IAEA-TECDOC-426

TROUBLESHOOTING IN NUCLEAR INSTRUMENTS

A TECHNICAL DOCUMENT ISSUED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1987

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Printed by the IAEA in Vienna
June 1987

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FOREWORD

The servicing and repair of nuclear instruments is a difficult task. The commercial manufacturers of nuclear equipment can assure reliable service only in the most advanced countries that have many instruments installed. In developing countries, as a rule, good service laboratories organized by the manufacturers do not exist. The nuclear research laboratories must rely upon their own resources to keep the instruments in operation.

The International Atomic Energy Agency is trying to assist the developing countries by providing different types of service in this field. This includes help in the establishment of suitable electronics laboratories, advice and assistance in the topic of preventive maintenance, and training. Obviously, a necessary prerequisite for staff responsible for servicing of nuclear instruments, is the understanding of nuclear electronics. In interregional, regional, and national courses, the IAEA is training nuclear electronics staff, both in basic and in advanced aspects. The present book is devoted to such persons who have either received IAEA training, or have studied nuclear electronics by themselves at home.

In preparing a book on troubleshooting of nuclear instruments, one is faced with a number of problems:

(i) The technical level of the book must be properly defined; it should not be too elementary, but should avoid the most advanced aspects. The present publication is meant for young electronics engineers who will specialize in nuclear electronics, for senior technicians, or for the scientists (physicists, chemists) who are forced to maintain and repair their instruments themselves.

(ii) Nuclear instrumentation is facing a period of rapid development. New instruments are appearing on the market each week. It would be impossible to analyze all the electronic circuits in these modern instruments. Therefore, the book must mainly focus on some general features and use some specific circuits to illustrate the troubleshooting and repair procedures that will hopefully be applicable to many different types of instruments.

(iii) The present effort to prepare a set of recommendations and tips on troubleshooting cannot replace a good service manual. However, good service manuals are an exception; as a rule, service manuals are not available, or are bad. Therefore, it is believed that the book will give valuable orientation for troubleshooting to the persons who are facing a malfunctioning instrument, and have no proper service manuals available.

The book is the product of several scientists and engineers who are closely associated with nuclear instrumentation, and with the IAEA activities in the field. Everybody contributed to all chapters, but the responsibility to prepare the basic text was distributed in the following manner:

Preamplifiers, Amplifiers	F. Manfredi (Italy)
Scalers, Timers, Ratemeters	J. Sousa Lopes (Portugal)
Multichannel Analyzers	J. Pahor (Yugosalia)
Dedicated Instruments	P. Ambro (Hungary)
Tools, Instruments, Accessories, Components, Skills	O. Mutz (IAEA)
Interfaces	S. Hollenthoner (IAEA)
Power Supplies	H. Kaufmann (IAEA)
Preventive Maintenance	P. Vuister (IAEA), J. Sousa Lopes (Portugal)
Troubleshooting in Systems	P. Vuister (IAEA)
Radiation Detectors	J. Dolnicar (IAEA)
Overall editing	K.D. Mueller (FRG)

The organization of the meeting where the first draft of the publication was prepared, and the subsequent improvement of the texts were in the hands of Mr. L. Kofi (Ghana) and Miss L. Hingston (IAEA).

Studying the book, it can be noted that there are different approaches and different styles used in individual sections. This is in part the consequence of the fact that each chapter was drafted by a different person, but it also reflects the observation that various parts of nuclear electronics require different ways of presentation. For this reason, no particular effort was taken to present all the chapters of the book in a uniform style.

All the persons who contributed to the first edition of the troubleshooting manual are well aware that the book needs further improvement. In the jargon of the electronics experts, we request the users of the book for "a fast, positive feedback" that will enable us to improve the text and make it more readable and understandable for the engineers, scientists and technicians to whom it is intended.

The troubleshooting and repair of instruments is illustrated by some real examples. The circuit diagrams and service manuals of ORTEC, CANBERRA and NARDEAUX instruments were selected for this purpose. Obviously the choice of these instruments was made only for training purposes and has no relevance to the Agency's preferences for particular brands of nuclear instruments.

CONTENTS

Chapter 1
INTRODUCTION

1 INTRODUCTION

Nuclear instrumentation can be found in many different institutions; there are nuclear research centres, universities, and hospitals with their nuclear medicine diagnostic or therapy units. In industry, radiation and associated nuclear instruments are applied in products and in process control. As a rule, nuclear instruments are rather sophisticated and delicate instruments. If they develop faults, as any instruments sooner or later do, they are not easy to repair. Considerable specialized knowledge, extensive experience, and suitable equipment is needed for their repair and servicing.

For a price, the manufacturers of nuclear instruments offer the required service for their instruments. If sufficient funds are available, a service contract can be established, and the manufacturer, or his service laboratory, will take care of the installed instrumentation. This is sound practice for a laboratory in an advanced country where the manufacturer's service person is available on call, and where the rather stiff prices of the service contracts can be accommodated in the laboratory budget. In developing countries, both commodities (available service and sufficient hard currency) are an exception rather than a rule. The management of developing laboratories must find an alternative solution.

Creating a maintenance and service laboratory in an institution in a developing country is not easy. Following reasonable advice, like some given in the present publication, can help in the selection of suitable testing instruments, tools and components. However, the training of the staff who must have all the required skills, knowledge and experience, is a long and difficult procedure.

It is very difficult to teach troubleshooting and repair of any instrument. In fact, the acquisition of the necessary experience for repair of electronic and electromechanical instruments is a typical case where on-the-job training is most effective. As a rule, one should not take the methods that the manufacturers apply to train their field engineers; their training is limited to a certain line of products, or even a single instrument, and for this they have developed efficient approaches to convey the required skills in a short time. The staff of a service laboratory in a developing country cannot be trained in this manner on all possible types of equipment, which there might be only one installed in the country. Their approach to the servicing and repair must be more general, and is more demanding.

In the nuclear field, the staff responsible for instrumentation maintenance and servicing face a number of additional problems.

(i) Nuclear electronics is not taught regularly at the universities or technical schools in developing countries.

(ii) Literature on nuclear instrumentation, and particularly on servicing of such devices, is scarce or non-existing.

(iii) Manufacturers' information on their products and servicing is generally either bad, incomplete or not available.

(iv) There are very few experts who are familiar with the repair of nuclear instruments.

(v) A talented person who received proper training in servicing of nuclear instruments can easily find a well-paid job in private enterprise, and would thus be lost for the nuclear laboratories.

Accordingly, it is not easy to create a team and a laboratory for nuclear instrumentation service. In an average laboratory, the maintenance and servicing abilities are hardly transferred to the junior staff. It takes much time to acquire the necessary skills for instrumentation repair, and it is difficult to share the experience within a group.

In many developing countries, there is no alternative to the decision to create and support a maintenance and repair service. Depending on the size of the country, and on the amount of nuclear instrumentation in the country, it might be sufficient to establish one central laboratory, or it might be necessary to plan for more of them, strategically located in different parts of the country. This laboratory, or laboratories, should be suitably staffed and equipped, and should maintain:

- a documentation library with data books, copies of all manuals, catalogues of equipment supplies, and a selection of electronics textbooks;

- a stock of components and spare parts;

- if possible, a stock of spare instruments;

- maintenance kits.

It is obviously not easy to create and staff such a laboratory in a developing country. The present publication should provide some help in this difficult task.

Chapter 2
ORGANIZATION OF THE LABORATORY

2 ORGANIZATION OF THE LABORATORY

2.1 GENERAL REMARKS

The contents of this chapter are limited to some general observations and conclusions on the organization and operation of an electronics laboratory that serves nuclear intrumentation and related equipment. The same recommendation applies as well for all donated instruments. It should be noted that there are several IAEA publications dealing with the topic (IAEA TECDOC-309, Nuclear Electronics Laboratory Manual, and TECDOC-363, Selected Topics in Nuclear Electronics).

The optimal set-up of a service laboratory depends, to a large extent, on the social, economic and policy situation in the country. As an example, consider the specific regulations in a country, referring to the financing and control of material support to the laboratories. Therefore, it is difficult to present a detailed assessment of the best approach for establishing and operating such a laboratory. Below, only some points that seem to apply to all countries and situations are summarized.

2.2 PHYSICAL ENVIRONMENT

A summary of the main items of recommended facilities required for a service laboratory is given here. Only a reminder on the essential features to be considered when a laboratory is created are presented. Further details are given in the following chapters.

1. The laboratory should have a minimal useful area of 10-12 square meters for each employee. If Computer Aided Engineering (CAE) facilities are envisaged, an air-conditioned computer room and a room for work stations should be made available.

2. For countries in tropical regions, the laboratory should be air-conditioned. At least a part of the laboratory should be equipped to have a dry area, i.e a room with reduced humidity.

3. An adequate storage room, for special packing material that has to be kept for emergency return shipment, should be available.

4. The electronics laboratory should have a good, reliable mains supply, properly arranged electrical power distribution, and, preferably, a good dedicated grounding system.

5. The laboratory should have good overall illumination. For precise work on electronics instruments, individual working places should have additional lights.

6. Depending on the size of the laboratory, and its activities, additional room space with reduced humidity for storage of electronic instruments and components, as well as the proper

laboratories for production of printed circuits, should be arranged.

2.3 ADMINISTRATION OF A NUCLEAR INSTRUMENTATION LABORATORY

2.3.1 Staff

The proper staffing of the maintenance and service of a nuclear electronics laboratory is obviously the most important part of good management. At the start of such a laboratory, it is advisable to make a complete inventory of all the instruments in the institute or institutions that are expected to be served by the laboratory. According to the volume and complexity of the instrumentation, the required skills should be determined, and on this basis, the persons with suitable professional profiles recruited.

It is highly advisable to recruit for the laboratory such staff members who can cover a wide spectrum of instruments. Nevertheless, it will be necessary, with the increasing demands placed on the work of the laboratory, to specialize some of the staff members in particular aspects of nuclear instrumentation. Some of the topics of such expertise are: radiation detectors, analog electronics, digital electronics, interfacing, computers and electromechanical apparatus. Note: the recent trends in electronics tend to over-emphasize digital electronics and computer software development. Particularly in the nuclear field, there is a critical need for persons with knowledge and experience in high quality analog electronics, and this should not be neglected. Furthermore, it should be kept in mind that many instruments in the nuclear laboratories are not strictly nuclear. Electronic balances, sample changers, optical spectrometers, diffractometers, and ph-meters are research tools that also need maintenance and service, and the electronics laboratory should be in a position to offer it.

The management of the laboratory should design a suitable scheme to evaluate and promote the activities of the staff. Special attention should be given to the fact that continuous training of the staff is required to keep up with the extremely fast progress in the world of electronics and computer science. The IAEA is developing a computer-based management scheme for preventive maintenance; such a system can be developed locally, not necessarily computer-supported, and can also include repair and servicing aspects.

2.4 INSTRUMENTATION AND ELECTRONICS COMPONENTS

Chapter 3 provides detailed information on the type and amount of testing instruments and tools required for normal operation of a service laboratory, at different levels.

It should be emphasized that the testing instruments in a laboratory should be regularly checked and calibrated for proper operation; such controls should include connectors and cables.

Furthermore, a certified recalibration of instruments used as measurement standard, at a national institution, should be planned.

The acquisition of any instrument, preferably with two sets of operator and service manuals even at additional expense, should be accompanied with the provision to order some spare parts and components. One set of operator and service manuals should stay at the location of each instrument while the other set should be kept in the technical library of the service laboratory.

A good rule can be that 1 1/2 % of the value of the instruments should be invested in spare parts, at the time when the purchase is made. In the following years, each instrument will need between 1 and 3 % for replacement parts, depending on the complexity and design of the instrument.

Each laboratory should have a basic supply of electronic components. A list is presented in Chapter 3, Section 3.4; this is considered to be a minimal set of components that have to be on stock in the laboratory and need to be updated regularly.

It is considered absolutely mandatory that a nuclear electronics laboratory have access to some local and foreign petty cash, for rapid and unbureaucratic acquisition of parts and components that are or are not available on the home market. This is essential for rapid turn-around of repairs; it is not tolerable that the staff must wait months for the appropriate approval to buy a minor electronic part, and the experimenter cannot use his instrument.

It should be pointed out here that there is a tendency more and more often in modern electronic instrumentation to make use of hybrid analog, customized digital circuits, EPROMs, PALs and other programmable chips, to achieve higher packing densities, better overall performance, and to reduce production cost. It will not be possible, even in a very well-equipped laboratory, to have all these special spare parts available in a stockroom. Fortunately, the failure rate of such components is low. These spare parts have to be ordered from the manufacturer of the instrument or its representative and are not available from the semiconductor manufacturer.

Even so, one has to realize the fact that the on-site service of highly sophisticated nuclear instrumentation may often have to limit itself to the board level just by swapping boards. Board test equipment, which is required to enable repair on the chip level, will only be affordable to the instrument manufacturer in some strategically located service centers worldwide.

One may complain about this situation, but it also offers a considerable advantage by reducing the number of boards in a typical nuclear instrument, and consequently, the failure rate. Many manufacturers are now able to use a functionally partitioned approach to break down a design to the board level, which allows them to provide diagnostic routines and facilities to the customer for easy fault location to the board level.

Special emphasis should therefore be given to this fact when ordering equipment if such diagnostic facilities are available. In such a case, return of an instrument to the manufacturer may never be necessary and the possibility of shipping damages when returning a board to the manufacturer largely vanishes.

Of specific importance for a service laboratory is the availability of suitable extension boards and cables. If they cannot be purchased, they must be produced in the laboratory.

Another essential activity of a properly organized laboratory, is the good organization of the technical library. This should include:

- Originals of all the operator manuals
- Originals of all available service manuals, circuit digrams, parts lists, and troubleshooting information;
- A set of data books on electronic components; as a minimum, it is recommended to have a set of D.A.T.A. Books (D.A.T.A., Inc. P.O. Box 26875, San Diego, California 92126, USA), possibly complemented with some publications of individual producers of electronic components;
- application notes referring to nuclear electronics from instrument manufacturers;
- catalogues.

2.5 ORGANIZATION OF THE WORK IN AN ELECTRONICS LABORATORY

Frequently, a nuclear electronics laboratory combines its activities in service with some development work in order to give its staff a chance to keep up with the rapid development in nuclear electronics. In such cases, the basic rule should be:

The repair and servicing of instruments has priority to any other activity of the laboratory.

The electronics laboratory should be involved in a research instrument from the moment of its delivery. A staff member should assist in the unpacking, installation, and initial testing of every newly acquired instrument. For those instruments that cannot be repaired locally, and where there is a possibility for them to be sent for repair, special shipment material should be stored.

> In laboratories and institutes in developing countries, we frequently observe the "wooden box effect": the delivered equipment is kept in boxes, sometimes for years. This is not tolerable, and the electronics laboratory can contribute to the action: upon delivery, each instrument should be immediately unpacked, inspected for possible damage (and all claims should be submitted as soon as possible, otherwise the warranty might be lost), installed and tested. A document should be prepared specifying the measured properties of the instrument; later, this will permit a comparison on the instrument's performance.

For every instrument, a logbook and repair list should be opened, at the time of its arrival. All subsequent actions, be it for preventive maintenance or repair of the instrument, should be registered in this book. The head of the workshop should set a good example on the utilization of the logbooks, otherwise it will not be used by the personnel. It is highly recommended to start weekly repair case discussions and to use the logbook during this session.

It is advisable for the repair of an instrument to be organized in the following way: a copy of the circuit diagram should be made, and the values obtained in measuring the quantities, such as DC voltage and signal shape, should be registered. Such an "updated" diagram should be stored in the logbook. If no diagrams are available, a careful record should be maintained of the measured values at selected points of the circuit.

The staff of nuclear electronics laboratories should learn from their mistakes. The staff member of the electronics laboratory who is expected to repair a faulty instrument should make inquiries on how the fault has developed. This might require an adequate approach, some careful, not inquisitory investigation, and should preferably be made by a senior person. The findings should be recorded in the logbook.

Preventive maintenance is described in Chapter 13.

Chapter 3
TOOLS, INSTRUMENTS, ACCESSORIES, COMPONENTS, SKILLS

3 TOOLS, INSTRUMENTS, ACCESSORIES, COMPONENTS, SKILLS

Tools are needed for proper maintenance of instruments. The number of tools, however, is very large, even if only a certain category of service work, let us say troubleshooting, of nuclear instruments has to be performed. The following compilation of tools shall give an idea of what is needed at a work bench or in the laboratory. The discussions on the appropriate tools and instruments will distinguish between different levels of troubleshooting. Accordingly, the following list of tools will be divided into three groups.

Group A: necessary as a minimum to solve simpler troubleshooting and maintenance tasks, e.g. cleaning, replacing of simple components, yes or no tests.

Group B: for advanced repair work, e.g. in addition to A, replacement or repair of more complex components like multiple step switches, hybrid circuits, connectors, moving coil instruments, etc.

Group C: for sophisticated repair work, e.g. calibration, verification of manufacturer specification, modification and new developments (or prototypes).

In the following list, you will also find a Group F: specially for field service. This group will strongly overlap the other groups of tools but is meant for troubleshooting and maintenance away from the work bench. For this purpose, pre-packed tool bags are available but mostly they do not fully satisfy the needs. Either some items are missing or some of them will never be used. Therefore, it seems better to put tools used at the work bench into a bag for field service.

3.1 LIST OF TOOLS (MATERIALS)

3.1.1	Room	ABC	
3.1.2	Work Benches	ABC	
3.1.3	Chairs	ABC	
3.1.4	Bench lights	ABC	
3.1.5	Trolley table	ABC	
3.1.6	Shelf	ABC	
3.1.7	Cupboard	ABC	
3.1.8	Storage cabinet	ABC	
3.1.9	Storage boxes	ABC	
3.1.10	Cabinet	ABC	
3.1.11	Screwdrivers	ABC	F
3.1.12	Allen keys	BC	F
3.1.13	Pliers	ABC	F
3.1.14	Diagonal cutting nippers	ABC	F
3.1.15	Jewellers snips	ABC	F
3.1.16	Knives	ABC	F
3.1.17	Spanners	ABC	F
3.1.18	Soldering units	ABC	F
3.1.19	Tin (different types)	ABC	F
3.1.20	Desoldering units	ABC	F
3.1.21	Desoldering tapes (different types)	ABC	F
3.1.22	Calipers	BC	
3.1.23	Steel ruler	BC	
3.1.24	Measuring tapes	ABC	F
3.1.25	Punches	ABC	F
3.1.26	Hammer	ABC	F
3.1.27	Drills	ABC	F
3.1.28	Trepanning cutters	BC	F
3.1.29	Correcut drills	C	
3.1.30	Drills for printed circuit boards	C	
3.1.31	Hand drilling machines	ABC	F
3.1.32	El. drilling machine (with stand)	BC	
3.1.33	Stand-alone drilling machine	C	
3.1.34	Dental drills	C	
3.1.35	Dental drilling machine	C	
3.1.36	Thread taps	C	
3.1.37	Die nuts (threading dies)	C	
3.1.38	Files	ABC	F
3.1.39	Vices	BC	
3.1.40	Clamps	C	F
3.1.41	Tweezers	ABC	F
3.1.42	Inspection mirrors	ABC	F
3.1.43	Magnifier mirrors, lenses	BC	F
3.1.44	Brushes (cleaning)	ABC	F
3.1.45	Sprays (liquids for different purposes)	ABC	F

3.1 List of tools (materials) (cont'd.)

3.1.46	Tapes	ABC F
3.1.47	Saws	ABC F
3.1.48	Saws (special)	C
3.1.49	Tool bags	F
3.1.50	Tool kits	F
3.1.51	Storage boxes	BC F
3.1.52	Cable crimping tools	BC F
3.1.53	Wrapping tools	C
3.1.54	Blower and vacuum cleaner	ABC F
3.1.55	Screw punches	C
3.1.56	Tools for surface mounted devices	C (F)
3.1.57	Glue (instant action type like Loctite or similar)	ABC F
3.1.58	Winding machine (small size with turn counter)	

Detailed descriptions of the most important tools are presented in the following pages.

3.1.1 Room

For construction, the following should be considered:

a. Size - big enough not only for the work bench but also to allow space for tools, test instruments, spare parts, components, documentation, faulty instruments (up to rack-size and detector with crystal assemblies), repaired instruments trolleys . . . . . . A

separate storeroom, dirty room . . . . B

separate clean room, documentation room C

b. Lighting system - preferably daylight with blinds (for screenwork) and daylight fluorescent lamp

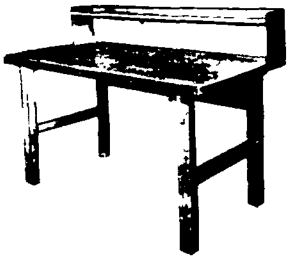
c. Floor - surface without cracks or chinks

d. Material - sealed and painted concrete, PVC, stone (terrazzo) . . . . A

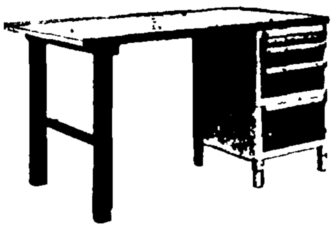
PVC antistatic . . . . B,C

e. Colour - green, grey, uni

3.1.2 Work Benches



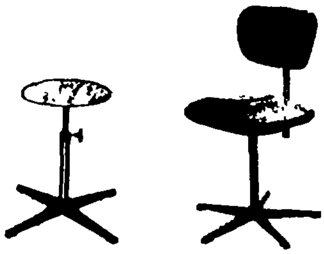
work bench with additional shelf of beech material . . . . ABC



solid construction (permissible load 100 kg min), non-inflammable surface, preferably with drawers and additional shelves . . . . A

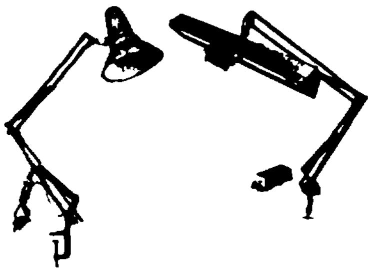
with antistatic bench mats . . . . B,C

3.1.3 Chairs



two for each working place with and without backplate; at least one with adjustable height and rolls . . . . . . A,B,C

3.1.4 Bench Lights

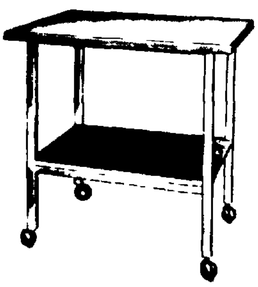


adjustable in all directions, arm length min 80 cm . . . . A

fluorescent lights and lenses . . . . . B

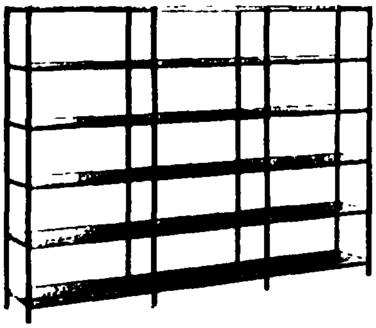
halogen lamp (spot light) C

3.1.5 Trolley Table



min. size 60 x 70 cm, min. load capacity 60 kg, should have the same height as the working table . . . . A,B,C

3.1.6 Shelf

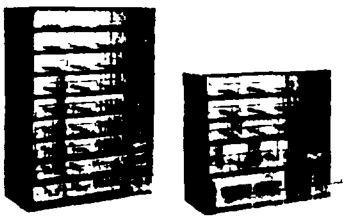


preferably a modular system with pillars adequate to the room height; precaution: shelf must be anchored to the wall at a reasonable height . . . . A,B,C

3.1.7 Cupboard

solid, preferably metal, lockable with drawers and adjustable shelves . . . . . A,B,C

3.1.8 Storage Cabinet

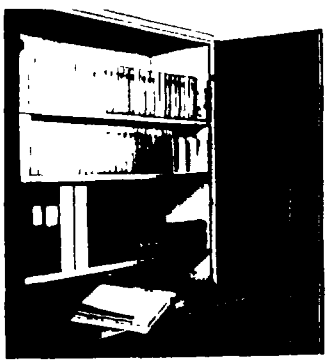


metal frame with plastic drawers, drawers with an edge to avoid inadvertant withdrawal. . . . . A,B,C

3.1.9 Storage Boxes

different sizes, plastic, stockable, mainly for spare parts . . . . A,B,C

3.1.10 Cabinet



with drawers, shelves suitable for files, documents and manuals, lockable . A,B,C

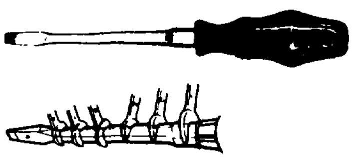
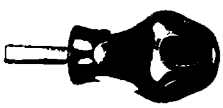
3.1.11 SCREWDRIVERS

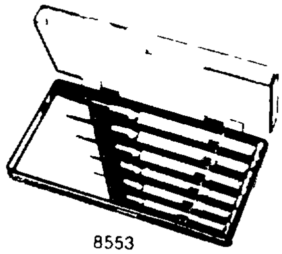
Hints for selection:

a. The shank should be made of a special alloy (chromium, etc.) better than nickel-plated. Layer shanks are not so handy but more universal. For bigger sizes, its profile should be hexagonal to give additional torque with a spanner.

b. The tip should be specially hardened; the two planes of the blade have to be parallel in the slot of the screw.

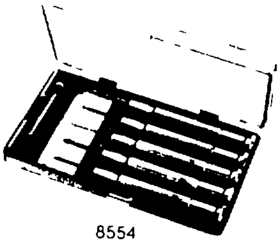
c. The handle should be of special plastic, preferably hammer hit-proof. Hits on the end of the handle are only allowed if the shank goes fully through the handle (precaution: no isolation!).

	length (mm)	bit profile (mm)	
	60-100 (shank), 100-120 (shank),	0.4x2.5 0.6x4	ABC F BC (F)
	125 (shank), 170 (shank),	0.8x5.5 1.6x8	ABC F BC (F)
	170 (shank), 200 (shank),	1.6x10 2 x12	BC F BC (F)
	25 (shank),	1 x 6	BC F
	60 (shank), 80 (shank), 150 (shank),	PZD 0 PZD 1 PZD 3	BC F ABC F ABC F
	100 (shank),	0.9x 5	C F
	100 (shank),	PZD 1-2	C F



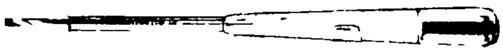
8553

watchmakers screwdrivers, set of 6
0.25x0.8 up to 0.6x3.8 mm BC F

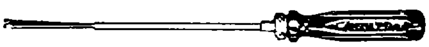


8554

set of 2 Philips 0,1 mm
and 3 Hex 1.5-2.5 mm C (F)



mains tester screwdriver ABC F



split blade holding screwdriver
200 mm long, 4 mm blade BC F

If special heads (other than e.g. Pozidrive) are needed, then use different bits in a holder; a spring collar or a magnet holds tne bit in a hexagon socket.

0286

100 mm long, 1/4 inch socket C (F)

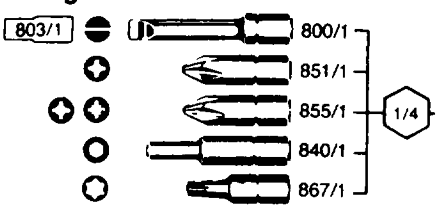
Example of different sizes of Pozidrive bits:

"Wera No 855 H". Screwdrivers for Pozidriv/Supadriv slots C form **Extra hard quality** HRC 64–65 *Specially intended for tightening sheet metal screws*

Orig. No. 855/1H=¼" ○					
Ref	***5014***	***0052***	***0102***	***0201***	***0250***
Pozidriv slots	No	0	1	2–25	2–50
Length	mm	25	25	25	50
Std	pack	10	10	10	10
Price each	SEK	5 25	5 25	5 25	8 75
Orig. No. 855/1H=¼" ○					
Ref.	***5014***	***0284***	***0300***	***0409***	
Pozidriv slots	No	3–25	3–32	4	
Length	mm	25	32	32	
Std	pack	10	10	10	
Price each	SEK	5 25	12 00	14 50	

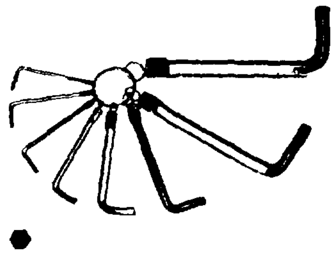
5014–5015
Bits for Pozidriv slots

Fitting in universal holders



different types of bits

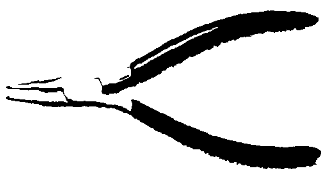
3.1.12 Allen Keys



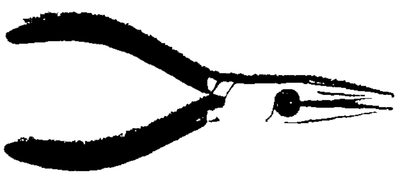
keys are removeable from the holder
metric set 1.5-6mm, hex BC (F)
inch set 1/16-1/4, hex BC (F)
for multiturn dials of precision pots, additional special sizes should be ordered

3.1.13 Pliers

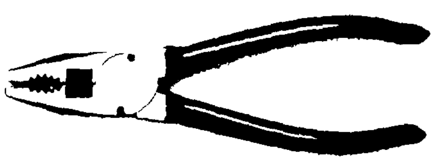
flat-nose plier, length 170 mm ABC F



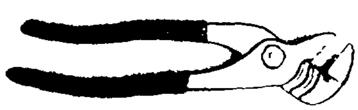
snipe-nose plier, length 120 mm C (F)



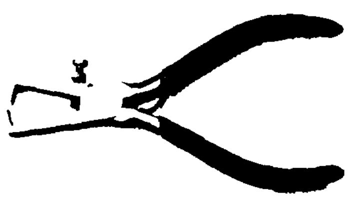
half-round-nose plier, length 140 mm ABC (F)



combination plier, length 160 mm ABC F



water pump plier, length 130-170 mm C (F)



wire strip plier, length 130 mm BC F

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

SKILLS: General instructions on soldering

Soldering (and desoldering) is one of the main tasks in electronic troubleshooting work. To solve these tasks properly, one has to consider several points:

1. The physical dimensions of the soldering point.
   The range is from tiny hybrid circuits, watches, double or multi-layer boards (e.g. pocket calculator) up to big area soldering e.g. for shield grounding.

2. Material on which soldering must be done.
   Normally, there will be a printed circuit board covered with special protection varnish or tin, silver, gold, etc., but also on stand-offs, leads, plates, cables, etc.

   Let us assume all material is tin-solderable; nevertheless, there are big differences, e.g. for iron and gold. In addition to the different heat transfer also different surface conditions have to be considered. IT IS ESSENTIAL THAT FOR THE SOLDERING PERIOD THE TWO MATERIALS REMAIN CLEAN (NO ORGANIC MATERIAL OR CORROSION).

3. Material used as solder.
   The material normally called "tin" is in reality an alloy which is mostly composed of other elements like Pb, Cd, Ag, Bi, Cu, and Sb.

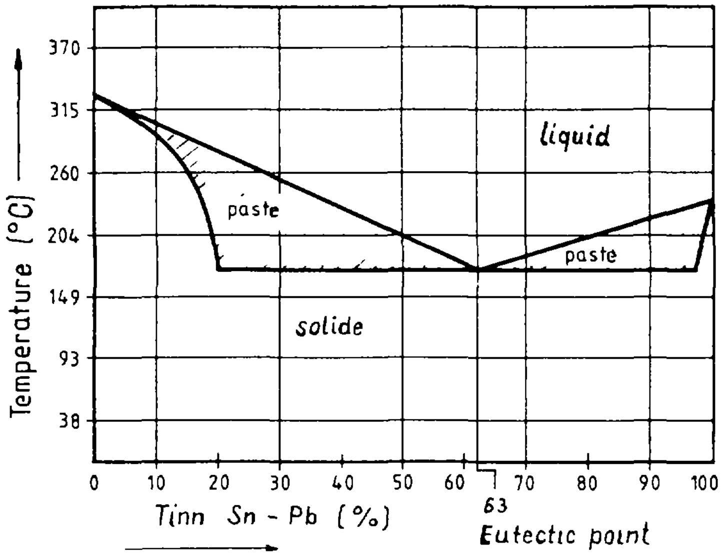
==

TABLE 3.1: Some common types of solder and their composition

Standard Alloy	Melting Point C	Specifications (A)=QQ=S-571E,(G)=DIN1707 (B)=BS 219		Used for
TLC	145	(B)T, (G)	L-SnPbCd18	solder of galv. gold
LMP	179	(B)62S	L-SnPbAG1,8	solder of galv. silver
SN63	183	(A)SN63	L-Sn63PbBi03	printed boards
60/40	188	(B)DP,(G)	L-Sn60Pb	electronic
SAVBIT 6	190	(G)	L-Sn60PbCu2	stops disintegration of cu
50/50	212	(B)F,(G)	L-Sn50Pb	electronic
SAVBIT 1	215	(G)	L-Sn50PbCu	stops disintegration of Cu
96S	221	(A)Sn96,(B)96S,(G)L-SnAg5		without lead
40/60	234	(B)G,(G)	L-PbSn40	common electric
95A	243	(B)95A,(G)	L-SnSb5	without lead
30/70	255	(B)J(G)	L-Pb70Sn	E-Motors
20/80	275	(B)V(G)	L-Pb80Sn	lamps
HMP	301	(B)5S		high temp. solder

==

Different amount of these elements result in alloys with different characteristics like melting point, conductivity, agressivity to other materials (copper), mechanical strength, etc.

