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Essentials of Electronic Circuits for Selected Medical Technology Instrumentation Applications

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ESSENTIALS OF ELECTRONIC CIRCUITS FOR SELECTED MEDICAL TECHNOLOGY INSTRUMENTATION APPLICATIONS

by
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This thesis submitted by Lowell P. Stanlake in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Signature Lowell P. Stanlake

Date 4/27/79

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ABSTRACT

The concern of this research was to investigate the applications of basic medical electronic instrument concepts pertinent to instrument operation for the education of medical technologists. A second concern involved a literature review regarding medical electronic instrument theory and the operational instructions included in instrument manuals supplied by manufacturers.

This study attempted to: (1) investigate medical electronic instrument theory and the operational instructions included in instrument manuals, (2) collect information from medical electronic instrument manufacturers pertaining to medical electronic instruments used by health personnel, (3) discern and identify the sectional circuit functioning of selected electronic instruments, and (4) illustrate common electronic circuits in selected medical electronic equipment.

Methods

The research design employed in conducting this study was that of descriptive analysis. A letter requesting information was developed to collect information from manufacturers of medical electronic instruments. The acquired information was analyzed and presented in narrative form supplemented by block diagrams of electronic circuits to augment the analysis.

Conclusions

The primary conclusions obtained from this analysis are: (1) basic knowledge of electronic theory in conjunction with comprehension of

operational circuit functions of medical electronic instruments is essential for proper utilization of medical electronic instruments or instrument systems, (2) operational and service manuals, supplied by manufacturers should be studied thoroughly before operating and/or troubleshooting a new or used electronic instrument, and (3) medical electronic instrument operators should only perform maintenance that is within the realm of their knowledge and experience, utilizing block diagrams to identify sectional circuits described in operational/service manuals.

Recommendations

It is recommended that: (1) further investigation should be undertaken to ascertain the essential aspects of research regarding electronic instruments or instrument systems, and (2) incorporate a different means of instrumentation categorization, (i.e., by instrument measurement methods) to subdivide medical electronic instrumentation for analysis of circuits, circuit blocks, and instrument functioning.

CHAPTER I

INTRODUCTION

Medical electronic instruments used in medical science are becoming increasingly complex in design. With the relentless increase in sophisticated circuitry, the problems encountered in equipment maintenance and operation increases commensurately. This, in turn, makes the services of an electronics expert mandatory for all but the simplest maintenance and repair (1). Thomas D. Schroeder (2) observed that usually, however, the responsibility for general maintenance of medical electronic instruments is bestowed upon the medical technologist who routinely operates them.

A knowledge of basic medical electronic concepts would then be essential to eradicate the fear of electronics often experienced by the novice. Such knowledge would permit medical technologists to operate sophisticated medical electronic instruments more effectively, interpret meter readings and display indications more meaningfully, and to recognize the need for recalibration and/or repair when the meter or display indications may be in error (3).

Philip G. Ackermann (1) proports that knowledge of basic theoretical operation will enable the medical technologist to use medical electronic instruments more intelligently. Ackermann (1) further proports that the technologist will have basic concepts of why the suggested operational and maintenance procedures are necessary and why certain shortcuts which may suggest themselves are not applicable.

A knowledge of how an instrument functions will give the medical technologist basis for appreciating its particular advantages and limitations. On the other hand, when the services of an electronics expert are required, valuable time will be saved by the knowledge that the simpler causes of malfunction have been eliminated and the probable causes already suggested (1, 3, 4).

Statement of the Problem

This research was concerned with the application of basic medical electronic instrument concepts pertinent to instrument operation for the education of medical technologists.

The objectives of this research were to: (1) review literature regarding medical electronic instrument theory and the operational instructions included in instrument manuals provided by manufacturers, (2) collect information from medical electronic instrument manufacturers pertaining to medical electronic instruments used by health personnel, (3) discern and identify the sectional circuit functioning of selected electronic equipment, and (4) illustrate common electronic circuits in selected medical electronic equipment without duplicating sectional circuits common to more than one electronic instrument.

Need for the Study

Edward J. Bukstein (3, Preface) Bioelectronics Specialist, Hennepin County General Hospital, Minneapolis, Minnesota has stated:

> Electronic instrumentation has become so much a part of medical science that an understanding of the basic medical electronic concepts has become mandatory for doctors, nurses, and other medical personnel. Although it is not necessary that medical personnel

become experts in the field of electronics, it is essential that that they acquire a familiarization-level of the subject.

The great variation in the complexity of instrumentation makes understanding instrument operation difficult. It is proposed that the application of the basic principles of instrument operation will result in improved ability to read and understand instrument operational manuals (4). Schroeder (2) suggests that rather than attempting to instruct individuals about specific instruments, a more appropriate approach would be to instruct health personnel in basic medical electronic instrument operation concepts which could be applied to all instruments regardless of function and complexity.

In most cases, it is the responsibility of the medical technologist operating the instrument to perform the necessary maintenance and to correct minor malfunctions. Unfortunately, few medical technologists possess the technical knowledge of electronic concepts to deal with such tasks. According to the National Council on Medical Technology Education (5), inadequate clinical instruction in instrumentation and application of theory to practical aspects of laboratory work, coupled with the rapid expansion of medical electronic instrumentation, has produced weaknesses in the area of medical electronic instrument education for medical technologists.

Therefore, when electronic failure is the cause of malfunctioning, the delay of non-operational status is costly until the manufacturer's representative alleviates the problem. The inflexibility to continuously rely upon the manufacturer's representative could be remedied, because, just as medical technologists can be taught to operate instruments, so can they be taught to recognize, test, and diagnose faulty circuitry (2).

With the large development of medical electronic instrumentation and manufacturers continually offering improvements, it is mandatory that medical technologists, and other health personnel, understand instrument functioning not only for educational purposes but to establish self confidence in the use of electronic instruments and in the evaluation of the output indications. Knowledge of basic instruments' operational electronic concepts would provide the background for medical technologists to operate equipment properly, detect certain malfunctions, and make minor and/or major repairs depending on the technologist's skill level and supplementary training (1, 3, 4).

Limitations

The scope of this study was to investigate and ascertain pertinent information associated with the basic understanding of medical electronic instruments' operational concepts. The information of this study was obtained by developing an information request letter and mailing it to selected manufacturers of medical electronic instruments. The mailing list of medical electronic instrument manufacturers was developed from the 1976 "Clinical Lab Products Guide" published by Clinical Lab Products, Inc., Wellesley, Massachusetts.

The selected medical instruments were limited by conducting personal interviews with medical technology instructors at the University of North Dakota and with the laboratory supervisor of the United Hospital, Grand Forks, North Dakota. The criteria for selecting the instruments was based on commonality throughout universities, hospitals, and research facilities utilizing medical electronic instrumentation.

The possibility of a self-imposing limitation was considered because of the apprehension of instrument manufacturers to divulge information on sophisticated electronic equipment. This limitation was nonregulatory and presented a significant barrier to the analysis of data appropriate to this study.

Definition of Terms

The following is a list of operational definitions used throughout the description of the research material.

Instrumentation Systems - a set of instruments and equipment utilized in the measurement of one or more characteristics or phenomena, plus the presentation of information obtained from those measurements in a form that can be read and interpreted by technologists.

Medical Electronic Instrumentation - Instrumentation used for the measurement and recording of electronic, chemical, and physiological variables.

Passive Elements (components) - An element (component, e.g., resistor, capacitor, inductor) which consumes or stores electrical energy.

Active Elements (components) - An element (component, e.g., transistor, vacuum tube, diode) which transmits electrical energy; or contains a voltage or current source.

Fibrometer - An instrument incorporated in medical science for measuring the clotting power of blood.

Osmometer - Measurement of osmotic pressure. The force that a dissolved substance exerts on a semipermeable membrane, through which it cannot penetrate, when separated by it from the pure solvent.

Scintillation Counter - A device employing scintillation for detecting and measuring radioactivity. Scintillation is a flash of light occurring as a result of the ionization of a phosphor when struck by an energetic photon or particle.

Fluorometer - An instrument for measuring fluorescence, often as a means of determining the nature of the substance emitting the fluorescence.

Densitometer - An instrument for measuring the density of a substance.

Photometer - An instrument that measures luminous intensity or brightness, luminous flux, light distribution, color, etc.

Medical Electronic Concepts - Cognitive areas within the scope of electronic education pertinent to medical science.

Gas Chromatograph - The instrument used in gas chromatography to detect volatile compounds present. Gas chromatography is a separation technique involving passage of a gaseous moving phase through a column containing a fixed absorbent phase.

Spectrophotometer - An instrument that measures transmission or apparent reflectance of visible light as a function of wave length, permitting accurate analysis of color or accurate comparison of luminous intensities of two sources or wave lengths.

Flame Photometer - An instrument for measuring the concentration of a substance in solution by measuring the light emitted by the substance when vaporized by flame.

Glucose Analyzer - An instrument that performs chemical analysis of glucose (sugar) composition; may be automated to do a sequence of analytical tests by continuous flow or discrete sample techniques and printout of record results.

Blood Gas Analyzer - An instrument for measuring blood gas content, giving either a digital readout or recorded results.

pH Meter - An instrument (analog or digital) for measuring the hydrogen ion activity of a solution.

Mass Spectrometer - An analytical instrument which identifies a substance by deflecting a stream of electrified particles (ions) according to their mass.

cl/co_2 Analyzer - An instrument for measuring chloride and carbon dioxide content of blood serum, urine, or other biological fluids.

UV Spectrophotometer - An instrument similar in function to a spectrophotometer, except utilizing ultraviolet light absorption by the specimen for identification.

CHAPTER II

REVIEW OF LITERATURE

Introduction

In recent years progress in medical electronic instrumentation has been rapid. A major reason for this progress is primarily due to the union of medicine and engineering. Because of the acceleration of medical and electronic technology, the understanding of instruments' electronic functioning is imperative for the proper operation and care of medical electronic systems (6).

This author has conducted an extensive literature search in the field of medical electronic instrumentation and has determined that the limited existing literature indicates a need for the education of medical electronic instrument operators. This is not only conducive to instrument operation and maintenance, but also to the advancement of the "state of the art" in electronics and technologists performance and/or competency levels.

Basic Function and Role of the Medical Technologist

The medical technologist is an invaluable member in a clinical laboratory. Generally considered as medical or laboratory technicians, they concentrate their skills toward laboratory research/diagnosis while operating the appropriate instrument to achieve analytical test results.

Laboratory research/diagnosis refers to the performing of analytical tests to provide data for disease determination. The medical technologist will utilize specimens of body fluids and/or secretions and, through the use of instrumentation systems, make the necessary qualitative and quantitative analyses. The medical technologist will then consult with associates of a medical or research team to evaluate the collected data and formulate correct diagnosis of a particular variable and disseminate this information to colleagues.

Furthermore, the medical technologist is a manager. He or she performs the necessary duties to establish and coordinate laboratory functions and maintain integrity within the medical laboratory environment. It is understandable, therefore, to see the necessity for medical technologists to have a basic knowledge of electronic instrumentation operation (7).

The complexity and sophistication of available medical electronic equipment has been both a blessing and a curse. To properly operate these sophisticated tools the medical technologists' function is to maintain a working knowledge of these instruments. Subsequently, the medical technologists' function is to be able to accurately recognize four basic questions in the medical laboratory environment (8):

1) Is the instrument capable of performing the appropriate test/analysis?
2) Is the instrument correctly aligned, calibrated, and operating properly?
3) If the test results are incorrect, is it due to faulty test techniques or instrument malfunction?

4) If the instrument is malfunctioning, where is the problem, and can it be repaired without additional assistance?

The roles of the medical technologist are multiple and diverse. However, the challenge can be met by maintaining knowledge levels proportional to medical electronic advancements.

Medical Electronic Instrumentation Technology Education Necessity

Lord Kelvin once stated: "When you can measure what you are studying, and express it in numbers, you have advanced to the stage of science" (9, p. 5). Medical electronic instrumentation has achieved such a level and is continuously perpetuating itself further into complexity and sophistication. Unfortunately, medical electronic instrumentation training for health personnel has not kept abreast with technological advancements.

This problem was recognized by Terence G. Karselis (5, p. 134) who observed:

> In recent years the need for a broader technological background in medical technology education has made itself obvious . . . The rapid expansion of instrumentation has produced weaknesses in some areas of medical technology education.

Scott D. Anderson (7) exemplifies this very fact indicating that medical electronic instrumentation sophistication has led to the need for trained personnel in operation and troubleshooting of equipment in medicine and/or research.

It is evident then that health personnel, especially medical technologists, must not only master the operation of medical electronic instruments, but also be responsible for the routine maintenance of this equipment (2, 10).

Karselis (5, p. 134) concluded that medical electronic instrumentation knowledge is essential for the development of confident and competent medical technologists:

> In an effort to provide confident and competent technologists capable of mastering complex instrumentation, instruction in basic electricity, electronics, and even computers is now being proposed. An electronics course that would help build such confidence in a technologist is needed.

Operationalism has plagued medical electronic instrumentation that is now currently at the disposal of health personnel. As instrumentation increases in complexity, the possibility of lengthy downtime increases. David Sohn (10) observed that major changes in design of medical electronic equipment is indicative of decreasing downtime, permitting rapid verification of proper operating conditions, and promoting ease of maintenance.

However, redesigning or maintenance-free designing of medical electronic instrumentation does not provide a thorough remedy. Even with decreased or easier routine maintenance many experienced medical technologists still express apprehension regarding troubleshooting of electronic instrumentation due to lack of adequate knowledge and/or training in the electronics of instrumentation (1, 2, 5, 11).

The acute need for medical technologists to acquire electronic instrumentation knowledge is not only necessary for promoting greater understanding of electronic instrument operationalism, but more significantly to provide a frontline service (as may be provided by medical technologists) of troubleshooting to alleviate costly and sometimes detrimental electronic equipment malfunction.

Understanding Medical Electronic Instrumentation

In a broad sense, medical electronic instrumentation includes many types of instruments used in connection with the various aspects of clinical medicine and/or medical research. Regardless of its complexity or simplicity, every medical electronic piece of equipment can be considered in a highly simplified manner. To accomplish its function, the instrument must have at least three elementary systems. These are: (1) the signal input, detecting or sensing system, (2) the signal processing, amplifying or modifying system, and (3) the signal display or readout system. Each of these three systems are in turn made up of individual stages and component chains. Figure 1 illustrates a block diagram approach for a typical instrument (11).

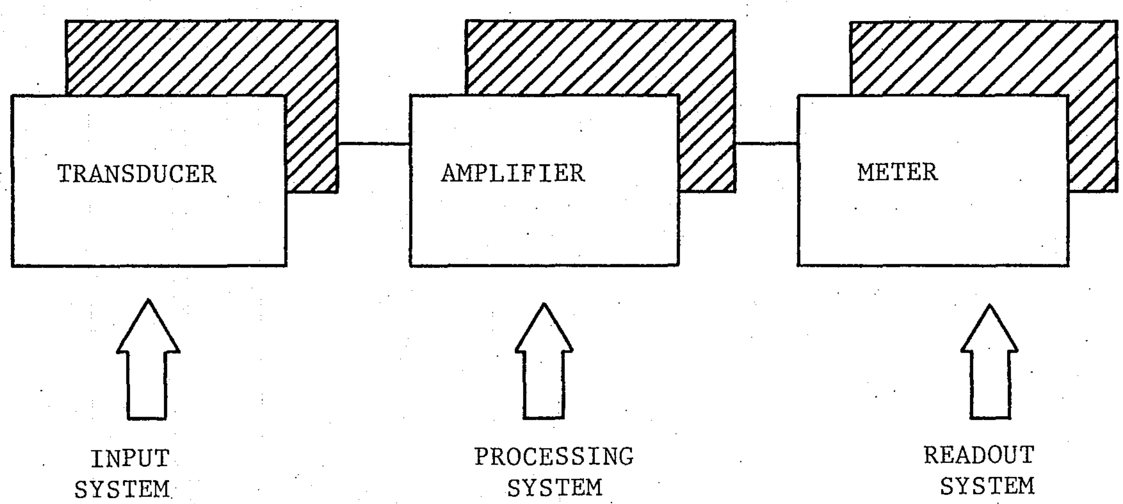


Fig. 1. Block diagram of electronic instrumentation (11, p. 201).

The systems mentioned above, associated with electronic instruments, are adaptations of one or more basic circuits. These circuits in turn are constructed from basically six fundamental types of components.

These six componets (elements) are:

1. Resistors 2. Capacitors (condensers) 3. Inductors (coils, chokes, transformers)	Passive elements
4. Vacuum tubes 5. Semiconductors 6. Integrated circuits	Active elements

Since electronic instrumentation is an extension of the range of human faculties, it is understandable that these instruments should be designed to meet the following criteria:

1. To increase human sensitivity for the purpose of detecting phenomena beyond normal human range
2. To increase the speed of performing a particular function
3. To be capable of performing more than one function simultaneously
4. To reliably be able to reproduce the desired results under the above conditions
5. To be economically feasible.

These five criteria make up the objectives that is hoped will coexist in any electronic instrument (6).

It is important that those who work with medical electronic instruments understand specific performance characteristics of such instruments. In doing so, the technologist is better able to interpret manufacturers' literature and make knowledgeable comparisons between similar electronic devices. Furthermore, it will enhance the process of selecting the specific instrument best suited to do a particular task and promote understanding of instructions for the instruments operation (6, 10, 11).

Advances in Medical Electronic Instrumentation

Through the use of technology, humanity has succeeded in developing electronic tools which can function rapidly, accurately, and require only very small sample amounts. In the near future, however, many of the present automated medical electronic instruments will be obsolete. The reason behind this is the fact that instruments which are even smaller, more accurate, and easier to manipulate are being developed. This, in turn, is possible through the development of microprocessors (computers on a "chip"), and large scale integration (10, 12, 13, 14).

The future of medical electronics probably lies in the hands of the manufacturer. Just in the last decade, developments for medical electronic instrumentation have been made in the realms of biomedical telemetry or telemedicine, miniaturization of equipment (i.e., gas chromatograph-mass spectrometer and x-ray fluorescence spectrometer utilzied in the Viking Mars land probe), light amplification by stimulated emission of radiation (laser), and computerized self-checking circuitry which pinpoints malfunctioning circuits of instruments sub-systems (15, 16, 17).

Certainly the next decade will see many changes in medical electronic instrumentation. The net result could be one of simplification and systemization of instruments providing much less downtime and greater stability, accuracy, and reliability. However, the ramifications of future medical electronic instrumentation developments may be plagued by troubleshooting and serviceability. Consequently, standardization of replaceable components or circuit sections, compatability between subsystems, and self-contained checking circuitry should be incorporated into future instrument designs (12, 15).

Future medical electronic instrumentation development and implementation has one other limitation, that being the issue of cost-effectiveness. Will the ultimate cost-benefit ratio be too high for practical applications? This question can only be answered by the restrictions, limitations, and regulations governing instrument manufacturing and sales. If these aspects are too stringent, then research and development of new medical electronic instruments would be impossible for manufacturers to fund (15, 18).

CHAPTER III

METHOD AND PROCEDURE

Type of Research

This study incorporated the method of descriptive analysis to investigate and ascertain the proposed subject matter. A letter requesting information was developed to collect the desired information from manufacturers of medical electronic instruments. The acquired information was analyzed and presented in narrative form.

Instrument Selection and Manufacturer Compliation

Personal interviews were conducted with staff members of the Department of Medical Technology, University of North Dakota, and with the laboratory supervisor of the United Hospital, Grand Forks, North Dakota, through which a list of medical electronic instruments was developed. This list, for all practical purposes, is indicative of instruments commonly found in a laboratory environment and normally operated by medical technologists.

The 1976 Clinical Lab Products Guide was used as a source to develop a mailing list of medical electronic instrument manufacturers. Two hundred and twenty-nine addresses were compiled and the information request letter mailed.

Information Letter Design

The information request letter was designed to elicit educational information which would be applicable to this study. The letter explained the basic objectives of the study along with specific information being sought concerning the selected medical electronic instruments. It should be noted that some manufacturers were reluctant to supply specific circuitry information on the medical electronic instruments manufactured by them. The reason given for this reluctance was due to the manufacturer's policies of not supplying detailed circuit information, except to laboratory and research facilities which own and operate their equipment.

Hoping for a greater response to the letter, the participants were given the option to request a copy of the summary and/or abstract of this thesis. The letter is featured in Appendix A.

Analysis of Information

Information received from the manufacturers was analyzed and grouped into basic instrumentation functions (i.e., conditioning equipment, special test equipment, auxiliary equipment) and placed in tabular form. A descriptive analysis of the circuit function common to some or all of the instruments was discussed for each instrument category.

CHAPTER IV

PRESENTATION AND ANALYSIS OF INFORMATION

Intent of Study

The nature of this research was to provide information about medical electronic instruments in comparison with established electronic theory for the education of medical technologists.

Categorization of Information

The instruments utilized in this study represent a large and diverse accumulation of specialized and nonspecialized medical equipment which the medical technologist may operate. Therefore, to maintain a logical order of instrument analysis, the medical electronic instruments identified for this study were categorized according to their basic function. The establishment of these categories is not indicative of the simplex or complex electronic circuitry contained in each instrument. For example, pH meters, classified as basic measuring equipment, in comparison to other equipment may have very simple circuitry, whereas chart recorders, classified as auxiliary equipment, may have extremely complex circuitry, all dependent on their intended use.

Table 1 shows the five instrumentation categories used in this study according to their basic function.

TABLE 1

INSTRUMENT CATEGORIZATION ACCORDING TO BASIC FUNCTION

Category	Device
Conditioning Equipment/Instruments	Freezers/Refrigeration Centrifuges (Bench, Refrigerated) Cell Washers Pumps Slide Stainers
Optical Equipment/Instruments	Microscopes (including Illuminators) Monitors (CRT)
Basic Measuring Equipment/Instruments	Analytical Balance (Electronic) pH Meters Electronic Thermometers
Specialized Test Equipment/Instruments	Fibrometer Osmometer Densitometer Fluorometer Photometers 1) Spectrophotometer 2) UV Spectrophotometer Analyzers 1) Blood Gas 2) Cl/Co_2 3) Glucose Gas Chromatograph Counters 1) Typical 2) Scintillation
Auxiliary Equipment/Instruments	Power Supplies Electronic Timers Scale Expanders Printers Chart Recorders

Population Return

Sixty-eight of the 229 manufacturers responded to the form letter requesting specific information on selected medical electronic instruments. This represents a 29.69 percent return. Fifty-three of the sixty-eight manufacturers who responded sent usable material. The other fifteen manufacturers who responded sent material that was not pertinent to the study or manufacturers who would not divulge the type of information requested.

The percent of return from the total number of manufacturers is, in itself, not significant. However, the percent return on the list of selected medical electronic instruments is very significant. Satisfactory information was received on twenty-five of the original twenty-nine instruments. This represents an 86.2 percent instrument return. Furthermore, information on the same type requested for the original instrument list was supplied on an additional eight instruments and/or special analyzer systems. The additional medical electronic instruments/systems, from this point on in the study will be categorized as "additional instrumentation systems."

Type of Analysis

The information received for each instrument was carefully reviewed and synthesized for the information pertinent to this study. This information will be presented in a descriptive form utilizing diagrammatical representations to supplement and augment the analysis.

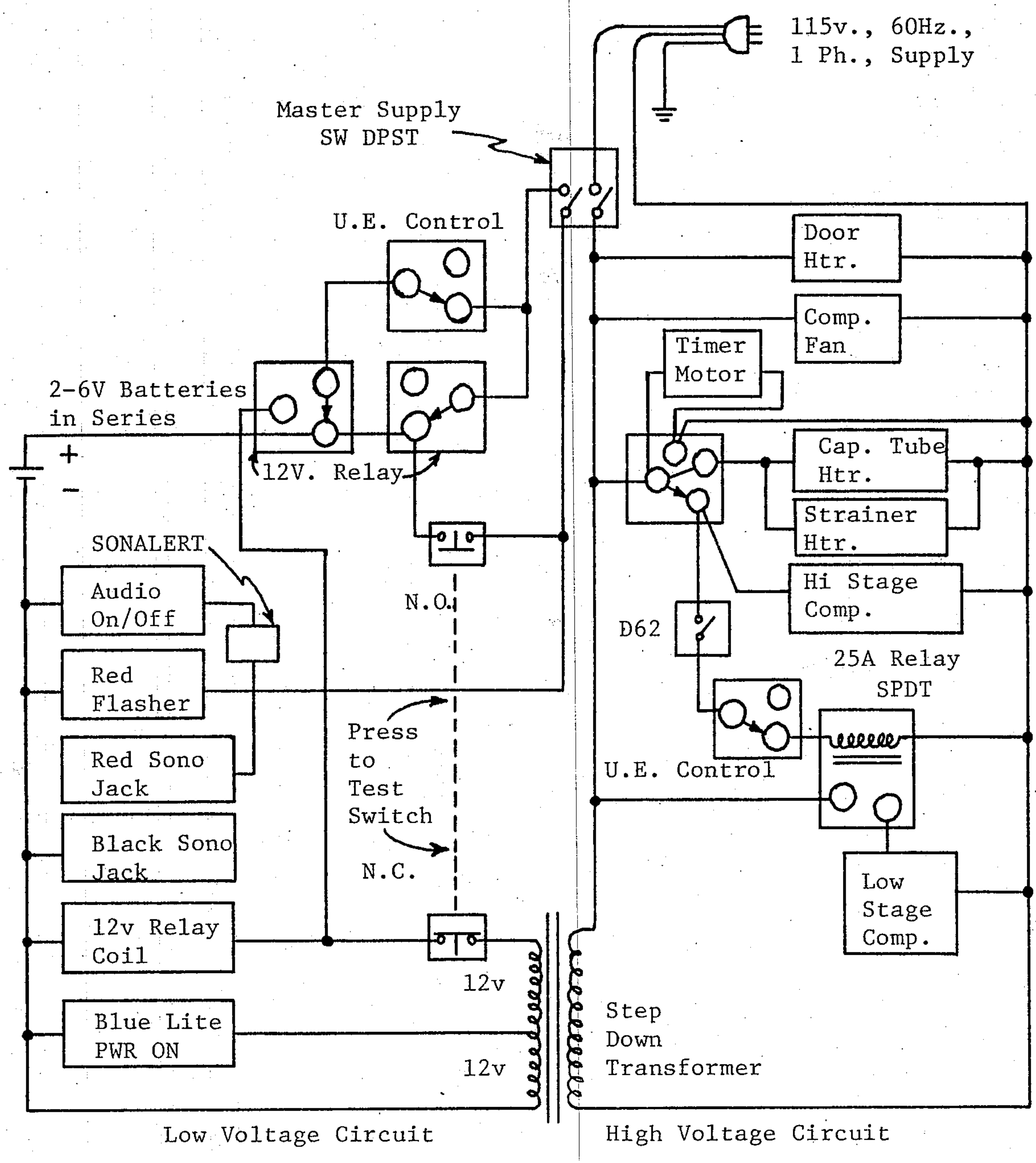
The sequence of information presentation will follow the categorization structure established in Table 1. It should be noted that the instruments listed in Table 1 are, in some cases, generic name classifications used for a group of instruments which provided the same function. For example, the term "freezer" can imply low temperature coolers, freezer-dryers, sub-arctic storage cabinets, or portable circulating heater/coolers. A few of the instruments or pieces of equipment may not contain sophisticated electronic components. This, however, does not detract from the importance of incorporating circuit schematics and diagrams of the lesser sophisticated equipment for the analysis of the collected information.

