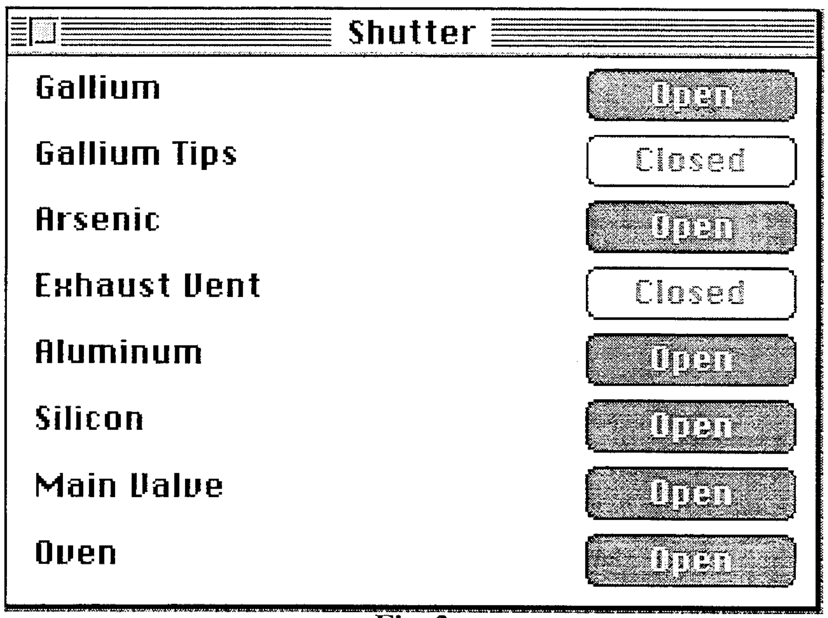


Fig. 2

Each bit has two components: the bit name and the status.

- **Bit Name**

  This is the bit name as defined in the Configure window for this port.

- **Status**

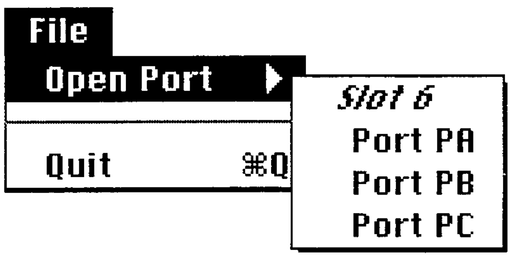
  The status button shows the status of the bit: 'Open' if the status matches the defined 'On State', 'Closed' if it does not match the 'On State'. The 'On State' is defined in the ports' Configure window. Please note that the buttons are grayed (i.e., inoperative) if the port is for input. However, if the port is for output the buttons are active, and clicking on a button will toggle the state of the bit.

VII. Using Digital I/O: Menus

While the windows provide the majority of the program control, the menus have some important options.

- **The Apple Menu**
  Choosing 'About DIO Control...' brings up the 'About' dialog, and then choosing 'Config' brings up the password dialog. This is what enables you to edit the input/output definition of each port. For more information refer to the previous section.

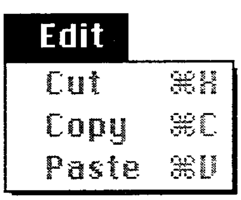
- **File Menu**



  - **Open Port**
    This option displays a sub menu that shows all available ports. Choosing a port displays the Status window for that port. Selecting the slot option displays all ports for that slot.

  - **Quit (Command-Q)**
    This quits the program. Note that if InfoSupervisor™ is running, it will automatically attempt to restart the program.

- **Edit Menu**

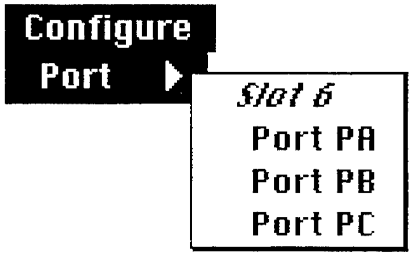


  - **Cut (Command-X)**
    Removes the current selection and places it in the clipboard.

  - **Copy (Command-C)**
    Places a copy of the current selection in the clipboard.

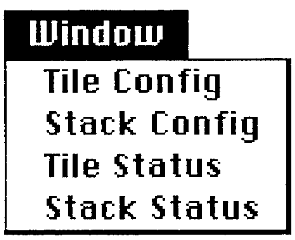
  - **Paste (Command-V)**
    Places the contents of the clipboard at the location of the cursor.

• **Configure Menu**



- **Port**
  This allows you to choose the slot and port to configure. If you select the slot number the program will open the Configure windows to all of the ports belonging to that slot.

• **Window Menu**



- **Tile Config**
  This will tile all open Configuration windows, allowing an easy view of all of the windows at once.

- **Stack Config**
  This option will stack all of the open Configuration windows, saving desktop space.

- **Tile Status**
  Tiles all open Status windows.

- **Stack Status**
  Stacks all open Status windows.

VIII. Shutting Down Digital I/O

Choosing the 'Quit' option from the file menu will terminate the program. Quitting InfoSupervisor™ will also terminate execution.