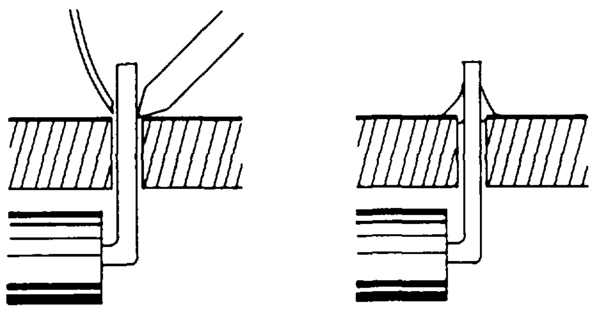


This diagram shows a solder wire composition of tin-lead.

There is a paste-region above and below the 63% tin concentration.

Flux is necessary to allow soldering or to make it easier. Normally the flux ought to be inagressive, especially against copper.

During the soldering procedure, some important considerations must be followed. After switch-on of mains, the soldering iron should heat up fast and should remain at a constant temperature. During the soldering period, it should warm up fast the material of the soldering point to a temperature close to the liquid region of the solder. Adequate solder has to be applied. During the melting time, the heat capacity of the solder tip has to be sufficient not to drop the temperature beyond the liquid region of the solder.



Why not take a soldering iron with a temperature far above the melting region? The followibg observations speak against such a procedure.

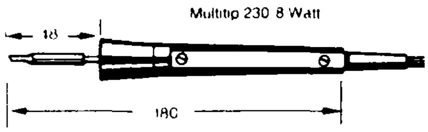
1. Sensitive components, cables, connectors, printed circuits, etc. will be destroyed if they are exposed too long to higher temperatures.

2. The temperature of the solder should drop into the solid state very fast because movement of the parts in liquid or paste condition will cause a bad contact (cold solder point).

Considering the previous, adequate soldering tools have to be selected.

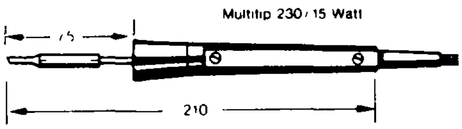
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

3.1.18 Soldering irons and bits



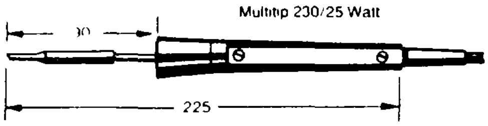
Wattage **8 W**
Heating up time ca 90 s
Bit temperature 290 °C
Weight without lead 26 g
with rubber rest
Voltages 6 V, 110 V, 130 V, 220 V, 240 V — BC

Order nos.
230 LN/8 W Iron with nickel-plated copper bit
230 LD/8 W Iron with ERSADUR long-life bit



Wattage **15 W**
Heating up time ca 60 s
Bit temperature 350 °C
Weight without lead 28 g
with rubber rest
Voltages 6 V, 12 V, 24 V 42 V, 48 V 110 V,
130 V, 220 V, 240 V

Order nos. — BC
230 LN/15 W Iron with nickel-plated copper bit
230 LD/15 W Iron with ERSADUR long-life bit



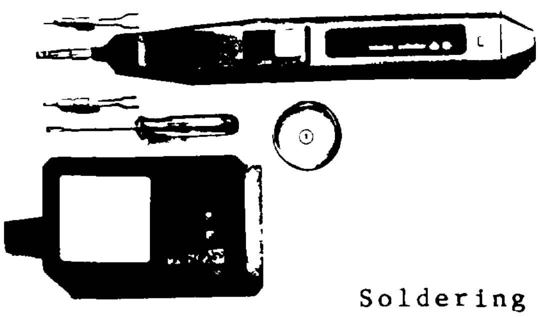
Wattage **25 W**
Heating up time ca 60 s
Bit temperature 450 °C
Weight without lead 34 g
with rubber rest
Voltages 6 V 12 V 24 V, 42 V, 48 V, 110 V,
130 V, 220 V, 240 V

Order nos.
230 LN/25 W Iron with nickel-plated copper bit — ABC F
230 LD/25 W Iron with ERSADUR long-life bit

Bits (surface like "Ersadur" type is recommended for all)

BC F
ABC F

	Multitip 230/8 W		Multitip 230/15 W		Multitip 230/25 W	
bits / pannes	vernickelt nickel-plated nickelée	ERSADUR	vernickelt nickel-plated nickelee	ERSADUR	vernickelt nickel-plated nickelee	ERSADUR
	132 LN	**132 LD**	**162 LN**	**162 LD**	**172 LN**	**172 LD**
	132 BN	**132 BD**	**162 BN**	**162 BD**	**172 BN**	**172 BD**
	132 KN	**132 KD**	**162 KN**	**162 KD**	**172 KN**	**172 KD**
	132 SN	**132 SD**	**162 SN**	**162 SD**	**172 SN**	**172 SD**

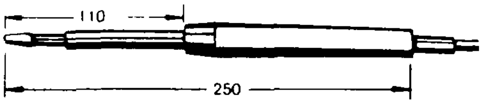


Cordless industrial soldering iron: The cordless industrial soldering iron is powered by long-life nickel cadmium batteries, which are easily replaceable, giving tip performance equivalent to up to 50 watts with over 370°C (700°F) tip temperature. C (F)

Soldering irons with buthan gas firing with heat regulation and different tips are suitable, especially for higher heat transfer (grounding) in the field service. F

(34)

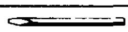
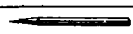
3.1.18 Soldering iron (cont'd.)

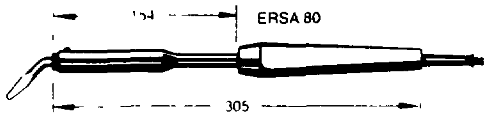


030 KK/30 W Iron with copper bit
030 KK/40 W
030 KD/30 W Iron with ERSADUR long-life bit
030 KD/40 W

Wattage **30 W** or **40 W**
Heating up time approx. 2 min
Bit temperature 380 °C, 420 °C
Weight without lead: 95 g
with plastic rest
Voltages 6 V, 12 V, 24 V, 42 V, 48 V, 110. 120 V, 125. 135 V, 220 V, 225.. 235 V, 240 ..250 V

ABC F

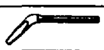
Lotspitzen / bits / pannes					
Kupfer / copper / cuivre	032 KK	032 JK	032 BK	032 CK	032 NK
ERSADUR	032 KD	032 JD	032 BD	032 CD	032 ND



Wattage **80 W**
Heating up time· 3 min
Bit temperature. 410 °C
Weight without lead. 220 g
Voltages: 12 V, 24 V, 42 V, 48 V, 110. .120 V, 125 ..135 V, 220 V, 225...235 V, 240...250 V

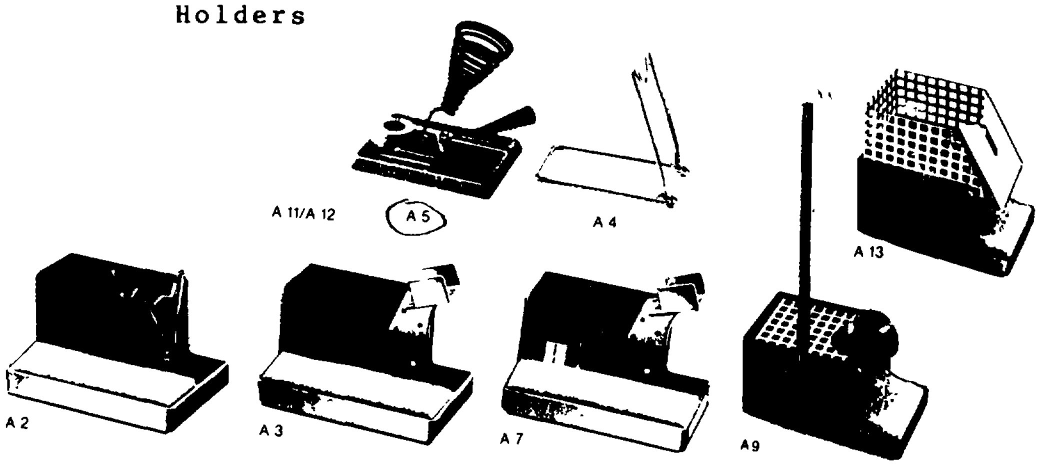
Order nos
080 JK Iron with copper bit
080 JD Iron with ERSADUR long-life bit

ABC

	ERSA 50		ERSA 80	
bits / pannes	Kupfer copper cuivre	ERSADUR	Kupfer copper cuivre	ERSADUR
	052 JK	052 JD	082 JK	082 JD
	052 KK	052 KD	082 KK	082 KD
	052 NK	052 ND	082 FK	
		052 DD		
		052 BD		
	052 CK	052 CD		

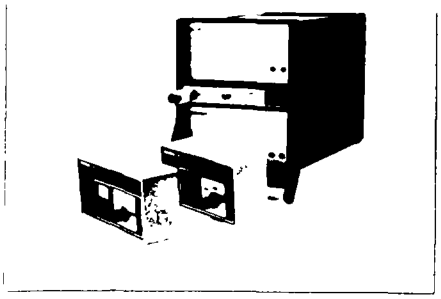
ABC

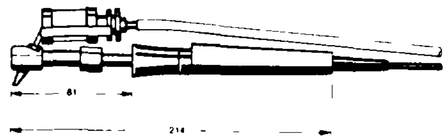
Holders

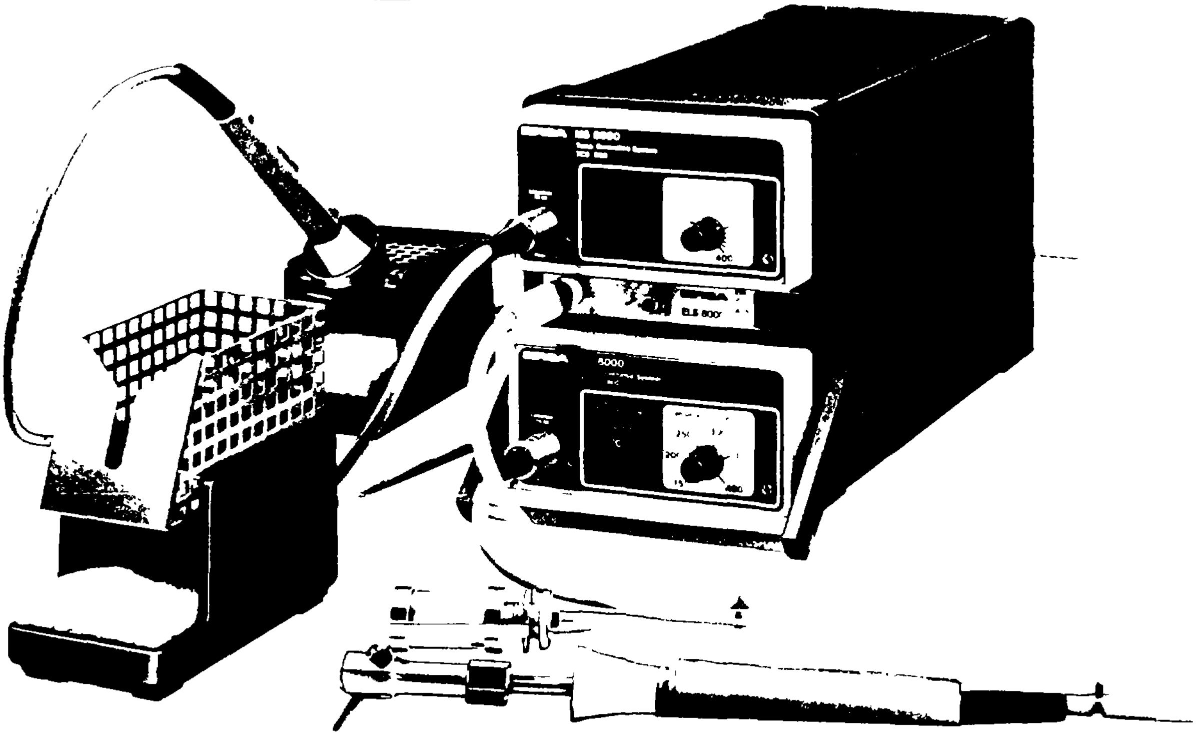


ABC

3.1.18 Soldering (desoldering station)







Lötspitzen / bits / pannes			
ERSADUR	602 CD	602 ED	602 BD

This electronic temperature regulated soldering and desoldering station is especially designed for industrial use, laboratories and repair works. The modular system permits a large field of applications. The single elements can be used in individual combinations.

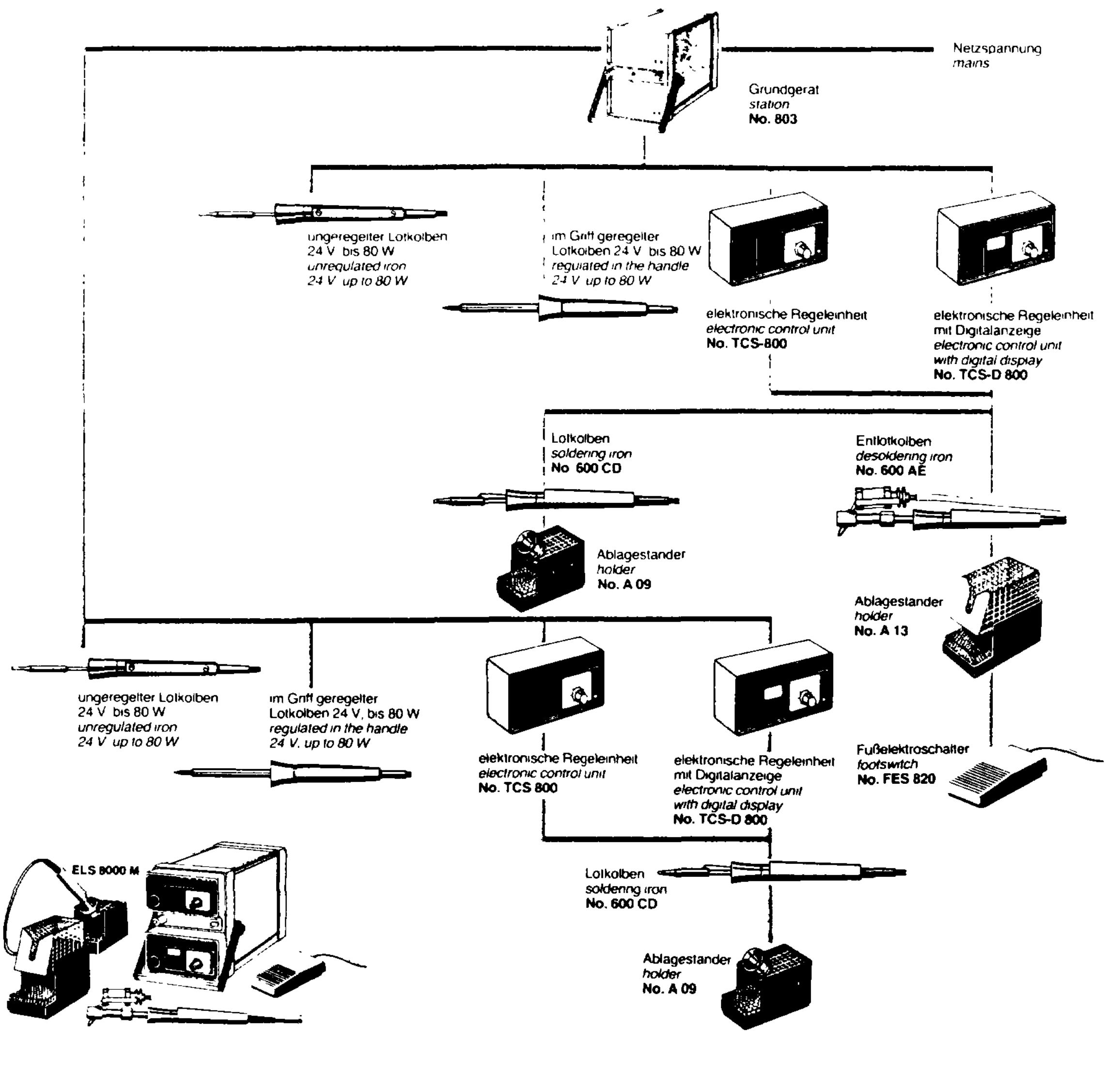
Because of a built-in vacuum pump the efficient station is independent of an air pressure connection. In addition, the basic station contains a power supply of 220V/24V which fits all 24V soldering irons and desoldering irons up to 80W rating.

An electronic control unit permits continuous variation of the soldering bit temperature between 150 and 400 degrees C. By means of a thermocouple sensor located in the soldering iron next to the bit, the electronic control measures the actual temperature and compares it to the nominal temperature setting. By means of an integrated zero voltage switch with full-wave logic and Triac, the temperature is electronically controlled and the operational state is indicated by a pilot light. Depending on the temperature difference or heat requirement, the sensitive electronic unit controls the heating energy input in accordance with the operational state (idling or load). The soldering bit and desoldering bit is connected to the level-potential terminal via an integrated high Ohm resistor.

The small soldering iron is very efficient thanks to its ceramic heating element, which has a pronounced positive temperature coefficient (PTC) and 80 Watts rating (at 350 degrees C).

The desoldering system consists of the iron on which a desoldering head is mounted. The transparent solder chamber can be emptied simply and quickly. The necessary vacuum impulse for desoldering is released by a foot switch.

The following picture gives an overview of an extendable solder-desolder station of one of the leading manufacturers.

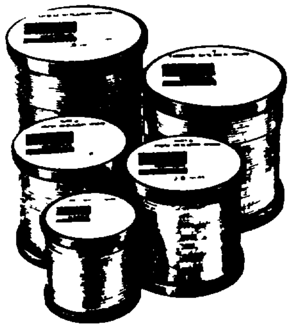


3.1.19 Tin

As shown on page 11, Table 3.1, one should also select for a special purpose the adequate solder.

In real life, however, one to three types of tin alloys will be enougn.

60/40	with low melting region	BC	
Savbit 6	protects copper	ABC	F
Savbit 1	protects copper, higher melting region	BC	

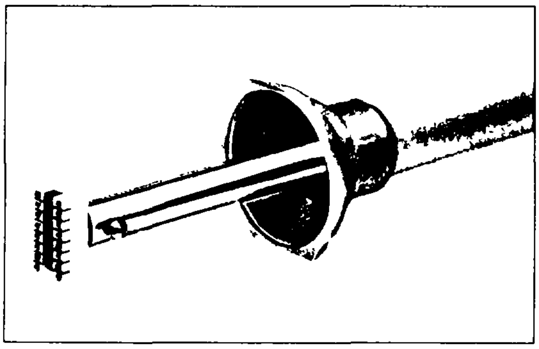


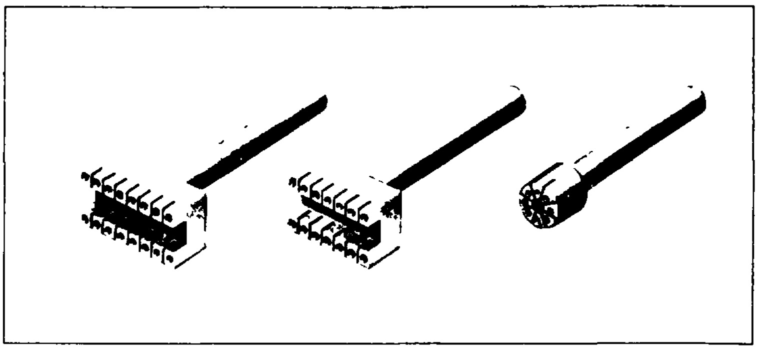
Tin of multi-con type with non-corrosive flux like rosin should be selected. The quantity is normally 100g, 250g, 500g per unit. A handy dimension gives the 250g spool.

The diameter of the solder wire should be about 1mm; only for tiny circuit-work, a small spool of about 0.3mm diameter solder wire is recommended to have on stock.

C (F)

3.1.20 Desoldering Tools





BC (F)

The desoldering bit can be inserted in soldering irons or soldering stations. In any case the applied temperature should not be too high and not too long, otherwise the PC board will be destroyed.

This is dangerous especially on multi-layer boards; in this case it is better to cut the leads of the IC and remove them one by one.

Tin suction devices

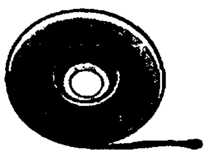
6750/SP

6750/XS

one-hand operation with
exchangeable teflon tip
length 210, 190 mm

ABC F

Desoldering tapes



length 1.6m
width 1.5, 2, 2.5

ABC F

Desoldering tapes are used for absorbing excess solder on circuit boards. A minimal quantity of mild and neutral flux is included. The desoldering tape is highly-absorbant.

3.2 LIST OF ACCESSORIES

3.2.1	Strips with banana plugs (0.5, 1, 1.5m)	ABC	F
3.2.2	Alligator clips	ABC	F
3.2.3	Test clips (for strips)	ABC	F
3.2.4	Test clip for IC-tests	BC	F
3.2.5	Cable reeling units	ABC	F
3.2.6	Oscilloscope probes (1:10, 1:1)	ABC	F
3.2.7	Oscilloscope current probe	BC	
3.2.8	Oscilloscope HV probe	BC	
3.2.9	HV probe for multimeter	ABC	F
3.2.10	Shielded black box	BC	
3.2.11	BNC 50-Ohm terminator (male) plug	BC	(F)
3.2.12	BNC 50-Ohm attenuator (1,3,6,10,10,10,20 dB)	BC	(F)
3.2.13	BNC T-type	ABC	F
3.2.14	BNC I-type male	ABC	F
3.2.15	BNC I-type female	ABC	F
3.2.16	MHV T-type	ABC	F
3.2.17	MHV I-type female	ABC	F
3.2.18	SHV T-type	ABC	F
3.2.19	SHV I-type female	ABC	F
3.2.20	SHV-MHV-adaptor	ABC	F
3.2.21	BNC 50-Ohm cables (0.3, 0.5, 1, 2, 4m length)	ABC	F
3.2.22	SHV - 5kV - cables (2, 4m)	ABC	F

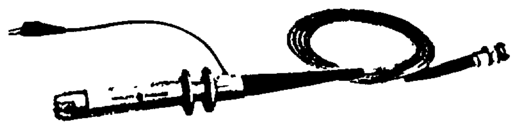
3.2.6 Oscilloscope Probes

Modular switchable probe
with x1 and x10 attenuation

AH. 10:1	Bandwidth:	DC-250 MHZ
	rise time:	1,4 nsec
	input resistance:	10 Mohm
AH. 1:1	Bandwidth:	DC-10 MHZ
	rise time:	35 nsec
	input resistance:	1 Mohm

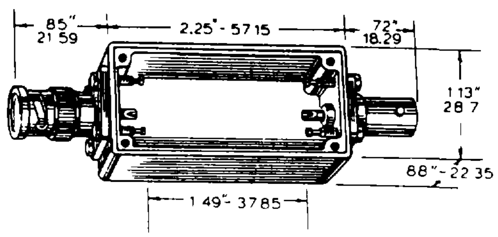
Modular probes allow easy repair of broken parts; any module can be simply replaced. ABC F

3.2.7 Oscilloscope Current Probe


1110B

Sensitivity:	1mV/mA
Accuracy:	$\pm$ 3%
Bandwidth:	1kHz to 40 MHz
rise time:	8 nsec
I max. dc:	0.5A
I max. ac:	15A

3.2.10 Shielded Black Box



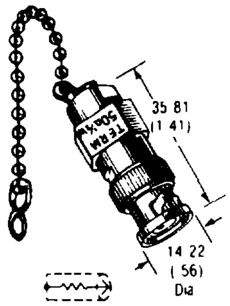
For compact packaging of matching networks.

Features shielded housing of die cast aluminum.

Includes cover and four self trapping screws.

BC

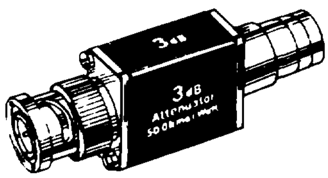
3.2.11 BNC 50-Ohm Terminator Plug



1%, 0.5 watts, + 100 C max gold-plated center contact

BC (F)

3.2.12 BNC 50-Ohm Attenuator



Impedance:	50-Ohm
f-range:	DC-1 GHz
Accuracy:	$\pm$ 0.2 dB
Max Power:	1 Watt

3.3 INSTRUMENTS

Selection of instruments for troubleshooting and development may be troublesome because nowadays a large amount of different types, even for similar purposes, are available on the market.

Even experts are only familiar with a few types of instruments and these are mostly instruments they are dealing with. The problem is to order the best for a certain purpose. To order the instruments at the lowest possible cost is not necessarily the best solution. Some additional factors have to be considered:

1. For which purpose the instruments are needed, i.e. which field of troubleshooting (development) should be covered?

2. Will the instrument be upgraded for additional purposes in the future?

3. Is the manufacturer represented on the local market?

4. Is the instrument supplied with all technical information and service manuals?

5. How is the situation in servicing the instrument (local service station, shipment, custom difficulties, etc.)?

6. Can the instrument be ordered together with spare parts, accessories, options, service kits, etc.?

7. Who is the user of the instrument (level of experience and knowledge)?

8. Where will the instrument be used (environmental situation)?

These eight points may be extended according to special situations. The instruments listed in the following pages are used in different nuclear electronics laboratories that have received assistance from the IAEA. Considerable experience of experts is incorporated into this selection. Nevertheless, only point 1 and 2, mentioned above, will be covered. For a final ordering decision, all other points should be considered.

The following listed instruments are to be understood as examples only. This list also should be upgraded periodically - old-fashioned equipment should be replaced.

List of instruments

For analog troubleshooting and development:

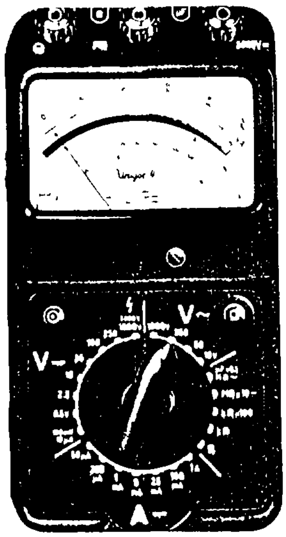
3.3.1	AVO-meter	ABC	F
3.3.2	Digital multimeter		
	3.3.2a handheld, 4 1/2 digit	ABC	F
	3.3.2b bench model, 4 1/2 digit	BC	
	3.3.2c bench model, 6 1/2 digit	C	
3.3.3	Capacity-Inductivity meter	ABC	F
3.3.4	Transistor tester	ABC	F
3.3.5	Insulation tester	BC	
3.3.6	Oscilloscopes		
	3.3.6a portable (up to 20 MHz)	A	F
	3.3.6b bench type (up to 40 MHz)	A	
	3.3.6c bench type (up to 100 MHz)	BC	
	3.3.6d storage type	C	
3.3.7	Pulse generators		
	3.3.8a double pulse generator	BC	F
	3.3.8b precision pulse generator	C	
	3.3.8c sliding pulse generator	C	
3.3.8	DC-power supplies	BC	
3.3.9	Transistor curve tracer	C	
3.3.10	DC-current meter (current probe)	BC	
3.3.11	Noise (RMS) meter	BC	
3.3.12	Complete equipment for -spectroscopy	C	

For digital troubleshooting and development:

3.3.13	Logic tester probe	ABC	F
3.3.14	Signal injector	BC	
3.3.15	Digital circuit tester (troubleshooter kit)	BC	F
3.3.16	Break-out box	BC	F
3.3.17	IC-tester	BC	
3.3.18	Logic analyzer	C	
3.3.19	Prom programmer	C	
3.3.20	In-circuit emulator (with terminal or PC)	C	
3.3.21	Development system (with printer)	C	
3.3.22	Experimental computer board (single board computer)	C	

3.3.1 AVO-Meter

Analog instrument with fast overload protection



internal battery (1.5V) for resistance measurements

similar types for higher current ranges are also available

Specifications:

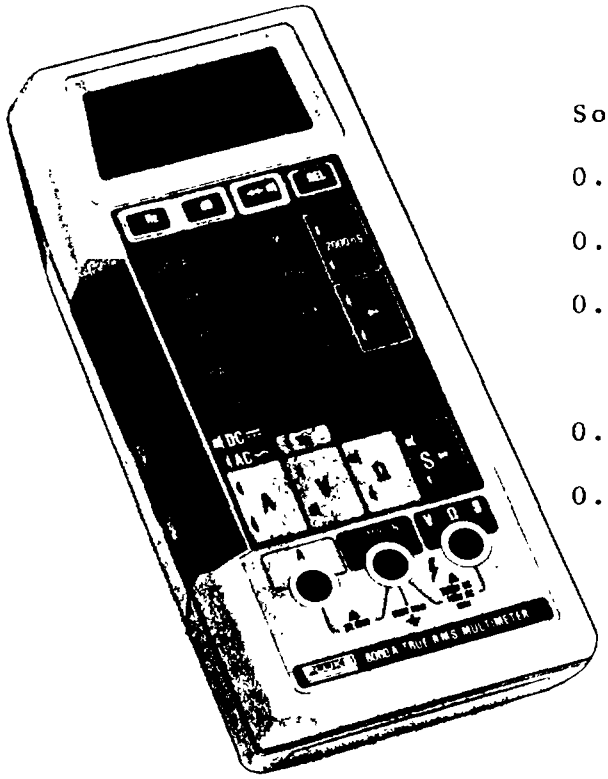
Vdc	0.1V	- 5000V	± 1.5%	(10k - 500M)
Adc	10uA	- 1A(10A)	± 1.5%	(10k - 0.24)
Vac	10V	- 1000V	± 2.5%	(200k - 20M)
R	1	- 5M	± 1.5%	(with internal 1.5V battery)

These kind of instruments have been used for many years and might seem old-fashioned nowadays, but nevertheless they are often needed where trends are to be analyzed or measurements under floating conditions are to be taken.

3.3.2a <u>Digital Multimeter</u>

4 1/2 digit, handheld, battery powered

This type is general purpose, useful for bench or field service.



Some specifications:

0.2V to 1000V dc (> 10M)	<	0.05%
0.2V to 750V ac (10M, 100pF)		0.2-3%
0.2k to 200k		0.07%
to 300k (auto)	<	2%
0.2mA to 2A dc	<	0.3%
0.2mA to 2A ac		1-2%

Some useful additional features of a digital multimeter:

Diode test: the voltage drop across on a diode can be measured up to 2V with a 1mA dc test current.

Frequency measurement: from 12Hz to 200kHz.

Suitable also for: RMS, dB (relative to a selected voltage), conductance, relative values (offset), etc.

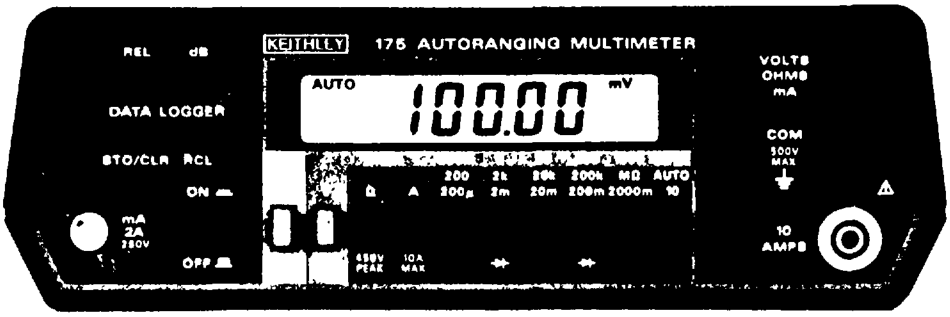
Big display, self-test, different additional display indicators

Extensions are available: H.V. probes (5kV, 40kV)
current probes
HF-probes
current shunt, etc.