Analysis of Conditioning Equipment/Instruments

Freezers/Refrigeration

The freezer/refrigeration systems reviewed are results of advancements in refrigeration technology. Until recent developments in ultra-low temperature refrigerant, combined with very small high-speed compressors, the greatest limitation to refrigeration systems was physical size. Now the new mechanical designs permit double the cooling capability incorporated in compact physical sizes. Two good examples of small cooling systems are the Multi-Cool System and Flexi-Cool System, both manufactured by FTS Systems, Inc. The former system can be used as a storage chamber, circulating cooling bath, cold plate, vacuum trap, or controlled temperature source. The latter system may be utilized in mass sprectrometers, photo detectors, or spot cooling.

Apart from freeze-dryer systems, refrigeration systems function basically the same and house similar electrical/electronic components. Some deviations will exist between manufacturers and models depending on the design specifications established by the purchaser. Figure 2 illustrates the block diagram of a typical "chest" type ultra-cold refrigeration system. The block diagram primarily shows the separation between the high and low voltage circuits. Vertical refrigeration storage systems require the same basic circuitry with the inclusion of lighting



115v., 60Hz.,
1 Ph., Supply
Master Supply
SW DPST
U.E. Control
Door
Htr.
Comp.
Fan
Timer
Motor
2-6V Batteries
in Series
Cap. Tube
Htr.
Strainer
Htr.
12V. Relay
SONALERT
Hi Stage
Comp.
N.O.
D62
Audio
On/Off
25A Relay
SPDT
Red
Flasher
Press
to
Test
Switch
Red Sono
Jack
U.E. Control
Black Sono
Jack
N.C.
Low
Stage
Comp.
12v Relay
Coil
12v
Step
Down
Transformer
Blue Lite
PWR ON
12v
Low Voltage Circuit
High Voltage Circuit

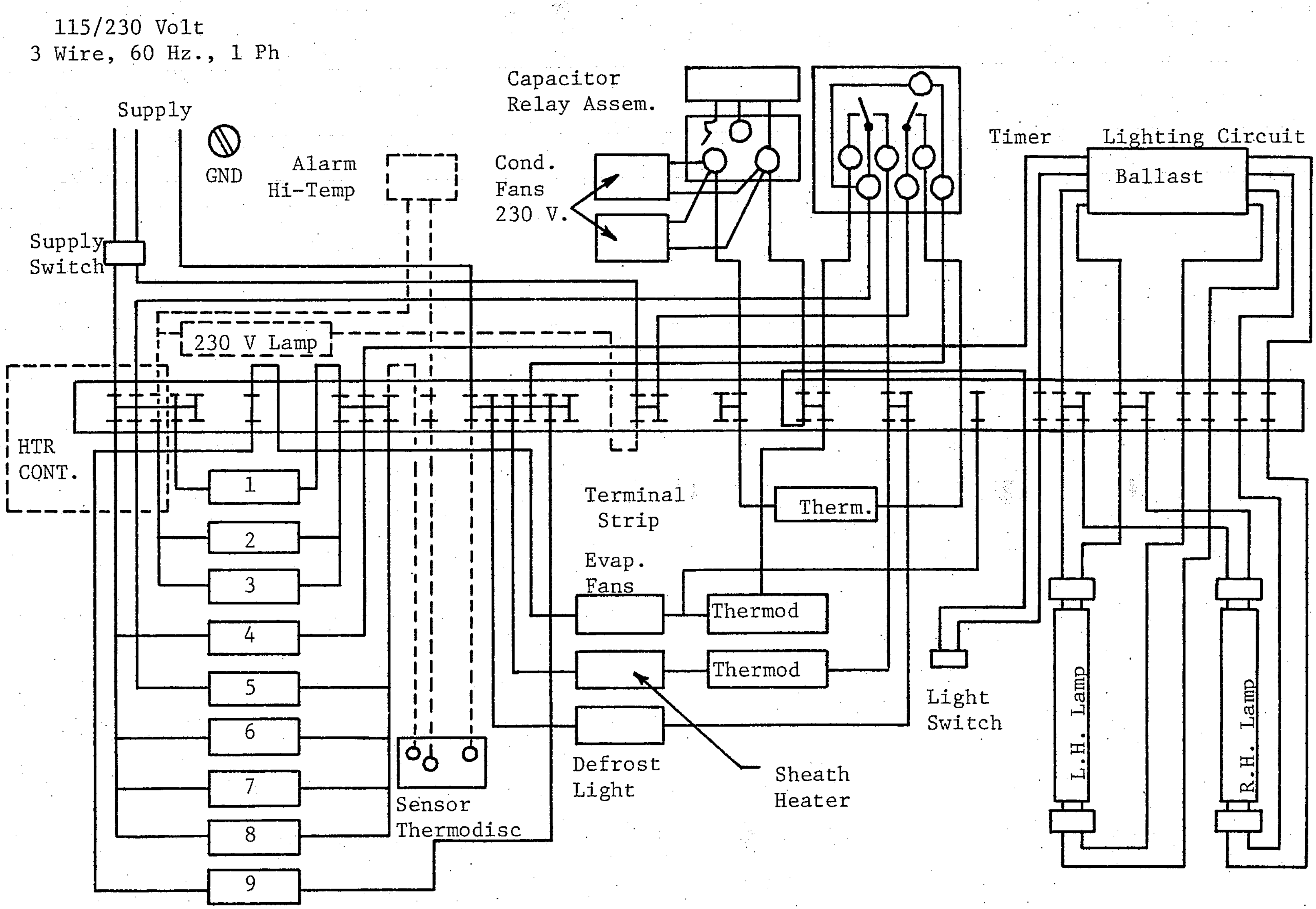
circuitry. Figure 3 illustrates a typical wiring diagram for vertical refrigeration systems. Note the addition of a "mullion" heater which is used for defrosting the center section of a two-door vertical freezer/refrigerator unit.

The freeze-dry systems essentially use freezer systems with the addition of a vacuum pump to extract water (which vaporizes from a substance under laboratory tests. The theory of operation consists of a pre-frozen sample that is introduced to a high vapor pressure differential created by the evacuated system. Ambient heat reaching through the walls of its container acts as the driving force to sublime water vapor from the sample. It then passes through the manifold system into the center of the refrigeration coil system of the condenser where its heat is absorbed and once again reappears as ice. The path of vapor and air being removed from the system is such that all vapor passes over the low temperature condenser coils and is frozen out before it can reach the vacuum pump. Figure 4 shows the block wiring diagram of a typical freezer-dry system.

Maintenance and repair on freezer/refrigeration systems is essentially uncomplicated by determining the general problem and working toward specific electrical aspects. A list of problem areas and their associated probable causes are listed in Table 2, Troubleshooting Freezer/Refrigeration Systems.

Centrifuges

No information was returned on refrigerated centrifugation, but the principles applied to simple centrifugation, with the inclusion of condensing coils for refrigeration, are applicable to refrigerated centrifuges.



115/230 Volt
3 Wire, 60 Hz., 1 Ph
Supply
GND
Supply Switch
Alarm Hi-Temp
230 V Lamp
HTR CONT.
Capacitor Relay Assem.
Cond. Fans 230 V.
Timer
Lighting Circuit
Ballast
Terminal Strip
Therm.
Evap. Fans
Thermod
Thermod
Defrost Light
Sheath Heater
Sensor Thermodisc
Light Switch
L.H. Lamp
R.H. Lamp
1
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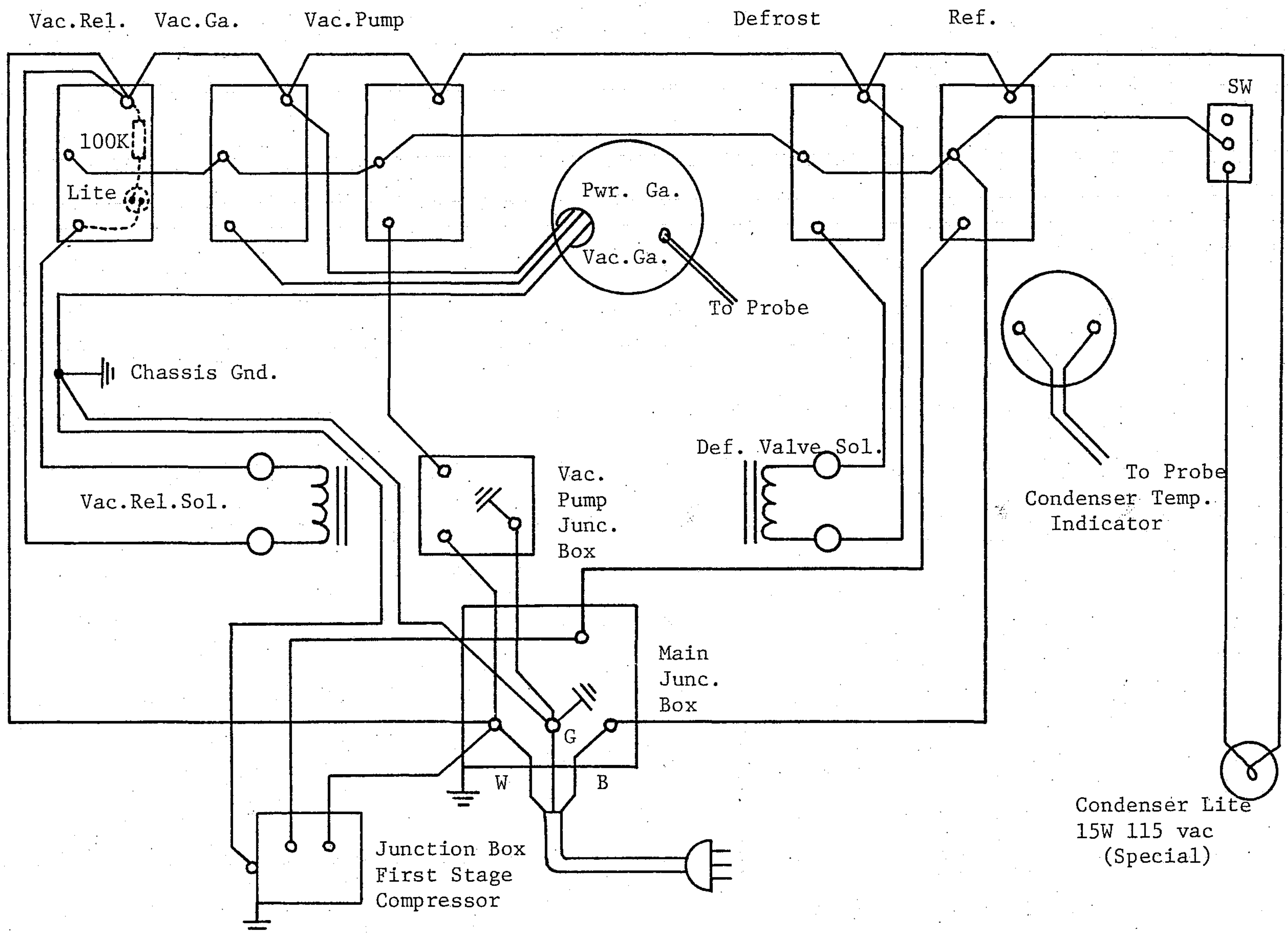

Vac.Rel.
Vac.Ga.
Vac.Pump
Defrost
Ref.
SW
100K
Lite
Pwr. Ga.
Vac.Ga.
To Probe
Chassis Gnd.
Vac.Rel.Sol.
Vac.
Pump
Junc.
Box
Def. Valve Sol.
To Probe
Condenser Temp.
Indicator
Main
Junc.
Box
G
W
B
Junction Box
First Stage
Compressor
Condenser Lite
15W 115 vac
(Special)

TABLE 2

TROUBLESHOOTING FREEZER/REFRIGERATION SYSTEMS

Generalized Problem	Probable Cause
Runs all the time	1. High ambient temperature 2. Dirty condenser 3. Fans not running - check switches 4. Low voltage - check power line 5. Restriction in system 6. Inefficient compressor
Compressor won't run	1. Power supply dead - check supply plug 2. Master switch off 3. Defective thermostat 4. Defective overload, relay or capacitors 5. Loose electrical connections 6. Timer stuck in defrost position 7. Defective compressor
Compressor short cycles or trips on overload	1. High or low voltage - voltage should be $\pm$ 10% of nameplate voltage while starting or running 2. Condenser dirty or fan not running 3. Defective relay, overload or capacitor 4. Loose electrical connections in cabinet 5. Defective thermostat 6. Inadequate supply wire size
Ice inside cabinet	1. Low voltage 2. Drain tube heater defective or not in position 3. Incorrect defrost seetings
Sweat and condensation buildup around and on door	1. Cross over plug disconnected 2. Faulty door heater
Lighting system inoperative	1. Light switch is in off position 2. Poor bulb contact in socket 3. One or more defective bulbs 4. Defective ballast 5. Defective socket 6. Open circuit in lighting circuitry

TABLE 2 -- Continued

Generalized Problem	Probable Cause
Freeze-dryer system malfunctioning	1. Power source, any switches or plug 2. Loose gauge tube cable and socket connections 3. Defective meters 4. Defective vacuum pump 5. Loose electrical connections 6. Any of the above associate problems

Essentially centrifuges are designed to serve many of the laboratory needs. Depending on the intended use, centrifuges can range in rotational speed up to 2000 (low speed) to above 5000 (high speed) revolutions per minute. They provide a convenient and safe method to accomplish difficult separations of solutions into their component parts.

The electrical circuitry for the basic centrifuge is very simple and straight forward. Referring to Figure 5, it can be seen that the schematic diagram does not require a further reduction into functional blocks.

Since speed control is accomplished by a powerstat variable transformer with a specific voltage and single phase operation, caution should be taken in making the proper electrical connections. For operation on other than specific voltages, a suitable transformer having a secondary of 120 volts, and a power rating of greater than 300 watts, is necessary.

Because of the simplicity of design, the first rule of troubleshooting applies: check the simplest, easiest, most obvious things first.

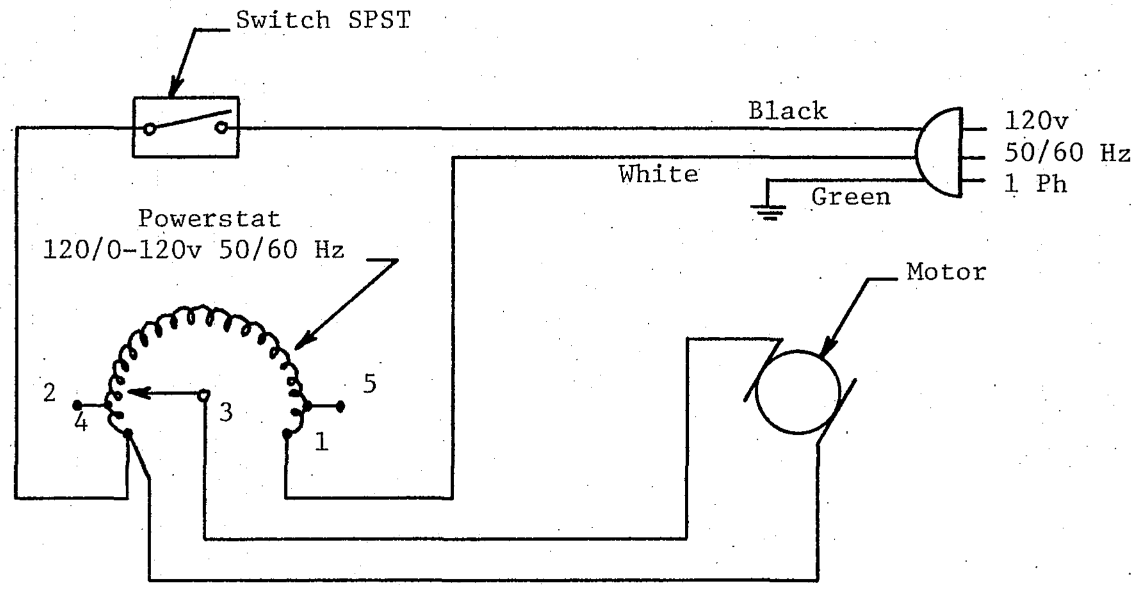
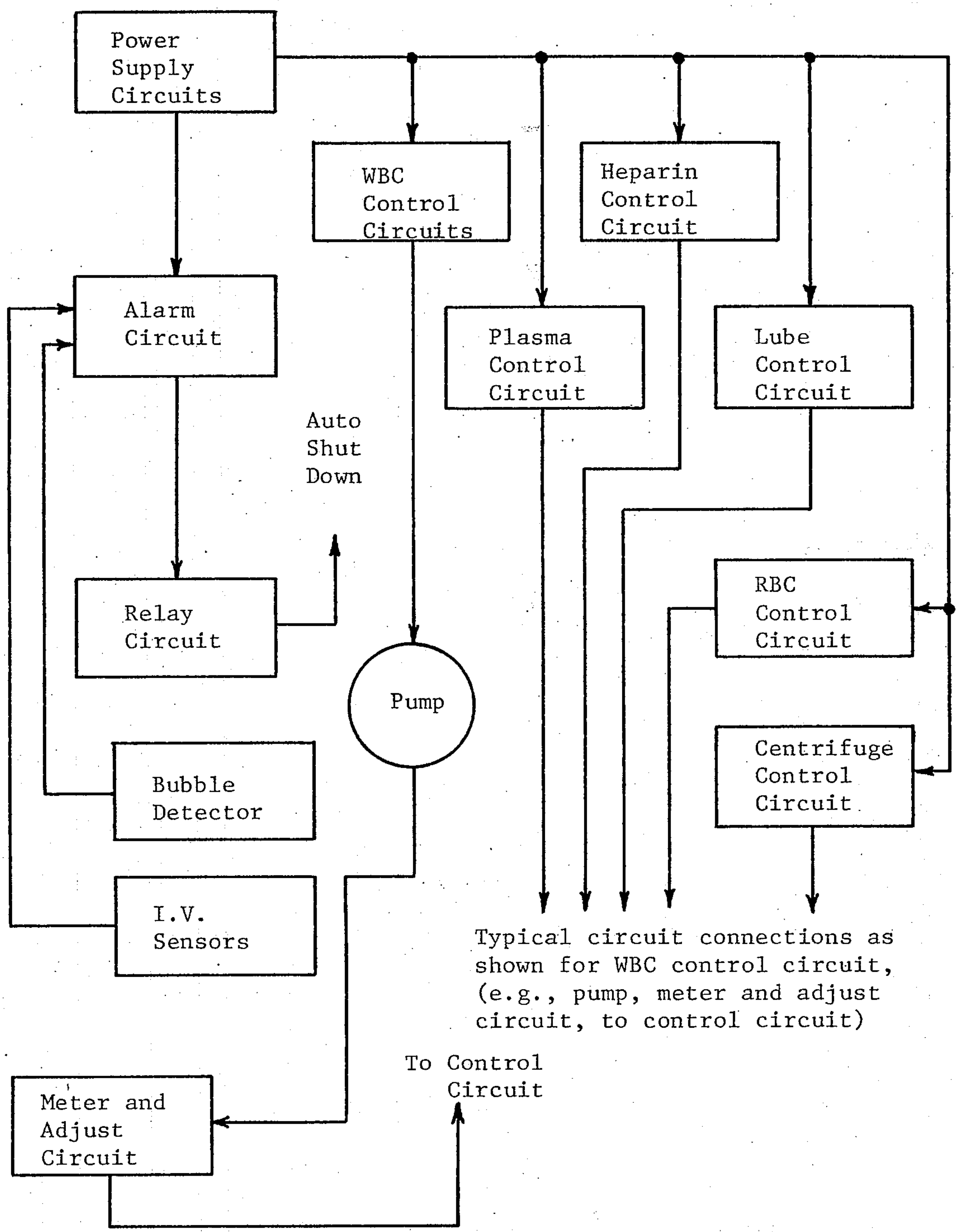


Fig. 5. Schematic diagram of a typical precision universal centrifuge (Courtesy of GCA/Precision Scientific, Chicago, Illinois).

For example, is the power cord plugged in, is the line voltage correct, is the master switch on. Subsequently, internal electrical connections and possible electrically shorted transformer and motor windings should be examined.

Some manufacturers design special purpose centrifuges for research or laboratory utilization. One example is the Celltrifuge Separator developed by the American Instrument Company. The purpose of this specialized centrifuge is to mechanically fractionate whole blood into some of its cellular components based on their specific gravities. The circuitry associated with this instrument is more complex than the previously discussed centrifuges. Subsequently, a block diagram, as represented in Figure 6, simplifies the complexity of the Celltrifuge Separator circuitry into its functional blocks.

The most important precaution that must be observed when operating the Celltrifuge Separator is the electrical grounding. Connecting this



Power Supply Circuits
WBC Control Circuits
Heparin Control Circuit
Alarm Circuit
Plasma Control Circuit
Lube Control Circuit
Auto Shut Down
Relay Circuit
RBC Control Circuit
Pump
Centrifuge Control Circuit
Bubble Detector
I.V. Sensors
Typical circuit connections as shown for WBC control circuit, (e.g., pump, meter and adjust circuit, to control circuit)
To Control Circuit
Meter and Adjust Circuit

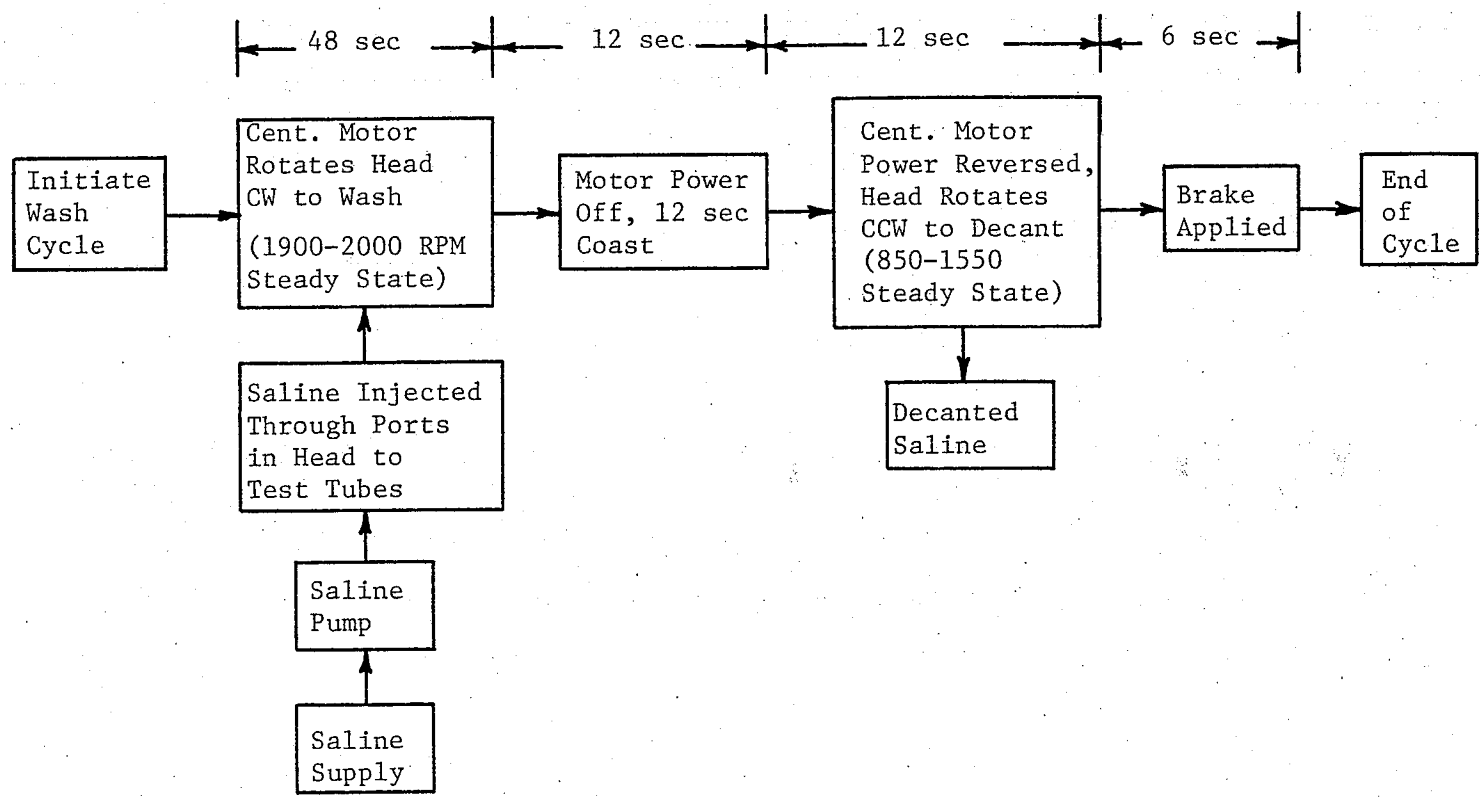
instrument to an electrical outlet which is improperly grounded and/or has incorrect polarity may create a safety hazard.