3.3.2b <u>Digital Multimeter</u>

4 1/2 digit, for laboratory and advanced field service (battery operated)

Suitable for long-time measurements



Features:

•4 ½ Digit LCD Display
•Fast Autoranging
•Bench or Portable
•Digital Calibration
•100 Point Data Logger
•10μV/10mΩ/10nA Sensitivity
•0.03% Basic DCV Accuracy
•TRMS AC
•dBm/Relative Functions
•Min/Max Reading Hold
•Safety Input Jacks
•10A Capability
•100kHz Specified AC Bandwidth

Options:

•Model 1758 Rechargeable Battery Pack
•Model 1753 IEEE-488 Interface

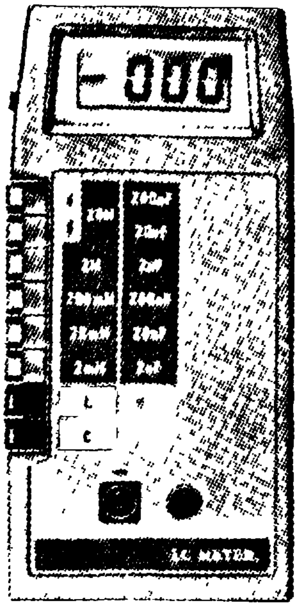
A remarkable feature of the instrument shown above is the Data Logger. This is specially suitable for longterm measurements, as for example the line fluctuations, instabilities, superimposed slow variations on dc-lines. 100 data + Hi and Lo can be stored in 6 different speeds from 3 reading/sec to 1 reading/h.

Options: battery pack, supply for 6h
IEEE-488 interface for remote control

BC (F)

3.3.3 Capacity and Inductivity Meter

digital, direct reading (3 1/2 digits)



Capacity:

1 pF	-	2 nF	
10 pF	-	20 nF	
100 pF	-	100 nF	
1 uF	-	1 uF	
10 uF	-	20 uF	
100 uF	-	200 uF	

Inductivity:

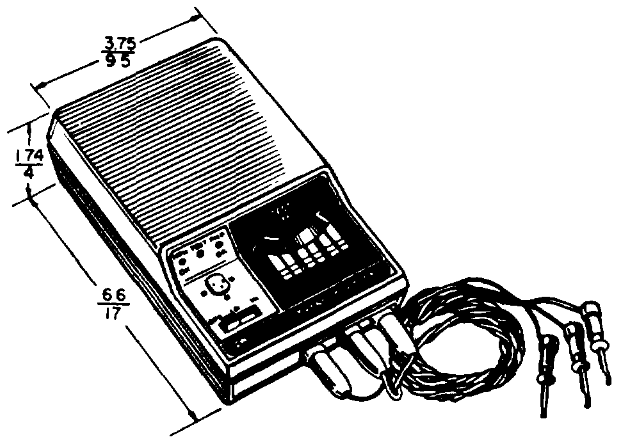
1 uH	-	2 mH
10 uH	-	20 mH
100 uH	-	200 mH
1 mH	-	2 H
10 mH	-	20 H

The instrument is battery powered (9V)

accuracy: < 0.5%

lead compensation possible

3.3.4 Portable Transistor Tester



AB(C) F

This low-cost type of transistor tester uses digital high current, low duty cycle pulse-testing technique to test semiconductors even with resistive and capacitive shunt impedances.

Fast GO/NO-GO in-circuit transistor testing.

Fast and thorough GOOD/BAD out-of-circuit testing.

Tests FETs and SCRs in-circuit or out-of-circuit.

Any test clip to any component lead gives positive emitter-base-collector identification on LO drive - positive base identification in HI drive.

Light-Emitting Diodes indicate NPN-OK or PNP-OK.

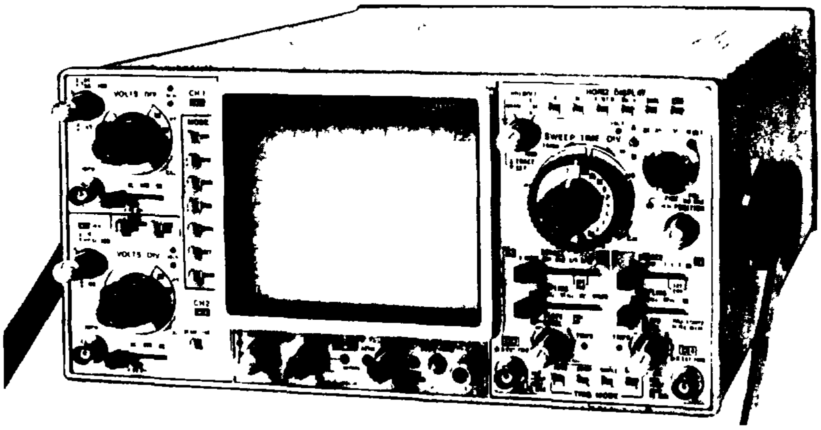
Power requirements: 6VDC from four "AA" cells.

Standby current, 4mA; average testing current, 12mA.

3.3.6 Oscilloscope

DC-100 MHz, Dual-trace, signal delay, delayed trigger
5mV (1mV)/div, 3.5ns

An economic instrument for advanced troubleshooting and development work.



Ch1, Ch2 used for vertical analysis (Y)

Ch3, Ch4 used for (X) and ext. trigger (time reference)

Specifications (abbreviated):

VERTICAL AXIS (Ch 1, Ch 2 identical)

sensitivity: 5mV/div to 5V/div(X1 mode)
1mV/div to 1V/div(X5 mode)
accuracy: ± 2%
attenuator: 5mV/div to 5V/div
input: 1M 22pF
f-response
DC: DC to 100MHz (-3 dB)
AC: 5Hz to 100MHz (-3 dB)
operating modes: Ch1, Ch2, DUAL, ADD QUAD, ALT, CHOP

VERTICAL AXIS (Ch3, Ch4)

sensitivity: 0.1V/div, 1V/div ± 2%
attenuator: 1/1, 1/10
input coupling mode: DC only

TRIGGERING

A modes: AUTO, NORM, SINGLE, FIX
source: V MODE, CH1, CH2, (EXT) CH3 1/1 and 1/10, LINE
coupling: AC, LFREJ, HFREJ, DC, VIDEO

INTENSITY MODULATION INPUT

VERTICAL AXIS, GATE OUTPUT (A and B)

HORIZONTAL AXIS (Ch 2)

modes: X-Y mode is switch selectable (HORIZ DISPLAY)

SWEEP

modes: A, ALT, A-INT-B, B DLY'D, DUAL, X-Y, HOLDOFF

delay method: continuous delay trigger delay

delay time: 0.2 to 10 times the sweep time from 200ns to 0.5s, continuously adjustable

B modes: STARTS AFTER DELAY, TRIGGERABLE AFTER DELAY

BC (F)

3.3.8a Double Pulse Generator

The simultaneous positive and negative outputs deliver 2 watts into 50 ohms.

Pulse amplitude, width, delay and repetition rate are continuously variable.

Other capabilities include single or double pulse operation, external triggering synchronous or asynchronous gating, reference trigger outputs, sine wave triggering, and manual single pulse operation.

Specifications:

repetition rate	10 Hz - 10 MHz
external trigger	± 0.25V, 20nsec min, 50 Hz - 10 MHz sin. 1Vrms manual cycle
synchronous, asynchronous	gating possibilities
advanced trigger	+ 1.7 V min, 15ns
reference trigger	+ 2 V min, 15ns
pulse mode - single:	one output pulse at the end of the delay period
- double:	two identical pulses per cycle first after the reference trigger, second after the selected delay
pulse delay	40 ns - 10 ms
pulse width	40 ns - 10 ms
pulse height	0.5 - 10V (50)

ABC F

3.3.9 DC-Power Supply

A large number of different types are available on the market, covering the range from rather simple ones to high performance power supplies.

Typical specifications for an application in a nuclear electronics laboratory are:

3 independent outputs

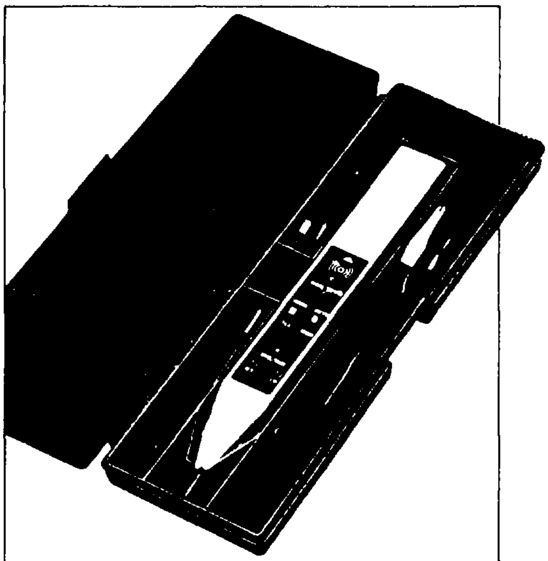
0-5.5 V/7A
0-30 V/1A
0-30(65) V/1.2 (0.6)A

Output voltage adjustable with precision pot.	± 0.3%
Output current adjustable, short circuit proof	
Load effect (0-100%)	< 5 (< 8) mV
Source effect (± 10%)	< 2 mV
Noise	< 5 mVpp
Over-voltage protection	

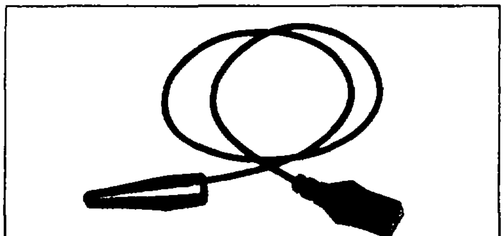
ABC

3.3.14 Digital Logic Probe

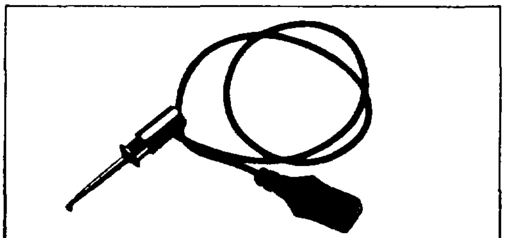
Compatible with DTL, TTL, CMOS. Min. pulse width 10nsec. supply voltages 4.5V to 30V dc.



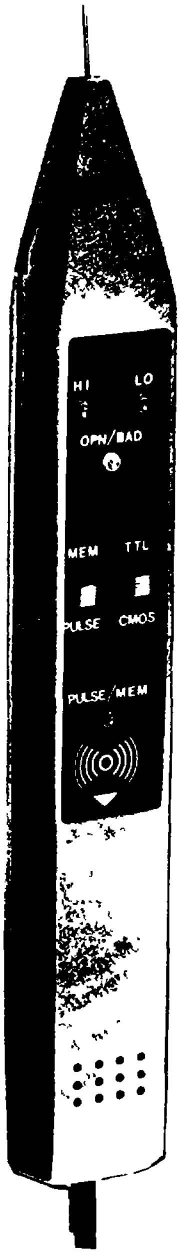
DELUXE MOLDED PLASTIC CARRYING CASE



GROUND LEAD



IC-CLIP LEAD



indications:

HI red
LO green

open-circuit:

yellow

pulse-memory:

red

mode:

pulse/memory

level:

TTL/CMOS

frequency range:

dc - 50 MHz

input impedance:

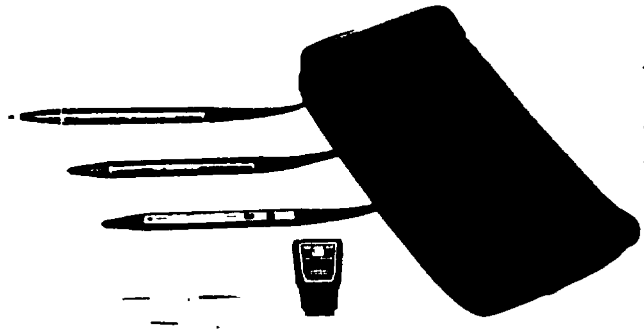
> 10 M

General specifications:
LOGIC THRESHOLD

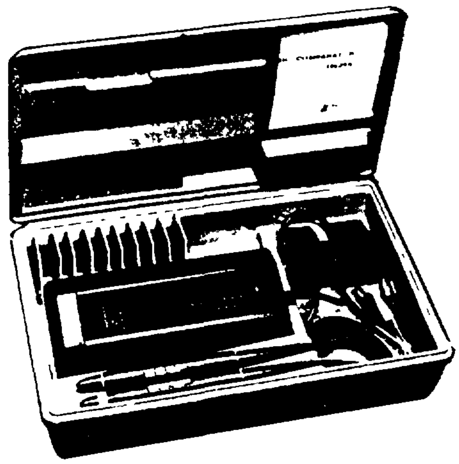
TTL Logic "1"HI: 2.2V +0.3V(@5V DC) CMOS Logic "1"HI: 70% VDD±10% VDD
Logic "0"LO: 0.7V +0.3V(@5V DC) Logic "0"LO: 30% VDD±10% VDD

Power: 4.5V to 30V DC, 50mA max. @5V DC
Input Overload Protection: ± 50V DC/AC continuous
Max. ± 120V DC/AC for 10 seconds
Power Input Protection: ± 50V DC/AC continuous
Max. ± 100V DC/AC peak for 10 seconds
Audible Warning: Built-in buzzer emits alarm when an input signal exceeds the VDD of the circuit being tested or when a voltage higher than 30V DC is applied to power input or when power lead is connected reversely or with AC line. ABC F

3.3.16 Digital Circuit Tester



A complete multi-family kit. Stimulus-response capability, in-circuit fault finding, dynamic and static testing, multi-pin testing.



To accomplish troubleshooting at the node and gate level, both stimulus (Pulser) and response (Probe, Tracer, Clip and Comparator) instruments are needed. Moreover, instruments with both voltage and current troubleshooting capability help isolate electrical faults where the precise physical location is hard to identify.

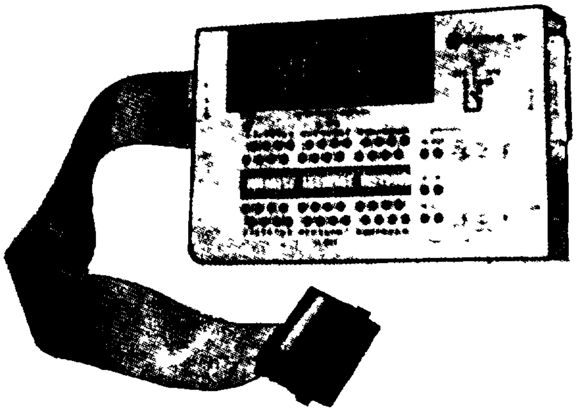
FAULT	STIMULUS	RESPONSE	TEST METHOD
Shorted Node[1]	Pulser[2]	Current Tracer	• Pulse shorted node • Follow current pulses to short
Stuck Data Bus	Pulser[2]	Current Tracer	• Pulse bus line(s) • Trace current to device holding the bus in a stuck condition
Signal Line Short to Vcc or Ground	Pulser	Probe, Current Tracer	• Pulse and probe test point simultaneously • Short to Vcc or Ground cannot be overridden by pulsing • Pulse test point and follow current pulses to the short
Supply to Ground Short	Pulser	Current Tracer	• Remove power from circuit under test • Disconnect electrolytic bypass capacitors • Pulse across Vcc and ground using accessory connectors provided • Trace current to fault
Internally Open IC	Pulser[2]	Probe	• Pulse device input(s) • Probe output for response
Solder Bridge	Pulser[2]	Current Tracer	• Pulse suspect line(s) • Trace current pulses to the fault • Light goes out when solder bridge passed
Sequential Logic Fault in Counter or Shift Register	Pulser	Clip	• Circuit clock de-activated • Use Pulser to enter desired number of pulses • Place Clip on counter or shift register and verify device truth table

The table shows a series of typical node and gate faults and the combination of tools used to troubleshoot the circuit. As with all sophisticated measuring instruments, operator skill and circuit knowledge are key factors once the various clues, or "bits" of information, are obtained using the IC Troubleshooters.

BC (F)

3.3.17 Break-Out Box

A tester for V24, RS-232 interfaces



The instrument is inserted into the RS-232 link.

LEDs show the status of each line.

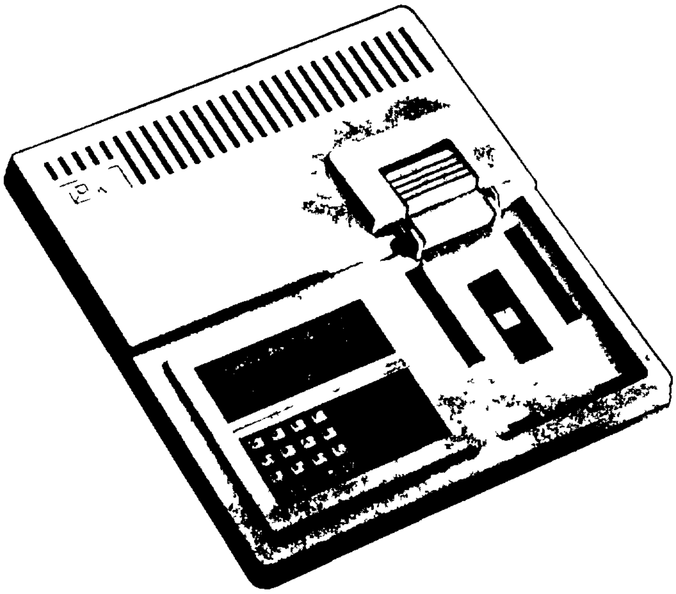
With DIP-switches each line can be interrupted and arranged, also a low or high level can be applied.

A delay of two adjustable times is possible for each signal.

Such economic instruments are recommended for fast troubleshooting of serial interfaces.

ABC F

3.3.20 Prom Programmer



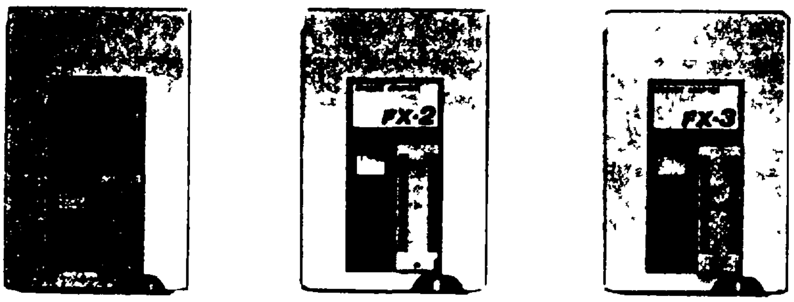
suitable for programming Proms of the type 2716 to 27512

serial and parallel interfaces

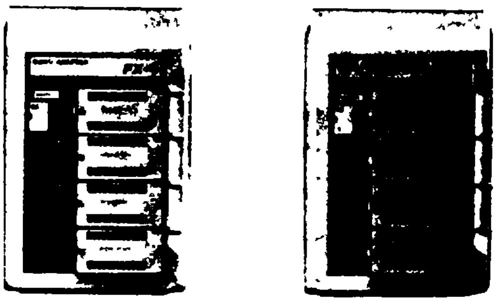
512 k-bit RAM internal memory

The capabilities of such an instrument are:

programming (4 programming algorithms)
editing (e.g. editing the buffer RAM)
CPU communication (operation from a host computer)
emulation (transfer data from buffer RAM to optional emulator module)
interface to an external device (RS-232, Centronics)



3 adaptors for copying different types of E-Proms



2 adaptors mainly used for multiple-copying of E-Proms (gang-programming)

Some Prom-programmers on the market are also able to program Bi-polar devices and PALs.

But normally, PAL-circuits are protected and therefore no copying is possible (spare PAL circuits have to be ordered from the manufacturer).

The Prom Programmer described requires for E-Proms a personality module for the individual Prom families to be programmed. Especially with new devices, it takes some time until such cards become available from the manufacturer and sometimes even a modification to the basic instrument is necessary to provide the required features.

New Prom Programmers which are now available allow programming of the individual parameters for burning a device into their memory and are therefore more flexible. Personality cards for these instruments are not necessary.

C

3.4 RECOMMENDED ELECTRONIC COMPONENTS

Below is a list of spare parts and electronic components that are considered to represent an optimal store for a medium large electronics service laboratory. The last column in the catalogue number refers to a large mail house in the FRG (Fa. Buerklin, P.O. Box 200440, 8000 Munich, FRG). The value of these components is about US$ 4.000.-. By adjusting the number of ordered components, a less or more expensive stock can be acquired.

Item	Quantity	Description		Cat. No.
	Resistors			
1	50	Metal resistor	1R00	31E710
2	50		3R32	31E760
3	50		5R90	31E778
4	50		6R81	31E781
5	100		10R0	30E100
6	100		33R2	30E150
7	100		51R1	30E168
8	100		75R0	30E184
9	100		100R	30E196
10	100		475R	30E261
11	200		1K00	30E292
12	100		3K48	30E345
13	200		10K0	30E389
14	200		100K	30E485
15	200		1M00	30E582
16	50		3M90	30E645
17	50		10M0	30E695
18	1	Service Sortiment, CCR-011R		27E230
19	5	Resistor 5W,0R33		62E112
20	5	0R47		62E116
21	5	0R68		62E118
22	5	1R0		62E124
23	3	Resistor network	10W,MR1	37E900
24	3		MR2	37E905
25	3		MR3	37E910
26	3		MR4	37E919
27	20	Varistors 275VAC,1W		82E2255
28	20	150VAC,1W		82E2235
	Capacitors, coils			
29	50	Tantal capacitor	6.8uF,16V	26D479
30	50		6.8uF,35V	26D600

31	50		10uF,16V	26D480
32	50		10uF,35V	26D605
33	50		22uF,16V	27D524
34	50		22uF,35V	27D568
35	50		47uF,16V	27D528
36	50		47uF,35V	27D572
37	1	Service Sortiment,	CCC-001	28D810
38	50	Electrolytic cap.	1000uF,40V	11D315
39	50		2200uF,40V	11D320
40	50		4700uF,40V	11D325
41	50		10000uF,25V	11D274
42	50	Ceramics cap.	10pF,63V	59D162
43	50		100pF,63V	59D174
44	50		470pF,63V	59D182
45	50		1nF,63V	59D200
46	50		10nF,40V	59D250
47	50		100nF,50V	53D661
48	20	Ceramics, high vol.	10pF,3kV	61D300
49	20		100pF,3kV	61D324
50	20		22pF,3kV	61D308
51	20		10nF,3kV 10uF,6kV	61D352
52	20	Styroflex capacitor	470pF,160V	49D304
53	20		1000pF,160V	49D308
54	20		10000pF,160V	49D314
55	20	HF-coil 22uH		74D316
56	20	100uH		74D324

<u>Potentiometers</u>

57	10	Potentiometer	1K	68E223
58	10		4K7	68E225
59	10		22K	68E227
60	10		100K	68E229
61	5	10turn potentiometer,	1K	67E853
62	3		2K	67E854
63	3		5K	67E855
64	3		10K	67E856
65	3		100K	67E860
66	3	Dial		20H712

<u>Transistors and linear integrated circuits</u>

67	10	JFET, 2N4416	27S7700
68	10	2N4861	27S8300
69	10	2N3819	27S4700
70	10	2N3823	27S4850

71	100	Bipolar Transistor, 2N3904	27S5200
72	100	2N3906	27S5300
73	20	Transistor, BFY90	17S4000
74	10	Comparator, LM710	41S5300
75	10	LM711	41S5350
76	10	LM311D	41S2290
77	10	Operational amplifier, LM741CD	41S5380
78	10	LM748CD	41S5405
79	10	LM318D	41S2575
80	10	LM324D	41S3175
81	10	LF356N	40S9000
82	10	LF357N	40S9060
83	10	TL071CP	49S5500
84	10	CA3140E	40S2950
85	20	Voltage regulators, LM723CD	41S5370
86	10	UA7805CKC	50S1450
87	10	UA7812CKC	50S1600
88	10	UA7824CKC	50S1750
89	10	UA7905CKC	50S1800
90	10	UA7912CKC	50S1950
91	10	UA7924CKC	50S2100
92	20	LM317T	41S2550
93	20	LM337T	41S3600
94	10	LM340K12	41S3750
95	10	Darlington Transistor, BD651	14S6150
96	10	BD652	14S6200
97	5	Power Transistor, 2N3055S	27S2500
98	5	Power switching Tr. MJE3055	24S4900
99	5	Power HV Transistor, BU208	19S2950
100	5	Power switching MOS FET BUZ80	19S6800
101	5	Power Transistor, TIP33F	25S2875
102	20	npn Transistor 2N2219A	27S1100
103	20	pnp Transistor 2N2905A	27S1950
104	20	npn Transistor, 2N2222A	27S1250
105	20	pnp Transistor, 2N2907A	27S2150
106	10	npn Transistor, BD139-16	13S5300
107	10	pnp Transistor, BD140-16	13S5500
108	5	Thyristor, 2N4441	27S7800

Diodes, zener diodes

109	50	Diode, 1N4007	26S8100
110	100	1N4148	26S8150
111	20	1N5408	26S8876
112	5	Bridge rectifier 3A,600V	55A658
113	3	10A,500V	57A190
114	5	Switching diode, MR854	24S4910
115	10	Zener diode ZPD 5.1	25S8000

116	10	ZPD 5.6	25S8050
117	10	ZPD 6.8	25S8150
118	10	ZPD 8.2	25S8250
119	10	ZPD 10	25S8350
120	10	ZPD 12	25S8450
121	10	ZPD 15	25S8550
122	10	ZPD 24	25S8800
123	10	ZPD 33	25S8950

Fuses

124	1	Servicesortiment, fast	46G240
125	1	slow	46G244
126	20	Precise fuse 0.1A	46G268
127	20	0.4A	46G274
128	20	1.6A	46G280
129	20	4A	46G284
130	20	slow, 0.4A	46G319
131	20	1.6A	46G325
132	20	4A	46G329

Soldering supplies

133	5	FLUITIN soldering wire, 100g, 0.75mm	11L402
134	5	Desoldering wire, 1.3mm	10L752
135	5	2.5mm	10L756

Connectors and cables

136	5	BNC extension connector	78F270
137	5	BNC, T	78F290
138	20	BNC, cable plug	78F200
139	3	NIM connector, male	55F7251
140	3	NIM connector, female	55F7253
141	50	Centering pin	55F760
142	50	Centering receptors	55F766
143	100	Contact pins	55F7725
144	100	Contact receptors	55F778
145	6	Protecting cover	55F798
146	3	Connector, 9pol, male	55F400
147	3	25pol, male	55F401
148	3	9pol, female	55F410
149	3	25pol, female	55F412
150	300	Pins	55F408
151	300	Pins	55F418
152	25m	Cable RG58C/U	96F730
153	10m	RG59B/U	96F746
154	20m	Cable, 5pol	94F306
155	10m	Flat cable, 50pol	94F439

Digital integrated circuits

156	50	SN74LS00N	43S2750
157	50	SN74LS02N	43S2900
158	50	SN74LS10N	43S3250
159	50	SN74LS74AN	43S4600
160	50	SN74LS90N	43S4950
161	20	SN74LS138N	43S5900
162	20	SN74LS123N	43S5550
163	20	SN74LS191N	43S7150
164	20	SN74LS193N	43S7250
165	10	SN74LS374N	43S9900
166	10	SN74LS245N	43S7800

LEDs

167	20	LED, 3mm, red	67S4350
168	20	3mm, green	67S4450
169	20	5mm, red	67S4500
170	20	5mm, green	67S4600

Switches

171	5	Switch, 1pol, E-E	10G700
172	5	2pol, E-E	10G740
173	5	2pol, E-A-E	10G750

Miscellaneous

174	1 set	Screws	16H695
175	1 set	Nuts	16H954
176	1	Heat conducting paste	80B533
177	1 pak.	Wire wrap pins	12H592
178	2	Fuse holder, 5x20mm	46G628
179	2	6.3x31.7mm	46G642
180	10	IC-breakable sockets	16B110

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SKILLS: Reading and Understanding of Circuit Diagrams

Diagrams are the main aids to repair. For fault location the most essential information is that concerning functional structure, i.e. how the components are connected to perform their required function. Circuit diagrams are often criticized on the basis of bad presentation; due to this, national standards were developed to specify the requirements for an efficient diagram.

According to British Standard: "Diagrams should be drawn so that the main sequence of cause-to-effect goes from left to right, and/or from top to bottom. The input should always be on the left, and the output on the right. When this is impractical, the direction of operation should be shown by an arrow. Components associated with each operational stage should be grouped together."

Unfortunately, really good circuit diagrams are still rare. It is often said that the after-sales policy of the manufacturer is mirrored in the diagrams. Some companies prefer to give repair services and they distribute almost useless circuit diagrams to scare away non-factory approaches to maintenance.

The standardization of the graphic symbols for components is much more efficient; however, some companies still use their own local standards in the nuclear field. The same applies to cable connection notations and markings. There is no general rule; each company has its own graphic symbols in multi-sheet diagrams for interconnections, test points, etc.

During repair work, correct reading of the graphic symbols is essential. This should be tested very carefully; even a single mistake in identifying the symbols indicates further learning requirements.

The next step is to test ones' colour code reading capabilities. For efficient repair work, one should acquire a faultless reading capability with a rate of ten items per minute. Colour blindness inhibits the correct identification of resistor values. This can be rather dangerous in repair work and it should be avoided by employing personnel without this deficiency.

It is very important to be able to locate certain components on the circuit board from the circuit diagram and vice versa. Skills can be quickly developed by training. An acceptable level is demonstrated by being able to correctly locate ten components, both ways, in ten minutes.

The capability to locate components running at high voltage is a needed skill in nuclear instrument repairs. The repair personnel should be able to correctly mark with red pencil all high voltage lines and components on the diagram within 30 minutes, and they should be able to locate the same in the instrument as well.

In many systems, interlocks, fuses, and thermo-switches might inhibit operation due to present or past hazard situations. Often they are connected to logic circuits, timers, etc. The technicians should be able to correctly identify such circuits within ten minutes.

Circuits can be inoperative because of faulty switch functions. It is important to be able to identify which circuit points should be connected together to secure operation and which lines should be cut. Such decisions should be correctly made within five minutes.

Signal propagation determination is very important. This can be a complicated task. The general rule is to find each active components inputs and outputs. This requires familiarity with the IC pin configurations: location of the power inputs and signal lines. It is not important to memorize these pins, however. In two minutes time one should be able to list the expected voltage levels and signals on a 14-pin IC, after looking on its diagram and the specifications in the catalogue.

A nuclear electronics service man should be able to discriminate between filtering circuits around the power lines and frequency characteristics determining components round amplifiers. They should be able to correctly group such components at a rate of four items per minute.

In some circuits the feedback loops are rather elaborated. However, they should be correctly identified as the time limit is one hour.

The real test of "understanding" a circuit is if the electronician can prepare a correct functional diagram of the circuit.

The general rules for producing functional diagrams are:

- the main signal flow must be from left to right;
- the signal flow must be emphasized; this can be done by showing flow paths in a straight line, avoiding crossover of flow paths;
- arrows may be used to indicate direction of flow, only to avoid ambiguity;
- main inputs must be on the left and outputs on the right; the source of all inputs and the destination of all outputs must be shown;
- all plugs, sockets, controls, test points and terminals useful in troubleshooting must be shown and referenced; normal state measurements for all test points must be available;
- symbols must be according to local standards.

It is a good practice to mark points where stages can be isolated from each other, with indication of possible test signals and expected correct outputs.

In the case of missing drawings and documentation, the functional diagram preparation is recommended as an efficient aid in repair work vs. the traditional draftsman approach.

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Chapter 4
TROUBLESHOOTING IN SYSTEMS

4 TROUBLESHOOTING IN SYSTEMS

4.1 INTRODUCTION

A NaI detector is used in many fields of application of nuclear techniques, e.g. in nuclear medicine, radioimmunoassay, agronomy, radiation protection and uranium prospection. Therefore, a NaI detector system was chosen as an example of troubleshooting in a detection system. Such a system consists of a detector, usually surrounded by a radiation absorbing shield and a collimator, a preamplifier, an amplifier, a single channel analyzer (SCA) and a scaler-timer or a ratemeter, or, instead of the last three, a multichannel analyzer (MCA). Furthermore, the system contains a high voltage supply (HV) and several low voltage DC supplies (LV). The units composing the system and their functions are given in Fig. 4.1. For other detectors, a similar set of electronic units is used with characteristics adapted to the particular detector. In the following text, examples are taken from medical applications. The reader should be able to find equivalent ones in his own field of application.

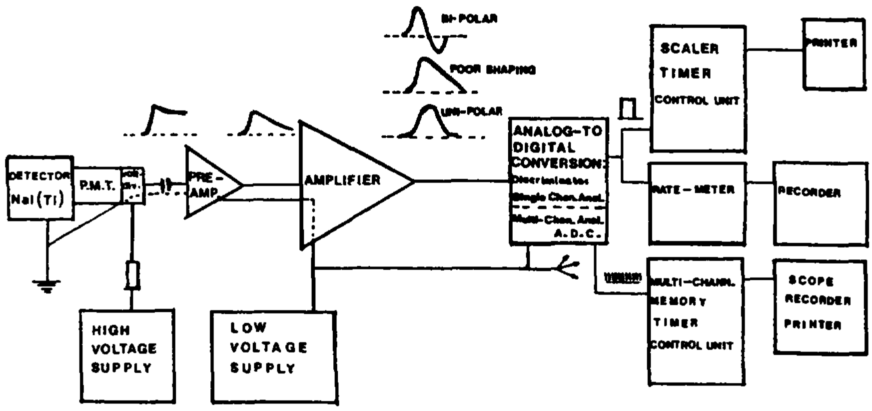


Fig. 4.1: A typical NaI system

Most of the instrument users, applying nuclear techniques, work in fixed geometry, and with fixed HV, amplifier and single-channel-analyzer settings. Most of their measurements are relative measurements: a comparison is made with radioactive standards. Thus when the user or operator says, "My instrument does not behave as it should", one expects that they have not changed their instrumental settings. However, checking those settings is the first part of troubleshooting, since a clear distinction must be made between user/operator errors and instrument failure.

Many of the questions which must be asked during troubleshooting can only be answered correctly when instrument settings and previous test results are available in a logbook.

4.2 INSTRUMENTS AND SKILLS

The following instruments and tools are required for a system check (for detailed information, see Chapter 3):

- a multimeter (MM);
- an oscilloscope (O) 0-15/20 MHz, with dual beam or dual trace, sensitive trigger properties (it must be possible to trigger both channels at the same time or alternatively with the signal on one channel) and with signal delay lines to enable visualization of the front edge of pulses;
- a set of screwdrivers, Allen keys, plyers, flat keys;
- (a) pulse generator(s) (PG) with which nuclear pulses can be simulated, both for analog pulses and for digital pulses; and
- a radioactive test source, with known activity, preferably the same as used during acceptance testing.

In order to do troubleshooting one should know: (1) the usual composition of a NaI detection system and the functions as given in Fig. 4.1; (2) the forms of the signals at the output of the PMT, the preamplifier, amplifier and single channel analyzer; (3) why one does not observe a signal at the input of a charge sensitive amplifier; (4) that the rise time of the pulse at the output of the PMT depends on the half life of the scintillation process in the detector; and (5) that the pulse heights and shapes at the output of the pulse amplifier are so chosen as to fit best to the SCA (or MCA) and to guarantee optimum spectrum resolution.

Each of the following paragraphs gives a possible indication of failures as may be given by instrument users/operators and a list of possible origins or reasons for these failures and, when not obvious, actions to be taken. There may be among the operators very unexperienced ones. This may lead to some reasons which seem ridiculous; nevertheless, they are based on experience in the field.

4.3 THE INSTRUMENT DOES NOT WORK

To be checked:

1. Is the instrument switched on?
2. Is there power on the AC outlet?
3. Are the connections in the AC plug all right? Is the power cable all right?
4. Are the fuses on the instrument all right (AC and DC)?
5. Are the DC power supplies all right?

6. Are the signal lamps faulty?

4.4 THE INSTRUMENT DOES NOT COUNT

To be checked:

1. Is the test scaler in test function?
2. Is the HV switched on and connected to the detector?
3. Is the input polarity of the amplifier correctly set?
4. Has the threshold of the SCA been set to maximum or the window to 0?
5. Are the DC fuses all right?
6. Are the DC supplies correct? Check voltages of HV and LV.
7. Are all signal cables alright? Check the presence of signals at the output or preamplifier, the input and output of the amplifier, the input and output of the SCA and at the input of the scaler. Check whether the plugs are correctly mounted, e.g. the pin in a male BNC may be moving backwards when connected to the socket.
8. Are the cables connected to correct inputs and outputs?

4.5 THE COUNT RATE IS LOWER THAN USUAL

Possible reasons:

1. There is no radioactive source in the measuring position, or a wrong source, a wrong patient or sample, a patient wrongly injected.
2. The instrument is set incorrectly for the radioisotope used.
3. There is more absorbing medium between source and detector than usual: different source (test-tube) shapes, or the test tube has thicker walls or is made of material other than what is usual.
4. The source-detector geometry has changed, or the sample did not fully reach the measuring position.
5. A wrong collimator is used (particularly for a scanner).
6. The AC frequency is too high (in case the timer uses the AC frequency as time base). Check with wristwatch.
7. The HV setting is incorrect.

8. The settings of the amplifier have been changed.

9. There is a change in the SCA setting.

10. There is a change in the scaler threshold setting, in the scale factor or input polarity.

11. The LV power supplies are faulty; the HV supply is faulty.

12. The preamplifier or amplifier is faulty, check pulse shapes.

13. There is a change in pulse height or shape. See section 4.7

14. The SCA is faulty: output pulse height or pulse duration incorrect.

15. The scaler has an intermittent failure or is faulty.

16. The time clock is defective. Check with wristwatch.

17. A broken resistor in the dynode chain, a bad photomultiplier, a bad optical coupling between scintillator and PM, a shorted capacitor in the dynode chain.

4.6 THE COUNT-RATE IS HIGHER THAN USUAL

Possible reasons:

1. There is an extra background source: detector directed to source preparation or store rooms, injected patients near to detector, radioactive contamination, a test source is not placed in its lead container, people in neighbouring laboratories are using radioactive sources, etc.

2. The patient is injected with the wrong radioisotope, wrong patient wrong source.

3. The patient was previously injected with another radioisotope.

4. The instrument is set incorrectly for the radioisotope used.

5. There is less absorbing medium between the source and the detector than usual; a different source (test tube) shape, the test tube has a thinner wall, or is made of a different material than usual.

6. The source-detector geometry has changed.

7. A wrong collimator is used.

8. The lead shield or collimator has been removed or changed in position.

9. There is a change in amplifier, SCA or HV setting.

10. The AC frequency is too low (in case the timer uses the AC frequency as time base). Check with wristwatch.

11. The scaler has a wrong setting of the scale factor and/or input polarity, or the setting of input discriminator has been changed.

12. For medical laboratories: the activity meter (dose calibrator) is faulty.

13. There are parasitic pulses, spurious counts or noise. See section 4.7

14. The output pulses of the amplifier have overshoots. Overshoots may be counted too! Pay attention to signal reflections in long cables. Overshoots may cause ghost peaks on MCA systems with a fast ADC. Check signal shapes. See section 4.7

15. The earthing has changed or ground connections have loosened.

16. The DC power supplies are not correct (LV, HV).

17. The amplifier or preamplifier is faulty. Check pulse shapes.

18. There is a change in pulse height or shape. See section 4.7

19. The SCA is faulty.

20. The scaler is defective.

21. The timer is defective.

22. There is a light leak in the PMT and/or the canning of the detector resulting in extra pulses in the low energy part of the spectra and peak widening.

4.7 THE PULSE HEIGHT IS LOWER OR HIGHER THAN USUAL

Possible reasons are:

A. Without change in pulse shape:

1. Incorrect radioactive source.

2. Incorrect HV setting.

3. Incorrect amplifier settings: amplification factor, pulse polarity.

4. The detector assembly has been interchanged.

5. The amplification factor of the preamplifier has been changed.

6. A channel shift or wrong setting of the SCA (this question comes up only when no oscilloscope is used).

7. The detector is broken or yellow-brown (this cannot be checked for an integral line assembly).

8. A bad optical joint between the detector and the PMT (this cannot be checked for an integral line assembly).

9. A HV supply failure.

B. <u>With change in pulse shape (rise time, fall time, over- and undershoots)</u>:

10. Incorrect setting of differentiation and integration time of the amplifier.

11. The pulse height and/or shape at the output of the preamplifier has changed.

12. A faulty pulse-shaping amplifier.

13. The ground connection to the detector canning is loosened or interrupted, or in general, a change in earthing.

14. The PMT is faulty or has changed its characteristics. The dynodes may have changed position or shape. Especially in portable instruments, rectilinear scanners and other instruments of which the detector heads are moving or are exposed to mechanical shock.

15. Bad contacts in or faulty HV voltage divider, or bad contacts between PMT and base. Attention should be paid to capacitors at the dynodes near the anode.

16. The μ-metal shield has changed its properties or is dislocated (in fact, such a deficiency mainly influences the height of the pulse).

17. A very low AC voltage.

18. A failure in one of the LV supplies.

19. Faulty plug-cable connections.

4.8 SPURIOUS COUNTS

1. Take all radioactive sources away, and check whether background is higher than usual. If yes:

2. Check whether background pulses appear as intermittant trains of (parasitic) pulses.

3. If this is the case, observe pulses on oscilloscope or scaler and try to detect relations between pulse trains and the switching of equipment (incubators, deep freezers, refrigerators, floor polishers, workmen with drills and other machines) in own or neighbouring laboratories.

4. Check whether pulses are coincident with the flickering of fluorescent lamps.

5. Or with starting or running motorbikes and cars on an outside parking.

6. Unproperly filtered AC.

Other origins of spurious counts may be:

7. Electrostatic discharges, especially in very dry laboratories.

8. HV sparking due to dust or humidity or parts starting to fail.

9. Nearby switching thyristors or triacs.

10. When there are nearby radio or TV receivers, check whether the instrument is properly grounded. Try different points, and check connections and coaxial cables.

11. Electrical discharge on surface of components, due to high humidity.

12. Loose cable contacts. Cable-movement-caused noise, microphonics in PM tube.

4.9 THE SPREAD IN THE NUMBER OF COUNTS IS LARGER THAN MAY BE EXPECTED ACCORDING TO STATISTICAL FLUCTUATIONS WHEN MEASUREMENTS OF THE SAME SOURCE IN FIXED GEOMETRICAL POSITIONS ARE DONE EACH DAY

Possible causes may be:

1. An irreproducible source positioning.

2. The use of different source holders or test tubes.

3. Changes in the absorbing medium: dust or dirt in factories.

4. The timer uses (the fluctuating) AC frequency as time base.

5. The setting of the HV is irreproducible or the HV is unstable.

6. Irreproducible settings of the amplifier and/or SCA.

7. Large temperature changes, or too short warming-up times of instrument.

8. Spurious counts.

9. Large AC fluctuations.

10. Unstable LV power supplies.

11. Bad earthing.

4.10 LOSS OF SPECTRUM RESOLUTION

Possible origins are:

1. Disturbances in the HV supply: ripple and fluctuations.
2. Detector colouration or a broken crystal.
3. A bad optical joint.
4. Unstable LV power supplies.
5. An unstable preamplifier or main amplifier.
6. Light leaks into the PMT or detector.
7. The deterioration of the photo-cathode of the PMT.
8. An oscillating preamplifier.
9. Bad earth connections.
10. Mechanical vibrations of dynodes in PMT (rectilinear scanners).

Chapter 5
POWER SUPPLIES

5 POWER SUPPLIES

5.1 GENERAL REMARKS

Before starting to discuss troubleshooting for specific power supplies, some general comments, and some hints for troubleshooting, are given. The discussion on some specific power supplies is presented in Sections 5.3 through 5.7.

> There are two main types of power supplies:
>
> - The linear regulated supplies with power transformer, rectifiers, capacitor filtering, pass transistor, current sense resistor for current limitation either for constant current or with foldback characteristics and the error amplifier including the voltage reference source.
>
> - The switched mode power supply with direct ac line rectifying, filtering, fast switching power transistors, ferrit-core transformer for power transfer, fast switching rectifier diodes, filters with chokes and capacitors current sense resistor for current limitation either for constant current or foldback characteristic, regulator with pulse width modulation including voltage reference source and in the feedback loop either an opto-coupler or a pulse transformer.

The first step in troubleshooting is a visual check, looking for burned components. If the instrument smells, or if smoke is coming out, there is obviously something wrong inside. Try to find out in which part of the circuit the fault appears. Look for cold soldering points. Check the fuses. Transformers are frequently damaged by an overload; fuses of the wrong value were inserted, and did not protect the circuits.

The rectifier diodes can get damaged; the most frequent reasons are:

a) repetitive peak current, and
b) reversed bias voltage.

Occasionally, we might find that the designer made a wrong selection of the diodes; the assumed specifications do not correspond with the ratings. Typical examples are with the frequency of the mains (50:60Hz) or voltage (117:220V).

In older equipment, capacitors may become defective due to heat; they are used at the limits of their voltage specifications; this is especially true for tantalium drop-form capacitors. Pass or power transistors are mainly destroyed by overvoltage, excessive current or overheating. Defects in regulators are caused by reversed bias and overvoltage (voltage spikes which are exceeding the maximum rating). Sense resistors may be destroyed by excessive output current. Dust and dirt obstructs cooling of components, which might lead to overheating and breakdown.

ATTENTION: NEVER trust fully the circuit diagram. Compare it with the circuitry and wiring.

ATTENTION: NO normal fuse can protect a semiconductor; it is always the other way around.

NOTE: After repair, a re-adjustment of the instrument has to be made. If electronic components were replaced by similar ones (and not exactly identical), a quality control check after repair has to be performed and recorded in a log book. This is very important for further troubleshooting.

Different power supplies are being used in nuclear instruments, and in auxiliary equipment that is being applied in nuclear laboratories. Typical types of power supplies are:

(i) NIM power supply, usually about 400W, with the following voltages: +12, +24, -12, -24 (+6, -6);

ATTENTION: Some of the NIM power supplies do not have +/-6V. There are NIM modules that require these voltages.

Some NIM power supplies are delivered in the form of a plug-in module; these usually have current specifications much less than a normal behind-the-crate supply. Furthermore, some of the module connectors in the crate are not supplied with the mains power, so a plug-in module, in such a case, would not work.

ATTENTION: The plug-in NIM power supplies, with their limited power capacity, are easily overloaded. With three modules inserted into the crate, the supply might collapse; DO NOT plug such a module into a NIM-crate that has a power supply in the back.

(ii) Special supplies for individual instruments, such as MCA or pulser;

(iii) Switched mode power supplies, used mainly in computers; they are rather noisy and usually not suitable for powering analog circuits;

(iv) High voltage power supplies; there are several different types, depending on the requirements of voltage, current, and stability.

NOTE: HV-Supplies are designed as DC/DC converters and very seldom as switched mode power supplies.

5.2 TOOLS, INSTRUMENTS, COMPONENTS

Below is a list of the most essential tools, instruments, and electronic components needed in repair and servicing of power supplies in nuclear instruments.

TOOLS: Pliers, cutter, tweezers, solder iron, desoldering tape

INSTRUMENTS:

- Voltmeter (digital), ammeter (5A), variac (220V, 3A, 50Hz)
- Power supplies, either a NIM crate with power supply, or two DC supplies 0-30V, 1A
- Oscilloscope 30MHz
- Variable power resistor 100 ohm with up to 3A load capacity; such a power resistor can be easily made using a power transistor on a heat sink controlled by a potentiometer at its base.

COMPONENTS:

- Rectifier diodes (1A, 3A, Usp 700-1000V)
- Rectifier bridges (5A, 25A Usp 200-500V)
- Transistors: 2N2219
  2N2905
  2N3904
  2N3906
  2N3055
  BD651
  MJE 371
  MJE 321
- Thyristor: 2N4441

- Set of zener diodes, from 5.1V up to 24V
- Switching diodes
- Operational amplifier LM356 or LM741 or almost any other internally compensated amplifier
- Electrolytic capacitors, 1000uF/35V(63V), 4700uF/35V, 10000uF/25V
- Tantalum foil electrolytic capacitors, 10uF/35V

5.3 BEHIND-THE-CRATE NIM POWER SUPPLY

A very common power supply is the one behind the NIM crate. Such a supply is very compact; it is difficult to reach all its components for servicing.

As an example, a NIM-crate power supply, Canberra Model 7021, is described below (see Figs. 5.1 and 5.2).

5.3.1 General Circuit Description

The voltages of the secondary winding of a power transformer are rectified by a bridge where the center tap technique is used. Therefore, one rectifier bridge can generate a positive and a negative voltage. After rectification, there is the classical capacitor filter. In addition to six regulated voltages, two unregulated voltages are generated by the voltage doubler technique (D203, C207, D205, C209 for a positive voltage; D204, C208, D206, C210 for a negative voltage), to supply the monolithic voltage regulator IC for the +24V line, or to bias the driver transistor of the -24V line. In order not to exceed the maximum ratings of the +24V regulator, the positive voltage is limited by a zener diode. An additional +5V voltage is generated by IC 201. All supplies use the common regulator 723 with built-in voltage reference source and the possibility of current limitation.

5.3.1.1 Positive output voltages

The unregulated DC voltage passes through a current sensing resistor to the collector of a npn-power transistor. This transistor is driven by an emitter follower transistor; its base is controlled by the voltage regulator. The DC output voltage is compared with the internal temperature compensated reference voltage. Any deviation from the nominal output voltage causes an amplified error signal to the base of the driver transistor. Each of these regulators is biased from the next higher unregulated supply line. The internal reference source is about 6.9V; therefore, for the 6V line, the voltage adjustment must be done at the non-inverting input instead of the inverting input. The capacitors in this circuit are used for frequency compensation. The voltage drop across the current sensing resistor drives the current

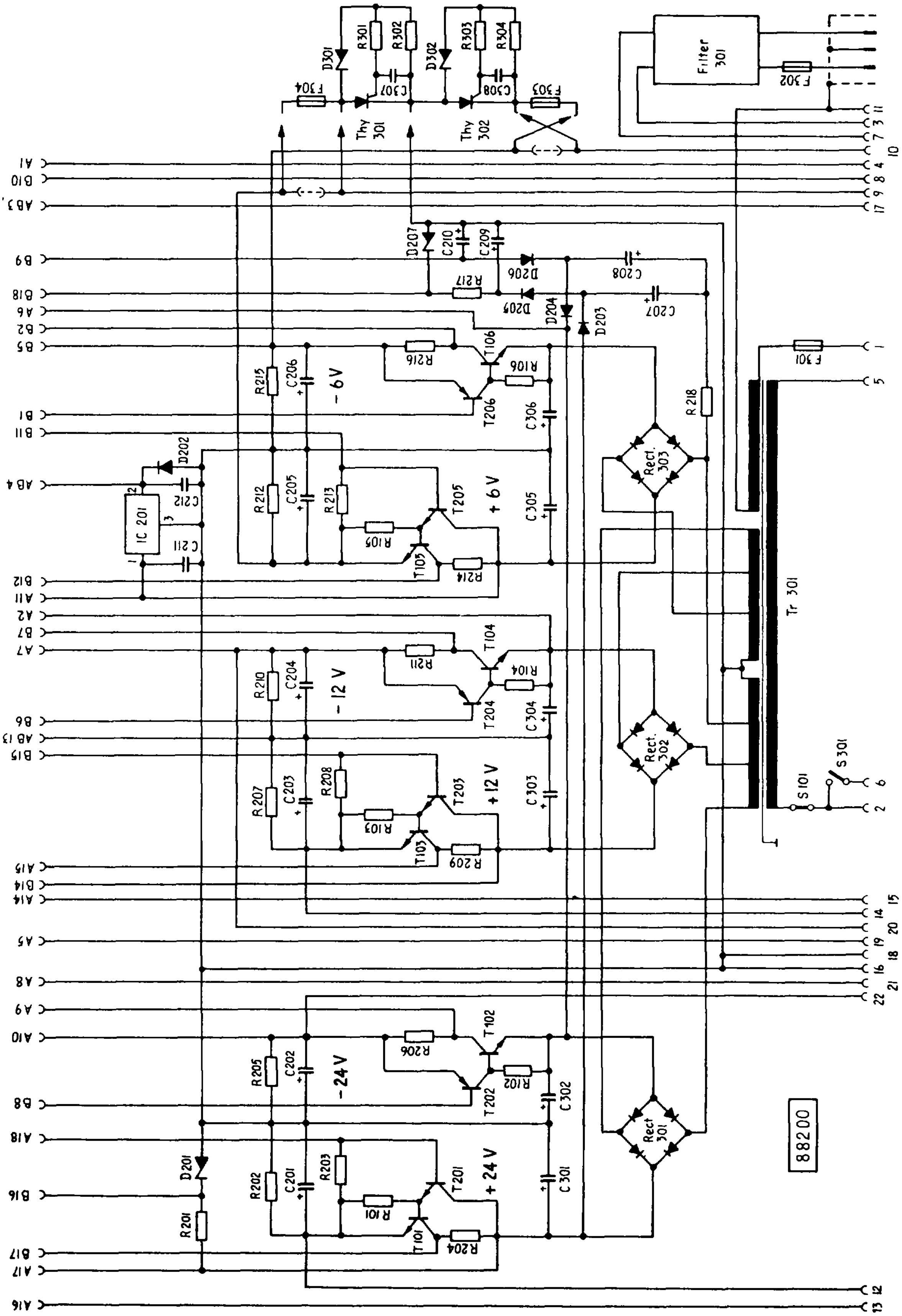


Fig. 5.1: NIM-crate power supply, Canberra Model 7021

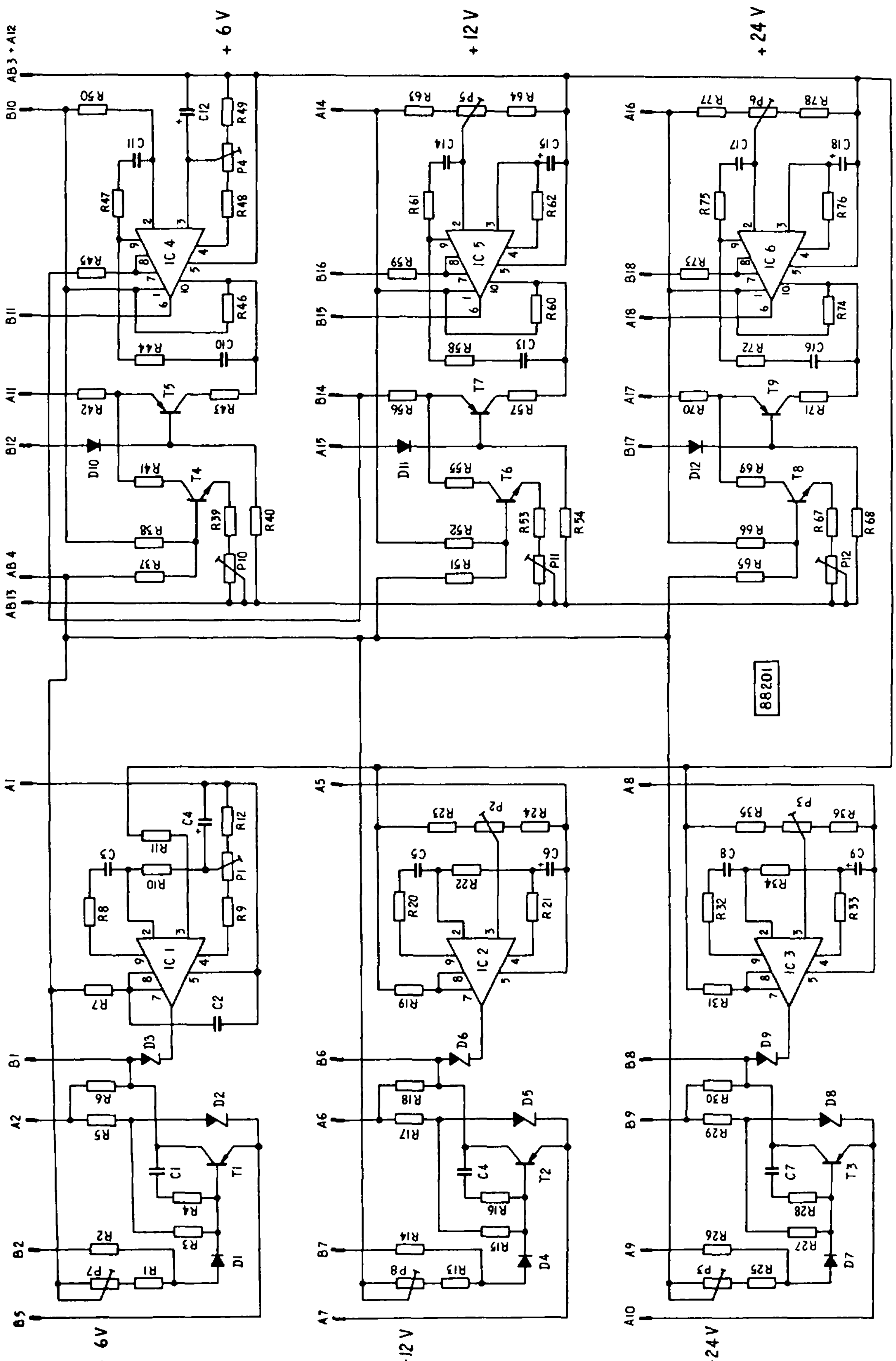


Fig. 5.2: NIM-crate power supply, Canberra Model 7021

limiting transistor that is biased by a constant current source. This constant current source is controlled by a fraction of the output voltage, to achieve foldback current limiting characteristics.

5.3.1.2 Negative output voltages

The unregulated DC voltage is fed to the emitter of a npn-power transistor; its base is driven by a pnp-transistor. An integrated voltage regulator gives the amplified error signal to the base of the driver transistor. For optimum operational conditions of the error amplifier, a zener diode is used for level shifting. The -6V line regulator gets its power at +V from the +5V line and its -V from the -6V sense line. The two other regulators are powered at +V from common and at -V from the corresponding sense line. The 6V regulator's non-inverting input is connected to common and the inverting input is wired to a resistor chain which is connected between the reference-voltage and the sense line. For the -12 and -24 voltages, the reference-voltage is fed to the inverting input and the non-inverting input of IC2 and IC3, and gets its signal from a fraction developed between common and the corresponding sense line. The negative regulated output voltage passes through a current sense resistor at the collector of the output power transistor. The voltage drop is added to the auxiliary +5V voltage and a fraction of the output voltage. The voltage of the matrix point drives a current limiter transistor in case of excessive load current.

5.3.2 Maintenance

For readjustment of output voltages and current, remove the upper cover of the power supply. The corresponding potentiometers for voltage and current adjustments are marked with U and I at the top of the regulation board. Maximum current shall not be adjusted above 120% of nominal value. To verify exact voltage measurements, a separate bin connector and probe cable must be used for load and measurement, to avoid any voltage drop error.

For removal of the chassis from the bin, the two screws on the left and right side of chassis behind the bin have to be removed.

5.3.3 Troubleshooting

When dealing with a nonfunctional NIM power supply, the first step is to measure all output voltages. If one or some output voltages are missing, measure the corresponding unregulated DC voltage. If all unregulated voltages are there, check if there is an excessive load current by measuring the voltage drop across the current sense resistor, corresponding to the missing output voltage. If until now everything seems normal, measure the voltages of the following pins at the corresponding regulator IC. Compare these values with the theoretical ones.

Pin 7, 8 (+V depends on supply)
Pin 5 (common for positive voltages or negative supply line)
Pin 4 (must always be 6.9V higher than pin 5)

No discrepancy found, check that the current limiting transistor is fully cut off (any one of the transistors T1, T2, T3, T5, T7, T9). In normal conditions the base must always be more positive than the emitter. If a fault is revealed, measure the DC voltages in the circuit around this point. Here you can already obtain the information of what could be the cause of the fault. If everything is normal, measure pin 6 of regulator IC.

The following considerations are valid for the positive supply lines: the output voltage of the error amplifier should be 1.2-1.4V higher than the corresponding output voltage line. If this voltage is much higher, one of the following transistors is defective because they are used as voltage follower. In this way, a defective component can be easily detected. If the IC-output does not show the mentioned voltage value, and the voltage between pin 10 and pin 1 is not higher than 0.4V, check the input voltages and compare them with the output voltages: if there is any discrepancy, replace the IC. If the voltage drop is higher, the fault might be either a defective shunt resistor (R46, R60, R74 depending on which line the fault occurs) or at the current limiting circuitry. Measure the voltages around the constant current source transistor (base, emitter, collector of transistor T4, T6, T8 depending on which line the fault occurs).

For the negative supply lines, proceed as follows: the output voltage of the error amplifier, measured after the zener diode, should be about 0.5V negative compared to the corresponding output voltage. If this voltage is more negative, one of the next following transistors are defective. If the output voltage measured after zener diode does not have the nominal voltage value, check the input voltages of the IC and compare them with the output. If any discrepancy is found, replace the IC. At the node of the zener diode and the collector of the limiting transistor, a voltage is developed by the current sum over a given resistor. Therefore, you must check that either this voltage is generated by the current limitation or by the voltage regulation. Due to the condition that no excessive current load should be there, the voltage regulation should be dominant. If this is not the case, the fault must be in the current limiting circuit. For the current limiting transistor the following rule is valid: the base must be more positive than the emitter. If it is not, you must find out how to detect the defective component.

<u>NOTE</u>: If any component was changed, a readjustment has to be made.

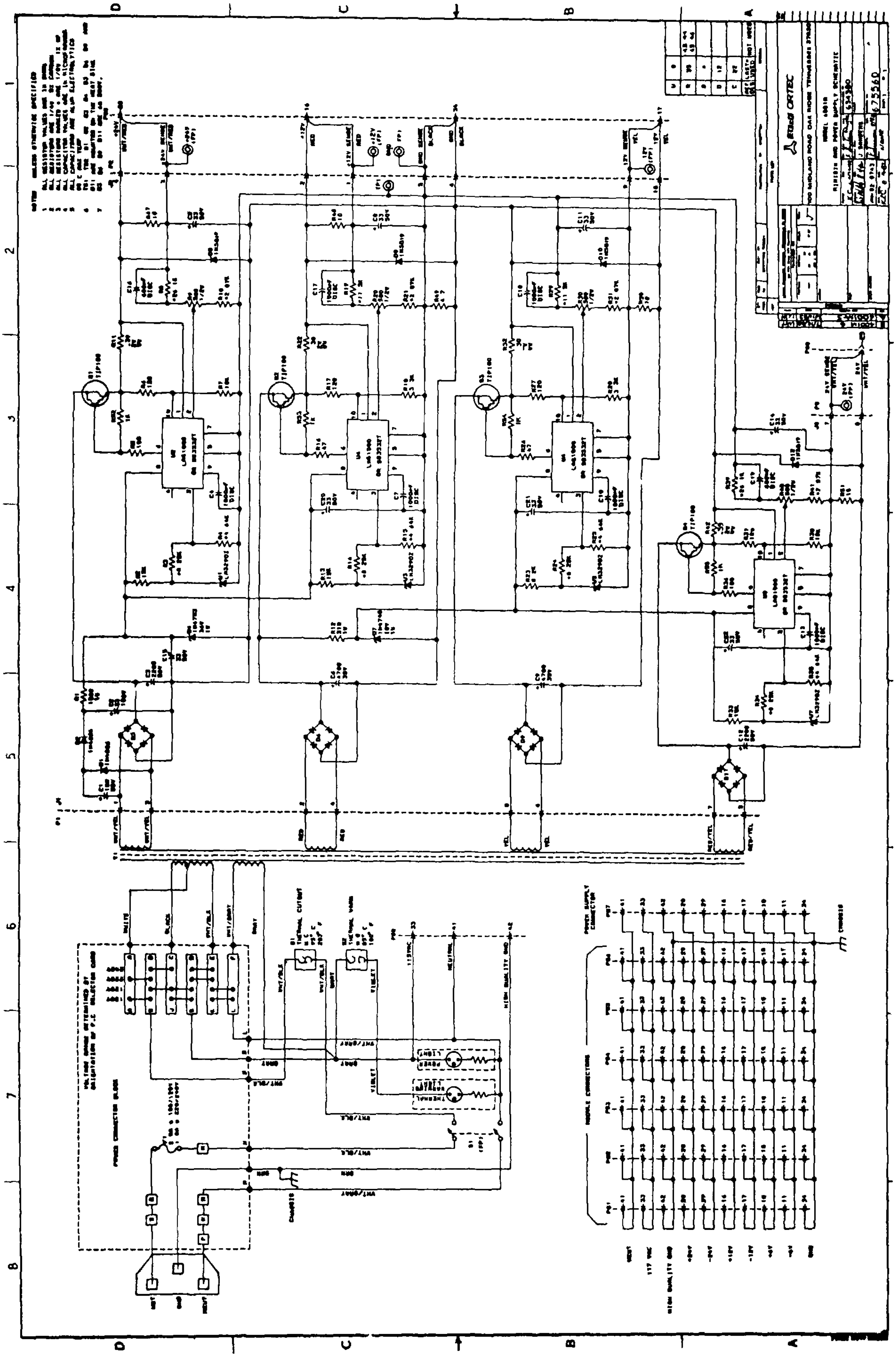


Fig. 5.3: NIM-module power supply of the type 4001M (EG&G)

5.4 PLUG-IN NIM POWER SUPPLY

As already mentioned, there are NIM-plug-in power supply modules available to supply a NIM bin. Such a supply module is described below, and shown in Fig. 5.3.