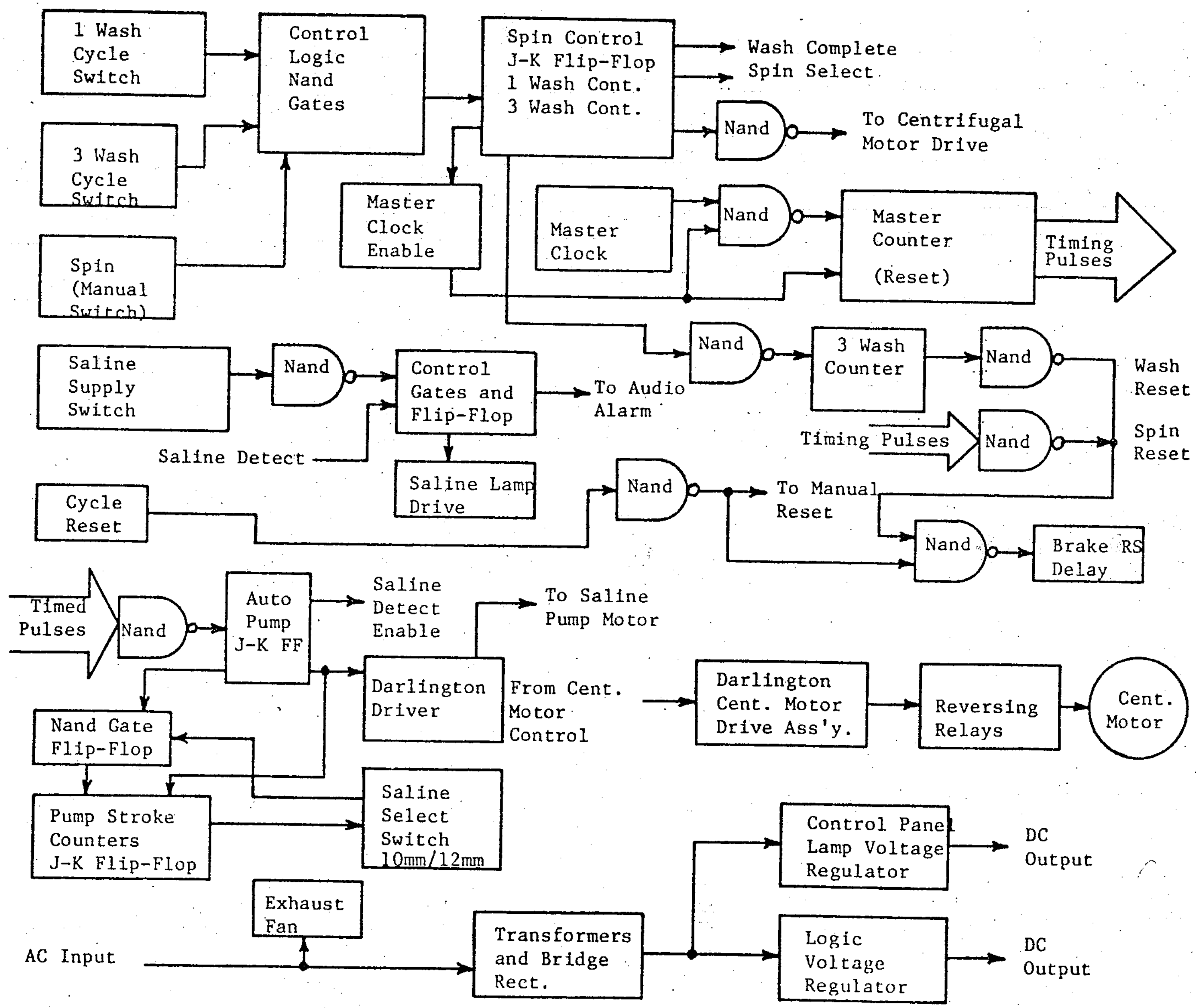
Further troubleshooting hints are: (1) if one or all pumps fail, check fuses; (2) press reset button if appropriate; (3) if all pumps and centrifuge do not function, check main fuse; (4) check all obvious electrical connections; (5) remove individual control circuit boards and examine discrete electronic components; (6) if instrument failure cannot be ascertained, call the appropriate service representative.

Cell Washers

A cell wash operation serves to remove certain extraneous blood compounds from specimens placed in a test tube. Washing operations are performed by mechanical components whose motions are controlled in a programmed sequence by pneumatic and electronic units. The cell washing unit will consist of a centrifuge head and drive motor with related components including the saline pump, supply system, saline detector, and electronic controls.

The functions performed by a cell washer during a typical wash cycle are illustrated in Figure 7. Depending on the sophistication of the instrument, the wash cycle will vary from one to three complete cycles. Dade, the manufacturer of the C-7M Instrument (a bench-top instrument with automated options to perform cell washing with Coombs serum addition) will be used primarily to illustrate simplified diagrams. Since this is an automated instrument which performs two functions, the cell washer aspect will be the only function in this discussion. Figure 8 depicts a simplified block diagram of the Dade C-7M cell washer function.


48 sec
12 sec
12 sec
6 sec
Initiate Wash Cycle
Cent. Motor Rotates Head CW to Wash (1900-2000 RPM Steady State)
Motor Power Off, 12 sec Coast
Cent. Motor Power Reversed, Head Rotates CCW to Decant (850-1550 Steady State)
Brake Applied
End of Cycle
Saline Injected Through Ports in Head to Test Tubes
Saline Pump
Saline Supply
Decanted Saline



1 Wash Cycle Switch
3 Wash Cycle Switch
Spin (Manual Switch)
Control Logic Nand Gates
Spin Control J-K Flip-Flop 1 Wash Cont. 3 Wash Cont.
Wash Complete
Spin Select
Nand
To Centrifugal Motor Drive
Master Clock Enable
Master Clock
Master Counter (Reset)
Timing Pulses
Saline Supply Switch
Control Gates and Flip-Flop
To Audio Alarm
Saline Detect
Saline Lamp Drive
3 Wash Counter
Wash Reset
Timing Pulses
Spin Reset
Cycle Reset
To Manual Reset
Brake RS Delay
Timed Pulses
Auto Pump J-K FF
Saline Detect Enable
To Saline Pump Motor
Darlington Driver
From Cent. Motor Control
Darlington Cent. Motor Drive Ass'y.
Reversing Relays
Cent. Motor
Nand Gate Flip-Flop
Pump Stroke Counters J-K Flip-Flop
Saline Select Switch 10mm/12mm
Exhaust Fan
AC Input
Transformers and Bridge Rect.
Control Panel Lamp Voltage Regulator
DC Output
Logic Voltage Regulator
DC Output

Due to the complicated circuitry of the C-7M cell washer, the possibility of component failure is higher in relation to less complex electronic instruments. However, this is overcome, somewhat, by the use of numerous integrated circuits, thus improving its reliability, stability, and base of use and repair. The main troubleshooting concern is proper supply and/or signal voltage levels to the integrated circuits. Proper supply and logic voltages are paramount for the assured functioning of integrated circuits according to the manufacturer's specifications.

Pumps

The most familiar type of pump is the peristaltic pump (pump head incorporates large or small rollers creating pulsations which cause the pumping action). The normal types of manifold tubing utilized with this type of pump is polyvinyl chloride for pumping aqueous solutions, and isoversinic for pumping strong acids, oils, gases and aromatic solvents. Another type is the syringe pump (a specialized type) sometimes encountered in the laboratory where a predetermined amount of fluid must be applied at a constant rate.

Figure 9 illustrates a block diagram of a peristaltic pump electronic motor speed control. This particular block diagram is based on the peristaltic pump manufactured by Gilson Medical Electronics, Inc. Other peristaltic pumps may or may not have similar electronic motor speed controls, depending on the manufacturer. The primary function of the tachometer generator is to maintain a precise speed for assured precision pumping of fluids. This characteristic gives superior performance over a wide range of speed settings as compared to less sophisticated electronic motor controls.

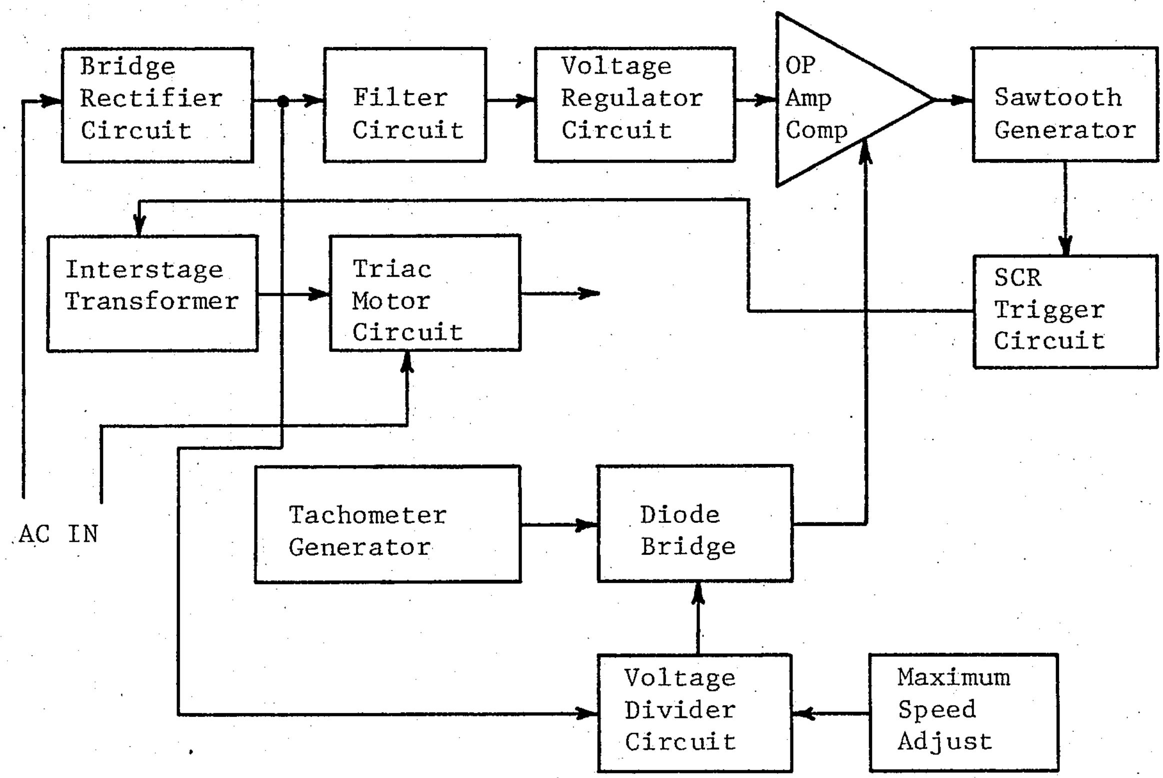


Fig. 9. Block diagram of a peristaltic pump electronic motor speed control.

Slide Stainers

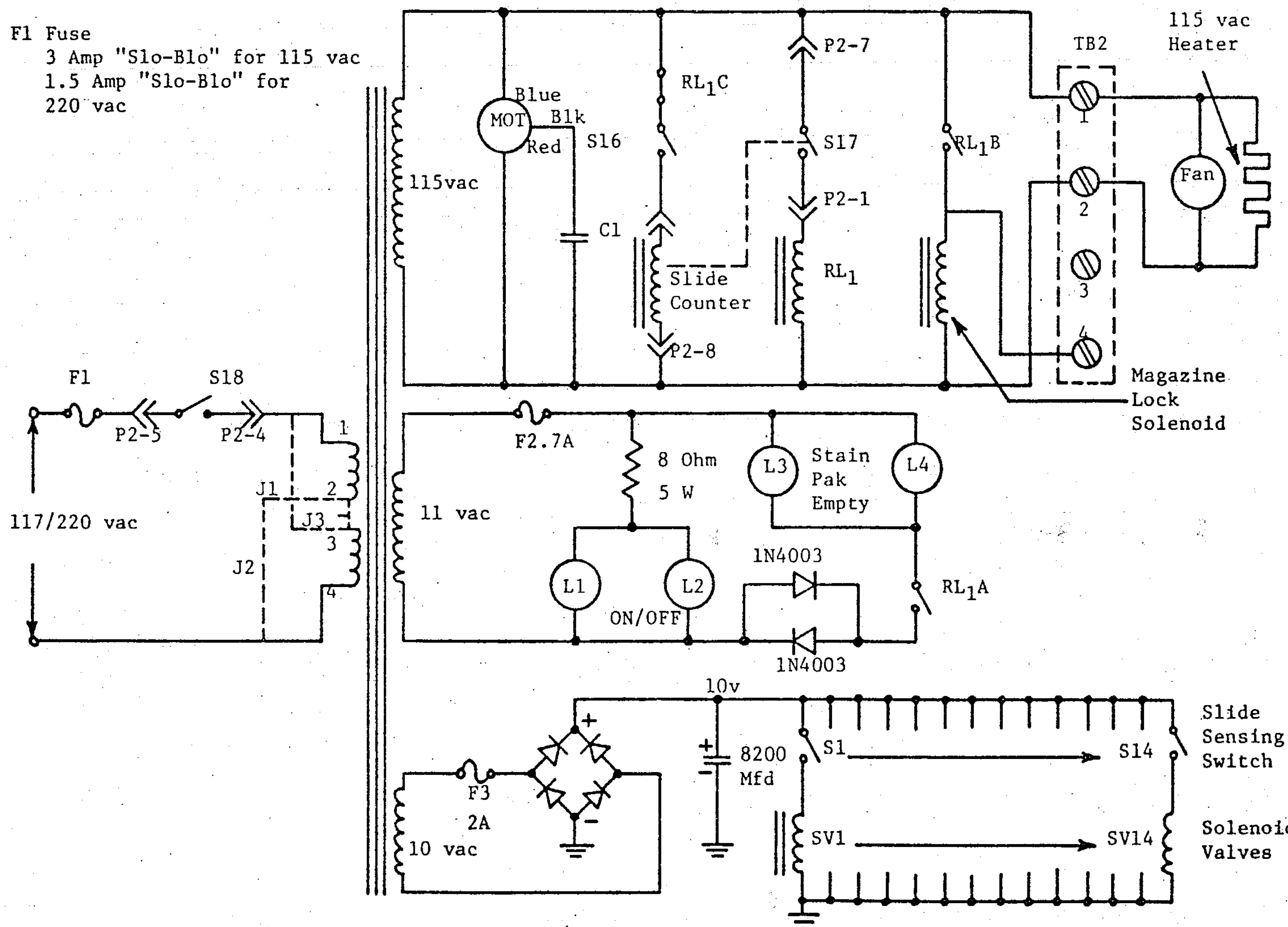
Depending on the intended use, slide stainers are identical in most respects. Essentially, they are self-contained electrically operated, fully automatic instruments designed to process (stain) a specific number of slides. The electro-mechanical operation is relatively straightforward. The slides (contained in a magazine) are placed on the loading bar of the instrument. They are automatically removed from the magazine by tabs which are attached at precise intervals to a conveyor chain. A second conveyor chain moves the slides over a platen area where metered amounts of reagent stains and solutions are applied to the slides. Each time a slide passes the counter switch, the slide counter will subtract one count from an initial setting of 1000. In this manner, the operator will always know the number of slides that can be processed with the remaining solutions. Also, indicator lights are provided for POWER ON and STAIN PAK EMPTY warning.

Figure 10 shows a typical electrical schematic of an automatic slide stainer. As shown, the only electronic components incorporated in the circuitry are the bridge rectifier diodes and the diodes in series with the stain pak empty indicator lamps. The two 1N4003 diodes maintain a constant voltage drop in series with lamps L3 and L4 regardless of the current drawn. Figure 11 depicts the schematic of Figure 10 in the block diagram form.

Daily maintenance of slide strainers is vitally important in maintaining consistently high quality staining results. Due to the simplicity of electrical circuitry, the primary electrical aspects to consider in troubleshooting are: (1) slide sensing switch malfunction, (2) solenoid valves sticking, (3) relay contacts corroded, (4) lamps burned out, and (5) loose or faulty connections.

Summary

In essence, refrigeration equipment, centrifuges, and slide stainers are relatively simple instruments in regard to circuitry design. The common electrical/electronic elements (components) for these devices would include transformers, motors, relays, indicator lights, switches (actuator or limit), solenoids, and related passive components. On the other hand, cell washers and pumps have more complex electronic circuitry. Each of these devices include both active and passive components and


F1 Fuse
3 Amp "Slo-Blo" for 115 vac
1.5 Amp "Slo-Blo" for
220 vac
115vac
MOT
Blue
Blk
Red
S16
C1
RL1C
Slide
Counter
P2-8
P2-7
S17
P2-1
RL1
RL1B
TB2
115 vac
Heater
Fan
1
2
3
4
Magazine
Lock
Solenoid
F1
S18
P2-5
P2-4
117/220 vac
J1
J2
J3
11 vac
F2.7A
8 Ohm
5 W
L1
L2
ON/OFF
L3
L4
Stain
Pak
Empty
1N4003
1N4003
RL1A
10v
8200
Mfd
F3
2A
10 vac
S1
S14
Slide
Sensing
Switch
SV1
SV14
Solenoid
Valves

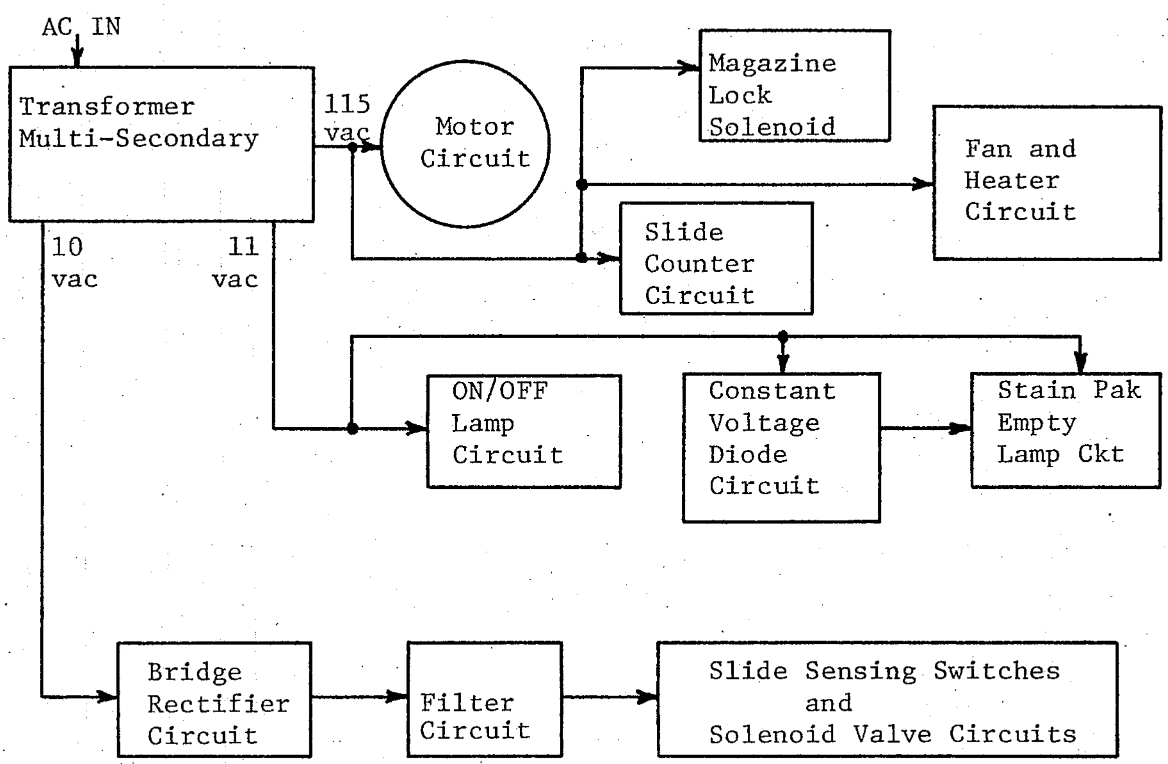


Fig. 11. Block diagram of slide stainer.

integrated circuits as indicated in the functional block diagrams.

However, for each instrument thus far discussed, the operating and service manuals supply detailed maintenance procedures and trouble-shooting charts listing probable causes of electrical/electronic malfunctioning in order of expected probability. Troubleshooting is then accomplished in the same sequence.

Analysis of Optical Equipment/Instruments

Microscopes/Microscope Illuminators

Microscopes are not electronic instruments per se, but their extensive use by medical technologists in laboratory environments makes it essential to include them in this discussion. Microscopes range in size and shape from student microscopes (utilized in education) to fluorescent microscopes, research microscopes, polarizing microscopes, and stereo-microscopes.

Regardless of their specialized use, microscopes share common features and functions. For example, they all have an optical path, some type of focusing mechanism, a single or multiple nose piece, and some come with their own illuminators. Furthermore, they perform basically the same function and that is to magnify microscopic entities or phenomenon. Therefore, microscopes also share similar problems. Examples and probable causes are given in Table 3. Table 3 in itself is not complete for all microscopes. However, many manufacturers of microscopes supply complete troubleshooting charts with their instruction manuals.

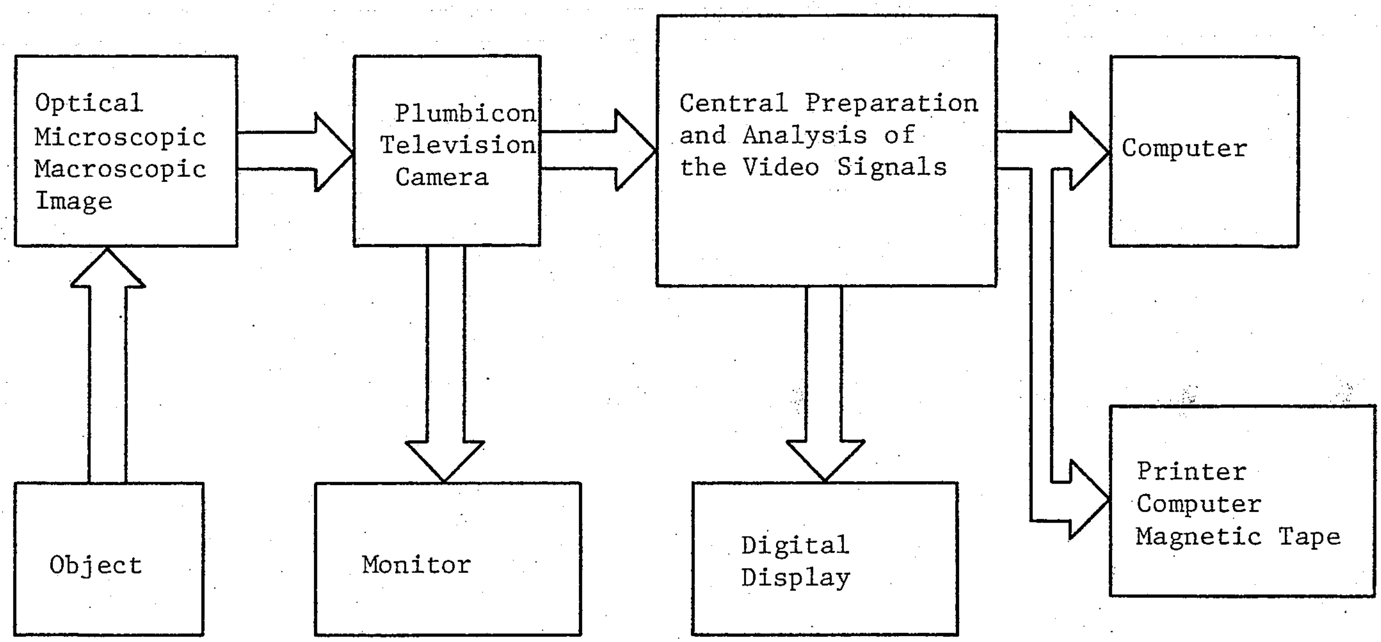
Beyond the realm of basic microscopy there exists extremely sophisticated computerized systems for automatic image analysis within microscopic and macroscopic ranges. An example of such a system is the CLASSIMAT manufactured by E. Leitz, Inc. This system has multiple uses; examples are metallography, ceramics, medicine, zoology, botany, and many more. Figure 12 depicts a simplified block diagram of the systems functional blocks. With this type of system it would not be advisable for a medical technologist to attempt electronic troubleshooting. A recommended procedure would be to isolate the piece of equipment that is malfunctioning and contact a technical representative or field engineer.