This module has some limitations:

- it is available only for +12V/1A, +24V/0.5A, -12/1A, -24V/0.5A;
- its maximum power capability is 48W at 50C.

> NOTE: DO NOT plug in such a module in a NIM crate that already has a power supply in the back.

5.4.1 Circuit Description

The power transformer provides four separate low-voltage ac sources. These sources are full-wave-rectified, capacitor-filtered, and regulated by electronic series regulator circuits, which have the capability of regulation and current limitation with foldback characteristics. Each supply voltage has its own reference source and the possibility to adjust the output voltage by a potentiometer.

All four supplies use the same active components; however, the voltage dividers are tuned to the requirements of the output voltage. Two different preregulators are used: one consists of the voltage doubler (D1, D2, C1, C2, na d zener diode D4) for the +12V and +24V supply. The second uses a 10V zener diode for -12V and -24V supply.

The reference voltages of 6.95V are derived from a reference diode (U1, U3, U5, U7).

The regulators are of the type LAS1000 or equivalent. As a pass transistor a npn-Darlington transistor is used (type TIP100 or equivalent).

A reverse-current protection is also built in by the reversed biased diode from the type 1N5819 or equivalent.

Following the above observations, it should be easy to troubleshoot the instrument.

Nevertheless, the following additional comments might be useful.

There are two shock-hazard locations to watch for: the wiring side of the input line cord connector block, and the two thermal switches (S1 for thermal cutout, S2 for thermal warning) mounted against the heatsink. These locations are exposed to the ac-line voltage.

In Table 5.1, the typical dc-voltages (measured with respect to TP1 or ground.), are given, which should be very helpful for troubleshooting. The pin assignments for the NIM connector are presented in Table 5.2.

5.5 MCA POWER SUPPLY

From the circuit diagram (Fig. 5.4), it is difficult to realize that the +24V line is the dominant supply voltage. From this voltage all others are derived by using the 24V either as reference voltage or by supplying it to the operational amplifiers which are used to generate the various voltages. This 24V line is controlled by a overheating sensor switch and appears only if the temperature of the heatsink at the back-panel is below the critical value.

In the 24V line regulation circuit, there is a zener diode. It is used to provide the regulated 24V as the reference voltage for the operational amplifier. This circuit reduces the influence of the line variations to the output voltage. At all other supply voltages, the regulation is implemented in a classical way using operational amplifier and current limitation with foldback characteristic. Only the 5V supply uses two parallel power transistors because a high current has to be delivered.

In addition, it is necessary to protect the digital ICs from overvoltage: an overvoltage protection circuit is introduced.

After power is switched on, 5 LEDs indicate the following voltages: +5V, +12V, +24V, -12V, -24V. This is very convenient because it is already an indication as to where and how to start with troubleshooting. If no LED is on, and the main fuse (F101) is not blown, the fault may be in the +24V supply line. Check the temperature switch; if it is closed, then measure the reference voltage D18. Next measure the output of the operational amplifier A3, which should be approximately 15V. The base voltage of Q2 compared to ground should be a little higher than +25V. If not, check the voltage across Q3. If this voltage is less than 1.5V, it indicates that there is an overload at this output and current limitation is active. This is valid for all other output voltages, except for the +5V. There, it is not easy to distinguish between an overload situation and the presence of the activated overvoltage protection. Due to the overvoltage protection, the thyristor Q19 is fired and shorts the output to ground. As long as the current limitation works properly, there is only one way to reset the current limitation: by switching the instrument off and on again, after removing the load. Only in this way is it possible to determine whether current limitation or overvoltage causes the action.

If you suspect that the overvoltage protection has become active, you should switch off the instruments, and connect it via a VARIAC to the mains, as shown in Fig. 5.5. Increase slowly the voltage to the instrument. In this way it is possible to distinguish if there was a bad adjustment of the overvoltage protection or if a transient occurred during the switching on of the instrument.

TABLE 5.1: Typical DC-Voltages (measured with respect to TP1 without load)

Node	Voltage	Node	Voltage
U2 pin 8	+36.5	U6 pin 8	+ 9.5
3	+ 2.5	3	− 9.5
5	0	5	−12.0
7	0	7	−12.0
2	+ 2.5	2	− 9.5
1	+24.0	1	0
10	+23.9	10	− 0.2
6	+25.3	6	+ 1.4
U4 pin 8	+36.5	U8 pin 8	+ 9.5
3	+ 2.5	3	−21.5
5	0	5	−24.0
7	0	7	−24.0
2	+ 2.5	2	−21.5
1	+12.0	1	0
10	+11.8	10	− 0.2
6	+13.5	6	+ 1.3

TABLE 5.2: Pin assignment, for NIM modules

BIN/MODULE CONNECTOR PIN ASSIGNMENTS FOR AEC STANDARD NUCLEAR INSTRUMENT MODULES PER TID-20893 (Rev 4) (adopted by DOE)

Pin	Function	Pin	Function
1	-3 volts	23	Reserved
2	-3 volts	24	Reserved
3	Spare Bus	25	Reserved
4	Reserved Bus	26	Spare
5	Coaxial	27	Spare
6	Coaxial	*28	+24 volts
7	Coaxial	*29	-24 volts
8	200 volts dc	30	Spare Bus
9	Spare	31	Spare
*10	+6 volts	32	Spare
*11	-6 volts	*33	117 volts ac (Hot)
12	Reserved Bus	*34	Power Return Ground
13	Spare	**35	Reset (Scaler)
14	Spare	**36	Gate
15	Reserved	**37	Reset (Auxiliary)
*16	+12 volts	38	Coaxial
*17	-12 volts	39	Coaxial
18	Spare Bus	40	Coaxial
19	Reserved Bus	*41	117 volts ac (Neut.)
20	Spare	*42	High Quality Ground
21	Spare	G	Ground Guide Pin
22	Reserved		

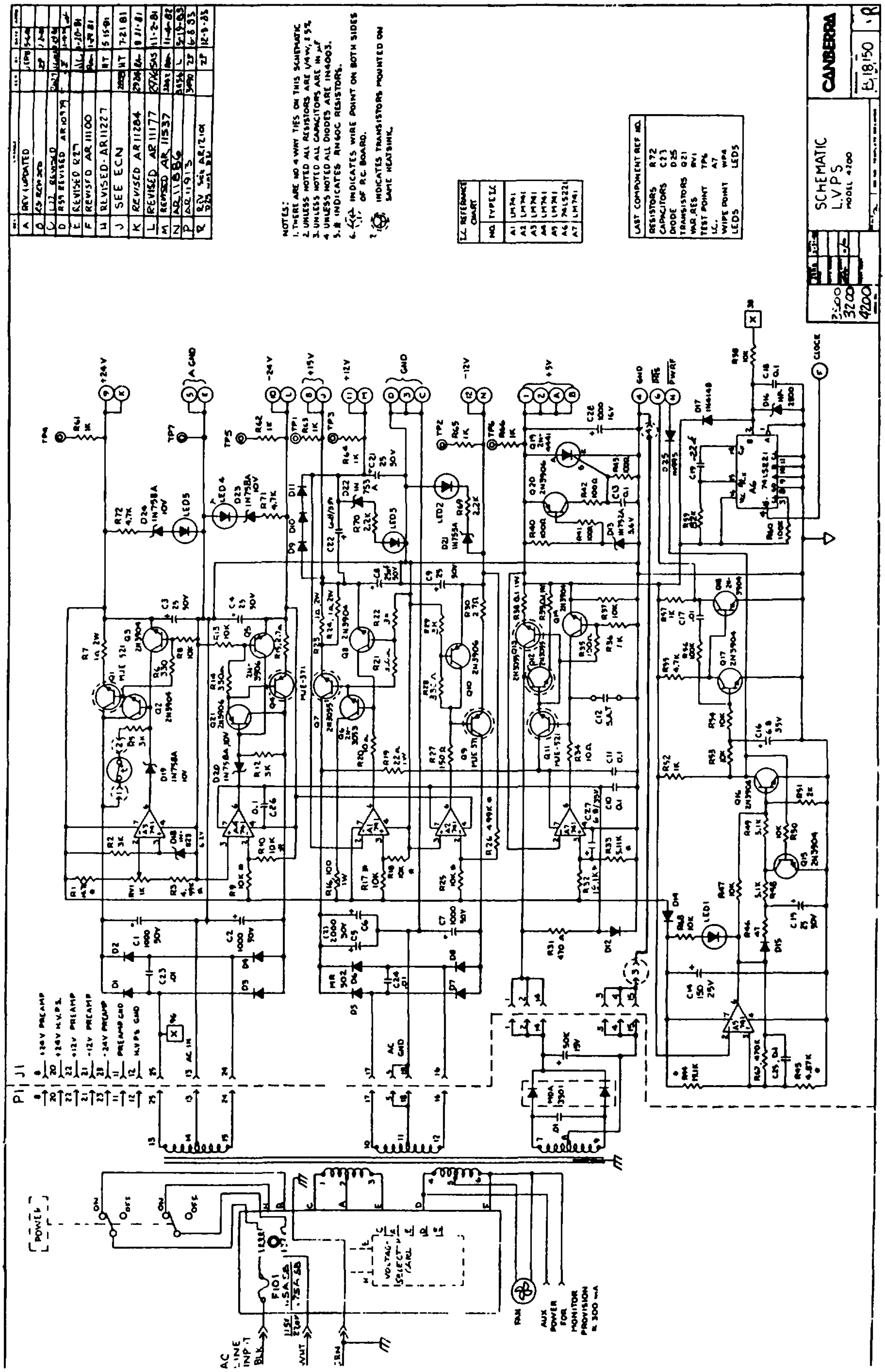


Fig. 5.4: Low Voltage Power Supply of a MCA

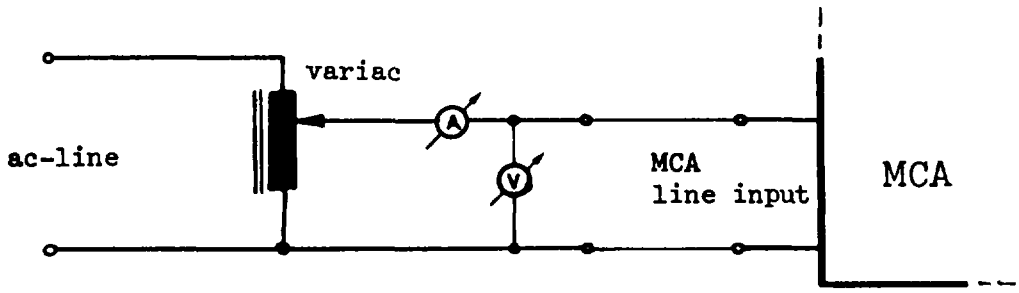


Fig 5.5: Using a variac to identify a fault

The arrangement as shown in Fig 5.5 can be used also for testing in the case when the fuse (F101) is blown immediately when the instrument is switched on. This indicates that there is a short circuit somewhere in the power supply. Before you start to look into the circuit in detail, remove the whole load (take out all boards, disconnect the display unit). Slowly increase the output voltage of the variac and observe the current with an ammeter (see Fig 5.5). When the ammeter indicates roughly 60-80% of the nominal fuse current, stop increasing the voltage. Now measure the voltage at the ouput of the variac. Here you will already have some indication as to where the short circuit might appear.

(i) Less than 4% of the ac line voltage indicates a defective line filter network, or a faulty transformer.

(ii) About 4% of line voltage can indicate a bad transformer or a bad rectifier. Separation of transformer and rectifier diodes or bridges has to be made to define the defective part of the supply.

(iii) 6-8% of line voltage indicates a short circuit either in the rectifier part or a defective filter capacitor; by separation of these two parts of the power supply, it is possible to detect the defective component.

(iv) 8-10% of the line voltage indicates a short circuit after the pass-transistor, and the current limitation is not working properly, therefore all output voltages have to be measured to locate the defective component.

The semiconductors must be checked in the conventional way. In measuring base-emitter voltage (around 0.7V), collector-emitter voltage must not be less than 0.7V otherwise the transistor would operate in the saturation region and would no longer be linear. If these voltages are completely different, as previously mentioned, remove the transistors and check it again. To check the operational amplifier, its two input voltages should have the same value. If they do not, compare them with the output. If there is a discrepancy, remove this operational amplifier.

After replacing the defective components, check the power supply again. Increase the output voltage of the variac to the nominal mains voltage, but also measure the ac current used by the power supply. This current should not be more than 20% of the fuse current since there is no load. Readjust all supply voltages according to the circuit diagram or service manual. After this procedure, the output voltage of the +5V line follows when the output voltage of the +24V line is increased. Simultaneously measure both output voltages. When the +5V line reaches around 5.6V, the overvoltage protection should be activated. In this case, decrease the output voltage of the +24V line to the nominal value, switch off the instrument to reset the memorized overvoltage, and switch the instrument on again. Then measure the output voltages to be sure that everything is properly set. If the overvoltage protection did not trigger, try to detect the defective components (D13, Q20, Q190, or the passive components around them).

The components IC A5, Q15, and Q16 are there for power reset, which is necessary for the microprocessor reset. IC A6 generates a fixed clock frequency.

The current limitation can now be checked. For this purpose, an ammeter in series with a variable power resistor has to be connected to the output, and simultaneously the output voltage has to be measured. Increase the current by changing the resistor. When exceeding 100% of the nominal current, the output voltage should decrease. After removing the load, the nominal output voltage should come back again.

After completing this procedure, you can install all removed boards and the display unit. Make sure the MCA is now working. If not see Chapter 9, MULTICHANNEL ANALYZER.

5.6 DETECTOR BIAS SUPPLIES

In this section, bias supplies for detectors are described. We can distinguish between several types of such supplies.

(i) High voltage supplies which are designed for scintillation detectors must be very stable in respect to output voltage, and relatively powerful (up to 1-2mA at about 2000V); noise and ripple is not so critical.

(ii) High voltage supplies which are designed for solid state detectors should have low noise and ripple, but are not required to be highly stable with respect to output voltage. The current required for detectors such as Si(Li), pure Ge, or Ge(Li), is in the order of less than 100nA. Surface barrier detectors sometimes require a higher current of up to 2uA (at relatively low voltage of about 100V).

> **NOTE:** For troubleshooting, a high-voltage instrument is recommended. This is
>
> - either a digital voltmeter with 10Mohm input resistance using a HV-probe with built-in voltage divider 1000:1 or 100:1, or
>
> - static voltmeter

5.6.1 Example 1: ORTEC Model 459

Fig. 5.6 shows a circuit diagram of a HV-bias supply for a solid state detector.

This HV-supply can deliver up to 100uA and the circuit is simple to understand.

> **NOTE:** NEVER measure with a digital voltmeter in the HV-path unless you use a HV-probe with a voltage divider 1000:1 (such a high voltage probe is available from Fluke) or 100:1. Through such a probe the input resistance of a digital voltmeter is 10000 MOhms. Another possibility is to use a static voltmeter, but pay attention to HV isolation problems.

A HV-bias supply is usually built around a DC/DC converter. An oscillator, push-pull circuitry, a transformer and a regulation circuit are necessary on the primary side; on the secondary side, the AC is rectified and filtered or a voltage multiplier may be used.

Before you start troubleshooting, make sure that the working area where the HV supply will be tested is free of all conducting material, such as wire ends, etc., to prevent HV-shock hazards.

5.6.1.1 Troubleshooting

The specific HV-bias supply described here has no feedback loop.

Be sure that all required input supply voltages are provided. Using an oscilloscope, check that the oscillator (Q1, Q2) is working. Frequency can be changed with potentiometer R42. If not, check Q1 and Q2. The next step is to inspect the operation by measuring with the voltmeter the emitter-voltage of transistor Q7 while changing the front panel potentiometer R23. Increasing the setting of the potentiometer should induce the voltage change of the emitter-voltage of transistor Q7 (from -24V up to +10V). If

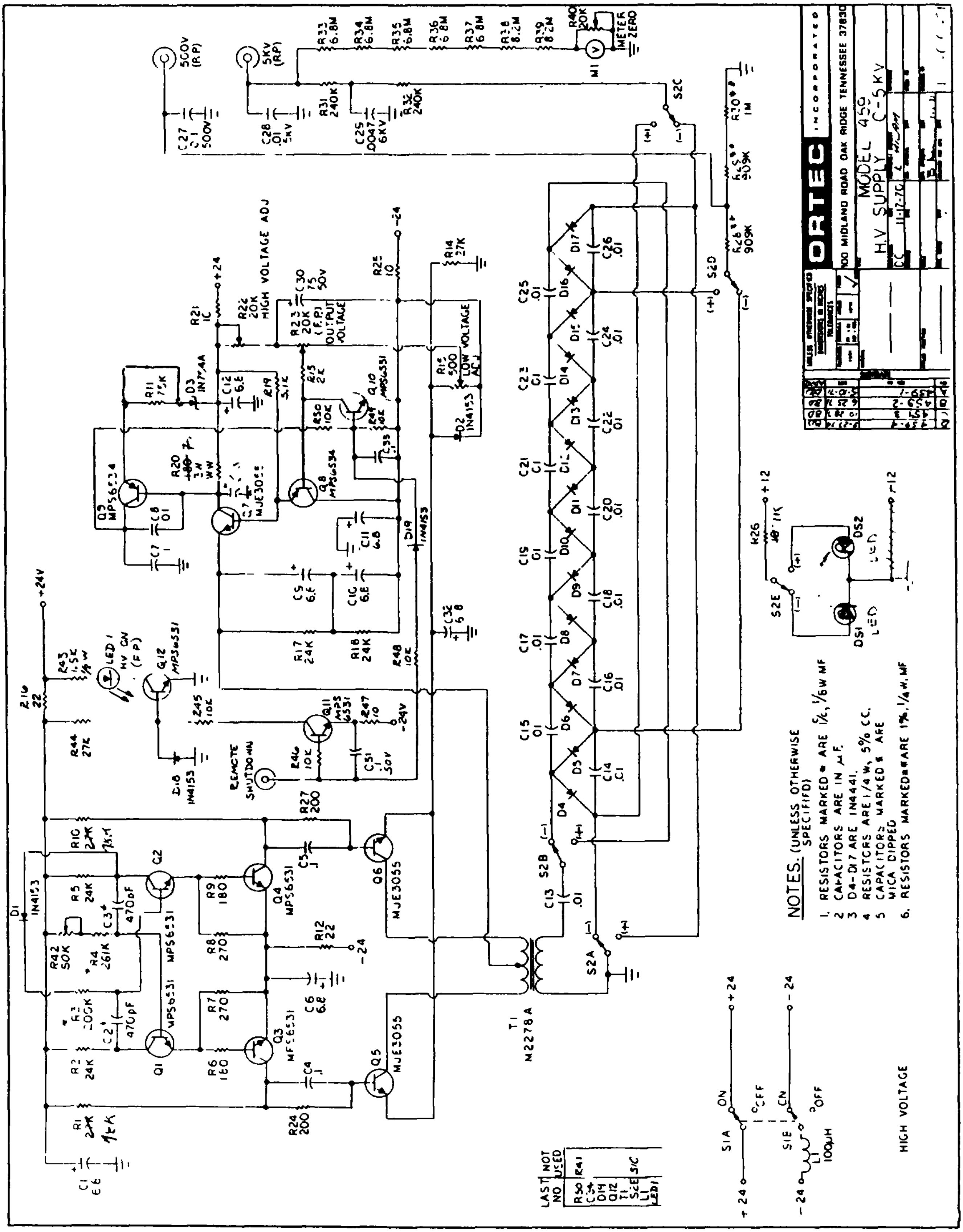


Fig. 5.6: HV-bias supply (ORTEC Model 459)

this is not observed, remove the load by unsoldering capacitor C13. Check again.

If there is no voltage at the output, check the current limiting circuitry which consists of zener diode D3 and transistor Q9; it works like a shutdown device by driving the transistor Q10 into saturation. When everything seems normal, check with the oscilloscope the waveform of the signal which appears at collector of transistors Q5, Q6. If there is no rectangular pulse visible (the amplitude of the pulse should be dependent on the emitter-voltage of transistor Q7) check transistors Q3 to Q6 or measure with an ohmmeter if the transformer winding has an interruption. When the transformer has a shorted winding, this appears as an overload, and current limitation should take place. In this case, transformer T1 has to be replaced.

After inserting capacitor C13 and you observe that an overload appears again, a defective component must either be in the filter capacitor C27 to C29 or in the voltage multiplier. Remove one after another capacitors C27, C28 or C29, and check again. If no defective component was found, the next step is the inspection of the voltage multiplier.

When troubleshooting a voltage multiplier, work carefully! Measure the voltage of each multiplier stage either with a HV-probe or with a static-voltmeter. If a stage has the same voltage level as the previous one, it is defective (either the diode or the capacitor). Replace the defective component and check again. When everything seems to be working properly, you can start to recalibrate the instrument.

Set the front panel dial to 5.00, which should correspond to 5000V, and measure the output voltage. With two potentiometers R22 and R15, the voltage can be adjusted: R22 is responsible for the setting of the 5000V level, R15 is used to adjust the low voltage region. Check the linearity of the dial setting by measuring the output voltage; do this slowly so that the capacitors can follow by increasing their charge. With potentiometer R42 you can change the oscillator frequency, which is necessary to minimize the current consumption of the +24V and -24V supply line.

Most of the faults in the earlier version of this HV-supply were the consequence of burning out of the polarity indication lamps. Nowadays, these lamps are replaced by LEDs. Also, there were sometimes problems with the tantalum capacitors due to the spikes which occur from switching an inductor on and off.

5.6.2 Example 2: Canberra Model 3102

Another type of HV-bias supply is the rather complicated one from Canberra, Model 3102. This circuit has a feedback circuitry to stabilize the HV-bias voltage. Canberra even uses special ICs, which are not very common on the market.

Fig. 5.7 shows the circuit of the above-mentioned bias supply. It is controlled and regulated by a feedback loop and the ratings are up to 2mA at 2000V.

> **NOTE:** This is an example of a case when you cannot trust the circuit diagram. There are some changes in the circuit, which are not shown in the circuit diagram, e.g. oscillator swing is from -10V to 0V and due to the slow rate of the used operational amplifier it has a trapezoidal waveform. The feedback resistor network R107, R111 is connected to -12V and not to ground. The positive supply of the operational amplifier is connected to ground and not as it is shown in the circuit diagram to +12V. Therefore, the oscillator operates without the module being switched on. Also, the component number IC104 does not correspond to the actual lay-out, which is in this case IC101. There might be other inconsistencies.

5.6.2.1 Circuit description

> **ATTENTION:** Circuit operation is described according to the diagram, and does not include the modifications later introduced by the manufacturer.

Zener diode CR101 and operational amplifier IC104A generate the -9V reference voltage. The oscillator is built around IC104B. The driver stage, built around IC105, is coupled through C108 and C107 to the power transistors Q101 and Q102 of the push-pull stage. The driver stage is controlled via capacitor C104 by the oscillator and dc-controlled via the amplifier bias current input by operational amplifier IC102B. This operational amplifier is itself controlled by the voltage setting operational amplifier IC103A. The output to the voltage monitor is taken from amplifier IC101. The over-voltage detection is performed by a summing amplifier (IC 103B, 1/2 of CA3240) and operates in the same way as the shut-down function of the inhibit gate.

5.6.2.2 Troubleshooting

> **NOTE:** Use the HV-probe to measure the output voltage. Such a probe should have a built-in 1000:1 or 100:1 voltage divider. Be careful when measuring high voltage.

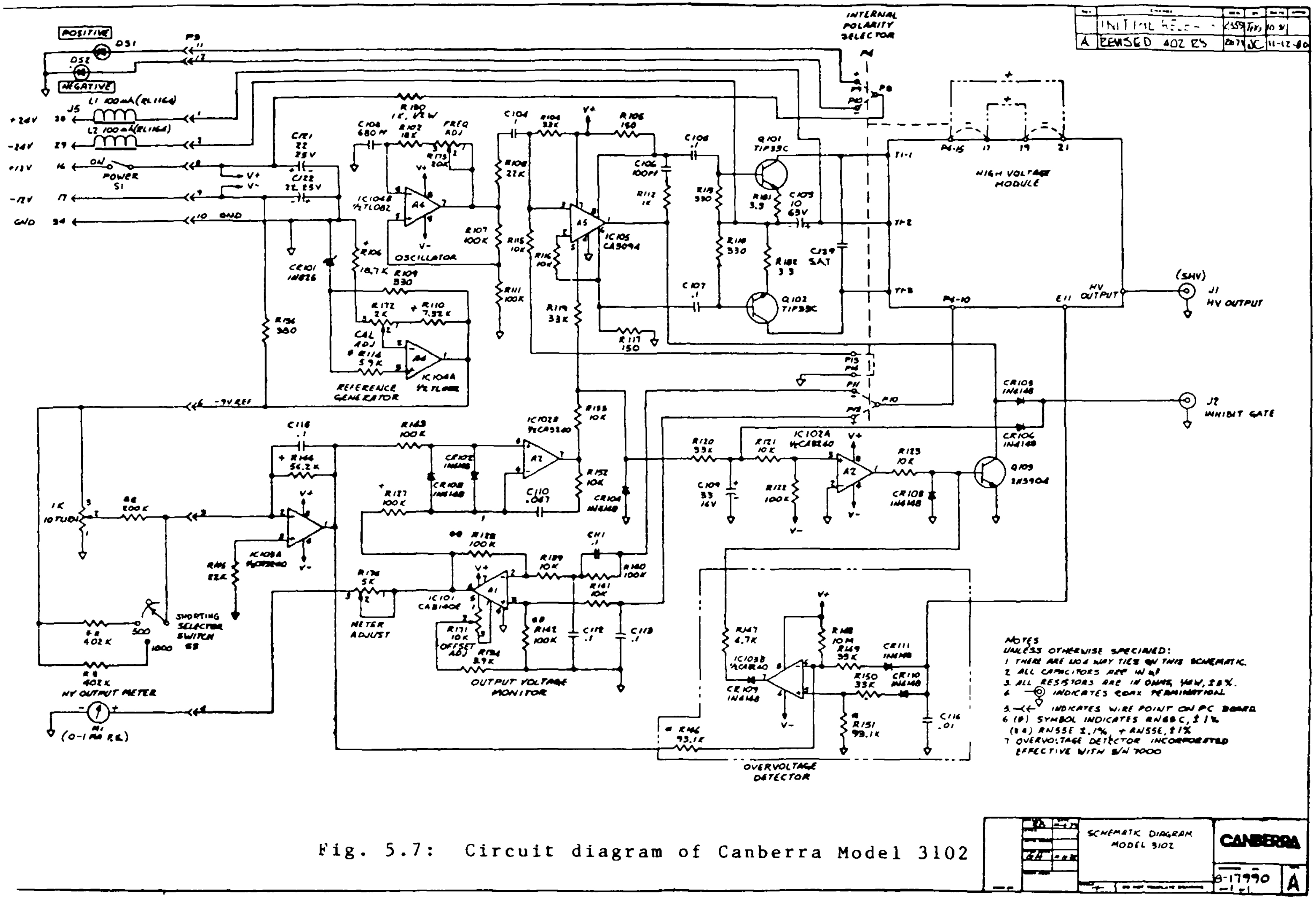


Fig. 5.7: Circuit diagram of Canberra Model 3102

Measure with the digital voltmeter the -9V reference. Adjustment can be done by changing the potentiometer R172 (IC 101 pin 1). Next check if the setting circuitry works properly. This is done by varying the front panel potentiometer or by changing the voltage selector switch at the front panel, while monitoring the voltage at the output of IC 103a pin 1. Now check with the oscilloscope to see if the oscillator is working; the signal at the output should have a trapezoidal signal with an amplitude of about 0V to -11V and a frequency of about 20kHz. If not, measure the inputs with an oscilloscope and compare them with the output. C108 should be charged and discharged (amplitude about -6V to -11V). Due to the not very sharp signals at the outputs of IC A5 pin 6 and 8, a triangular signal sitting on a dc level should appear. If not, change the IC. On the collector of the power transistor Q101 and Q102, you should measure +24V when the instrument is switched off. If not, there must be an interruption in the HV-module. After switching on the instrument, a sinusoidal waveform should appear, with the amplitude depending on the HV-voltage setting. If not, the HV-module is defective and must be replaced by a new one.

The HV-module consists of transformer, voltage doubler, filtering network and feedback resistor chain, and is sealed so that no humidity can reach the components. If for any reason the feedback loop is interrupted, an over-voltage detection is activated and shuts down the instrument. For test purposes, it is necessary to disconnect (or remove) diode CR109.

5.7 SWITCHED MODE POWER SUPPLIES

Nowadays the so-called "SWITCHED MODE" power supplies are frequently used. This type of supply has some advantages; an important one is that they are smaller and lighter compared to the linear regulated ones. They are frequency independent (40-400Hz) over a wide range, and the voltage variations range covers from +10% to -20% of the nominal line voltage. The efficiency of such supplies is in the order of 75%; this means less heat production. On the other hand, there are also some disadvantages. A lot of filtering is absolutely necessary otherwise this supply would be very noisy. The load regulation is critical. From the theory of matched oscillators, it is easy to understand that the load can only change about 1:10 otherwise the oscillator would not be matched. This is true, for example, for computers where the load changes are small and load regulation not critical. The recovery time is about 3-5 msec. For nuclear applications such a long recovery time could be critical if a supply voltage is used for a reference purpose.

A module for NIM crate is available (EG&G Model 495) to supply an additional 6V-line, either positive or negative switchable, if this voltage is missing in the crate. Fig. 5.8 shows the circuit of this module. Such a module can be used to supply the digital logic of an ADC which is now produced as a NIM-module.