All microscopes require a source of light, either natural or artificial, to illuminate the specimen for image projection. Natural light is normally obtained by reflecting sunlight or surrounding ambient light off of mirrors for specimen illumination. Artificial light, however, can

TABLE 3

GENERAL TROUBLESHOOTING PROCEDURES FOR MICROSCOPES

Trouble	Cause	Remedy
Field of view is cut off, or illuminated irregularly.	1) Nose piece did not change properly.	1) Slightly rotate the nose piece until it clicks into position.
	2) Condenser is not correctly mounted on ring mount.	2) Re-insert the condenser all the way.
Excessive image contrast.	1) Condenser is lowered excessively.	1) Raise the condenser.
	2) Aperture iris diaphragm is stopped down excessively.	2) Open the diaphragm.
Illuminator is too bright or too dark.	1) Voltage selector switch is not matched with the main voltage.	1) Set the switch to match the main voltage.
	2) Main voltage is too high or too low.	2) Adjust the main voltage with a variable voltage transformer.
	3) Rheostat trimmer screw is not correctly adjusted.	3) Adjust it correctly.
Dust or dirt is visible in the field of view.	1) Dust or dirt on the glass surface at the light exit on the lens.	
	2) Dust on condenser top lens.	
	3) Dust on objective front lens.	Clean off the dust or dirt with appropriate cleaning fluids and/or cloths.
	4) Dirty specimens.	
	5) Dust on eyepieces.	


Optical Microscopic Macroscopic Image
Plumbicon Television Camera
Central Preparation and Analysis of the Video Signals
Computer
Object
Monitor
Digital Display
Printer Computer Magnetic Tape

be produced by various means such as mercury vapor burners, halogen gas lamps, and tungsten filament lamps. These artificial illuminators can be integral parts of the microscope or attachments with separate power supplies. Unfortunately, no electrical or electronic information was made available on microscope illuminator circuitry.

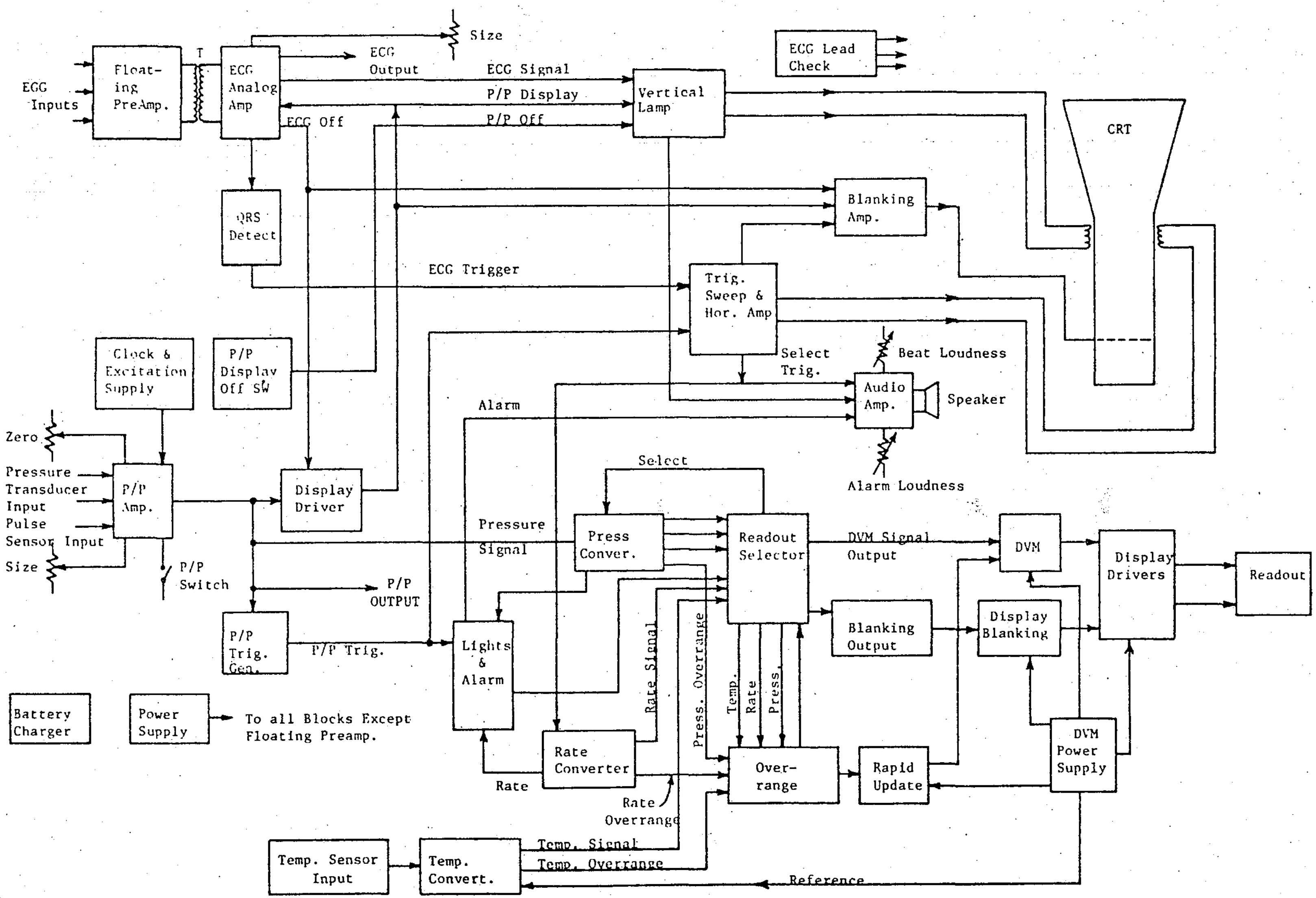
Monitors

Figure 13 illustrates a simplified block diagram of a portable cathode-ray tube (CRT) monitor. The block diagram is patterned after the Model 414 patient monitor manufactured by Tektronix, Inc. Medical technologists working in a hospital-patient environment would possibly operate this kind of monitoring instrument. The instrument itself is primarily designed to display electrocardiograph and blood pressure or peripheral pulse waveforms. Also, a digital readout is available of heart rate, systolic/diastolic blood pressure, mean blood pressure, or temperature.

A routine maintenance schedule is mandatory for the complexity of this instrument, including both preventive maintenance (cleaning, inspections, calibration) and corrective maintenance (component removal and replacement). A major concern of either type of maintenance performed is the electrocardiograph leakage. The manufacturer's recommendation is to perform a leakage check every six months or after physical repairs have been completed. Electrocardiograph leakage current generated by this type of monitor may become too dangerous for proper usage.

Summary

Basically, microscopes have no electronic components per se. Natural or artificial light is used to illuminate the specimen under



EGG Inputs
Float-ing PreAmp.
T
ECG Analog Amp
Size
ECG Output
ECG Signal
P/P Display
P/P Off
ECG Off
Vertical Lamp
ECG Lead Check
CRT
QRS Detect
Blanking Amp.
ECG Trigger
Trig. Sweep & Hor. Amp
Select Trig.
Beat Loudness
Audio Amp.
Speaker
Alarm Loudness
Clock & Excitation Supply
P/P Display Off SW
Alarm
Zero
Pressure Transducer Input
Pulse Sensor Input
Size
P/P Amp.
Display Driver
P/P Switch
P/P OUTPUT
Pressure Signal
Select
Press Conver.
Readout Selector
DVM Signal Output
DVM
Display Drivers
Readout
Blanking Output
Display Blanking
P/P Trig. Gen.
P/P Trig.
Lights & Alarm
Rate Signal
Press. Overrange
Temp.
Rate
Press.
Battery Charger
Power Supply
To all Blocks Except Floating Preamp.
Rate Converter
Rate
Rate Overrange
Over-range
Rapid Update
DVM Power Supply
Temp. Sensor Input
Temp. Convert.
Temp. Signal
Temp. Overrange
Reference

observation. Specialized systems utilizing the microscope and many sophisticated instruments, as shown in Figure 12, are found where extremely accurate specimen analysis is essential.

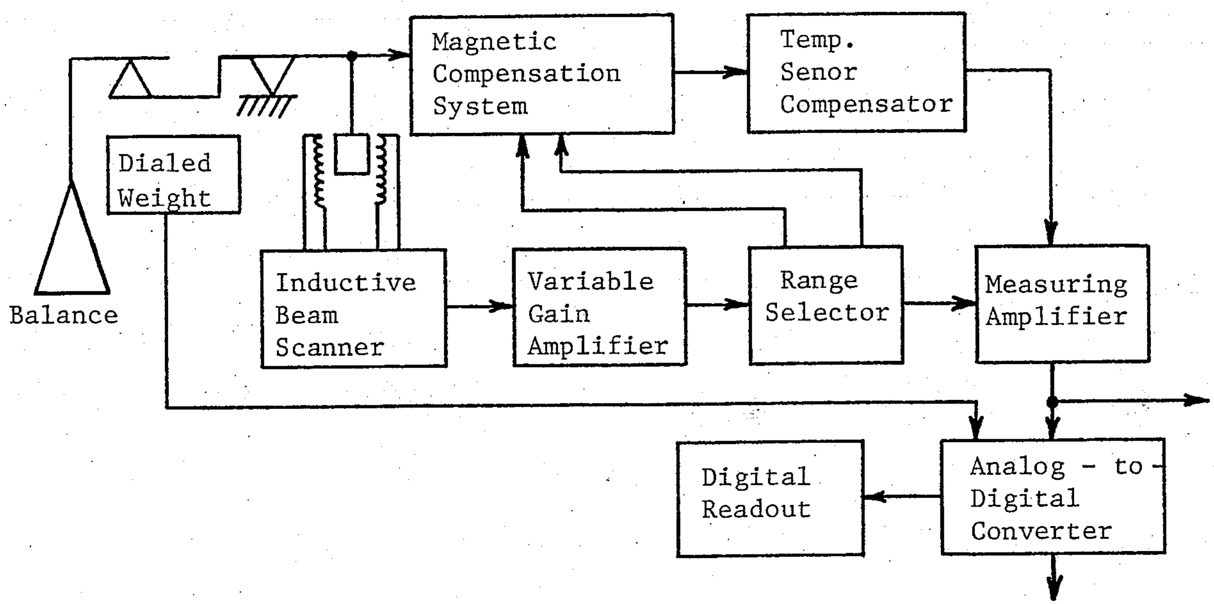
Cathode-ray tube monitors contain many circuits, as illustrated in Figure 13. For instance, the monitor illustrated in block diagram form incorporates input sensors and transducers, pre-amplifiers and amplifiers, display drivers, detectors, converters, trigger generators, a CRT (Cathode-ray Tube), digital readout, and a power supply. The circuits which appear in the functional blocks contain either discrete or integrate circuit components or both, depending on the manufacturer's specifications. The instrument manual illustrates these circuits in full electronic schematic form for the purpose of complete instrument troubleshooting.

Analysis of Basic Measuring Equipment/Instruments

Analytical Balance

The analytic balance is an important instrument used in the preparation of solutions or where accuracy of 1 mg or less is required. Performance characteristics of a quality analytical balance are sensitivity, precision, accuracy, and readability, regardless of whether the readout is digital or analog. The Mettler Instrument Corporation manufactures a force compensation analytical balance with an external control system and digital readout system. Figure 14 shows a simplified block diagram of the analytical balance system manufactured by the Mettler Instrument Corporation.

The measuring principle is based on the following analysis. The beam scanner determines the deflection of the balance beam and transmits


Magnetic Compensation System
Temp. Senor Compensator
Dialed Weight
Balance
Inductive Beam Scanner
Variable Gain Amplifier
Range Selector
Measuring Amplifier
Digital Readout
Analog - to - Digital Converter

a signal to the variable-gain amplifier. This amplifier amplifies the signal from the beam scanner and, acting in conjunction with the range selector, generates the coil current which acts as countertorque in the magnetic compensation system. Also, the variable-gain amplifier supplies the input voltage for the measurement amplifier. The output of the measurement amplifier is then transmitted to the analog-to-digital converter and finally to the digital readout. The temperature sensor compensator makes sure the sensitivity of the balance is not affected by temperature changes.

Troubleshooting an analytical balance or system should be done periodically. That is to say, checks on zero adjustments, sensitivity, adjustments, and accuracy will ensure optimum balance performance. No further information was made available on electronic troubleshooting of the external control and readout units. However, troubleshooting procedures applicable to some or all electronic devices also would apply to digital analytical balances.

pH Meters

pH is a measure of H + ion concentration as determined by the small electrical voltage present between the inside and outside walls of the measuring electrode. A stabilizing reference electrode provides a constant potential to balance the measuring electrode. Whether the pH meter incorporates an analog or digital readout, the functional circuitry is basically the same. Figure 15 depicts a simplified block

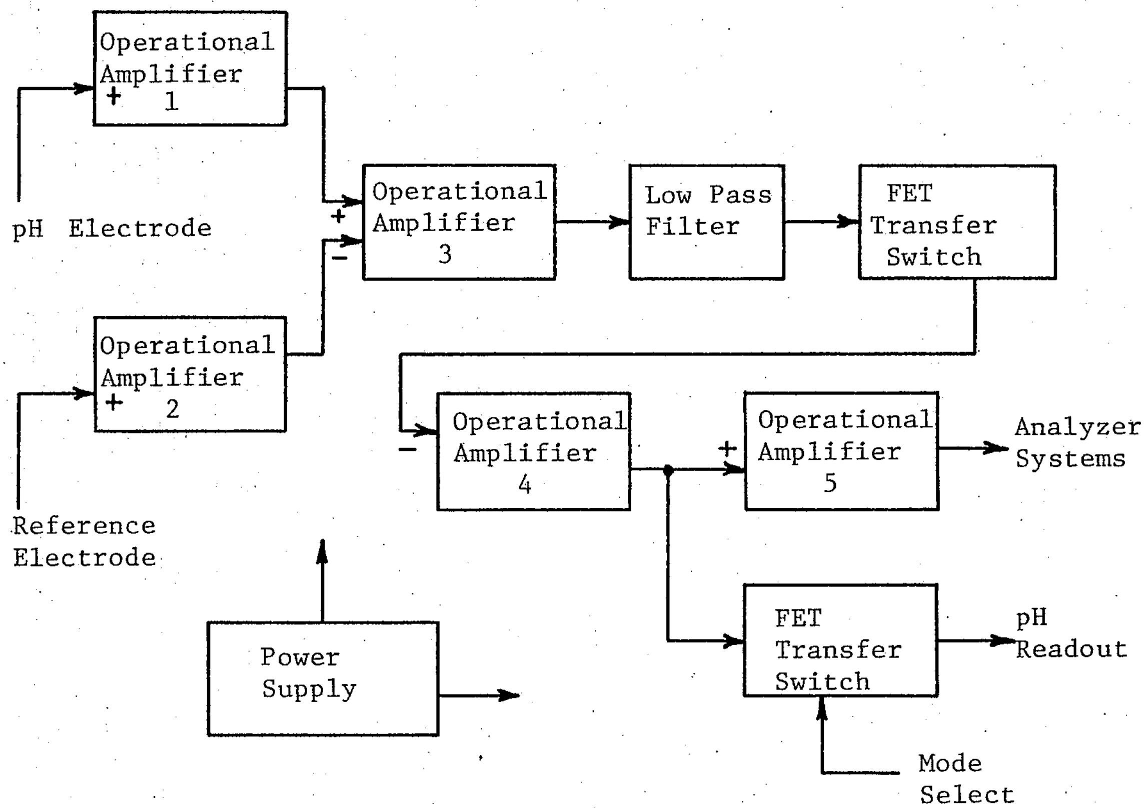


Fig. 15. Simplified block diagram of a typical pH meter amplifier section.

manufactured by Instrumentation Laboratory, Inc. If the pH instrument is strictly used in measuring pH and not a part of a larger system, the fifth operational amplifier probably would be used for signal amplification to the readout.

For routine care of pH meters the following points are recommended: (1) The reference chamber of the pH electrode system should always be kept nearly full with saturated potassium chloride solution; (2) always keep the pH electrode submerged in a buffer solution between periods of use. When troubleshooting a pH meter, several guidelines presented in Table 4 help in isolating and correcting faulty operations.

TABLE 4

GENERAL PROCEDURES FOR pH METER TROUBLESHOOTING

Problem	Cause	Remedy
Meter needle oscillates erratically	1) Bubbles around reference junction.	1) Insure good contact with sample.
	2) Grounding not adequate.	2) Soak external surface in warm water.
	3) Contamination of reference electrode.	3) Check receptacle ground.
Unable to control meter needle with balance control	1) Open circuit.	1) Check controls and circuit board for continuity.
	2) pH electrode system not plugged in correctly.	2) Check all connections for proper contact.
	3) Open connection in electrode plug or lead.	3) Check continuity of lead and electrode.
Meter needle will not balance at the buffer points	1) Unsaturated reference chamber.	1) Resaturate chamber.
	2) Contamination of reference half-cell.	2) Remove old electrolyte and replace with new.

Electronic Thermometers

There are numerous manufacturers of precision temperature measuring devices (electronic thermometers) with widely applied uses in scientific and industrial areas, such as biology, medicine, ecology, physiology, and oceanography to name a few. In most cases, however, whether the instrument readout is digital or analog, the measuring method utilizes the basic Wheatstone Bridge principle. Unfortunately, no specific information was made available on any kind of electronic thermometer circuitry.

Analysis of Specialized Test Equipment/Instruments

Fibrometers and Osmometers

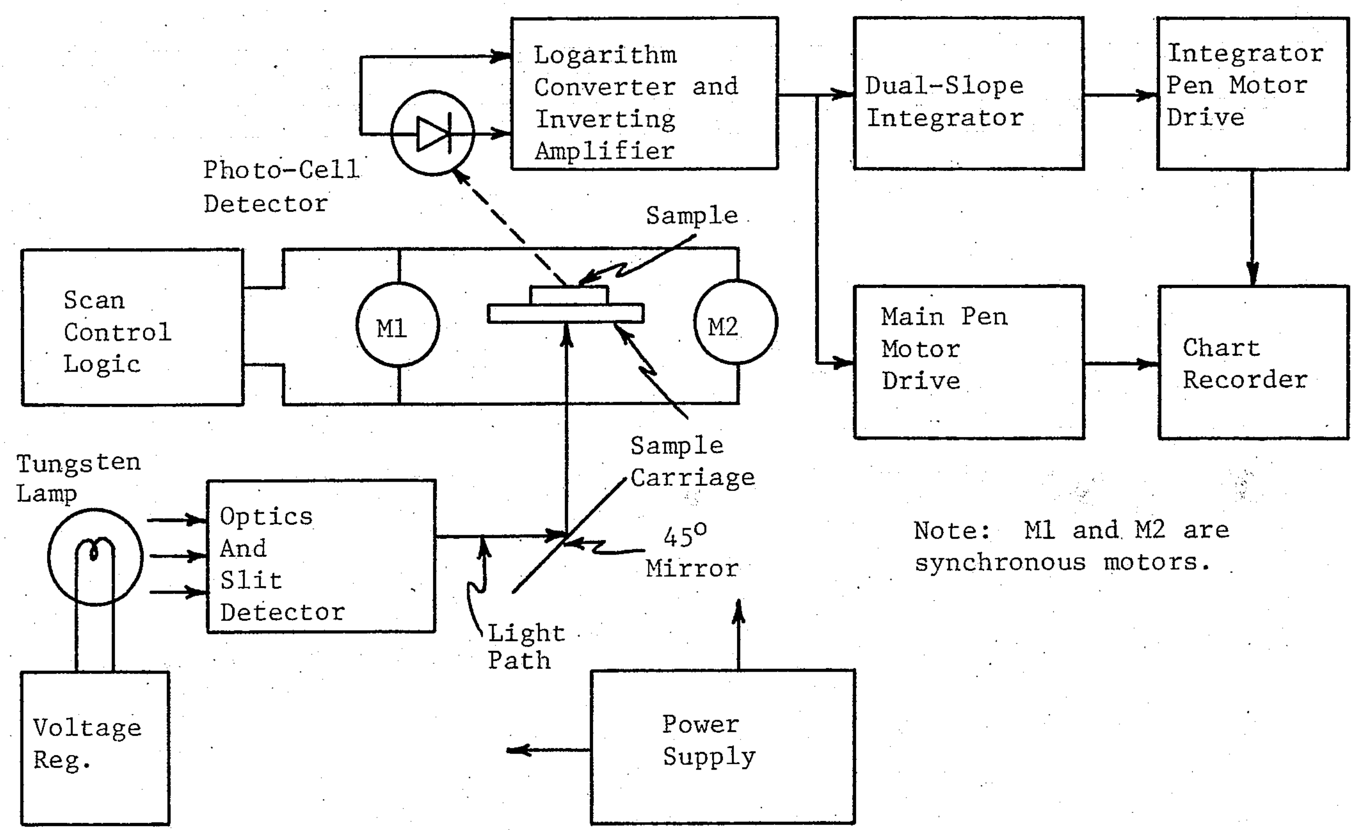
No information was received on these particular instruments from manufacturers.

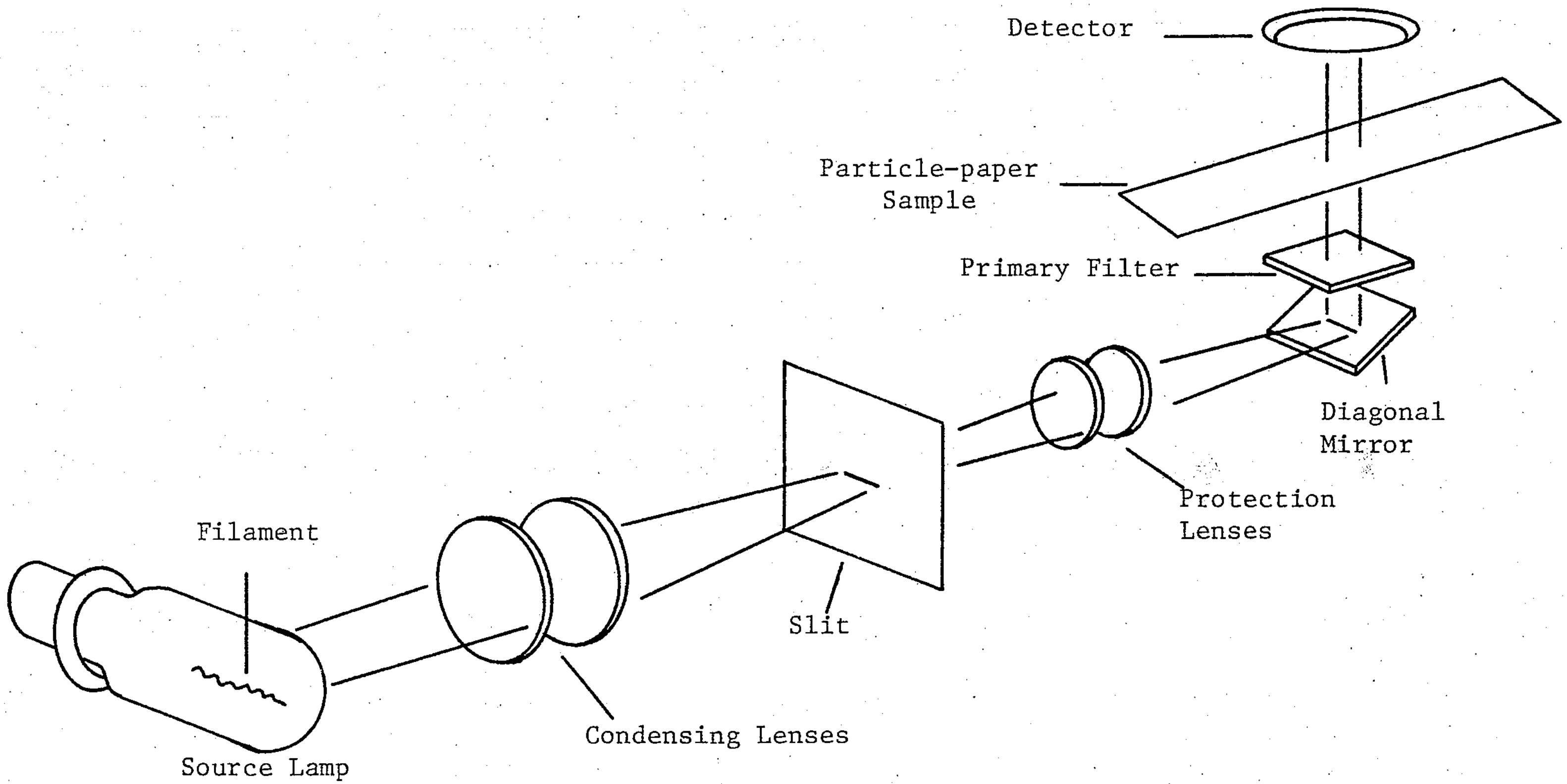
Densitometers

The densitometer provides a means for scanning electrophoresis separations and provides a recording of the optical density along with a recording of the integral of the optical density. In essence, a densitometer is designed to measure the density of a deposit of material as separated by particle shape, size, and electric charge. The particles, suspended in solution, are separated according to their migration characteristics on a strip of transparent or translucent paper by the electrophoric method. This strip of paper is then placed in the densitometer and moved past a light scanner. The amount of light detected coming through the paper-particle sample determines the density of that material.