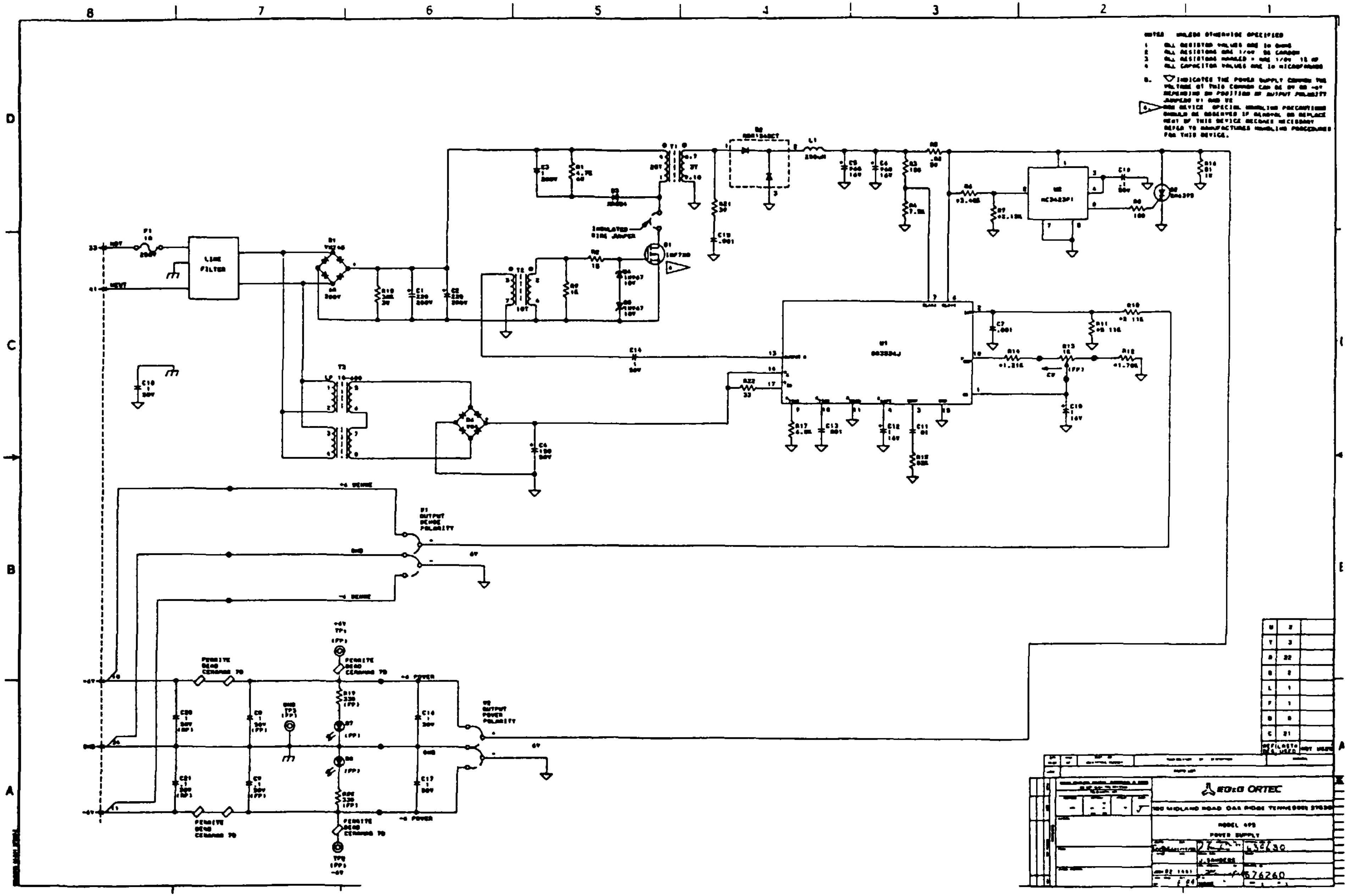


Fig. 5.8: Circuit diagram of the EG&G module 495

5.7.1 Circuit Diagram Description

The regulation is done by a single pulse-width-modulating integrated circuit U1. This IC is powered by transformer T3, rectified by bridge D6 and filtering capacitor C4. The ac power is rectified by bridge D1, filtered by capacitors C1, C2 and transformed by T1. This transformer is controlled by power MOS-FET Q1 which is controlled by IC U1 via transformer T2. (Note: line separation can be achieved only by transformer or opto-coupler, depending on the power which has to transferred.) On the secondary side of the transformer, the line is rectified by a fast switching diode bridge D2 filtered by inductance L1 and Capacitors C5, C6. The pulse-width-modulating integrated circuit U1 has, besides regulation, the capability of current limitation with foldback characteristics. The current is sensed by the resistor R5. If overvoltage occurs for any reason, a crowbar circuitry is fired (IC U2, thyristor Q2). Reset is only possible by switching off the NIM module.

5.7.2 Troubleshooting

ATTENTION: NEVER operate the power supply with the jumpers W1 and W2 set for opposite polarities; the internal circuits will be damaged. Be careful when measuring: some components are at ac-line potential.

NOTE: For troubleshooting, do not plug the module in a crate where 6V is already supplied.

If the module is not working, check the NIM crate that proper ac input voltage (nominal 117V) through bin pin 33 and 41 is supplied.

Check the ac input fuse on the rear panel. Replace if necessary.

If the output voltage has exceeded the crowbar trigger level, the front panel LEDs will not light. To restore operation, remove the ac power input from the module and then turn it on again.

If the instrument still does not work, remove the load and try again. When this does not work, remove jumper between transistor Q1 and transformer T1.

Now measure the voltage across C4 (about 16V). If there is no voltage, remove IC U1 and check by measuring the supply path (transformer T3, rectifier bridge D6 and capacitor C4). If voltage is present, the defective IC has to be replaced.

The next step is to check with the oscilloscope if trigger pulses are coming out from the output of the IC. If not, check the voltage drop across resistor R5. It should be near zero, otherwise IC U1 is defective and has to be replaced.

ATTENTION:	With the next steps you enter into, this is where line potential occurs. REMOVE the grounding lead from oscilloscope probe to prevent a short circuit from a mains phase via oscilloscope earth ground.

As the next step, check whether pulses appear at the gate of power MOS-FET Q1. If not, check the path, (capacitor C14, transformer T2, resistors R2, R9 and clipping zener diodes D4, D5). If everything is OK insert the jumper which connects transistor Q1 and transformer T1.

Now check with the oscilloscope at this jumper if pulses occur; due to current limitation being activated, this could be prevented. Therefore, the voltage drop across resistor R5 has to be monitored. Under normal conditions there should be only a small voltage drop because there is no load. It could be that due to bad adjustment of the output voltage, the crowbar trigger level has already been exceeded. Remove IC U2, and check again. If the voltage drop is again too high, check the value of resistor R5 (may be broken or value change due to overload). If the value of R5 is correct, remove thyristor Q2 and when pulses occur, replace thyristor. When the output voltage comes back, a bad adjustment of the output voltage may be the reason for the shut-down or a defective IC U2. Measure the output voltage of the module and adjust with potentiometer R13. If the adjustment is not possible, check the feedback loop. If this is OK, replace IC U1.

If there is no output voltage, connect the oscilloscope probe to common and look at the diode bridge D1 pin 1 (this diode looks like a power transistor). Pulses must be there; if not, either transformer T1, capacitor C3 or switching diode D3 is defective. To find the defective component, the components must be removed from the circuit. If pulses are observed but still there is no output voltage, the components D2, L1 may be faulty, or one of the capacitors C5, C6 may be shorted. After these checks the output voltage should be there. Measure and if necessary readjust output voltage. Insert IC U2, check again; if no output voltage is present, replace IC U2.

Chapter 6
PREAMPLIFIERS, AMPLIFIERS

6 PREAMLIFIERS, AMPLIFIERS

6.1 GENERAL ASPECTS OF EFFECTIVE TROUBLESHOOTING OF ANALOG INSTRUMENTATION

Analog instruments basically consist of analog circuits, either linear or non-linear. Some logic functions, however, may also be present.

Therefore, when you open an analog instrument, you will see inside discrete components, analog integrated circuits, like operational amplifiers, comparators, analog switches, and, more rarely, multipliers and possibly some digital integrated circuits.

It is important to point out that even in the most modern analog instruments, there are some parts that must be mandatorily implemented in discrete form, for integrated technology is still unable to provide the level of performance required for some functions. So, typically, low-noise sections in preamplifiers and amplifiers are still built in discrete or hybrid form. The same applies to some high-speed amplifying circuits. The sections implemented in discrete form are usually the more important sources of failure or malfunctioning in analog instruments. These sections, during the lifetime of the instrument, are more prone to suffer partial modifications and incorrect component replacement from the user and are more exposed to adverse environmental conditions.

Besides evident failures and easy-to-appreciate kinds of malfunctioning, analog instruments may present some performance degradations whose detection may imply application of sophisticated tests. The last point represents the peculiar difference in troubleshooting between analog and digital instruments.

The steps of intervention required to eliminate a given trouble in analog instrumentation are described in Table 6.1.

Steps a) and b) are carried out in the same way regardless of the nature of the faulty instruments; test c) has to be tailored to the actual nature of the faulty instrument, though requiring a common testing structure which exists in most laboratories; while d) may require even purposely developed instrumentation.

The correct way of carrying out steps a) to c) will now be discussed, while test d) will be described with reference to the specific instruments that will be considered afterwards.

The analog instrument you will be required to repair or to bring back to operate within the manufacturer's specification can be either:

- a desktop instrument with a built-in power supply;
- a rack instrument with a built-in power supply; or
- a module to be fitted into a NIM, CAMAC, or EUROCARD crate without built-in power supplies.

TABLE 6.1: What to do in case of trouble?

	STEPS TO BE TAKEN
evident failure (input signal not transmitted to the output, basic function no longer implemented and so forth) or **obvious type of malfunctioning** (signal distortion, excessive noise of any nature, reduction in the dynamic range and so forth)	a) VISUAL INSPECTION b) ANALYSIS OF dc WORKING CONDITIONS c) INVESTIGATION OF THE SIGNAL BEHAVIOUR WITH ARTIFICIAL PULSES
performance degradation (appearance of a small non-linearity, slight increase of noise, rise-time, time jitter and so forth)	a), b), c) d) SPECIFIC TESTS

6.1.1 Visual Inspection

Visual inspection aims at discovering whether:

a. there is any stray jumper shorting two wires;

b. there is any resistor, which because of a change in colour or a deformed shape, suggests that the maximum ratings have been exceeded;

c. there is any cold-looking soldering;

d. there is any wire or component pin disconnected.

> NOTE: The instrument under repair should be illuminated by an intense lamp. Even if you have good eyes, a magnifying lens can help you to see more details.

6.1.2 Checking dc Conditions

If the visual did not reveal any faults, proceed to the next step, namely to check dc conditions throughout the instrument.

NOTE: The analysis of dc conditions, if done properly, will help you to detect the fault in most cases.

Several precautions must to be taken during a dc analysis.

1. Check the condition of the fuses if the instrument to be repaired is supplied directly from the mains. Then, remove the cover and after turning the power ON, check that the supply voltages are present at the correct values on the output lines of the power supply. If the instrument to be repaired is a module which receives the supply voltages from a crate, check with an ohmmeter that no short circuit exists between the supply voltage inputs and ground on the rear connection. If no short circuit is present, connect it to the crate supply through a flat cable or through an extension and turn power ON. Check on the module under repair whether the correct supply voltages appear at the relevant points.

2. If a short-circuit is detected from either resistance measurement or supply voltage measurement at the relevant points in the instrument, repeat the visual inspection following the power supply wire where the short circuit exists. If the visual inspection remains unsuccessful, remove one at a time the filtering capacitors connected between the power supply and ground and repeatedly check whether the short circuit still exists or not. Most likely, the short circuit is due to one of these filtering capacitors.

3. Once the possible short circuits are removed and the correct dc supplies appear on the relevant lines, measure the dc levels inside the instrument by using a digital voltmeter with at least 3 1/2 digit resolution and 10 M or more input resistance. MAKE SURE THAT ONE INPUT OF THE VOLTMETER IS SAFELY GROUNDED; SOLDER ON THE TIP OF ITS LIVE PROBE A 10K RESISTOR. Such a resistor has a decoupling purpose and avoids the situation where the relatively large input capacitance of the voltmeter connected between the emitter of a high frequency transistor and ground make it oscillate.

6.1.3 Checking a Faulty Transistor

The following simple rules will help you understand whether or not a transistor is faulty.

Assume that the transistor of Fig. 6.1 is expected to be ON. All transistors in the amplifying part of an analog instrument should actually be ON.

Determine the currents through R1 and R2 by measuring the voltage across R1 and R2 and applying Ohm's Law and the VBE voltage of T1. If IC, IE and VBE lies in the range 600-700 mV for a silicon transistor or 300-500 mV for a germanium transistor, then T1 works properly.

If R1 is not present, but there is a resistance in series with the base of T1, like in Fig. 6.2, then determine the currents through R3 and R2 and the V(BE) voltage. If VBE lies in the same range as before and I(B) is 10 to 100 times or more lower than IE, then again T1 works properly.

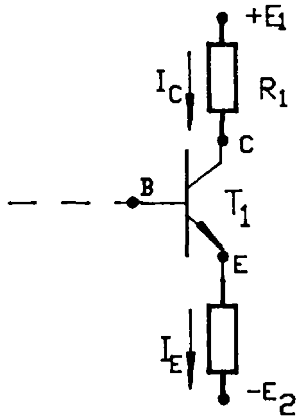


Fig. 6.1: Basic transistor stage

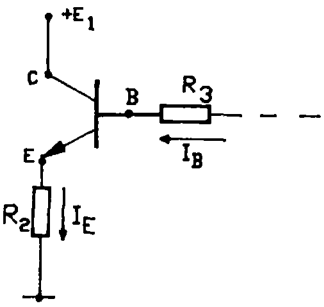


Fig. 6.2: Transistor stage with base resistor

The transistor has to be replaced if:

a. While VBE falls into the correct range, IC is much smaller than IE (Fig. 6.1) or IB is nearly equal to IE (Fig. 6.2). (These symptoms are typical for a transistor where the base-to-collector junction is OPEN).

b. VBE exceeds +1V. This happens when the emitter-to-base junction is OPEN.

c. VBE is not within the correct range and VCE is almost zero. This happens when the base has been punched through or collector and emitter are short-circuited. Such a short circuit may also be due to an external unwanted jumper, in which case VISUAL INSPECTION IS ADVISABLE BEFORE REPLACEMENT.

d. V(BE) is zero, yet IE is different from zero. Base and emitter are short-circuited, either inside or outside the device. VISUAL INSPECTION IS AGAIN ADVISABLE BEFORE REPLACEMENT.

NOTE: The resistors may also be responsible for incorrect operation of a circuit. actually, a resistor can have changed its value because of a previous incorrect intervention on the circuit, during which excessive power was dissipated owing to an accidental short circuit, because of a manufacturing defect or because of strongly adverse environmental conditions.

As a limiting case, a resistor can either be open-circuited or short-circuited. Table 6.2 describes what happens in the circuits of Figs. 6.1 and 6.2 with R1 or R2 either open-circuited or short-circuited.

TABLE 6.2: Failures in the circuit of Fig. 6.1 caused by resistors

R1 open-circuited	VCE ≈ 0	VBE in normal range	T1 saturated
R2 open-circuited	IC ≈ 0	VBE ≈ 0	T1 off
R2 short-circuited	VE ≈ -E2	VBE ≈ 0.6V	VBC small and negative or positive
R1 short-circuited	no voltage drop across R1	VBE in normal range	

What happens in the circuit of Fig. 6.2 if R3 is open-circuited is described in Table 6.3.

TABLE 6.3: Failures in the circuit of Fig. 6.2 due to resistors

R3 open-circuited	VB ≈ - E2	VE ≈ - E2	IE ≈ 0

The case of RB short-circuited can be investigated only by direct RB measurements.

If the above described tests (visual inspection, transistor fault diagnosis, and resistor "short-circuit/open-circuit" test do not show anything abnormal, measure the resistor values after removing the transistor.

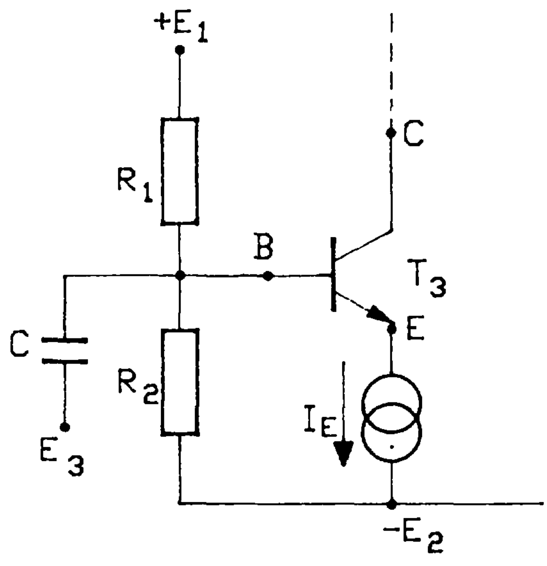


Fig. 6.3: Transistor stage with ac coupling

Consider now the circuit of Fig. 6.3, which shows a transistor, T3, in the common-base configuration. If you suspect that there is something wrong in this circuit and that it may be responsible for the wrong behaviour of the network to which it is connected, check first the voltage between B and ground. If such a voltage substantially differs from the nominal value

$$\frac{E1R2 - E2R1}{R1 + R2}$$

it has to be concluded that the circuit is faulty. The fault may actually depend on C behaving as a short circuit because of an irreversible damage occurred to it, on transistor T2 or on the voltage divider R1, R2.

If you conclude that C is short-circuited, disconnect C on one side and measure VB again, to have experimental evidence that your hypothesis is correct.

There may be some situations in which C is not a true short circuit, but presents a finite resistance across its terminals, in which case it is difficult to distinguish whether the wrong value of VB depends on C or on the open BC junction of T2. In such a case, first disconnect C on one side and check VB again. If VB remains at the wrong value, then turn off power and check the resistor values.

NOTE:	Some defective resistors exhibit the correct value when measured with the ohmmeter, but then present a different value under applied voltage. In a difficult case, you can consider to replace them even if the resistance measurement gives the correct resistor values.

The fault symptoms are described in Table 6.4.

TABLE 6.4: Diagnostics of the fault symptoms of the circuit in Fig. 6.3.

1. C behaving as a short circuit, E3 at ground potential

   VB 0 VBE in the normal range

2. C behaving as a short circuit, E3 = - E2

   VB = - E2 VE = - E2

3. T2 with open-circuited BC junction

   VB lower than the nominal value by

$$\frac{R1R2 \cdot IE}{R1 + R2}$$

4. R2 short-circuited

   VB = - E2 VE = - E2

   indistinguishable from 2. and 5.

5. R1 open-circuited

   VB = - E2 VE = - E2

   indistinguishable from 2. and 4.

6. R1 short-circuited

   VB = + E1 VB in normal range

7. R2 open-circuited

   VB much closer to E1 than predictable according to nominal values of the components

   VBE in the normal range

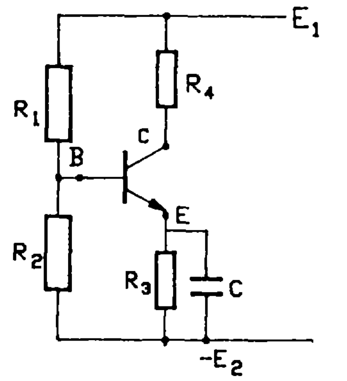


Fig. 6.4: Common-emitter transistor stage

Consider now the common-emitter transistor connection of Fig. 6.4. Besides the faults depending on the R1, R2 voltage divider and on T3 that fall under the discussion developed for the circuit of Fig. 6.2, one has to consider now the problems related to a short circuit on C or R3. The relevant symptoms are:

$$VE \approx -E2$$

$$VB \approx -E2 + .7V.$$

If these symptoms appear, disconnect C on one side and measure VE and VBE again. If the hypothesis of C is confirmed, in the sense that with C disconnected

$$VB \approx \frac{E1R2 - E2R1}{R1 + R2} \qquad VE \approx VB - 0.7V,$$

replace C. If with C disconnected the fault does not disappear, you have to suspect that R3 is short-circuited, therefore replace it.

ATTENTION:	Some of the short-circuit/open-circuit situations may not necessarily be due to a defective component, but could be simulated by a stray jumper or an ill-soldered terminal in the layout. Therefore, prior to proceeding to disconnect a suspected component, visually inspect the concerned part of your circuit.

Replacement of a defective transistor cannot always be done with the same type of device. This is especially true if the instrument under repair is of old design and the components to be replaced are obsolete. It may sometimes happen that the specimen used for replacement actually has better gain-bandwidth properties, in which case the new transistor may exhibit high frequency oscillations. Sometimes the frequency of these spurious oscillations is so high that you cannot detect it unless a sampling scope is available. However, there is a very simple trick to judge whether GHz oscillation is present simply by reading dc levels. The trick is based upon the fact that the high frequency oscillation, rectified by the non-linearities present in active devices, actually modifies the dc levels in the circuit. Monitor then the dc levels in the proximity of the replaced transistors and see whether or not they change by adding a small capacitance between base, collector, emitter of the new transistor and ground. Such a capacitance will modify the amplitude of the oscillation and along with it the dc levels. To add such a capacitance, just handle an ordinary screwdriver, possibly long and thin, and touch with its metallic top the transistor leads, being careful to avoid short circuits (see Fig. 6.5).

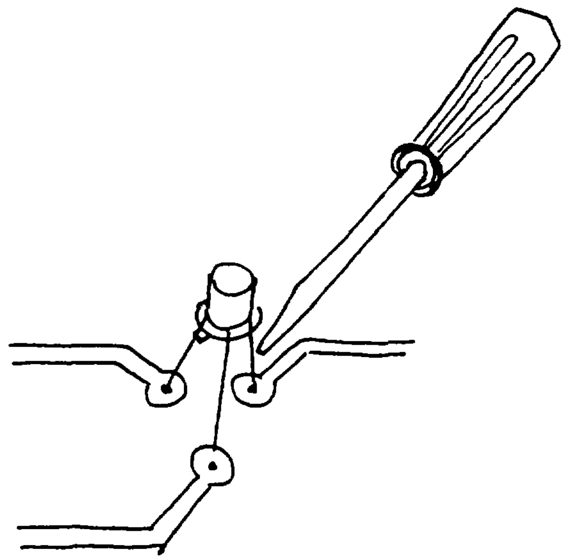


Fig. 6.5: Testing of a transistor stage for oscillation with a screwdriver

If no modifications occur in the dc levels, no high frequency oscillation is present. If, however, the dc levels change when you touch or simply approach the transistor leads with the screwdriver tip, then the oscillation is present.

In this case the newly connected transistor can be neutralized by adding a 100 ohm resistor in series with the collector lead or the base lead and as close as possible to the transistor can.

The previously analyzed situations refer to elementary circuits, but the methods employed can easily be extended to more complicated circuits built up from these simple ones. The dotted lines in Figs. 6.1, 6.2, and 6.3 imply connections to other parts.

Sometimes an instrument undergoes a catastrophic failure, owing to which, in the individual elementary circuits like those of Figs. 6.1 through 6.4, more than one component may be damaged. There are so many possible combinations of faulty elements that troubleshooting may require a procedure-describing flowchart. A flowchart will be developed here with reference to a single transistor circuit of broad validity, the one shown in Fig. 6.6. To judge whether this circuit is properly operating or not, the voltages VB, VC, VE are to be measured and compared with the nominal values:

$$VB \approx \frac{E1R2 - E2R1}{R1 + R2} \qquad VE \approx VB - 0.7V$$

$$VC \approx E1 - \frac{VE + E2}{R4} \cdot R3$$

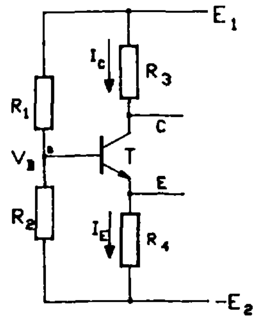


Fig. 6.6: Basic transistor stage

If the measured values differ from the nominal ones by more than 10%, which accounts for the worst case component tolerances, the circuit has to be considered faulty. As previously pointed out, the fault may be due to either:

1. defective voltage divider,
2. defective transistor,
3. defective emitter resistor,
4. defective collector resistor, or
5. defects in layout,

or to all the possible combinations of two, three, four or five causes of fault.

Referring to the circuit in Fig. 6.6 immediately removes any doubt about whether the fault depends on the voltage divider or on the active device and associated resistors. If VB is at its nominal value, the fault has to be attributed to the active device and/or to the R3, R4 resistors.

If, however, VB is not correct, the voltage divider or the (T, R3, R4) amplifier or both may be defective. To disentangle responsibilities, remove the transistor and check VB again. If VB is near its nominal value, then the fault has to be attributed to (T, R3, R4). As T was removed, you have a very effective way of checking (R3, R4), Fig. 6.7. Connect in series with R3 and R4 a resistor of accurately known value and such that the current I flowing across the series connection R3, R*, R4:

$$I = \frac{E1 + E2}{R3 + R4 + R^*}$$

will be equal to the current IE IC which would flow across transistor T and resistors R3, R4 if no fault were present. Such a current is easily evaluated from the table of nominal values (1):

$$IE \approx IC \approx \frac{VE + E2}{R4} \approx \frac{VB - 0.7V + E2}{R4} .$$

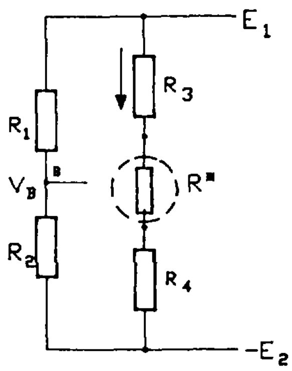


Fig. 6.7: Replacement of a transistor by a resistor

Besides, R* must be able to stand a power of at least

$$5 \cdot \frac{(E1 + E2)2}{R^*} .$$

Once R* is connected, check whether or not the voltage drops across R3, R4 coincide with the nominal values determined by the knowledge of I and of the nominal values of R3, R4. If they coincide, then R3 and R4 are not defective and you can focus your suspicion on the transistor. If, however, any or none of the voltage drops across R3, R4 stick to their nominal values, concentrate on R3, R4.

Mind the following:

1. If the voltage drops across R3 or R4 or both are zero, but the one across R* is equal to E1 + E2, then R3 and R4 behave as short circuits. The short circuits may depend on the resistors themselves or on some stray jumper on the layout. Check the latter possibility by accurate visual inspection. If there is no evidence of stray jumpers, proceed to replace R3 and R4 and check the voltage drops across the R3, R*, R4 divider again. Most likely the fault has been eliminated.

2. If the voltage drops across R3, R*, R4 are all zero, there is a circuit interruption along it. Again this may depend on R3 or R4 or both being interrupted or on some broken connection on the layout. Search for it by accurate visual inspection and if you discover any defective connection, repair it. Otherwise, again replace R3 and R4 and check the voltage drop across the R3, R*, R4 divider again. Either way the fault should have been eliminated.

Once you have removed the transistor and made sure that no defect had to be attributed to R3 and R4, or if there was a defect, that it has been fixed, proceed to check the transistor.

> <u>NOTE</u>: The most reliable procedure would be to test the transistor with a transistor curve tracer. This instrument will tell you whether the transistor is still alive or definitely gone, but would also enable you to determine whether a deterioration in its characteristics has occurred.

If a curve tracer is not available in your laboratory, you can construct the very simple transistor tester of Fig. 6.8. The tester accepts on two different sockets both NPN and PNP transistor. The two-position, two-pole switch selects either type. The tester is basically a B meter and is surely much more effective than a simple ohmmeter employed to determine whether either junction is open or not. With the tester of Fig. 6.8 you put the transistor under test on the relevant socket having previously correctly positioned the switch, and take note of the panel meter reading. If such a reading is between 0 and 3V, your transistor has to be replaced.

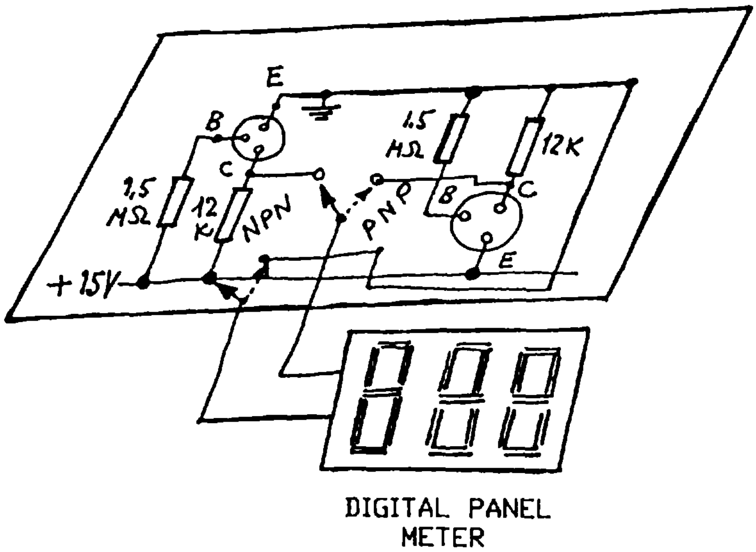


Fig. 6.8: Simple transistor tester

It should be realized that transistor testers are available on the market (References: PORTABLE TRANSISTOR TESTER MODEL 510 FOR IN-CIRCUIT TESTS, BK PRECISION). They usually can be directly applied to the transistor to be tested without removing it from the printed circuit board. If such a fixture is available, then you may immediately make clear whether the fault in your circuit depends on the transistor or not. If it does, you simply replace the transistor and check whether the circuit works or not. If it does not work, then in any case you must disconnect the transistor and check (R3, R4) and (R1, R2).

It has still to be considered how to proceed if the VB voltage turns out to be wrong, after the transistor has been disconnected. The troubleshooting procedure for a voltage divider consists of checking whether VB is either equal to E1 or to -E2. In the former case, R1 is short-circuited or the B-through R2- to -E2 line is interrupted. Short circuit and interruption may actually reside on the printed circuit board, in which case accurate visual inspection may lead to their detection. Otherwise, they have to be attributed to R1 or R2 or to both. Replace both resistors.

Check VB again and you will see that now VB is at its nominal value.

Having the transistor disconnected, check it with a curve tracer, a self-constructed tester or with a commercial transistor fixture and decide whether to replace it or not.

Check R3 and R4 and decide accordingly whether they can be kept or must be replaced.

Finally, reassemble the circuit and check VB, VE, VC again.

The flow-chart summarizing the described troubleshooting procedure is given in Fig. 6.9.

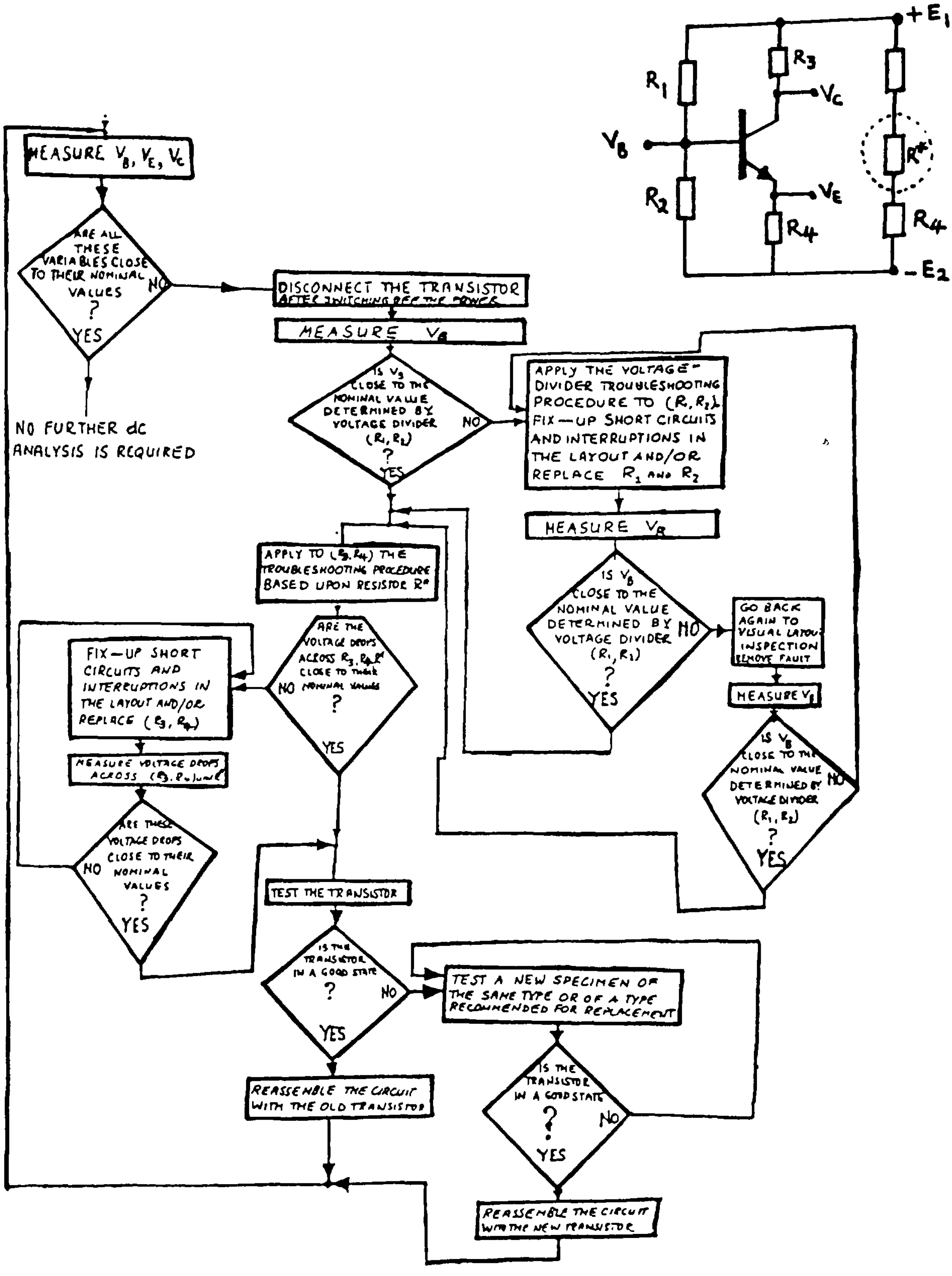


Fig. 6.9: Flowchart for troubleshooting a basic transistor stage

Troubleshooting considerations similar to the previous ones can be applied to instruments or parts of them based upon operational amplifiers.