The numerous manufacturers of densitometers, such as E-C Apparatus Corporation, Helena Laboratories, and Beckman Instruments, Inc., design basically the same type of densitometer with minor differences incorporated by individual manufacturers. Figure 16 depicts a typical over-all block diagram of a densitometer. Also, Figure 17 illustrates a typical light path in the scanner section of a densitometer.

Due to the precision of alignment needed in the light scanning section, no troubleshooting is recommended by the manufacturers except for changing of the source lamp. However, for all other electrical/


Logarithm Converter and Inverting Amplifier
Dual-Slope Integrator
Integrator Pen Motor Drive
Photo-Cell Detector
Sample
Scan Control Logic
M1
M2
Main Pen Motor Drive
Chart Recorder
Sample Carriage
Tungsten Lamp
Optics And Slit Detector
45° Mirror
Note: M1 and M2 are synchronous motors.
Light Path
Voltage Reg.
Power Supply


Detector
Particle-paper
Sample
Primary Filter
Diagonal
Mirror
Protection
Lenses
Slit
Filament
Condensing Lenses
Source Lamp

electronic malfunctions, general procedures of operator service and maintenance can be employed as described by the operators manual.

Fluorometers

Fluorometric instruments are useful devices in the measurement and use of fluorescence, called fluorometry. The phenomenon being measured, fluorescence, is the instantaneous light emission from a molecule or atom which has previously absorbed light. The fundamental principles of fluorescence measurements are illustrated by a simplified diagram of a typical fluorometer operation. See Figure 18.

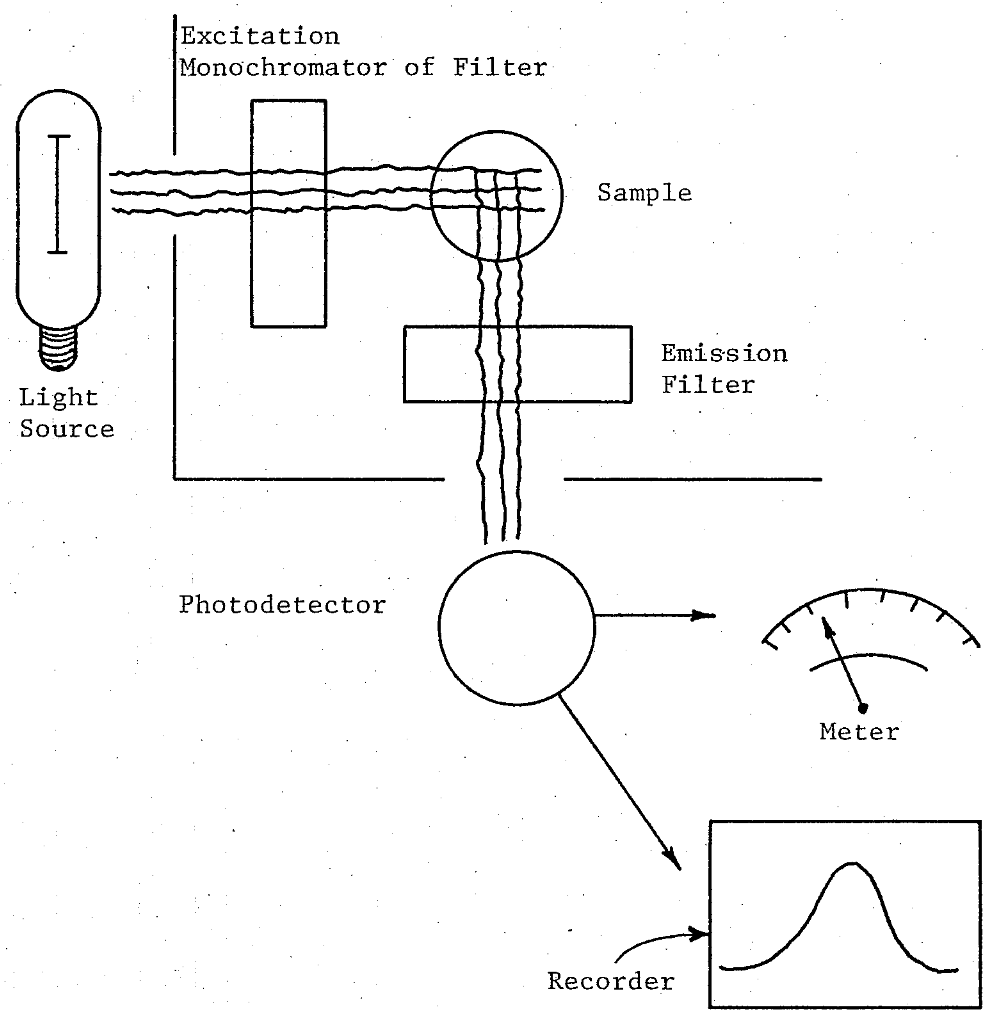


Fig. 18. Simplified diagram of Fluorometer operation.

Under the general category of fluorometers exist specific instruments such as filter fluorometers, spectrofluorometers, spectrophotofluorometers, and spectra/glo fluorometers. Regardless of the type of device used to select the light wave lengths, filter or monochromators, all fluorometers function basically the same. Each instrument will contain a light source, some type of wavelength selector, a photomultiplier cell, signal amplifiers, voltage regulators, and some type of readout. Figure 19 illustrates in block diagram form the electronic circuits utilized in typical fluorometers.

Due to the very high voltage hazards, troubleshooting of fluorometers must be undertaken with extreme caution. This applies mainly to the high voltage power supply of the photomultiplier circuitry and the source lamp's power supply. A second major caution point is the amount of light striking the photomultiplier tube. Excessive exposure of ambient light can "flood" the sensitive photomultiplier. Flooding of the photomultiplier may require up to several hours for restabilization. Further problem areas and their causes are offered in Table 5.

Along with the generalized procedures of Table 5, detailed circuit troubleshooting should be undertaken if the instrument continues to malfunction.

Photometers

As stated in the definition of terms, a photometer is any device for measuring light in any situation. Specific instruments such as flame photometers, spectrophotometers, UV spectrophotometers, dual-beam photometers, and absorbance spectrophotometers all fall under the general category of photometers. Their basic functions and design are similar

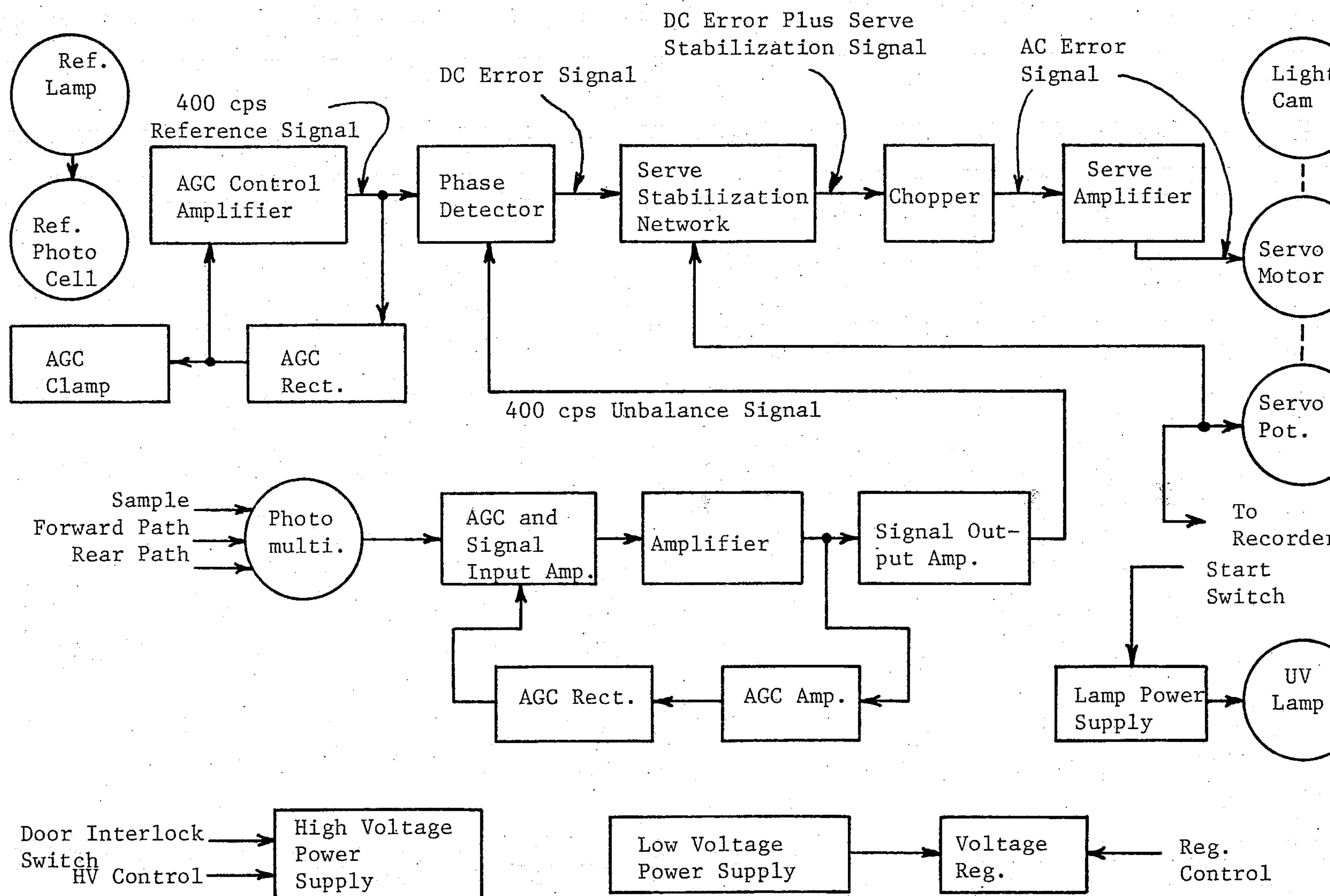

Ref. Lamp
Ref. Photo Cell
400 cps Reference Signal
AGC Control Amplifier
AGC Clamp
AGC Rect.
Phase Detector
DC Error Signal
DC Error Plus Serve Stabilization Signal
Serve Stabilization Network
Chopper
AC Error Signal
Serve Amplifier
Light Cam
Servo Motor
Servo Pot.
400 cps Unbalance Signal
To Recorder
Sample
Forward Path
Rear Path
Photo multi.
AGC and Signal Input Amp.
Amplifier
Signal Output Amp.
AGC Rect.
AGC Amp.
Start Switch
Lamp Power Supply
UV Lamp
Door Interlock Switch
HV Control
High Voltage Power Supply
Low Voltage Power Supply
Voltage Reg.
Reg. Control

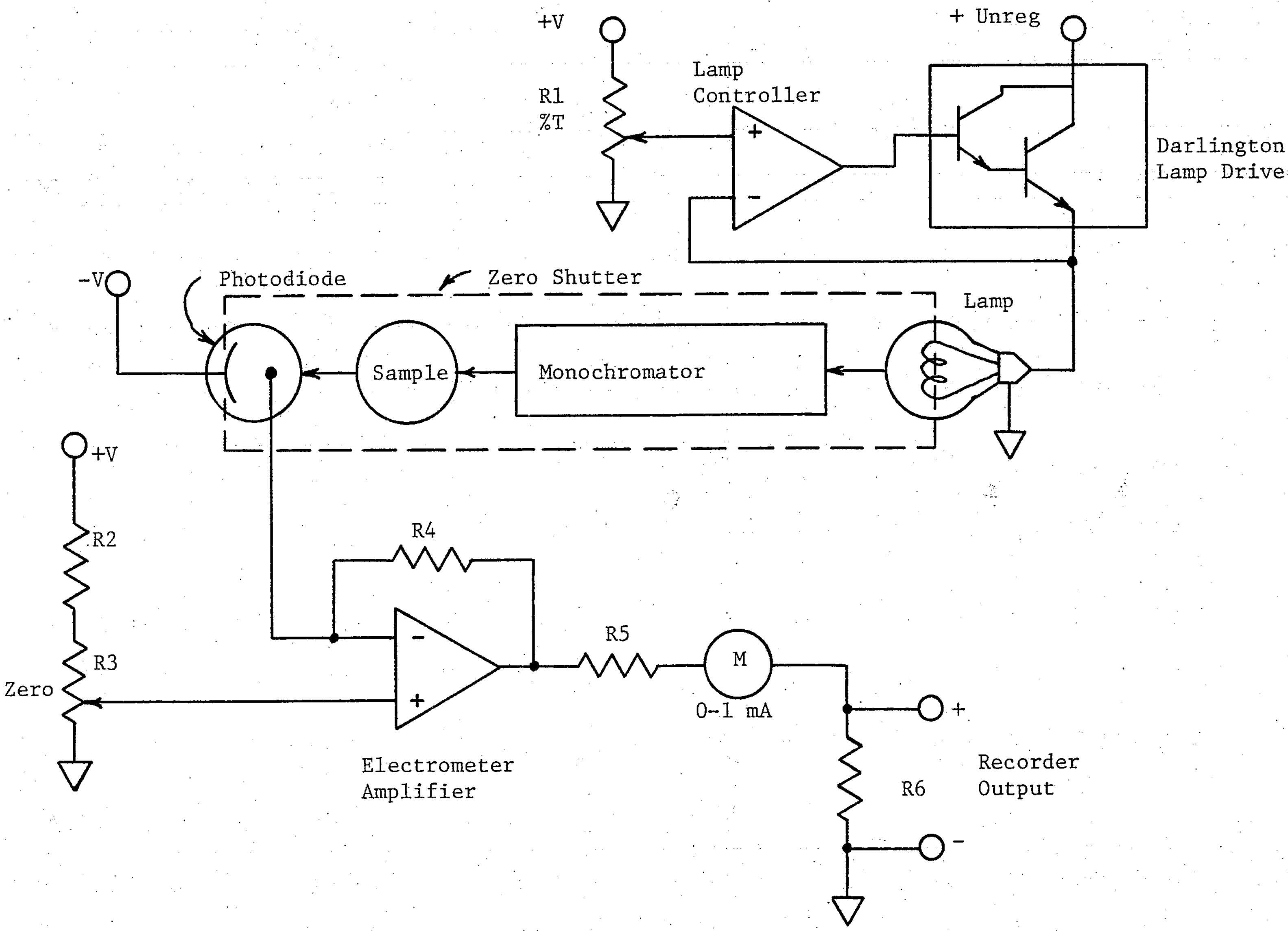
TABLE 5

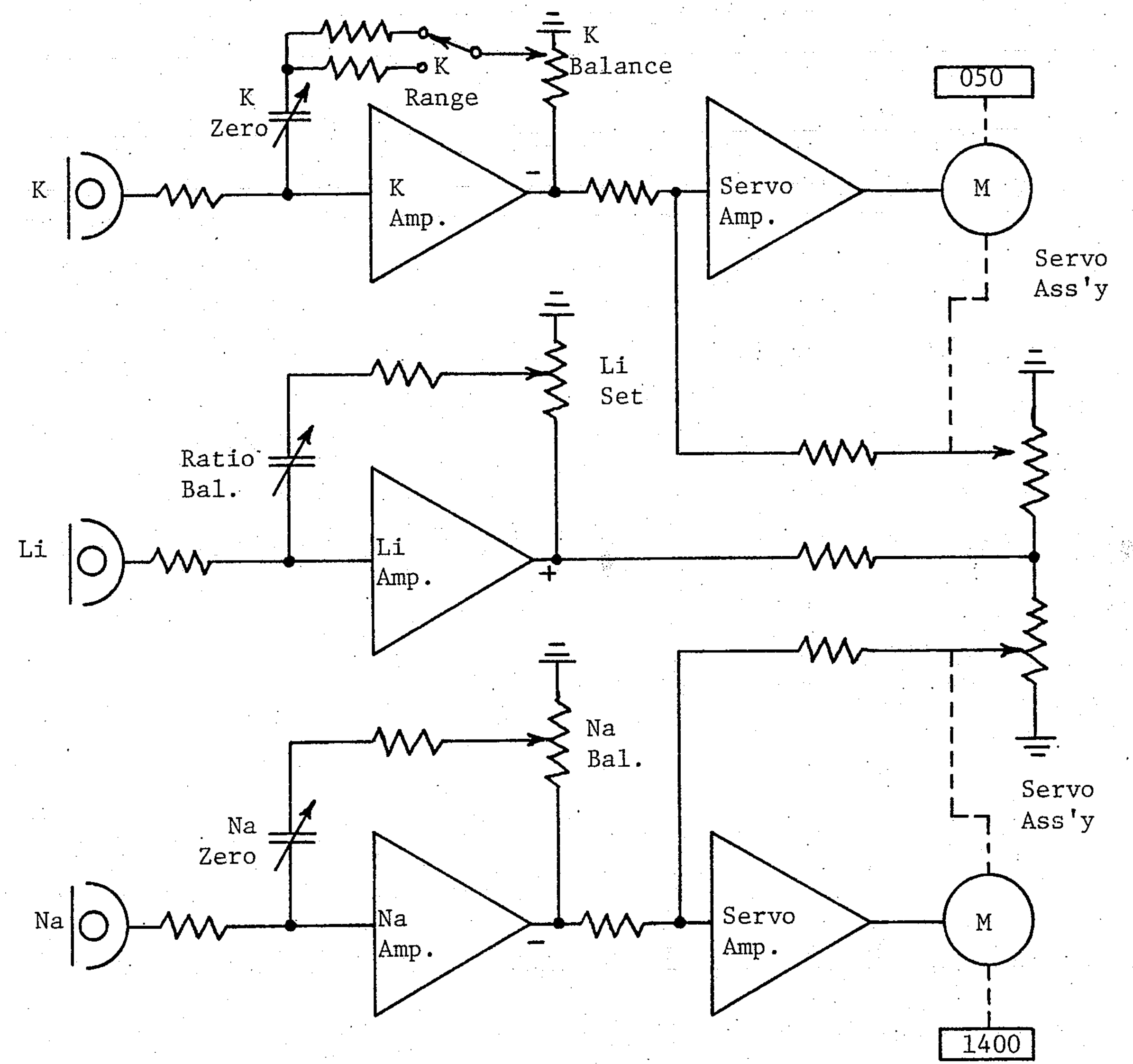
GENERAL PROCEDURES FOR TROUBLESHOOTING FLUOROMETERS

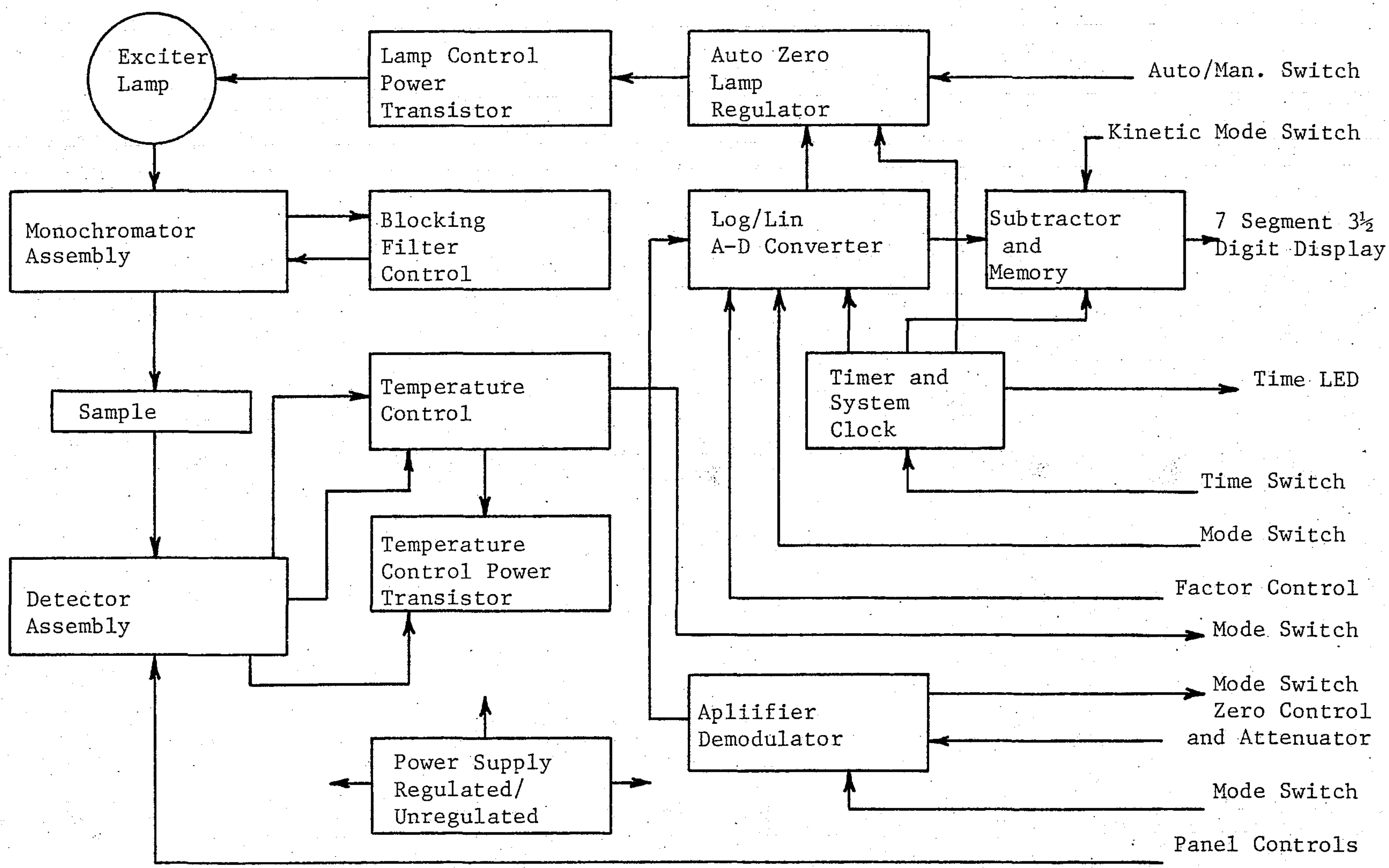
Problem	Cause
Large drift of baseline	1) Leakage 2) Light source unstable
Baseline shifts at higher sensitivities	1) Stray light entering optical chamber
Excessive noise	1) Machine ungrounded 2) Particles in sample solution
No response to known solution	1) Blockage of light path 2) Light source burned out 3) Photomultiplier defective

with exceptions to specific applications. Except for the flame photometer which utilizes a sample burning method (refer to definition of terms), the essential components of photometers consist of (a) a light source, (b) a monochromator (filter, prism, etc.) which separates the light into individual wave lengths, (c) a slit which further isolates the light, (d) the sample, (e) a photodetector, and (f) a meter, digital, or other type of readout device. These instruments are somewhat similar to fluorometers with deviations in their intended use or the type of analysis being performed.

Figures 20, 21, and 22 illustrate the various circuits in block diagram form associated with simplified and specific photometer instruments. The circuits range from simple to complex depending on the sample analysis intended and the type of output required, varying from simple meter display to digital readouts with printer and recorder auxiliaries.


+V
R1
%T
Lamp
Controller
+ Unreg
Darlington
Lamp Drive
-V
Photodiode
Zero Shutter
Lamp
Sample
Monochromator
+V
R2
R4
R3
Zero
R5
M
0-1 mA
Electrometer
Amplifier
R6
Recorder
Output


K
Balance
K
K
Range
K
Zero
K
K
Amp.
050
Servo
Amp.
M
Servo
Ass'y
Li
Set
Ratio
Bal.
Li
Li
Amp.
Na
Bal.
Na
Zero
Na
Na
Amp.
Servo
Ass'y
Servo
Amp.
M
1400


Exciter Lamp
Lamp Control Power Transistor
Auto Zero Lamp Regulator
Auto/Man. Switch
Kinetic Mode Switch
Monochromator Assembly
Blocking Filter Control
Log/Lin A-D Converter
Subtractor and Memory
7 Segment 3½ Digit Display
Sample
Temperature Control
Timer and System Clock
Time LED
Time Switch
Temperature Control Power Transistor
Mode Switch
Detector Assembly
Factor Control
Mode Switch
Apliifier Demodulator
Mode Switch
Zero Control and Attenuator
Power Supply Regulated/ Unregulated
Mode Switch
Panel Controls

Many of the photometer manufacturers incorporate in their operation service manuals such troubleshooting aids as detailed flow charts and signal path layouts including voltage and oscilloscope waveform illustrations. A typical troubleshooting flow chart is depicted in Figure 23. This type of troubleshooting technique allows the instrument operator to perform electronic malfunctioning analysis without extensive electronic training.