An instrument may be designed to use several operational amplifiers. The search for a fault in the instrument requires a fault analysis for the individual operational amplifier circuits, which can be introduced with a quite general approach by discussing the connections as shown in Fig 6.10.

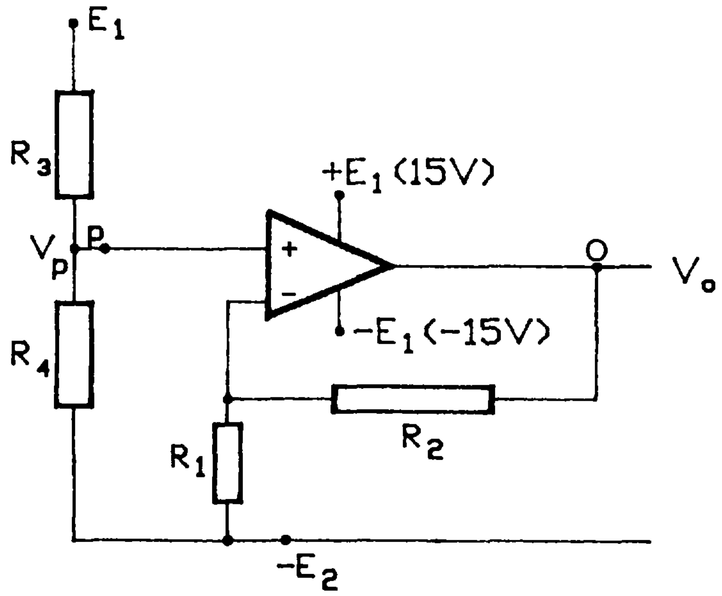


Fig. 6.10: Basic operational amplifier configuration

Suppose that the output voltage Vo, which should be close to zero if this circuit is intended to be a linear amplifier, is found instead to be close to the positive saturation voltage (+11 to +14V, depending on the type of operational amplifier employed, for a +15V bias). Assume also that visual inspection has been accurately carried out on the circuit and that nothing has come to your attention.

Follow the instructions suggested in the flow chart presented in Fig. 6.11.

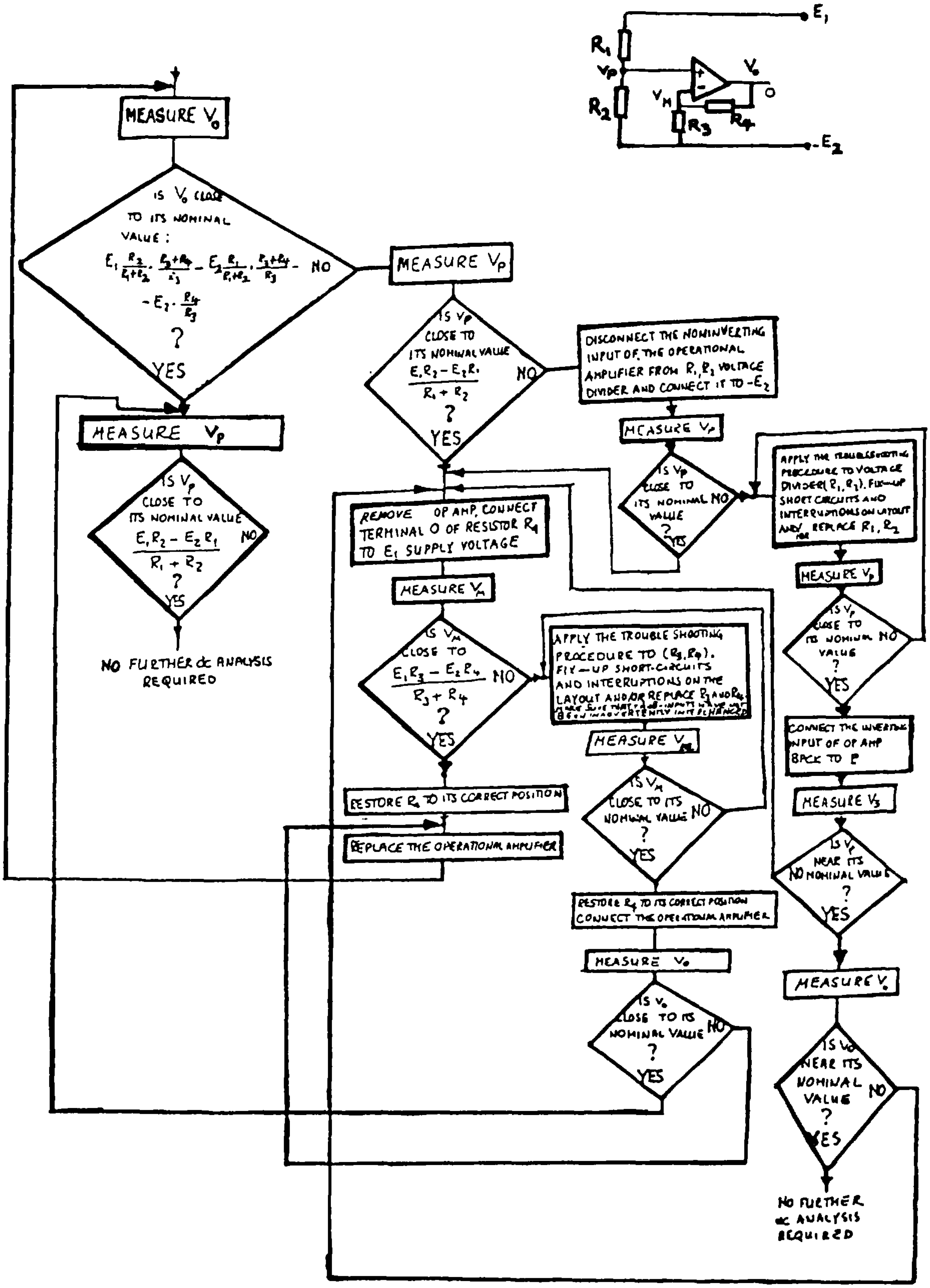


Fig. 6.11: Flowchart for troubleshooting a basic operational amplifier configuration

6.1.4 Signal Analysis

Have you finished the dc analysis of the individual parts of your instrument?

Have you made sure that everywhere in the instrument the dc conditions meet the expected values?

If so, you can quickly check whether your instrument implements its basic function. For instance:

a. If the instrument is a preamplifier or an amplifier, does a signal appear at the output when you apply a signal at the input, and are the shape and the amplitude of the output signal reasonable?

b. If the instrument is a single channel analyzer, does the logic output signal appear at the output when you apply an input signal, and slowly move the threshold positioning potentiometer until the input signal falls into the channel?

c. If the instrument is a time-to-amplitude converter, does a ramp signal appear at the output when you apply a signal at the START input and a delayed one at the STOP input?

d. If the instrument is a linear gate, is the signal applied at the analog input transmitted almost unaltered to the output during those intervals when it overlaps in time with the gating command applied at the LOGIC INPUT?

Some situations are summarized in Fig. 6.12. For each instrument there is an approximate indication of the correct and of a possible defective output signal. If the signal is acceptable, you can go on with a detailed analysis and calibration of the instrument. If the signal is strange, it is necessary to carry on with a signal analysis of the individual stages.

To apply signal analysis, you must send a signal to the input and then follow its path throughout the instrument, making sure that every circuit performs on the signal the correct function. Signal analysis will tell you some very important facts.

1. The signal is present at the input of a certain circuit and is no longer present at the output. The circuit under test has an interruption on the signal path.

2. The signal appears at the output of an amplifier clipped on the top, although the input was in the correct range. The circuit dynamic range is out of the specified value.

3. The signal passing through a linear amplifier appears at the output smeared by an oscillation whose frequency exceeds 100 MHz. You can almost be sure that in the circuit there is an ill-neutralized transistor.

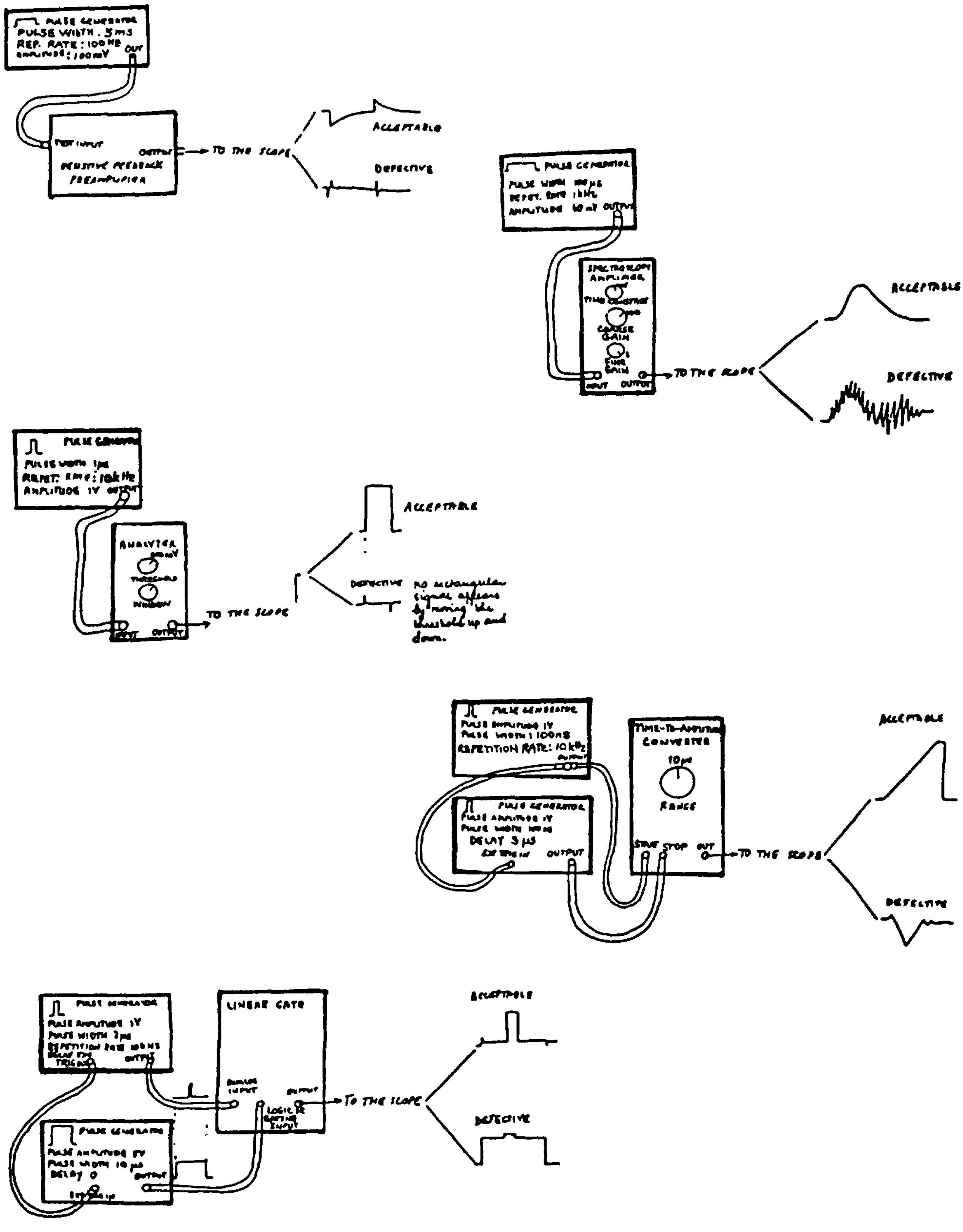


Fig. 6.12: Test set-up for some typical nuclear electronic instruments with acceptable and defective output signals

4. The signal passing through a linear feedback amplifier presents at the output a damped oscillatory behaviour. Most probably the feedback loop is not sufficiently compensated.

5. A linear feedback amplifier, whose function is that of amplifying and not that of shaping, slows down excessively the signal. Your feedback loop is over-compensated.

NOTE: To carry on signal analysis, you need a rectangular pulse generator and a dual channel oscilloscope with at least 100 MHz bandwidth. It must be equipped with two 1x probes and two 10x probes. Do not use the 1x probes if this is not necessary to achieve a high sensitivity of your scope. For an easier observation on the scope, use an external trigger by sending to the oscilloscope input the advanced trigger signal from the generator. Set on the generator a 200ns delay. Make sure that no false contacts exist in the cables, connectors and probes. Check the ground wires of the probes; make sure that they are safely soldered to their alligator-clips. Add in series with each probe a 300 resistor to avoid spurious effects due to probe capacitance. Having done this, send the signal from the generator output to the input of the instrument under test. Use the two channels of the scope to monitor, for each part or elementary circuit in your instrument, input and output signals. Ground the probes to the ground conductors that are closest to the points you are going to monitor.

Some ideas about how to proceed with the signal analysis will now be discussed. They will refer to particularly simple situations where the instrument is made only of amplifying parts, all working in the linear range and not requiring any logic command. More complicated situations will be considered afterwards with specific cases. The analysis referred to in the linear case is, however, extremely useful in introducing the basic principles.

Suppose that following the signal path, you arrive at a circuit illustrated in Fig. 6.13, with signal shapes as indicated.

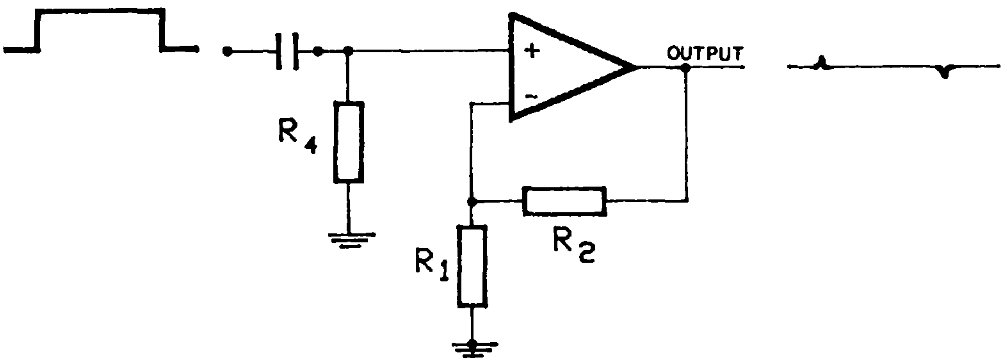


Fig. 6.13: AC-coupled operational amplifier with open signal path

If the circuit had previously undergone dc analysis and was found to operate correctly dc-wise, then the present fault, that is, open signal path between input and output, may depend on an open C capacitor or on an interrupted connection in series with C on the printed-circuit board.

ATTENTION:	Such a fault cannot be detected from the analysis of DC conditions.

Another frequent source of fault is a shunting capacitor which, because of a mistake made in a previous repair, is much larger than it should be. Such a situation is illustrated in Fig. 6.14. The signal actually does not appear to the output, as it is short-circuited to ground by the 100nF capacitor connected by mistake. The collector-to-ground capacitor of large value interrupts the signal path again. In this case DC analysis would not reveal the fault.

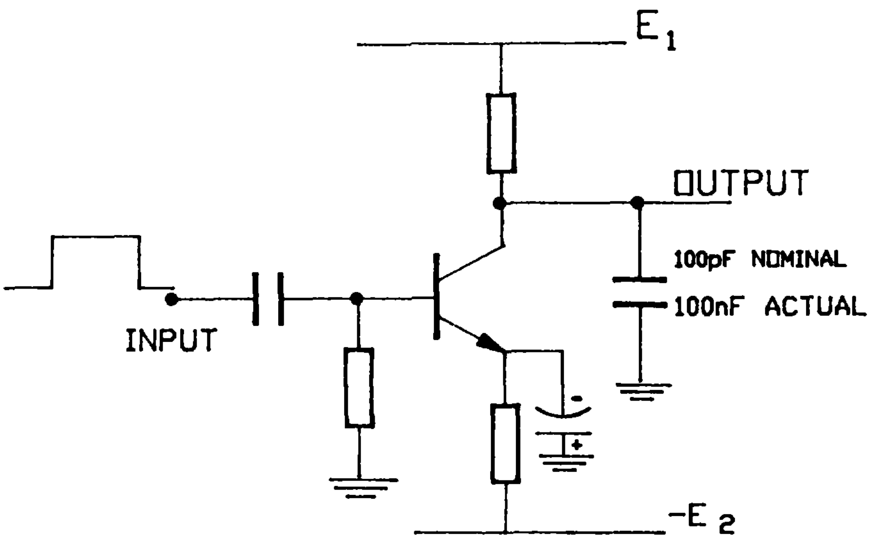


Fig. 6.14: Transistor stage with defective output signal

Consider now the following two-transistor operational amplifier (Fig. 6.15) and look at the output signal (a). Suppose that the oscillation frequency exceeds 100 MHz. Such a limit is purely empirical, but it helps you to guess whether an oscillation has to be attributed to a component or to the feedback loop. The transistor T2 appears to be unneutralized. Most likely the oscillation is due to T2. To damp it, add a 100 ohm transistor in series with the collector lead at T2, and as close as possible to its can.

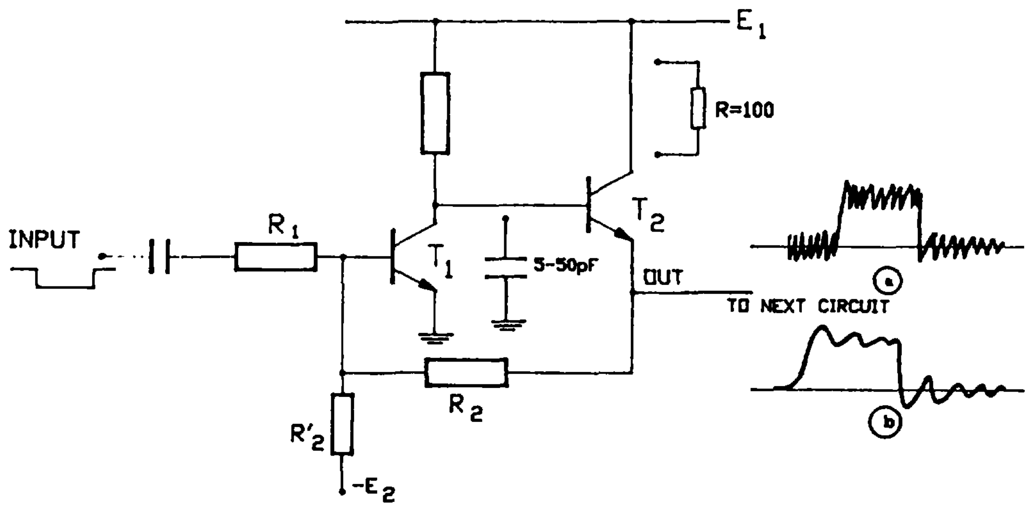


Fig. 6.15: Two-transistor operational amplifier with signal oscillator

If the output signal looks like that of case (b), with the frequency of the damped oscillation of 50 MHz or less, most likely the oscillation is determined by the feedback loop. Add then a small compensating capacitor, 5pF to 50pF, between the collector of T1 and ground. The damped oscillation will disappear.

Look now at the amplifier circuit of Fig. 6.16. Suppose you find that its signal gain differs considerably from the nominal value of 10. Such a defect may depend on a change that occurred in one or both resistors because of some kind of accident or on the fact that for some reason the operational amplifier is completely out of specifications as far as its signal gain is concerned. In this case the resistors do not draw current in the standing state. Turn off power, disconnect them from the circuit and measure their values with an ohmmeter. If the measured values are close to the nominal ones, proceed to replace the operational amplifier. The described fault obviously escaped dc analysis.

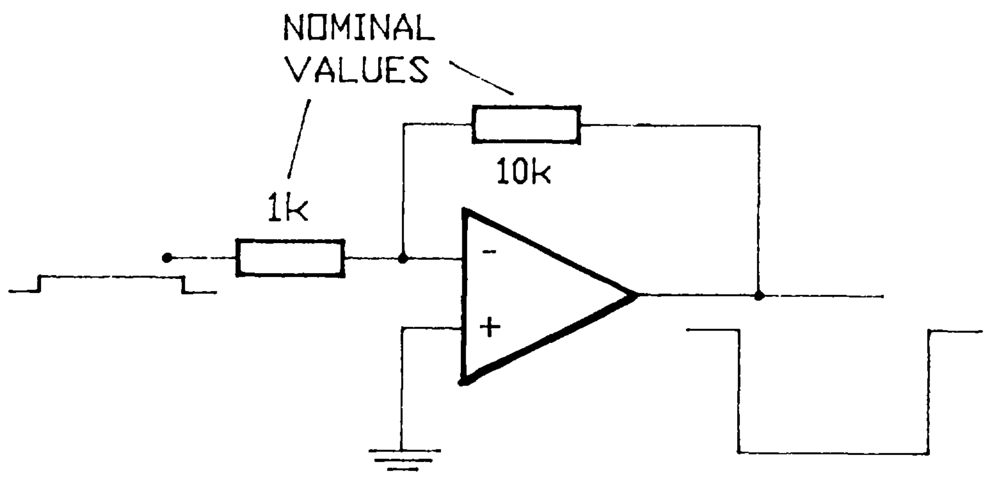


Fig. 6.16: Operational amplifier with a gain of 10

Consider now the following amplifier, whose nominal gain should be 10, but actually is found to be 1 (Fig. 6.17). The fault may depend on R1 open-circuited or R2 short-circuited. Open and short circuit may be related to faults on the printed circuit board. In this case visual inspection aiming at detecting possible interruptions, accidentally disconnected components, or stray jumpers has to be carried out first. If nothing comes out of this inspection, measure the resistors R1 and R2 and change the defective one(s). Remember that there is still the possibility of a gain in the operational amplifier much below the nominal value, in which case it has to be replaced.

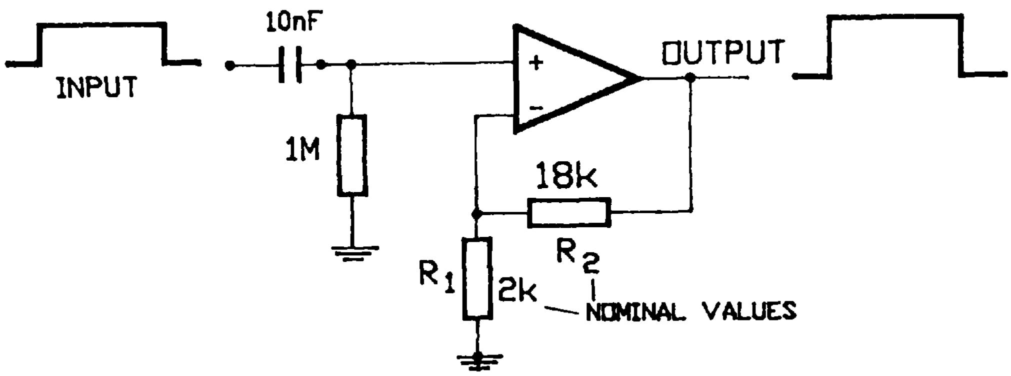


Fig. 6.17: AC-connected operational amplifier with a gain of 10

6.2 TROUBLESHOOTING OF SPECIFIC EQUIPMENT

6.2.1 Troubleshooting of a Charge-Sensitive Preamplifier

Existing commercial charge-sensitive preamplifiers fall into four categories.

(i)	Resistive feedback preamplifiers:	with input FET operating at room temperature
(ii)	Resistive feedback preamplifiers:	with input FET cooled
(iii)	Optical feedback preamplifiers:	with input FET operating at room temperature
(iv)	Optical feedback preamplifiers:	with input FET cooled

Each category requires specific troubleshooting procedures. As an example, a preamplifier with resistive feedback and input FET operating at room temperature is analyzed.

6.2.1.1 General considerations

A typical block diagram of such a preamplifier (PA) is given in Fig. 6.18, where the shielding box, the connectors, the detector biasing and the test networks are also indicated.

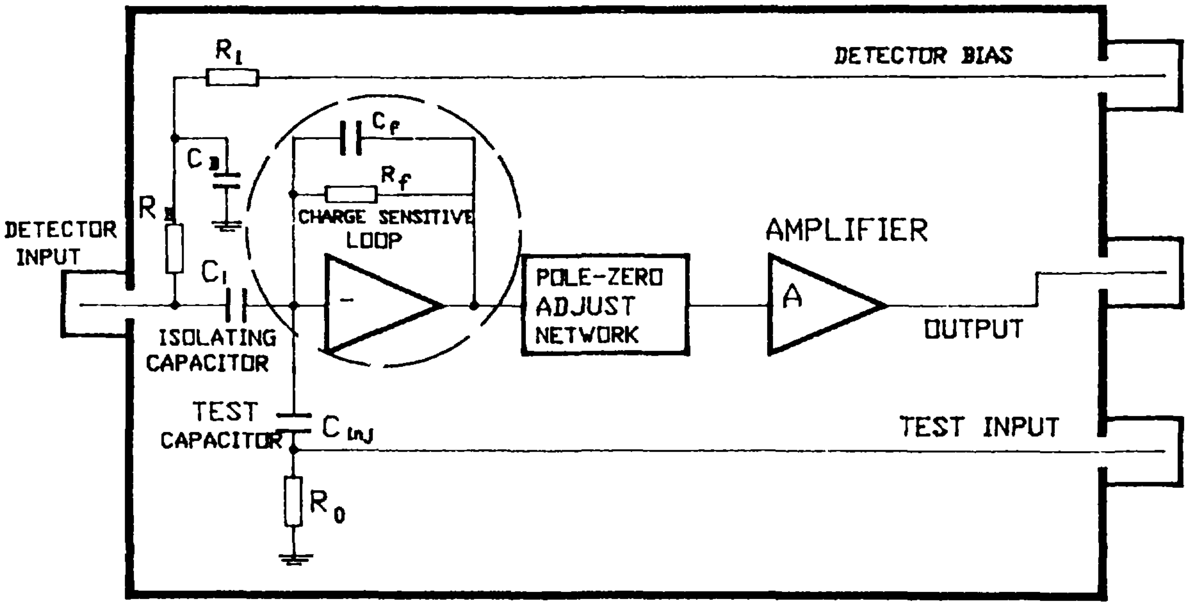


Fig. 6.18: Charge-sensitive preamplifier

The basic blocks are the charge-sensitive loop, the pole-zero adjustment network, and the output amplifier. The charge-sensitive loop determines, to a major extent, the noise performance of the preamplifier.

The fundamental concepts about these blocks can be found in the document IAEA TECDOC-363, SELECTED TOPICS IN NUCLEAR ELECTRONICS, pages 72 through 77, and in the document IAEA TECDOC-309, NUCLEAR ELECTRONICS LABORATORY MANUAL, pages 77 through 83. The drawing of Fig. 6.16 also shows, inside the shielding box, the detector bias network consisting of (R1CB) low-pass filter, and decoupling resistor RB, the isolating capacitor Ci, and the test network consisting of terminating resistor Ro and injection capacitance Cinj.

If you have such a type of preamplifier to troubleshoot, check first whether or not the output lies within its linear range, without even opening the PA box. For such a purpose:

- connect the PA output to a scope;
- put the scope on the position of highest vertical sensitivity, possibly 2 to 5 mV/cm;
- use ac coupling in the scope;
- trigger the scope on AUTOMATIC;
- turn on power on PA and look at the output baseline.

If the output baseline looks to be smeared by noise (Fig. 6.19a), then your PA is likely to be in a correct dc condition.

NOISY LINE NOISE-FREE LINE

a) b)

Fig. 6.19: Output baseline of a preamplifier as seen on a scope

In this case you can go on by sending a signal to the test input, and see whether, according to Fig. 6.12, the output signal is acceptable or badly distorted. In the former case, your PA has successfully passed the simplest test and most likely it requires more sophisticated and specific procedures. If instead the output signal looks to be badly distorted or unexisting at all, you must carry on a complete troubleshooting procedure. Open the PA box and start with dc analysis.

Returning to the output baseline displayed on the oscilloscope, if it is not smeared at all by noise, then the PA is saturated somewhere. Again, in this case, a complete troubleshooting procedure has to be carried out starting from dc analysis.

To illustrate the above consideration on the example of a commercial product, let us consider the CANBERRA 2004 preamplifier, with its circuitry shown in Fig. 6.20.

The charge-sensitive loop consists of JFET Q1 of the long-tailed pair Q2, Q3 non-inverting gain stage, and of emitter-follower Q4, which is the output stage. Transistors Q5 and Q6 are current sources, respectively absorbing the collector current of Q3 and forcing the current into the emitter of Q4.

The pole-zero adjustment network consists of potentiometer RV2, of resistors R8, R18, R27 and of capacitor C6.

Transistors Q7, Q8, Q9, Q10, and Q11 constitute a discrete-component operational amplifier, whose gain can be fixed to 1 or to 5 with the jumper connected respectively between A and C or A and B.

6.2.1.2 DC analysis to the charge-sensitive loop

Take out the sliding lid, connect the preamplifier box to earth, and switch power ON.

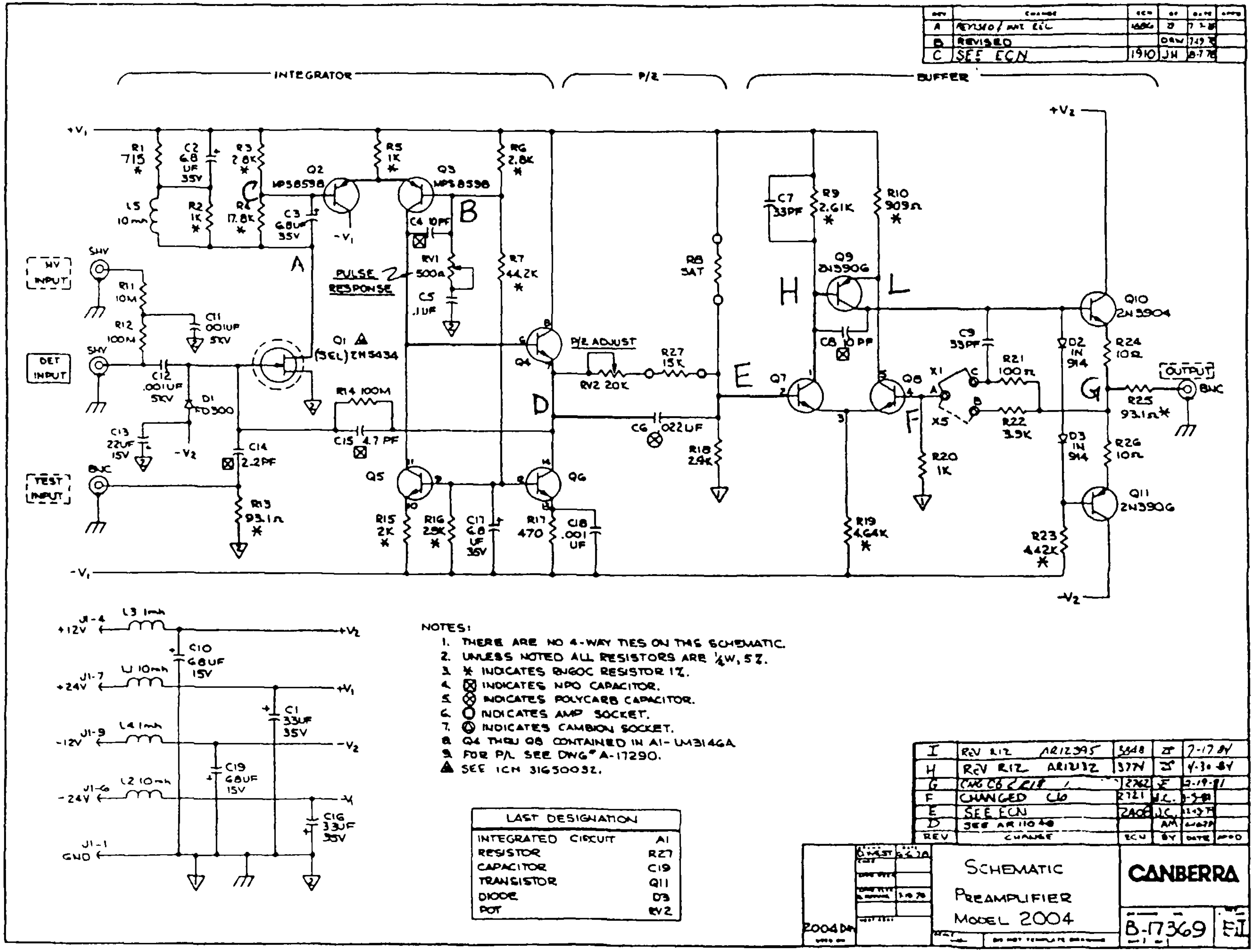


Fig. 6.20: Schematic of the CANBERRA charge-sensitive preamplifier Model 2004

Check whether the voltages at points A, B, C, and D are close to the values specified before:

$$VB = \frac{(R7 + R16)V1 - R6V1}{R6 + R7 + R16}$$

$$VC \approx VB$$

$VD < 0$ ranging between -0.1 and -1V

$$VA \approx VC - \frac{R4 \times 2V1}{R6 + R7 + R16} \quad \text{(note that R3=R6)}$$

There are three possible sources of trouble:

1. The channel of JFET Q1 is OPEN.

2. The transistor Q2 has got either base-emitter junction OPEN or emitter-collector path OPEN.

3. The current source Q5 does not provide current.

You can easily distinguish situation 1 from 2 and 3 by measuring the voltage at point A. If such a voltage is equal to +V1, then JFET Q1 has an open channel, for it drives no current although the positive voltage at Q4 emitter through the 100 MΩ resistor forces a forward bias of Q1 gate-to-source junction.