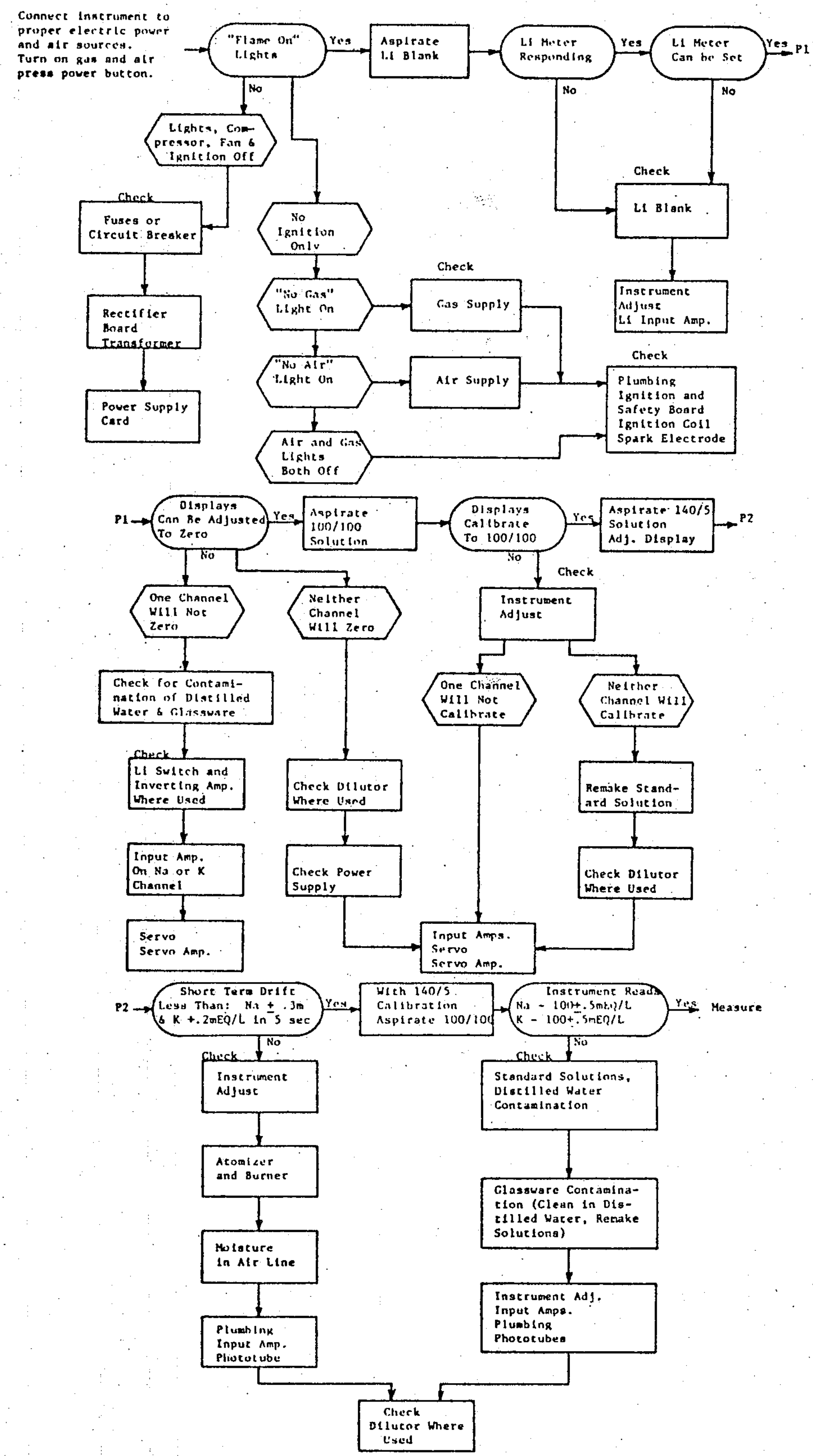
A major hazard with the photomultiplier tube, as was the case with fluorometer instruments, is that it is operated to extremely high voltages (in excess of 600 VDC). Therefore, every precaution should be taken to avoid contact with these voltages. In addition, the photometer instruments which use an Xenon lamp for a light source generate radio frequency pulses that can damage nearby energized high-impedance instruments when the lamp arc is struck.

Performance monitoring of photometer instruments can be carried out by checking on their function as a whole and by evaluating each of the component parts mentioned in the beginning of this discussion. Overall performance is checked by processing standard solutions or control samples of known value along with the unknown samples under analysis.

Analyzers

Most analyzers utilized in clinical laboratories or research facilities serve a specifically designed function. Therefore, the instruments which fall under the generalized category of analyzers will be examined and discussed separately.

Glucose analyzers provide a rapid measurement of glucose in blood plasma or serum. The amount of glucose is measured by following the

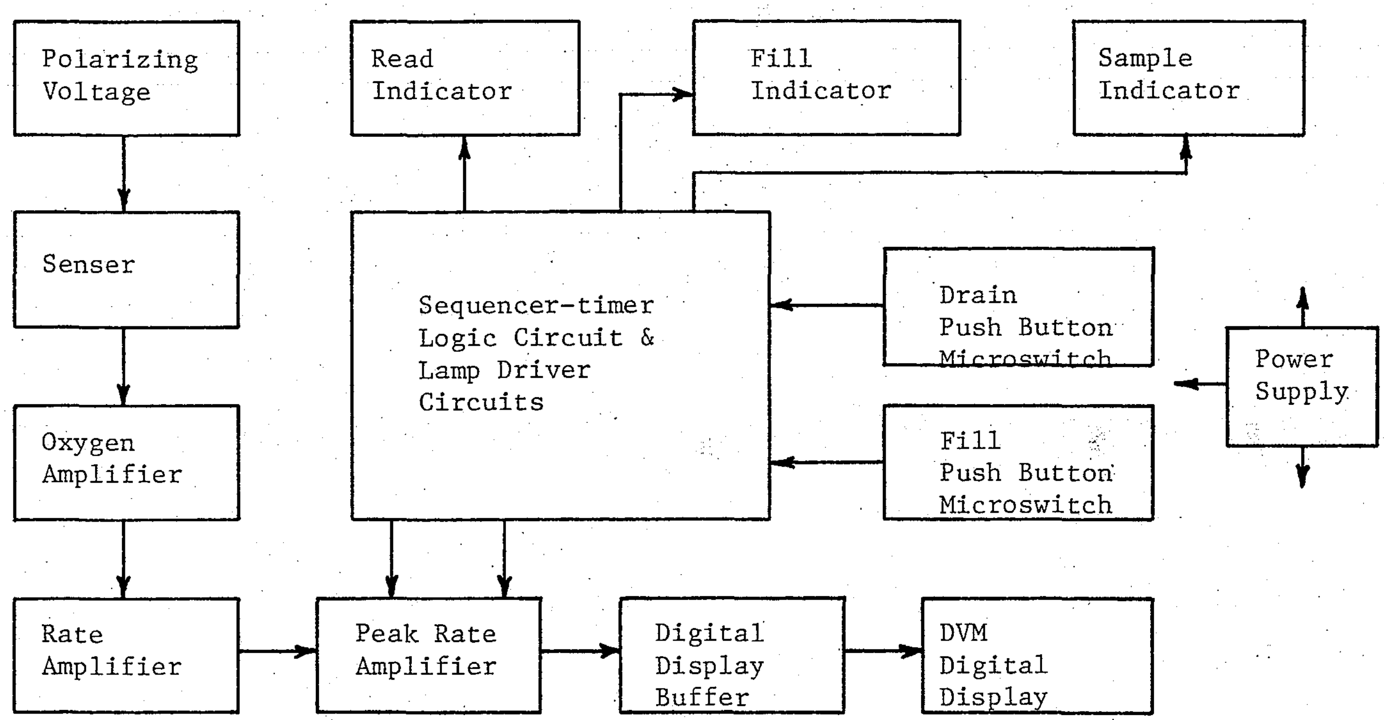

Connect instrument to proper electric power and air sources. Turn on gas and air press power button.
"Flame On" Lights
Yes
Aspirate Li Blank
Li Meter Responding
Yes
Li Meter Can be Set
Yes
P1
No
No
No
Lights, Compressor, Fan & Ignition Off
Check
Fuses or Circuit Breaker
Rectifier Board Transformer
Power Supply Card
No Ignition Only
"No Gas" Light On
"No Air" Light On
Air and Gas Lights Both Off
Check
Gas Supply
Air Supply
Check
Li Blank
Instrument Adjust Li Input Amp.
Check
Plumbing Ignition and Safety Board Ignition Coil Spark Electrode
P1
Displays Can Be Adjusted To Zero
Yes
Aspirate 100/100 Solution
Displays Calibrate To 100/100
Yes
Aspirate 140/5 Solution Adj. Display
P2
No
No
One Channel Will Not Zero
Neither Channel Will Zero
Check
Instrument Adjust
Check for Contamination of Distilled Water & Glassware
Check
Li Switch and Inverting Amp. Where Used
Input Amp. On Na or K Channel
Servo Servo Amp.
Check Dilutor Where Used
Check Power Supply
One Channel Will Not Calibrate
Neither Channel Will Calibrate
Remake Standard Solution
Check Dilutor Where Used
Input Amps. Servo Servo Amp.
P2
Short Term Drift Less Than: Na ± .3m & K +.2mEQ/L in 5 sec
Yes
With 140/5 Calibration Aspirate 100/100
Instrument Reads Na - 100±.5mEQ/L K - 100±.5mEQ/L
Yes
Measure
No
No
Check
Instrument Adjust
Atomizer and Burner
Moisture in Air Line
Plumbing Input Amp. Phototube
Check
Standard Solutions, Distilled Water Contamination
Glassware Contamination (Clean in Distilled Water, Remake Solutions)
Instrument Adj. Input Amps. Plumbing Phototubes
Check Dilutor Where Used

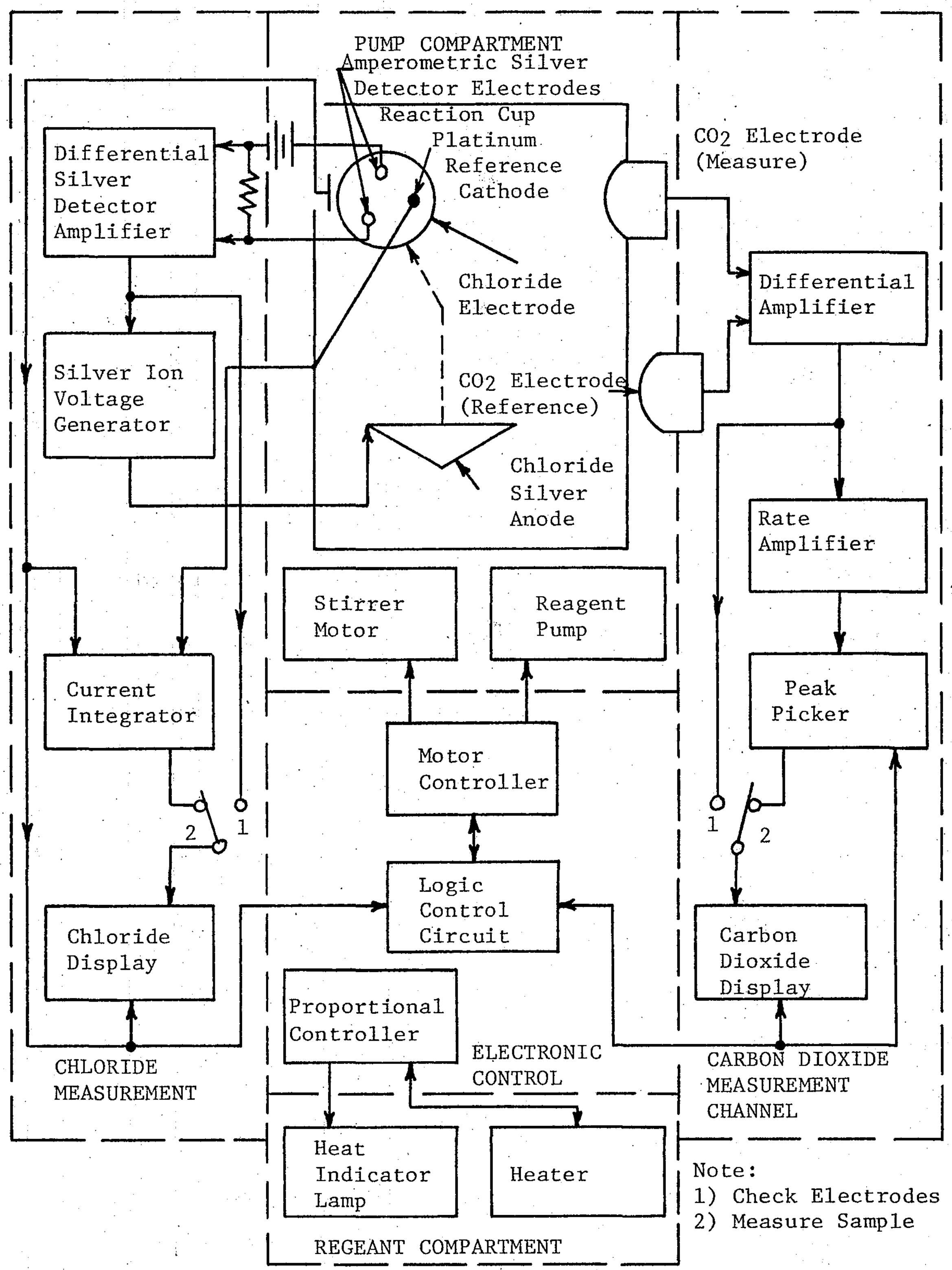
consumption of oxygen during its reaction with glucose in the presence of an enzyme catalyst. The interaction between oxygen and glucose is detected by an electrochemical sensor. The initial rate and peak rate of oxygen consumption are directly proportional to the amount of glucose concentration in the sample with the peak rate occurring approximately ten seconds after sample injection.

Some manufacturers of glucose analyzers may vary minor design features but the circuit functioning and method of analysis will remain the same. Figure 24 illustrates a simplified block diagram of a typical glucose analyzer.

The sequence-timer and its associated circuitry gives assistance to the operator by visually indicating with lighted indicators the necessary steps to be taken, and monitors the sample handling functions, and provides a time delay in the operational sequence to allow time for proper oxygen sensor recovery. Additonally, these circuits also are utilized as test signal sources to ascertain if operational problems originate in the system electronics, in the chemistry of measurement, or in the sensor.

Chloride/carbon dioxide (Cl/CO_2) analyzers are instruments used for simultaneous determination of carbon dioxide and chloride in serum, plasma, or sweat samples. In essence, a Cl/CO_2 analyzer measures the quantity of chloride and carbon dioxide based on the principles of coulometric titration and rate pH sensing, respectively. Figure 25 illustrates a simplified block diagram of a Cl/CO_2 analyzer. The instrument incorporates two separate channels to detect, analyze, display, and hold the readout until a new sample is introduced. In addition, like with the glucose analyzer, the Cl/CO_2 analyzer instrument incorporates capabilities


Polarizing Voltage
Read Indicator
Fill Indicator
Sample Indicator
Senser
Sequencer-timer Logic Circuit & Lamp Driver Circuits
Drain Push Button Microswitch
Power Supply
Oxygen Amplifier
Fill Push Button Microswitch
Rate Amplifier
Peak Rate Amplifier
Digital Display Buffer
DVM Digital Display


PUMP COMPARTMENT
Amperometric Silver
Detector Electrodes
Reaction Cup
Platinum
Reference
Cathode
Differential
Silver
Detector
Amplifier
Chloride
Electrode
Silver Ion
Voltage
Generator
CO2 Electrode
(Reference)
Chloride
Silver
Anode
CO2 Electrode
(Measure)
Differential
Amplifier
Rate
Amplifier
Stirrer
Motor
Reagent
Pump
Current
Integrator
Peak
Picker
Motor
Controller
2
1
1
2
Logic
Control
Circuit
Chloride
Display
Carbon
Dioxide
Display
Proportional
Controller
ELECTRONIC
CONTROL
CHLORIDE
MEASUREMENT
CARBON DIOXIDE
MEASUREMENT
CHANNEL
Heat
Indicator
Lamp
Heater
REGEANT COMPARTMENT
Note:
1) Check Electrodes
2) Measure Sample

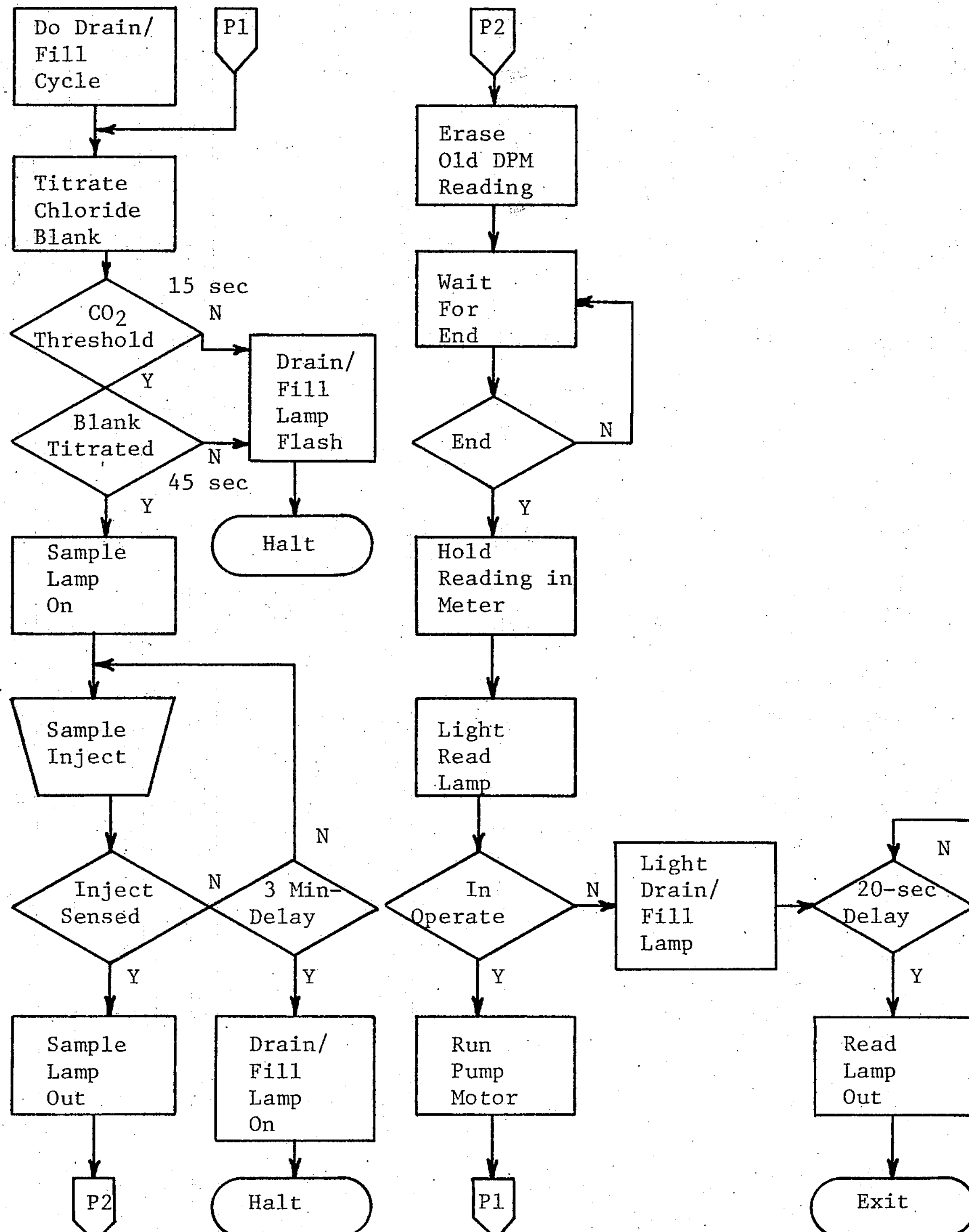
to verify analyzer performance and isolate problems to main instrument functions of chemistry, electrodes, or electronics.

Figure 26 illustrates an operational flow chart for the Beckman Cl/CO_2 analyzer which can be reviewed while the instrument is being operated. This allows the operator to check the proper functioning of both the sample run and the electronic circuitry to recognize and evaluate performance problems when they arise.

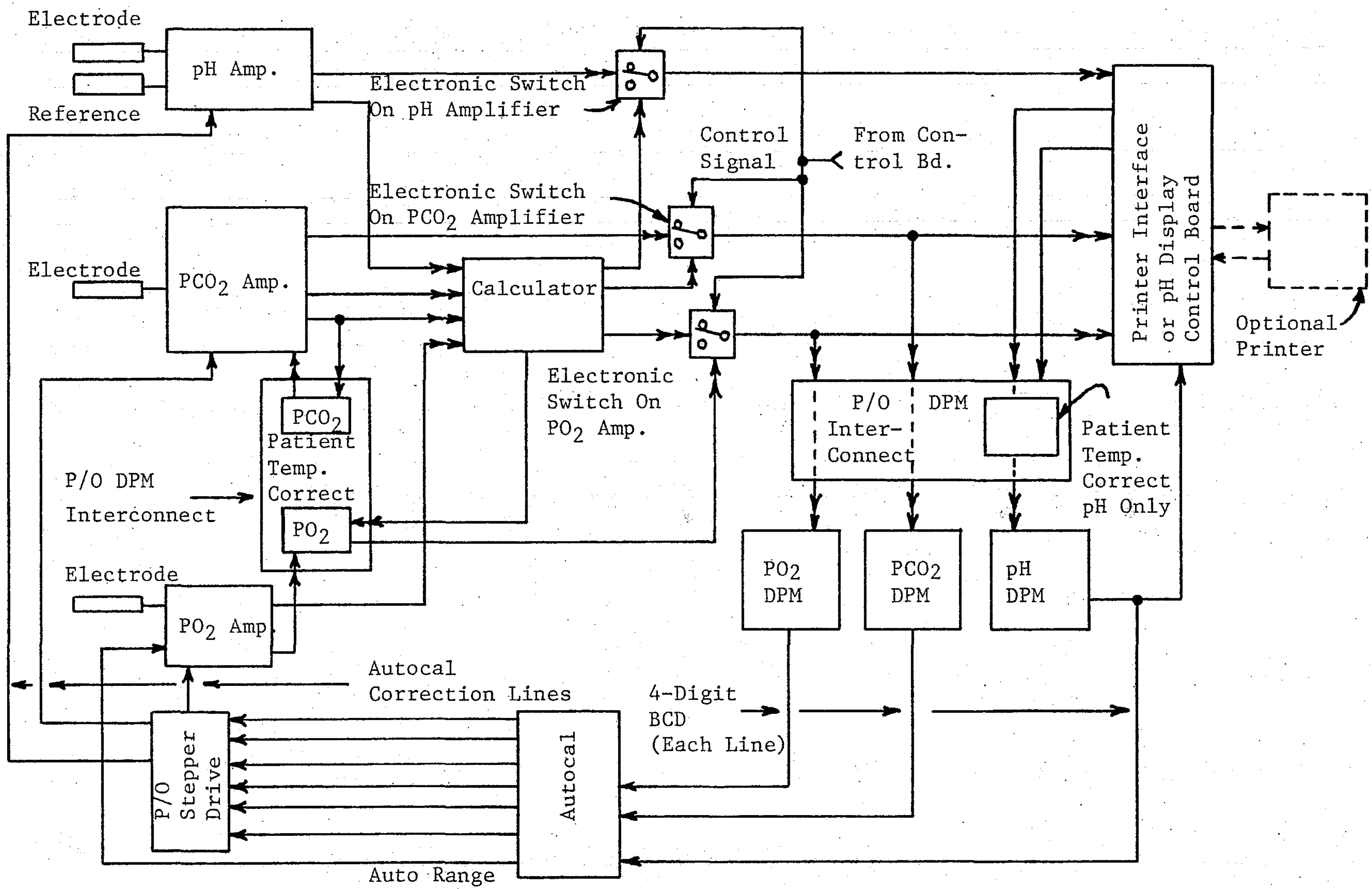
Blood gas analyzers are designed to provide a rapid and accurate method for determining the quantity of oxygen, carbon dioxide, and pH of whole blood and other body fluid samples. Figure 27 shows a simplified block diagram of a blood gas analyzer manufactured by Instrumentation Laboratory, with signal flow designations for all three channels; PCO_2, PO_2, and pH.

Note that this particular instrument has a calculator included in the blood gas analyzer circuitry. The function of the calculator is to obtain values for base excess, serum bicarbonate concentration, and the total carbon dioxide from the measured values of pH, carbon dioxide, and oxygen. Not all blood gas analyzers will incorporate a calculator to perform the previously stated functions. The specialty of usage will dictate the degree of circuit specialization.

Due to the fact that the above analyzers incorporate some type of electronic circuitry to aid in performance troubleshooting, it is emphasized that the need for troubleshooting is reduced to a minimum by properly performed maintenance procedures. However, if circuit troubleshooting is necessary, it should begin with a definition of the symptom of trouble according to what the operator was doing at the time the trouble was encountered. A number of operational malfunction symptoms



Do Drain/ Fill Cycle
P1
Titrate Chloride Blank
15 sec
N
CO_2 Threshold
Y
Drain/ Fill Lamp Flash
Blank Titrated
N
45 sec
Y
Halt
Sample Lamp On
Sample Inject
N
Inject Sensed
N
3 Min-Delay
Y
Y
Sample Lamp Out
Drain/ Fill Lamp On
P2
Halt
P2
Erase Old DPM Reading
Wait For End
End
N
Y
Hold Reading in Meter
Light Read Lamp
In Operate
N
Y
Run Pump Motor
P1
Light Drain/ Fill Lamp
N
20-sec Delay
Y
Read Lamp Out
Exit



Electrode
pH Amp.
Reference
Electronic Switch
On pH Amplifier
Control
Signal
From Con-
trol Bd.
Electronic Switch
On PCO2 Amplifier
Electrode
PCO2 Amp.
Calculator
Printer Interface
or pH Display
Control Board
Optional
Printer
PCO2
Patient
Temp.
Correct
PO2
P/O DPM
Interconnect
Electronic
Switch On
PO2 Amp.
P/O
Inter-
Connect
DPM
Patient
Temp.
Correct
pH Only
Electrode
PO2 Amp.
PO2
DPM
PCO2
DPM
pH
DPM
Autocal
Correction Lines
4-Digit
BCD
(Each Line)
P/O
Stepper
Drive
Autocal
Auto Range

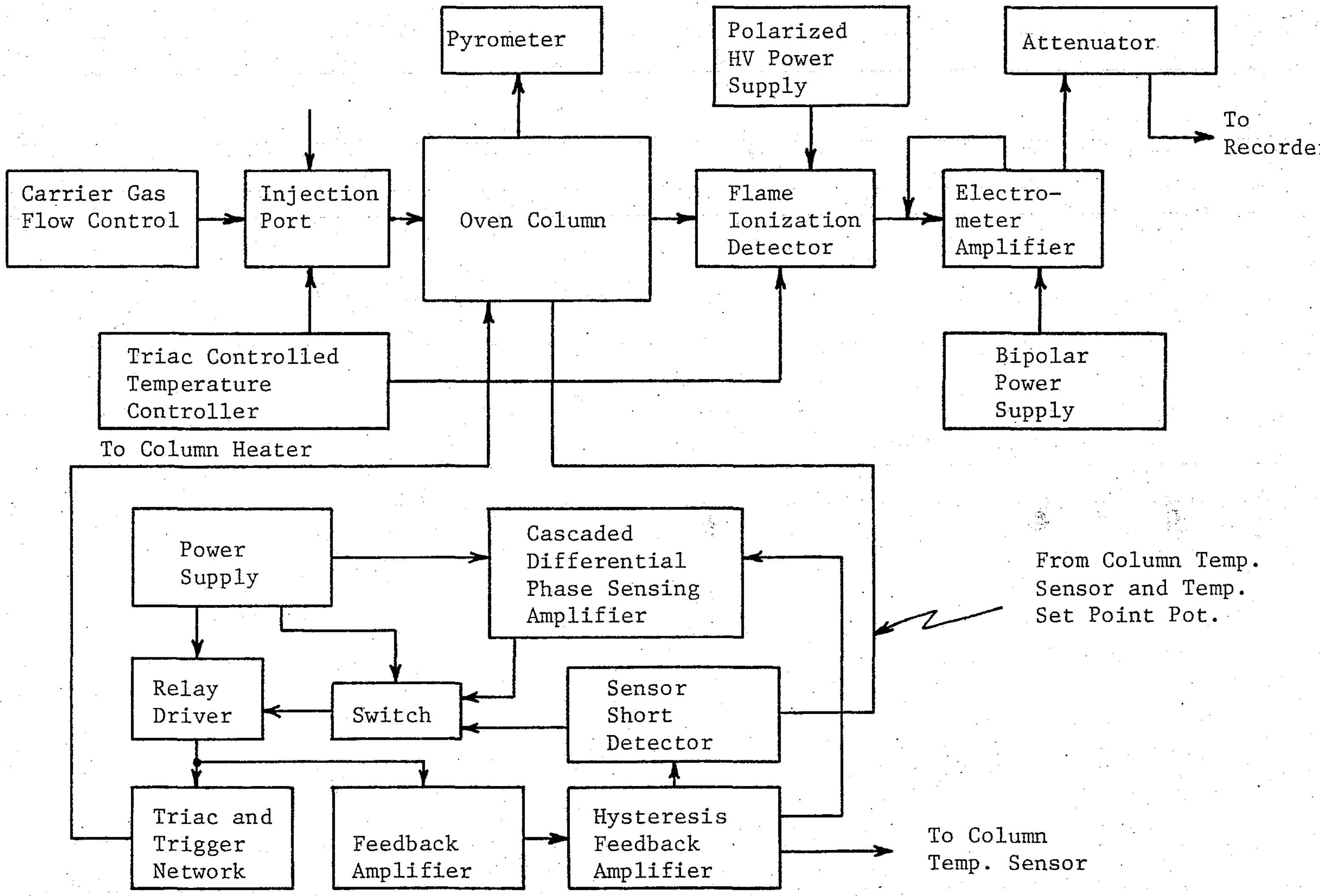
are presented below that would be the most obvious and common problem areas: (1) sensors give improper response in check mode, (2) zero reading is unstable when instrument is ready to receive a sample, (3) erratic or irreproducible results are obtained on replicate sampling, and (4) indicator lamps will not illuminate in proper sequence.

Additionally, analyzers share common operational cautions and hazards that include: (1) to avoid possible electrical hazard, analyzer systems must be grounded at all times, (2) use only factory approved parts, components, and procedures to service analyzers, (3) do not remove electronics compartment covers without disconnecting the power cord from the wall receptacle, and (4) observe all laboratory policies or procedures which pertain to the handling of analyzer systems.

Gas Chromatographs

Gas chromatography (GC) is a most valuable technique for organic analysis. It has been applied to the separation, identification, and analysis of practically all gas and volatile fluid mixtures from air to drugs, gasoline, water, moon dust, and even anti-freeze. Essentially, then, chromatography is a method of separating the compounds of a mixture, and the gas chromatograph is an instrument that performs this function.

The detection device on gas chromatographs can vary, depending on the intended use. The two most common detectors are the thermal conductivity detector (TCD) and the flame ionization detector (FID). Figure 28 shows a simplified block diagram of a single-channel gas chromatograph incorporating a flame ionization detector. With the aid of an additional recorder, gas chromatographs can supply a continuous


Pyrometer
Polarized HV Power Supply
Attenuator
To Recorder
Carrier Gas Flow Control
Injection Port
Oven Column
Flame Ionization Detector
Electro-meter Amplifier
Triac Controlled Temperature Controller
Bipolar Power Supply
To Column Heater
Power Supply
Cascaded Differential Phase Sensing Amplifier
From Column Temp. Sensor and Temp. Set Point Pot.
Relay Driver
Switch
Sensor Short Detector
Triac and Trigger Network
Feedback Amplifier
Hysteresis Feedback Amplifier
To Column Temp. Sensor

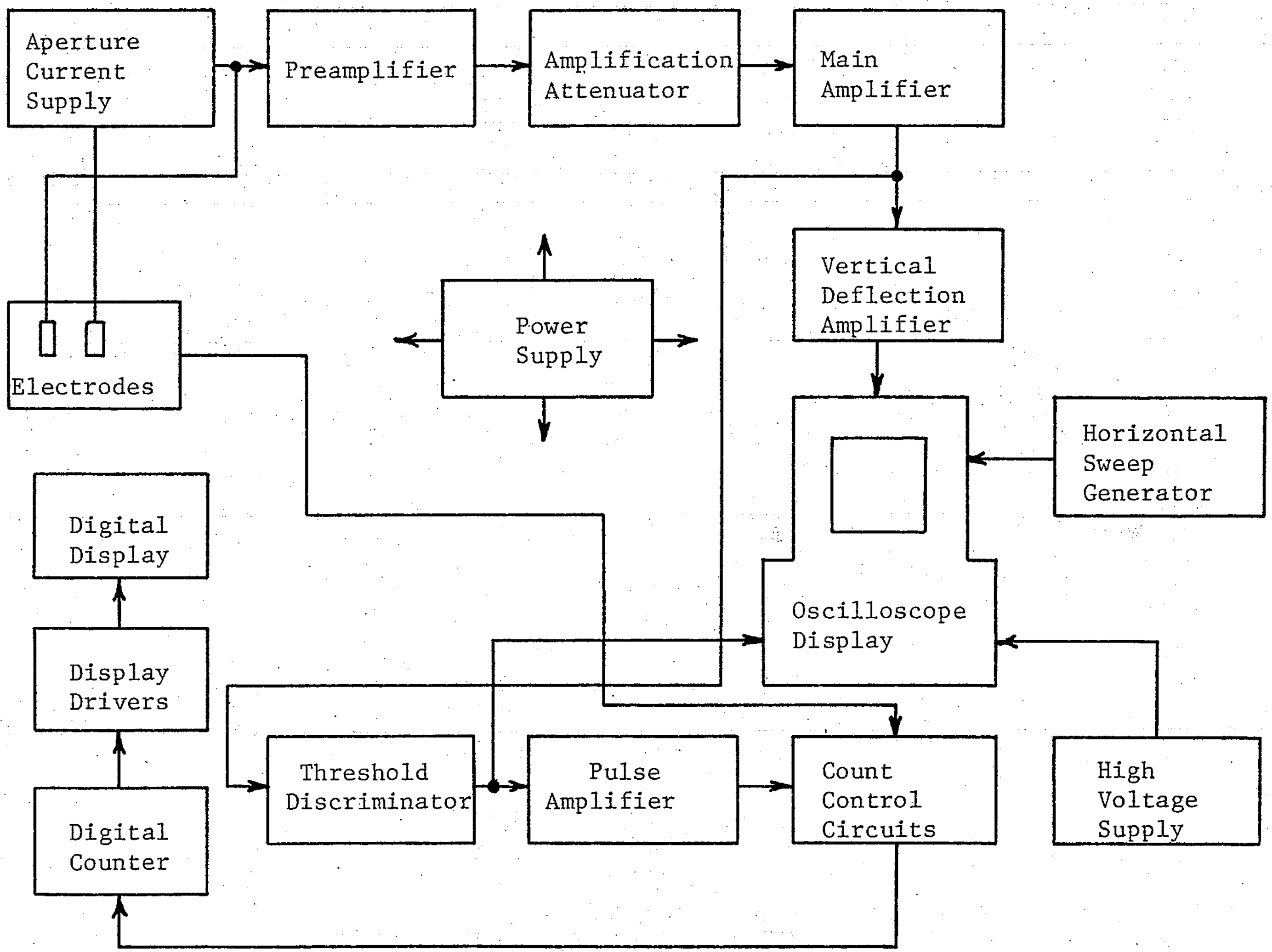
record (strip chart recording) of the separated sample compounds. This allows identification and measurement of relative sample concentrations.

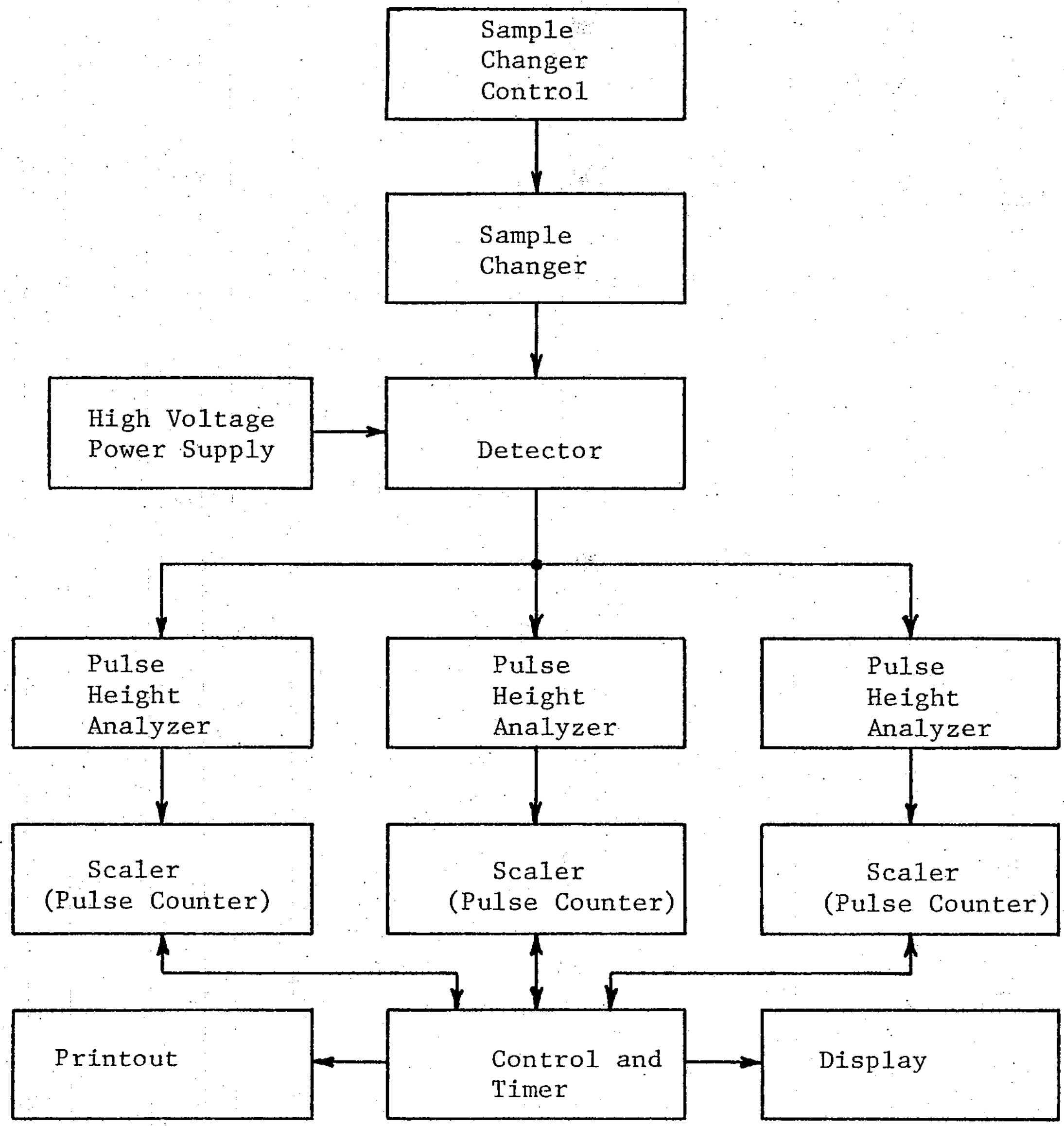
Troubleshooting gas chromatographs is accomplished by applying the troubleshooting charts (supplied by the manufacturer) as an aid to interpretation and correction of difficulties encountered in gas chromatography by illustration of associated responses on the recorder printout. The procedures for remedy of most of the problems indicated in such charts may be performed by the instrument operator.

Counters

The particle counting instruments now in common clinical laboratory use depend on one of two primary counting techniques. One consists of counting by means of light signal flashes (scintillation) and the other consists of counting by means of particles interrupting a flow of current between two electrodes and counting the signal thus produced.

Figure 29 illustrates a block diagram of a Coulter Counter which uses the current-flow interrupt technique for particle counting. The other type of counting technique (scintillation) is represented in Figure 30 showing a block diagram of a gamma scintillation counter. Since scintillation counters count by the detection of light impulses, the detector assembly is similar to those used on photometers, spectrometers, and colorimeters. Apart from the inclusion of a scintillation crystal, the detector assembly will contain a photomultiplier tube, preamplifier, and appropriate shielding. The purpose of the pulse-height analyzer is to allow the selection of the energy range of radiation to be counted. The color-coded scalers (pulse counters) indicate the energy range.


Aperture Current Supply
Preamplifier
Amplification Attenuator
Main Amplifier
Vertical Deflection Amplifier
Power Supply
Electrodes
Horizontal Sweep Generator
Digital Display
Oscilloscope Display
Display Drivers
Threshold Discriminator
Pulse Amplifier
Count Control Circuits
High Voltage Supply
Digital Counter



Sample Changer Control
Sample Changer
High Voltage Power Supply
Detector
Pulse Height Analyzer
Pulse Height Analyzer
Pulse Height Analyzer
Scaler (Pulse Counter)
Scaler (Pulse Counter)
Scaler (Pulse Counter)
Printout
Control and Timer
Display

As with other extremely sophisticated medical electronic instruments, daily preventive maintenance is a must for particle counters. Maintaining the equipment as outlined in the respective instrument operation manuals is essential to the production of reliable results. A major precaution with the scintillation type of counter is the high voltage required for the photomultiplier tube. When electronic troubleshooting of the detector assembly is necessary the appropriate safety measures must be maintained. Further troubleshooting details for counters are presented in Table 6.

TABLE 6

GENERAL FAILURE TO FUNCTION TROUBLESHOOTING CHART

Trouble	Indication	Possible Source
No operation	No light, no readout etc.	Fuses Power supply circuit High/low voltage Switch Voltage selection switch
No count	Unit stays on same value	Power supply circuit Preamp circuit Readout circuit Connections of internal wire harness
No display	Display not lighted	Readout circuit Power supply circuit Internal connections
Numeric readout counting incorrectly	Numeric readout skips digits, counts backwards, or counts the same for all channels	Readout circuit

Summary

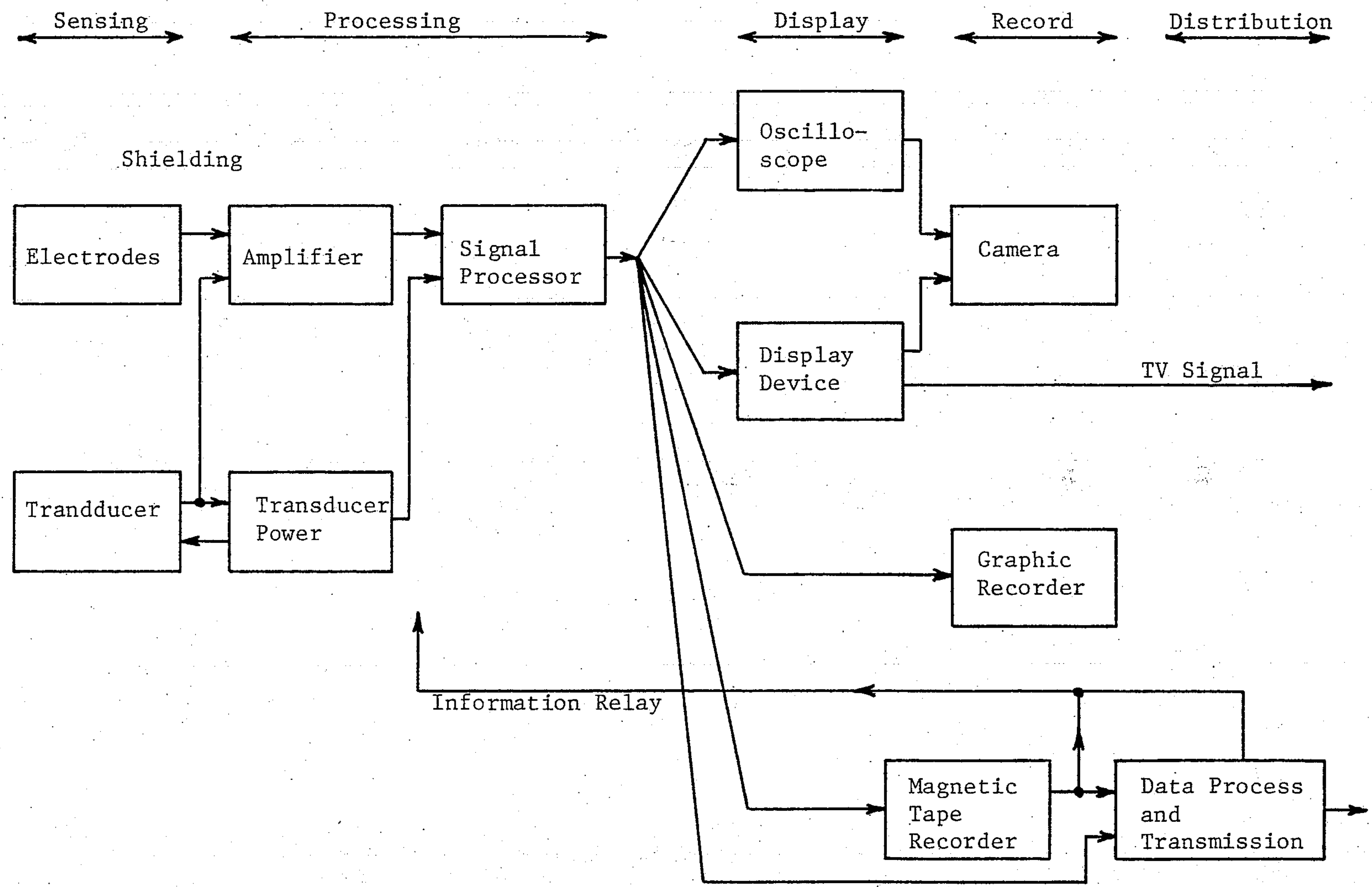
The instruments discussed in the previous paragraphs (relating to specialized test equipment/instruments) represent a diverse accumulation of medical electronic devices. Each instrument will incorporate some or all of the block diagram circuit functions illustrated in Figure 31. Some instruments can be subcategorized such as photometers, analyzers, or counters. Other instruments are specific devices designed to perform a particular function, such as pH meters or gas chromatographs. Regardless of the circuit complexity, after consulting the circuit diagrams and the circuit explanations offered in instrument operational and/or service manuals, the instrument operator should have a means of formulating the general functioning and circuit sections of a specific instrument. Consequently, development of block diagrams and mental images of the circuitry will facilitate in troubleshooting procedures when malfunctions occur.

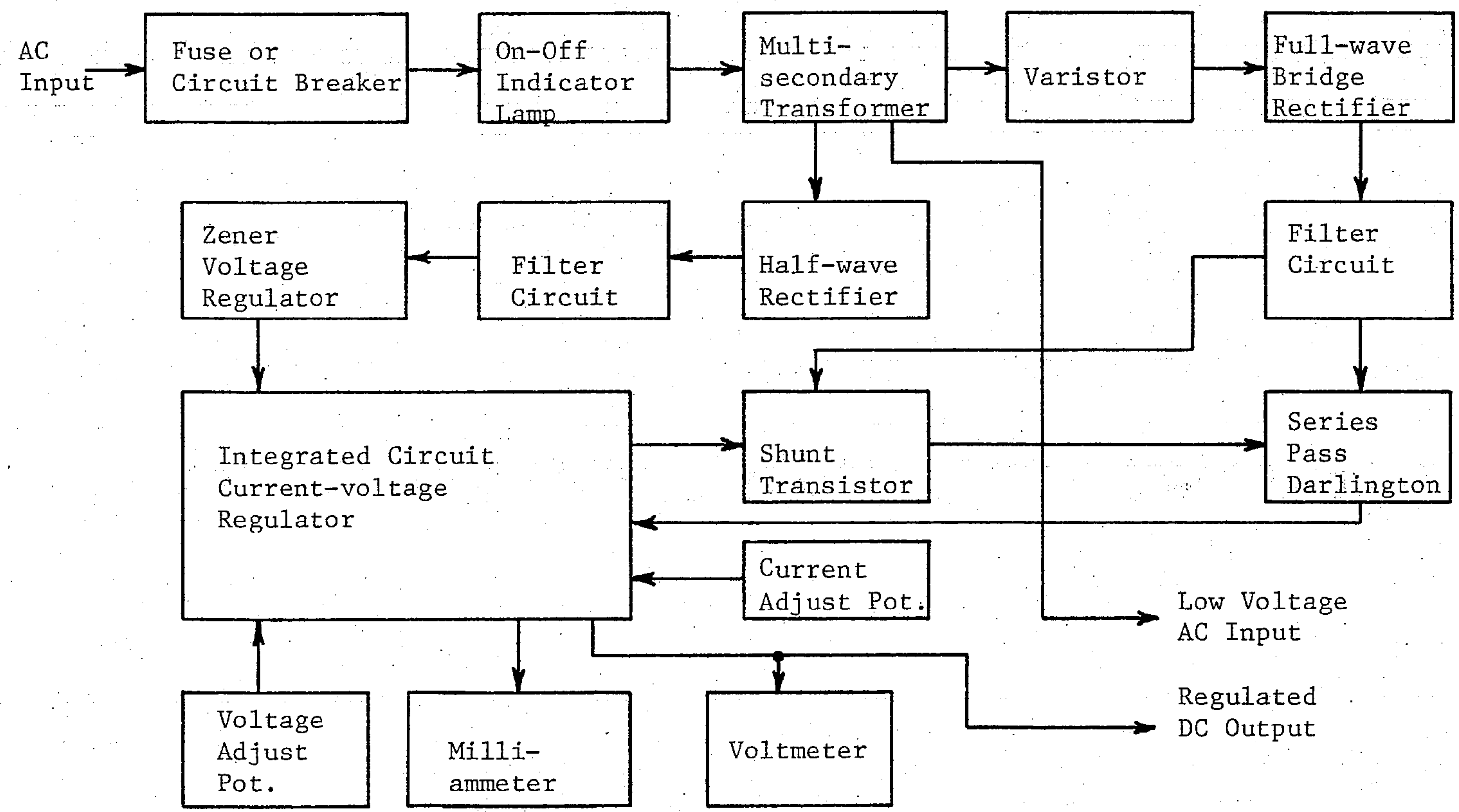
Analysis of Auxiliary Equipment/Instruments

Power Supplies

In many instances external power supplies are required for instrument operation, voltage calibration or phenomena excitation (such as in electrophoresis). Most power supplies in clinical laboratory use are solid-state devices incorporating either integrated circuits or discrete devices or both. Figure 32 illustrates a typical regulated power supply in block diagram form.

Troubleshooting of power supplies is accomplished by first checking the obvious component parts such as the fuse, on-off switch, transformer, meters, and external adjustment controls. Troubleshooting


Sensing
Processing
Display
Record
Distribution
Shielding
Electrodes
Amplifier
Signal Processor
Oscillo- scope
Camera
Display Device
TV Signal
Trandducer
Transducer Power
Graphic Recorder
Information Relay
Magnetic Tape Recorder
Data Process and Transmission



AC Input
Fuse or Circuit Breaker
On-Off Indicator Lamp
Multi-secondary Transformer
Varistor
Full-wave Bridge Rectifier
Zener Voltage Regulator
Filter Circuit
Half-wave Rectifier
Filter Circuit
Integrated Circuit Current-voltage Regulator
Shunt Transistor
Series Pass Darlington
Current Adjust Pot.
Low Voltage AC Input
Regulated DC Output
Voltage Adjust Pot.
Milli-ammeter
Voltmeter

procedures would then progress to the solid-state component parts, both active and passive. Measurements of component voltages and circuit currents, when performing electronic troubleshooting, should be approximately the values that are indicated on the schematic diagrams. These values are only aids in tracking down the malfunction. The values are established at the time the instrument is functionally checked, and may vary depending on age of components, line voltage fluctuations, and the voltmeter used.

Electronic Timers and Scale Expanders

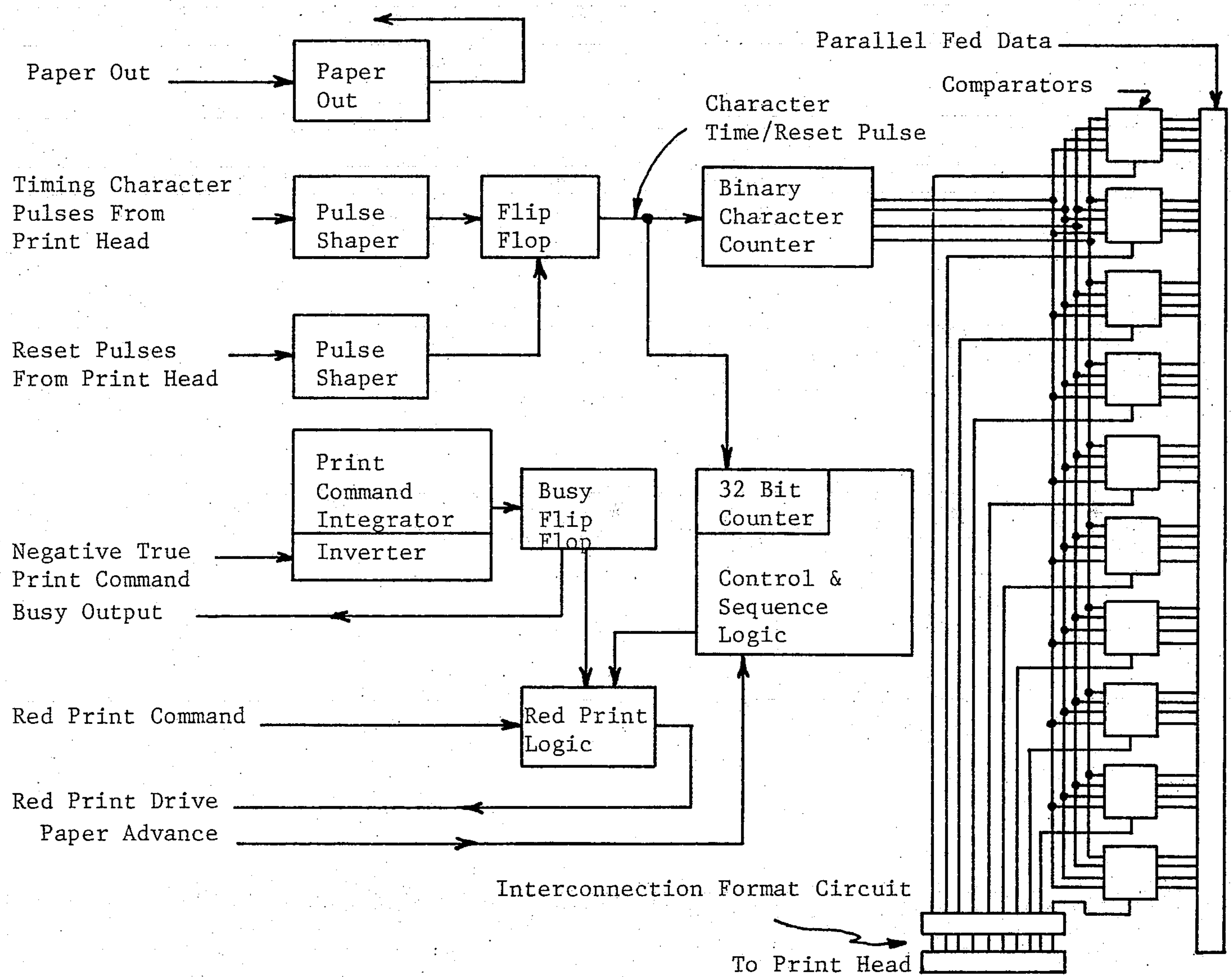
No information was made available from manufacturers on these instruments.

Printers

Printers have become a commonplace device in the clinical laboratory. The printers under discussion here are devices that provide a readable paper-tape record of certain phenomena in a digitized form. Most printers consist of a power supply, logic circuitry, interconnection circuitry, print head, and interface circuitry, if required. Figure 33 shows one type of printer circuitry in block diagram form.

The interface circuitry provides the conversion requirements to drive the printer. Binary coded decimal data is received in serial form and converts this data to parallel outputs required to drive the logic comparators in the circuitry. The data conversion is accomplished by means of a twenty-four bit shift register and related logic controls.

The logic circuitry consists of all the circuits shown in Figure 33 excluding the power supply, interface, and interconnection format circuitry. Essentially, the logic circuitry responds to information


Paper Out
Paper Out
Timing Character Pulses From Print Head
Pulse Shaper
Flip Flop
Character Time/Reset Pulse
Binary Character Counter
Parallel Fed Data
Comparators
Reset Pulses From Print Head
Pulse Shaper
Print Command Integrator
Inverter
Busy Flip Flop
32 Bit Counter
Control & Sequence Logic
Negative True Print Command
Busy Output
Red Print Command
Red Print Logic
Red Print Drive
Paper Advance
Interconnection Format Circuit
To Print Head

fed in from the interface circuitry and out to the print head. Timed outputs are provided to the print head to synchronize the printout of information.

An interconnection formal circuit is incorporated to provide interconnection between the logic circuitry and the print head. The design specifications of printers and the specific medical electronic instruments they are systemized with will dictate internal circuit requirements.

The print head is a self-contained assembly consisting of a continuously revolving motor-driven drum containing the print characters. Printout is produced by solenoid-activated hammers striking the desired character on the rotating drum at the precise time. The print head also contains signal detectors for timing purposes. The signals produced are sent to the logic circuitry, consisting of reset and character timing pulses.

Troubleshooting printers is not a complex task. However, care must be taken when dealing with the print head. The print head assembly should be cleaned of foreign material and accumulated dust periodically. This will ensure proper functioning of the solenoid hammer mechanism and paper-ribbon advance mechanism. The following chart contains a list of troubleshooting steps applicable to printer instrumentation. See Table 7.

Chart Recorders

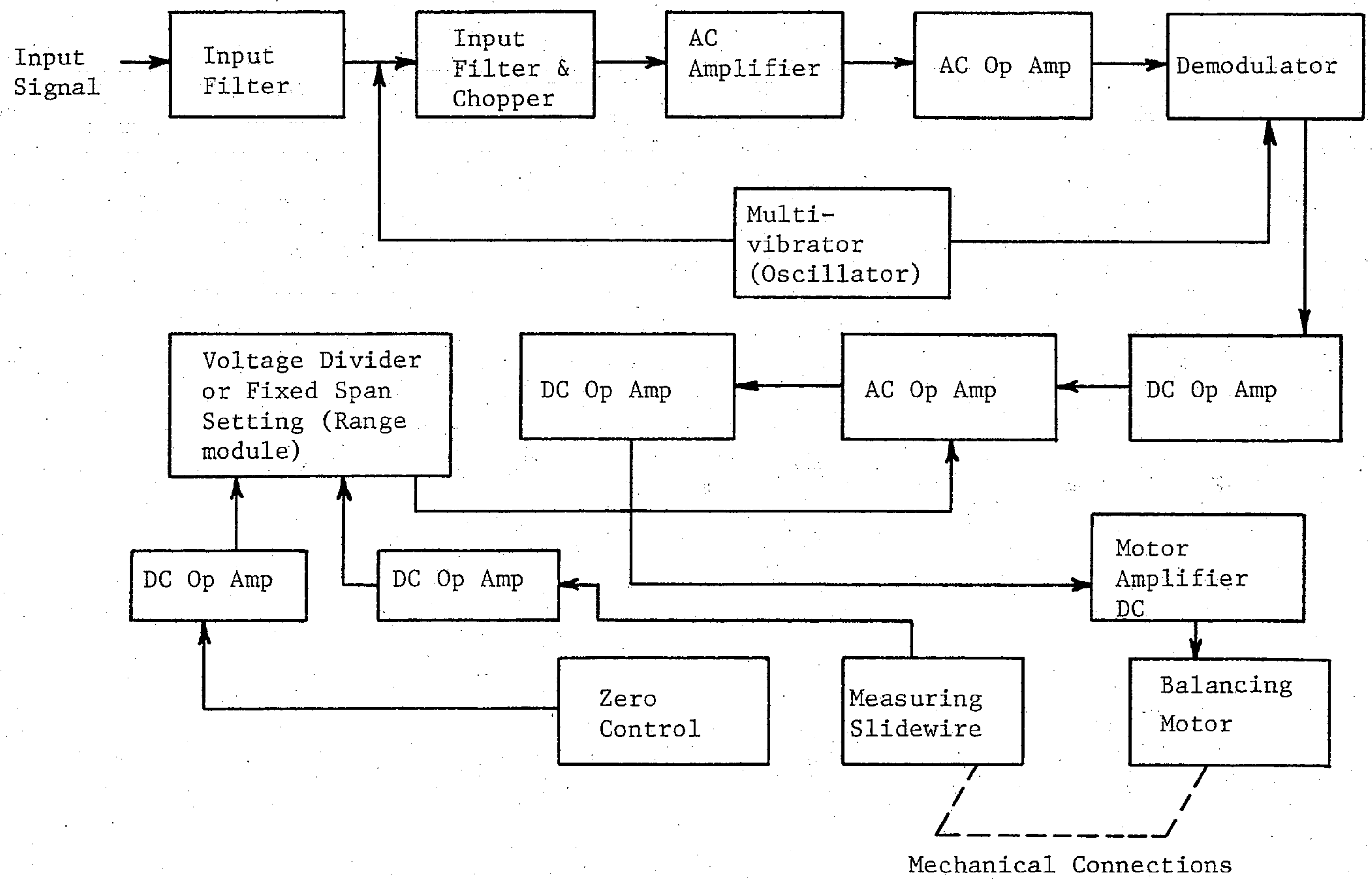
Chart recorders, like printers, are very commonplace in clinical laboratories. Essentially, chart recorders are devices for marking on a strip of chart paper certain phenomena as a function of time. They are

TABLE 7

GENERAL TROUBLESHOOTING PROCEDURES FOR PRINTERS

Trouble	Cause
Printer will not turn on	1) Line fuse defective 2) Power supply defective 3) No electrical power applied to printer connector
Printer turns on but will not print	1) Motor fuse defective 2) Power supply defective 3) Printer busy command in logic circuitry defective 4) Printer head defective
Paper out light stays continuously on	1) Actuating arm of light control switch defective or out of alignment
Random missing characters	1) Paper not inserted in tray properly 2) Logic circuits dropping characters (defective)
Solid missing characters	1) Column drive channel defective
Paper out command will not inhibit sample handler	1) Defective paper out command channel

basically simple in design and relatively trouble free. However, the varying types in use and the terminology to describe them can be confusing. For instance, there are single-channel and multi-channel recorders, potentiometric and galvanometric, x-y and pressure recorders, to name a few. Figure 34 depicts a block diagram of a chart recorder.


Input Signal
Input Filter
Input Filter & Chopper
AC Amplifier
AC Op Amp
Demodulator
Multi-vibrator (Oscillator)
Voltage Divider or Fixed Span Setting (Range module)
DC Op Amp
AC Op Amp
DC Op Amp
Motor Amplifier DC
DC Op Amp
DC Op Amp
Zero Control
Measuring Slidewire
Balancing Motor
Mechanical Connections

Depending on the intended use, recorder circuitry may vary from manufacturer to manufacturer and between system sub-groups. For instance, a variable to be recorded emitting a low-level input signal will need a preamplifier, whereas one with a high-level input signal might be injected directly to the amplifier-driver section of a recorder. Subsequently, many phenomena require special purpose amplifiers especially designed for the particular measurable variable being recorded.

The major components which probably cause the most recorder downtime are the writing mechanism and the balancing motor/slidewire mechanism. These items, especially the writing mechanism, must be maintained on a routine basis to eliminate malfunctioning. Troubleshooting will be simplified when daily inspections and maintenance are conducted. If the malfunction still persists after preliminary checks have been made, the following procedures (see Table 8) will help to isolate the problem.

TABLE 8

RECORDER CHECKING AND REPLACEMENT PROCEDURE

Symptom	Recommended Checks and Replacements
Balancing motor is inoperative	Check the power cord is connected to power source and that power switch is in ON position. Check that fuse is in place and that it is operative. Check that amplifier and/or preamplifier cards are plugged in properly. Check that STANDBY switch is in its energized position. Check that amplifier power connector is properly plugged in. Check that motor leads are connected properly. Check that foils of amplifier card connectors are not dirty. Check that power transistors are not burned out. Check that the amplifier is operative and is not malfunctioning.

TABLE 8 -- Continued

Symptom	Recommended Checks and Replacements
Balancing motor causes ink reservoir to bear against stop (voltage spans)	Check that input is not greater than recorder span. Check that input filter and/or preamplifier are properly plugged in. Check that slidewire contacts are contacting slidewire properly and are not dirty. Check that drive cord is not loose. Check that drive cord has not slipped off capstan and/or any pulley and is not jammed. Check that balancing motor connections are not reversed. Check that input connections have been made correctly. Check that no power transistor is burned out. Check that amplifier is not burned out. Check that amplifier is operative and is not malfunctioning.
Damping is erratic (especially for certain positions of scale pointer)	Check that slidewire is not dirty. Check that slidewire contact force is sufficient to maintain good electrical contact. Check that no drive cord pulleys are stuck. Check that normal or common-mode signals do not exceed limits specified in specificiations. Check that amplifier is operative and is not malfunctioning. Check that amplifier damping adjuster has been set properly. Check that power voltage is within limit as specified in specifications.
Recorder is noisy	Check that input filter is mounted in correct position. Check that noise level of input signal is not excessive. Check that power voltage is within lower limit as specified in specifications. Check that amplifier damping adjuster is not grossly maladjusted. Check that amplifier and/or preamplifier is operative and is not malfunctioning. Check that zener diodes and filter capacitors are not defective.

TABLE 8 — Continued

Symptom	Recommended Checks and Replacements
Recorder is completely inoperative including its chart motor or motors	Replace fuse(s). If new fuse blows immediately, refer to next symptom. If fuse does not blow, check voltage of line source.
Fuse blows when replaced	Place power switch in OFF position and slide STANDBY switch to STANDBY position. Check power circuit wiring for possible shorts. If none are found, replace main fuse. Turn power switch first to ON, next to chart ON, and then slide STANDBY switch to its energized position, one at a time until fuse blows. Trouble is probably in circuit that was energized last. If fuse blows when STANDBY switch is in its energized position, isolate the balancing motor from the amplifier by disconnecting the balancing motor leads from the motor. If a new fuse blows, trouble is in amplifier of power output transistors; if not, trouble is in balancing motor. Test for shorts between all motor leads and case ground. If the fault cannot be easily repaired, replace the defective part with a known good one.
Response is sluggish and/or dead band is excessive	With recorder energized, manually move ink reservoir pen about ½" upscale and slowly allow it to return to balance point. Repeat above procedure moving pen downscale. If dead band is excessive, replace preamplifier and amplifier with known good ones. Also check all drive cord pulleys.
Operates erratically, oscillates, or overshoots balance point	Check all connections to printed-circuit cards, terminal boards, and primary element.
Operation appears normal, but scale reading is in error	Check calibration of primary element. Also check calibration of recorder.

Summary

External power supplies are used in the clinical or research laboratory to supply specific voltage and/or current outputs for instrument or phenomenon excitation. Printers and chart recorders are very common devices utilized in the laboratory environment to provide a readable permanent record of the many and varied natural and/or man-made phenomena.

Additional Medical Instrumentation

In addition to the original listing of medical instruments that were considered in this thesis, some manufacturers supplied information on additional instrumentation which the medical technologist may utilize in a laboratory environment. These instruments will not be discussed in great detail but the inclusion by the contributing manufacturers warrants their mention.

The medical technologist's instrumentation background would also probably cover such devices as diluters, colorimeters, electrophoresis systems, constant temperature baths, urinalysis systems, coagulation instruments, and cystic fibrosis analyzers. In essence, these instruments serve the following functions.

Diluters are capable of sampling, dispensing, and diluting a specimen with a predetermined solution or reagent. Diluters provide constantly accurate repetitive dispensing of liquids when performing analysis procedures which are required in preparing specimen components for photometric readings, chemical determinations, and cell counts.

Colorimeters are utilized in the clinical laboratory for measuring light absorption in a liquid, using light of a particular color.

Colorimeters were, in many respects, the prelude to the development of densitometers, fluorometers, and other light measuring/detecting medical electronic analyzing instruments.

Electrophoresis systems are devices used to separate charged particles suspended in a liquid medium by the application of an electrical potential. Separation of the particles is determined by the migration rates of each particle, varying with particle characteristics. Electrophoresis instruments provide for further specimen analysis by such instruments as densitometers.

Many laboratory instruments and systems are maintained at a constant temperature by the circulation of water through a heat jacket. Typical examples are spectrophotometer cell holders, blood gas analyzers, and chromatography columns. In such applications constant temperature baths are incorporated to provide an efficient and accurate means of maintaining specific temperatures.

Urinalysis systems provide clinically meaningful results of tested urine reagent strips for pH, protein, glucose, and many other chemical properties. The analysis from this type of instrument system helps in patient diagnostic procedures.

Coagulation instruments are designed to perform coagulation procedures in a clinical laboratory. These instruments are important for the testing of blood coagulates and their reaction-time characteristics.

The cystic fibrosis analyzers perform two basic functions, ionotophoresis and analysis. Ionotophoresis is used to promote local sweating of the sweat glands. The analysis function measures the conductivity of the sweat samples and relates this measurement to the amount of electrolyte present. Thus, the determination of the electrolyte concentration is a valuable tool for diagnosing cystic fibrosis.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The foremost concern of this study was to provide technical information on selected medical electronic instruments which would interconnect the existing literature on medical electronic instrument theory and the operational/service manuals provided by instrument manufacturers. Furthermore, the technical data solicited from numerous medical electronic manufacturers would be applicable to the formulation of medical electronic laboratory experience for development of educational subject matter.

The second major regard was to discern and identify electronic instrumentation functioning on the selected medical electronic instruments by embodying the block diagram approach for circuit comprehension and analysis. Electronic circuits illustrated in block diagram form exemplify the circuit functionings of the selected medical electronic equipment. Standardized circuits (i.e., power supply circuits) prevalent to more than one instrument/system were interpreted as necessary circuitry designed into all electronic instrumentation.

The impact of electronic instrumentation in the field of medical science has placed a large responsibility on the medical technologist. Subsequently, it is imperative that the operators of these sophisticated electronic systems of science maintain knowledge of electronic functional circuitry. This can be accomplished through the consolidation of basic electronic theory and practical experience with laboratory equipment as pertaining to field servicing.

Conclusions

In the process of conducting this study and in regard to the stated objectives, various conclusions can be formulated and are presented as follows:

1. Basic knowledge of electronic theory in conjunction with comprehension of operational circuit functions (as supplied in operational/service instrument manuals) of medical electronic instruments is essential for proper perception and manipulation of clinical laboratory medical instruments or instrument systems.

2. The study and operation of medical electronic instrumentation is an integral part of education for medical technologists as applied through practical laboratory experience.

3. Ability to perform equipment maintenance is reflective of the ability to identify sectional circuits and their primary function.

4. Electronic troubleshooting of medical electronic instruments is simplified by utilizing the circuit descriptions and the block diagrams presented in instrument manuals.

5. Operational and service manuals should be studied thoroughly before operating and/or troubleshooting a new or used instrument.

6. The greatest electrical hazard pointed out in all instrument manuals is improper grounding of equipment.

7. When performing maintenance, either routine or electronic, the instrument should always be disconnected from any electrical service.

8. Medical technologists should only perform maintenance that is within the realm of their knowledge and experience. All other complex circuitry malfunctions should be handled by an appropriate field servicing representative.

9. Manufacturers of medical electronic instruments suggest only plug-in modules be replaced and not individually repaired when instruments are designed around the modular circuit system.

10. In some instances of malfunctioning instruments, the source of trouble will be immediately apparent. In others, this will not hold true, since a given malfunction may be due to any one of several causes. In locating and eliminating such faults, two methods are suggested:

A. When trouble occurs, a number of simple preliminary checks normally listed in operational/service manuals should be performed before progressing to more elaborate tests. These simple checks are designed to detect and correct the most frequently occurring defects.

B. If the trouble is not remedied by the preliminary checks, a series of tests outlined in troubleshooting charts can be used to isolate the fault to a major section of a particular system. The malfunctioning circuit section would then be systematically checked for defective components.

11. Numerous manufacturers that were solicited for instrument information agreed there is a need for education of medical technologists on medical electronic instruments combining both fundamental theory and operational instructions included in instrument manuals.

12. The selected medical electronic instruments used in this study were representative of those found in clinical laboratory environments.

13. Block diagrams can be established by identifying sectional circuits described in operational/service manuals and referenced to circuit schematics.

14. The continuing development of new complex electronic systems requires continuing acquisition of electronic principles on the part of instrument operators.

Recommendations

Based on the results of this investigation, the following recommendations are presented.

1. Incorporate a different means of instrumentation classification, such as measurement methods, to separate medical electronic instrumentation for further understanding.

2. Applicable laboratory experience should take place on the actual instruments medical technologists would have contact with if they can be made available.

3. Fundamental electronic operational theory should not be overshadowed by excessive practical hands-on experience. The two are essential for complete comprehension of medical electronic instruments or instrument systems.

4. Due to the ever increasing modular design of instrumentation incorporating microprocessor circuitry, the circuit module approach to troubleshooting should be utilized instead of isolating individual components.

5. Further research should be undertaken to ascertain and formulate the essential aspects of research regarding electronic instruments or instrument systems.

APPENDIX A

Letter

APPENDIX A

March 15, 1977

Attention: Technical Information Director

Dear Director:

I am a graduate student specializing in electronics in Industrial Technology at the University of North Dakota. I am currently conducting research on a graduate thesis titled, "Essentials of Electronic Circuits for Selected Medical Technology Instrumentation Applications." This research could lead to future development and implementation in course work in electronics for medical technologists offered through the Department of Industrial Technology at the University of North Dakota.

Electronic instrumentation has become so much a part of medical science that an understanding of the basic medical electronic concepts is mandatory for medical technologists. Although it is not necessary for technologists to become experts in the field of electronics, it is essential that they acquire at least an understanding of basic instrument operational electronic concepts.

An objective of this research is to attempt to bridge the gaps which exist between various textbooks on medical electronic theory and the operational instructions included in instrument manuals provided by manufacturers. Furthermore, an attempt will be made to explain sectional circuit functioning (i.e., sensors, input circuitry, signal amplifying circuitry, signal processing circuitry, displays, transducers, . . .), and to illustrate the use of electronic circuits in representative laboratory equipment without duplicating sectional circuitry common to electronic instruments.

To facilitate this study, information is being requested on selected electronic instruments commonly used in the medical technology field. This information could include circuit description/analysis, circuit schematics and block diagrams, calibration procedures, troubleshooting procedures, safety precautions pertinent to equipment operation, and computerized self-checking of internal electronic circuitry. The selected instruments included in this study are as follows:

(1) Microscope(s) (Illuminators, fluorescence, etc.)
(2) Freezer(s)
(3) Cell Wash(s)
(4) Bench Centrifuge(s)
(5) Fibrometer
(6) Refrigerated Centrifuge(s)
(7) Slide Stainer (Automatic)
(8) Blood Gas Analyzer
(9) Spectrophotometer

(10) UV Spectrophotometer
(11) Flame Photometer
(12) Cl/CO_2 Analyzer
(13) Glucose Analyzer
(14) pH Meter (Digital and/or Analog)
(15) Chart Recorder (Typical)
(16) Gas Chromatograph
(17) Osmometer
(18) Analytical Balance (Digital and/or Analog)
(19) Scintillation Counter
(20) Flourometer
(21) Densitometer
(22) Power Supplies
(23) Printers (Digital)
(24) Thermometer(s) (Electronic)
(25) Timer(s) (Electronic)
(26) Monitor(s) (Electronic power, Liquid level, Temp., etc.)
(27) Pumps (Metering, Liquid, Multi-Channel, etc.)
(28) Scale Expander(s)
(29) Counter(s) (Typical)

Any information your company provides will be applied only toward the educational aspects of the thesis while maintaining confidentiality. The information your company provides (circuit analysis, schematics, block diagrams, etc.) will be returned to your company if so requested. Also, a copy of the abstract and/or summary of the thesis could be made available to your company upon request. Please indicate on the detachable form below if your company desires copies of the summary and/or abstract.

Thank you for your assistance in this educational endeavor,

Graduate Committee Chairperson: Sincerely,

______________________________ Lowell P. Stanlake

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