If the FET is suspected, remove it from the circuit and check it with the circuit of Fig. 6.21 a) and b).

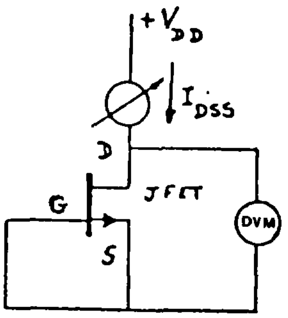


Fig. 6.21a: Measuring IDSS of a JFET

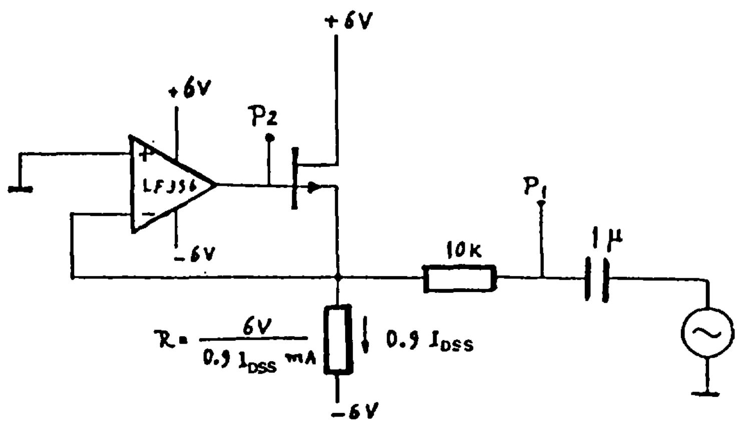


Fig. 6.21b: A circuit to measure the transductance

If the charge-sensitive loop has correct dc conditions, troubleshooting can continue by checking the output amplifier.

However, if these voltages are far from the specified values, and, as frequently happens in a damaged charge-sensitive preamplifier, VD is some volts positive, the following failures may have occurred.

(a) No drain current is measured in the JFET; it is definitely damaged and has to be replaced. If, however, current flows in the JFET, and this current is not smaller than 5mA, it is worth going to a dynamic transconductance test, according to the circuit of Fig. 6.21b. For detailed information about FET tests, read IAEA TECDOC-309, pages 78 through 81.

(b) The FET exhibits an open channel with the test of Fig. 6.21a or a value of gm which is typically below 10 mA/V; proceed to its replacement.

Actual FET replacement is not a simple operation because most commercial charge-sensitive preamplifiers employ SELECTED FETs. If the type of FET is specified, you can try to purchase some of them and then make a selection, choosing, according to the procedure outlined in IAEA TECDOC-309, the specimen which has the largest gm. Pay attention, however, to the following point. If you do not want to change other components in the circuit, the new specimen should also be not too different in IDSS from the previous one. The current actually flowing in the FET is given by

$$\frac{V1 - VA}{R1}.$$

For instance, with the components of Fig. 6.20, VA ~ 4V, the current in the FET is approximately 28mA. Therefore, your new FET should not have an IDSS below 30 mA, but should also not exceed IDSS 40mA.

Things are more complicated when the FET type is not specified or, if specified, is not available. The replacement then will rarely be completely satisfactory and the original noise performances will not be reached. Nevertheless, replace your FET following the recommendations below so you will not keep the PA out of use. In the meantime, order a specimen closer to the one which was originally put in your instrument.

6.2.1.3 Replacement recommendations

1. Deduce from the circuit diagram of the PA the value of the standing drain current ID.

2. If ID is near or below 10 mA, then stick to a FET of the 2N4416 type. This type should be available in your laboratory. Select the one which features the highest gm value (circuit 21 b) among those, rather than have IDSS values between 10 and 12 mA.

3. If ID is above 10 mA, typically 20 to 30 mA, make your selection among FETs of the 2N4861A type.

Remember, incidentally, that a very reliable manufacturer of FETs for low noise is INTERFET, 322 Gold Street, Garland, Texas 75042 USA. You can ask for their catalogue and determine their equivalents of 2N4416 and 2N4861A.

More complicated is the selection when the PA employs two paralleled FETs and one or both have to be replaced. Although one FET may have survived, this can be useless, for it may be very difficult to match it without having components of the same type or even not knowing the type. Proceed to group out of your batch of either type, depending on the standing current they worked at, the pairs of FETs that have IDSS close in value. Then parallel these pairs and measure the gm of the parallel combination. Next select the pair with the highest gm.

Once your selection is made, it would be better to check the condition of transistors Q3, Q5, Q4, Q6 anyway, just to make sure that your accurately selected FET(s), once put on the circuit, won't be damaged because of the charge-sensitive loop. Only if Q3, Q5, Q4, Q6 are in good condition, introduce the FET(s) you have selected. Now the charge-sensitive loop should be in the correct dc condition.

Consider now the case in which, being VD positive of some volts, VA is much lower than V1, which shows that the FET is in a good state; if so the failure is likely to have occurred in Q2, Q3, Q4. Apply the already-explained dc analysis to these transistors one at a time, following the recommendations of section 6.1.3. Once you make the necessary replacements, check again the dc conditions of the charge-sensitive loop.

Once this is fixed, you can go ahead by testing the dc condition of the output amplifier. Measure voltages at points E, F, G, H, L, after removing R8. Point out that VE must be close to VF, and that VG must be near 0V. Besides, the current flowing across R19 (5 mV) splits in almost equal parts between Q7 and Q8, that is, about 2.5 mA in each transistor. 2.5 mA will then flow across R9, thus keeping VH to about 17.7V. VL must be about .7 V more positive. If the voltages VE, VF, VG, VH, VL differ considerably from the stated values, and especially if VG is positive or negative of some volts, then the output amplifier is defective. To troubleshoot it, first of all check the output stage and determine whether or not current flows across R24 and R26. The presence of current across R24 and R26 tells you that Q10 and Q11 are alive. If it is so, focus your attention on Q7, Q8, Q9. Disconnect jumper AC-AB, in which case you open the feedback loop, and you can check the behaviour of Q7, Q8 in the open-loop situation. Disconnect Q9 and make sure that the currents across Q7, Q8 are not very different from each other, or at least that none of them are at zero. In this way you check the condition of Q7, Q8. If required, replace the defective component. Check then with the transistor tester Q9, and if necessary, replace it. Then, again connect Q9 and reintroduce the jumper. The dc condition of the output amplifier should now be correct.

Consequently, the whole preamplifier should now be in order from the dc standpoint and you can proceed to signal analysis.

6.2.2 Troubleshooting of Spectroscopy Amplifiers

Modern spectroscopy amplifiers have reached a high level of sophistication, as dictated by the need of ensuring advanced performances in terms of resolution, counting rate capabilities and fast recovery from heavy overload.

To meet the demand arising from high resolution spectroscopy, a considerable improvement has been introduced on the built-in base-line restorers and pile-up rejectors in order to avoid spectral distortions that may arise from baseline fluctuations at high counting rates and from pulse-on-pulse pile-up.

Restoring a spectroscopy amplifier which has undergone a failure to within the factory guaranteed performances may be outside the reach of anybody but the designer and a few service engineers. However, rescuing a faulty spectroscopy amplifier and bringing it back to an acceptable working condition can be done by somebody who has clearly understood the previous troubleshooting procedures referring to elementary linear circuits.

Before proceeding to the repair, find in the manual the block diagram of the amplifier and try to understand the functions it implements. Although the spectroscopy amplifiers from the different manufacturers may differ considerably from each other, the differences are usually restricted to the more advanced parts, like baseline restorer, pile-up inspector, dead-time and live-time monitors. The basic functions still follow a well-established pattern, which is recognizable in the block diagram of Fig. 6.22.

As shown in Fig. 6.22, the amplifier consists of an input section, which generally includes an impedance matching buffer, the pole-zero adjustment network and the first differentiator. The input buffer may not be provided in some spectroscopy amplifiers.

The input section is followed by the gain section, which usually consists of three wideband feedback amplifiers, with provisions for coarse and fine gain settings. A signal with short risetime is usually taken from the first amplifier of the gain section and sent to a fast channel. The fast channel shapes the incoming signal to a narrow width, a few tens of nanoseconds, and through a threshold discriminator provides the triggering signal for the PILE-UP REJECTOR.

The fast channel is an auxiliary signal path which has the purpose of enabling the PILE-UP REJECTOR to detect couples of events coming too closely spaced in time. The main signal path from the output of the GAIN SECTION goes to the shaping section which, in most cases, consists of two, second-order differentiators. The signal it provides is unipolar, nearly gaussian in shape, and its path goes through the baseline restorer to the UNIPOLAR SIGNAL OUTPUT. An alternative path, through the second differentiator, provides a bipolar output, available at the relevant connector.

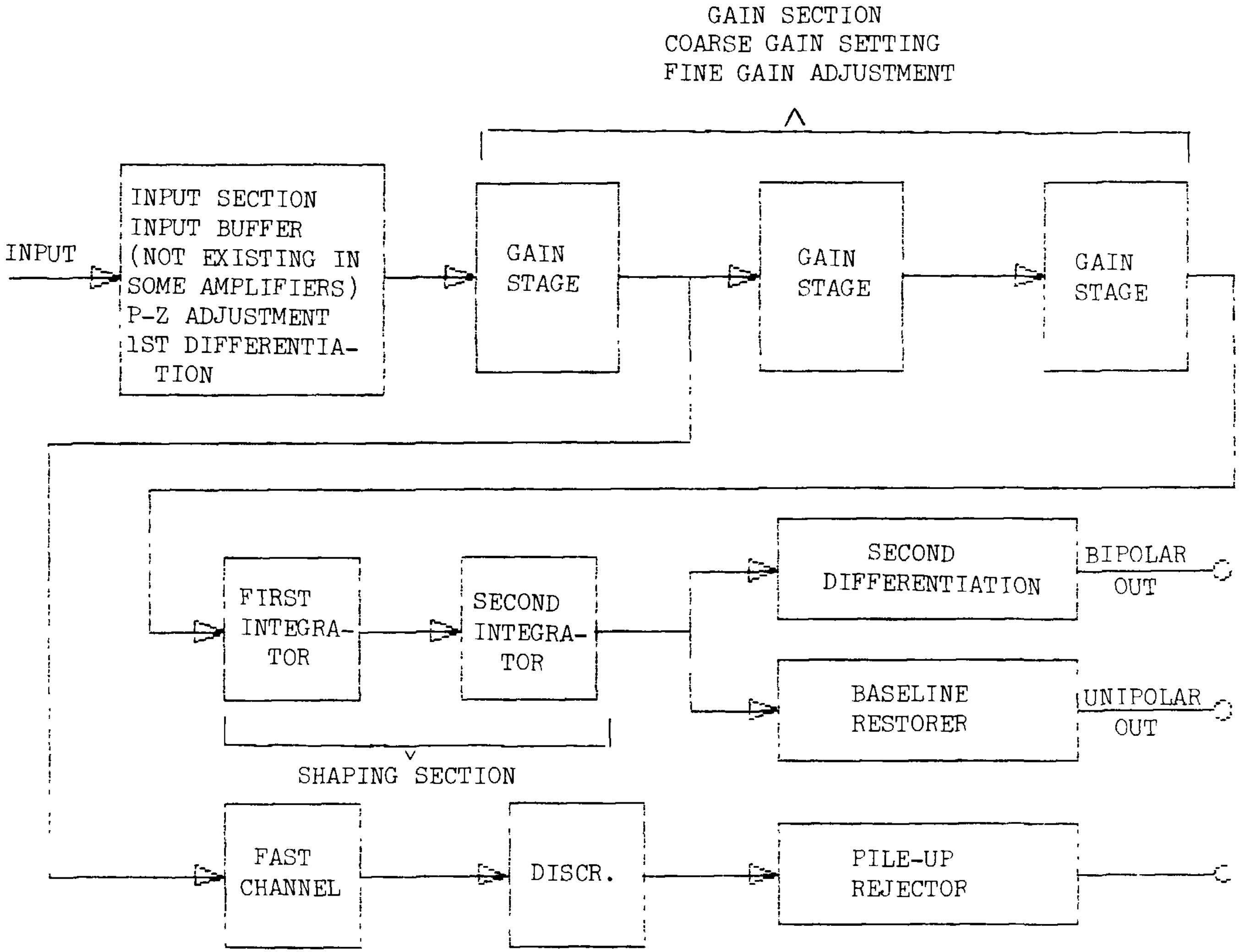


Fig. 6.22: Spectroscopy amplifier block diagram

To troubleshoot a faulty spectroscopy amplifier, start applying at the input a 10mV square signal with a 2KHz signal and set on the relevant panel knob a value of the gain around 500. Connect the output of the amplifier to an oscilloscope through a 2m long cable. In this condition you should see on the scope a sequence of positive and negative gaussian signals of about 5V in amplitude and related in time to the LOW-TO-HIGH and to the HIGH-TO-LOW transitions in the input square wave. Use of a two-channel oscilloscope displaying, in the ALTERNATE position, the input square wave and the output gaussian signals, is appropriate.

If the signals are present at the amplifier output, synchronise the scope on the channel displaying the output signals, make a single gaussian pulse firmly visible on the display, and proceed to the following tests.

a. Switch the COARSE GAIN knob through all its available positions and make sure that the signal never disappears on the scope and that simply its amplitude changes according to the knob setting. If, for a given position of the COARSE GAIN knob, the signal disappears or looks to be badly deformed, check the condition of the resistors, and in that particular position of the COARSE GAIN knob, determine the gain. The resistive network which determines the COARSE GAIN in that particular COARSE GAIN setting might be badly soldered, or even disconnected.

b. If the COARSE GAIN setting reveals no defects, keep it fixed in a given position and rotate the fine gain potentiometer throughout its range. Make sure that no sudden jumps, dc level variations, appear at the preamplifier output. Otherwise, concentrate your attention on the fine-gain potentiometer and possibly proceed to change it.

c. Check whether or not all the positions of the time constant controlling knob perform their function by leaving the shape and amplitude unchanged and by simply modifying the width of the signal.

d. Check the presence of the signal at the bipolar output and repeat on it checks a), b) and c).

If, instead, upon application of the input square wave no signal appears at the output, pull your amplifier out of the NIM BIN and put it open on the desk by powering it through an extending cable. Increase the amplitude of the input square wave to about 100mV and follow its path through the gain section by looking with a 1x probe at the input and at the output of the subsequent gain stages. If the signal is present at the input of a gain stage and is no longer present at the output, stop the signal analysis and after switching off the generator, proceed to dc analysis of that particular gain stage. Check whether this is in the linear range or its output is saturated. dc analysis should reveal where the defect is. Proceed to remove it and only after dc conditions have returned to satisfactory levels, switch on the generator again and carry on signal analysis. It may easily occur, in a misused instrument, that more than one gain or shaping stage is faulty. Then, proceeding from input towards the output, repeat the outlined procedure for all the defective stages.

As an example of real troubleshooting action, a specific amplifier, Canberra 2020, which is very frequently used in high resolution spectroscopy systems, will be considered.

This amplifier is composed of several stages (see Figs. 6.23a, 6.23b, and 6.23c):

1. Input buffer for impedance matching.

2. First differentiation stage.

3. First amplifying stage (gain 3-10 adjustable by fine gain potentiometer).

4. Second amplifying stage (gain 30 fixed, at the first 3 gain positions amplifier is by-passed).

5. Third amplifying stage (gain 1-10).

6. First active integrator stage.

7. Polarity amplifier.

8. Second active integrator stage.

After this stage, the signal is split along two paths:

a) Second differentiation and buffer amplifier for bipolar output; and

b) Output buffer stage for unipolar output; it is reached by either direct feed or via delay line; the output driver stage is controlled by the baseline-restorer-circuitry.

The amplifying stages 1, 2 and 3 are similar in their configuration and must be made out of discrete components, due to noise rise time and overload recovery requirements. In the integrators monolithic operational amplifier circuits can be used because the pulses are already slowed down. In the baseline restorer, comparators are used.

The pile-up rejector receives a signal from the third amplifying stage and provides a TTL compatible signal.

For troubleshooting it is necessary to follow the rules listed below:

1. Switch off baseline restorer.

2. Switch off pile-up rejector.

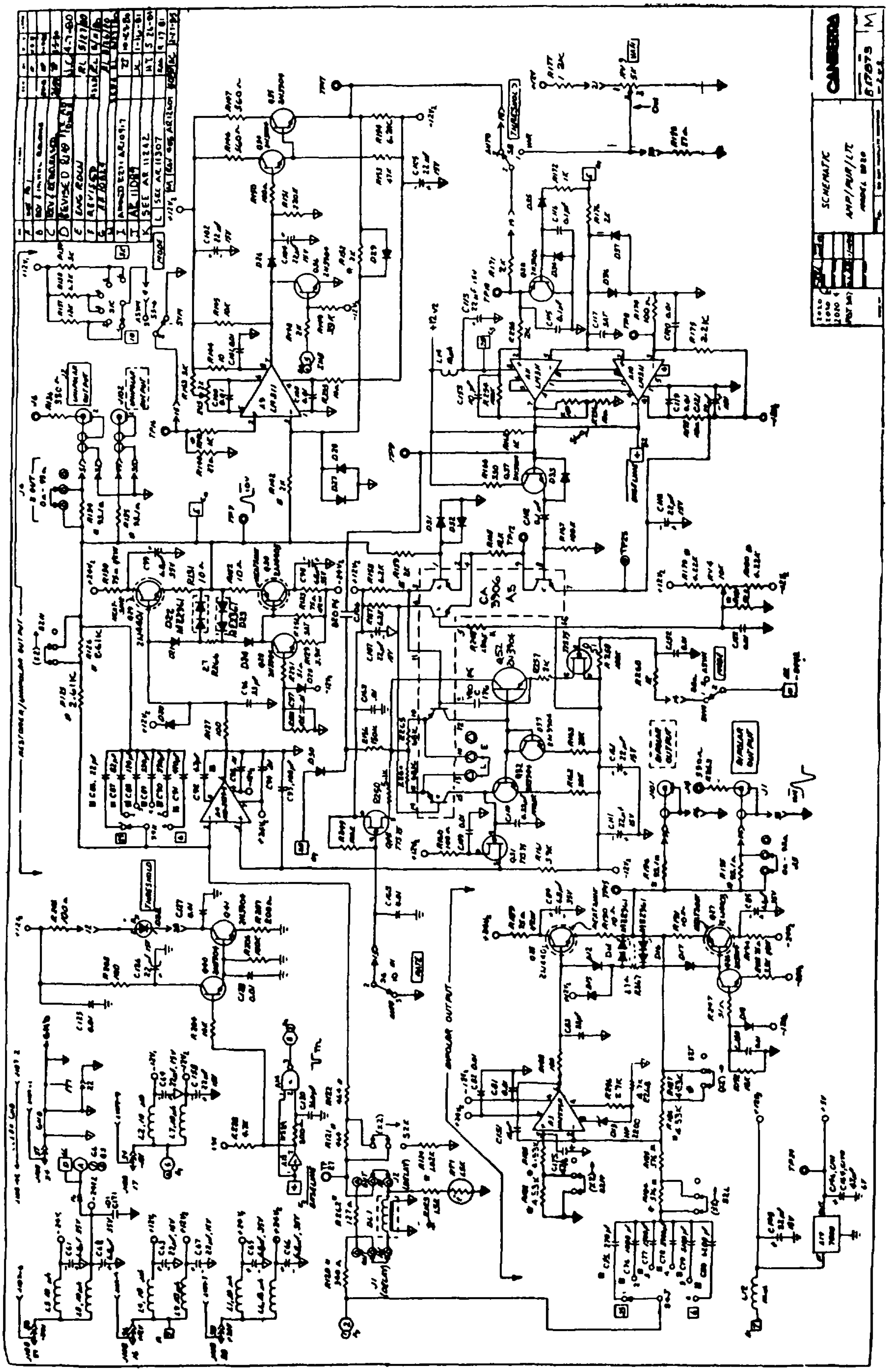


Fig. 6.23a: Spectroscopy amplifier circuit diagram

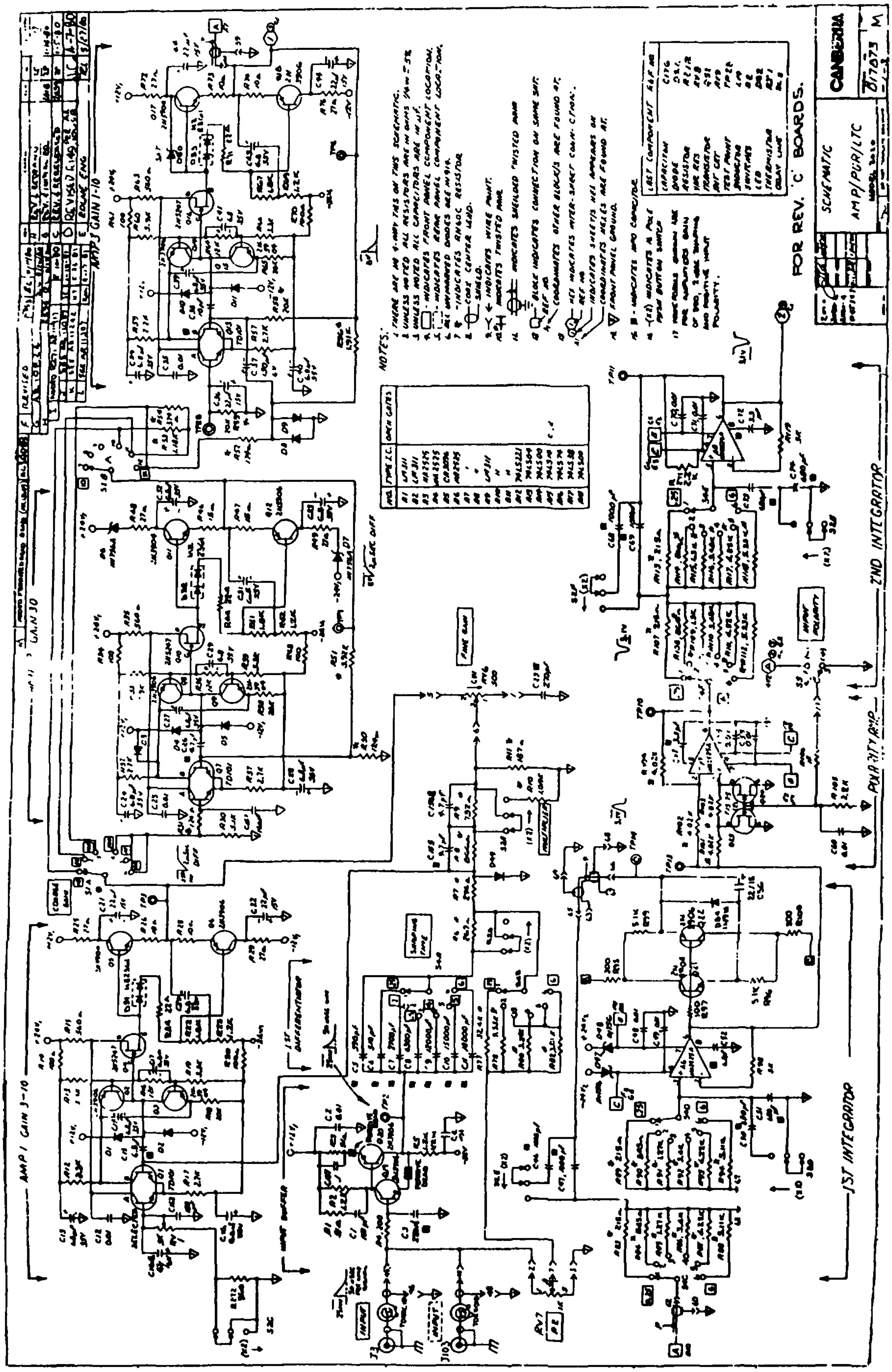


Fig. 6.23b: Spectroscopy amplifier circuit diagram

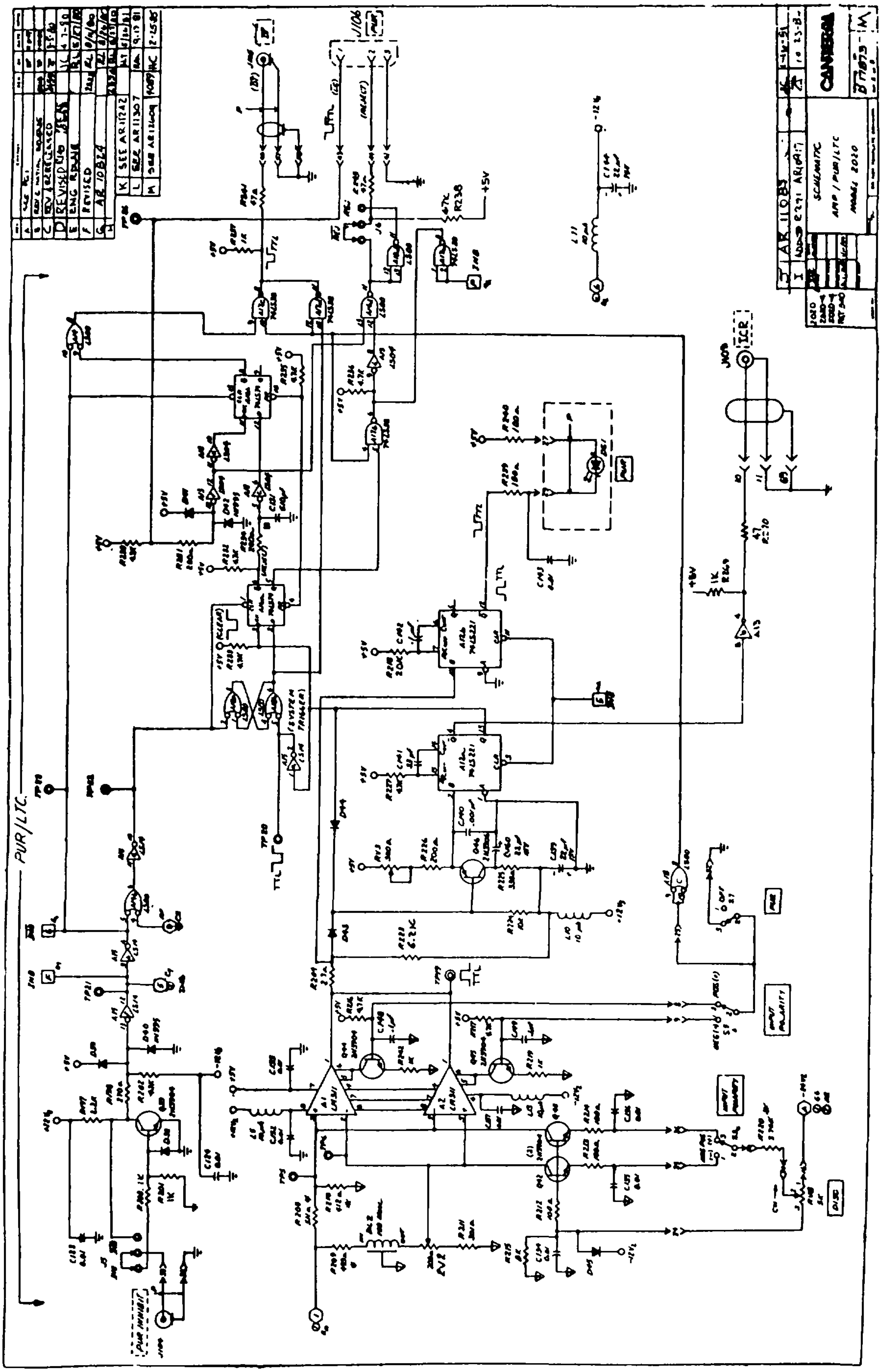


Fig. 6.23c: Spectroscopy amplifier circuit diagram

3. Do not connect a BNC-cable to the front panel connector, because sometimes the outputs are not properly terminated and therefore oscillation might occur.

4. Place the input selector switch in the positive position.

Feed a positive signal from a pulse generator through the input-plug to the amplifier (pulse repetition 1kHz, pulse width about 100 msec.; to achieve a stable picture on the scope, trigger your scope by the external trigger from the pulse generator). Follow this signal with an oscilloscope-probe 10:1 stage by stage and compare the pictures between circuit diagram and oscilloscope. If at the output of a stage there is a discrepancy, there is usually a fault in this stage. Start measuring with the digital voltmeter the DC levels of the base, emitter and collector of the various transistors. A defective component can be detected by these measurements.

After the above-mentioned procedure, an output signal of the right shape should be visible at the unipolar as well as at the bipolar output.

Now switch on the baseline-restorer and compare the signal with the previous one. If its positive going lobe is left unchanged and only the recovery towards the baseline is affected, you can assume that the BLR is working.

Connect the oscilloscope to the output, feed a pulse to the amplifier and change the gain reducing the amplitude of the test pulse. In this way the various feedback loops are checked.

The next step is to check, by setting the several shaping time constants, that the output amplitude varies only over a small range. If there is a big change in amplitude, you can assume that either the switch gives a bad contact or one of the RC networks are defective.

The pile-up rejector cannot be checked with a normal pulse generator. There are two types of pile-up: trailing edge pile-up and leading edge pile-up. A test is possible with a short double pulse fed into a RC-network (time constant about 50 usec.). To compare the signals with the manual, the scope must be triggered by the first pulse; Fig. 6.24 indicates the pulse forming network.

The settings of the double pulse generator without load should be the following:

1. amplitude 5V
2. pulse width 1usec.
3. repetition frequency 1kHz
4. double pulse selection
5. pulse delay variable from 3usec. up to 100usec.

Check the several signals at the test points and compare them with the manual.

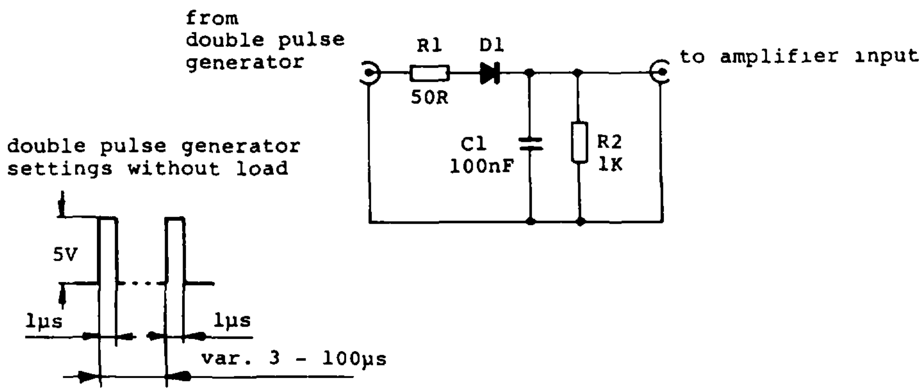


Fig. 6.24: Check circuit, which enables you to check the pile-up rejector

Chapter 7
DISCRIMINATORS, SINGLE CHANNEL ANALYZERS, TIMING CIRCUITS

7 DISCRIMINATORS, SINGLE CHANNEL ANALYZERS, TIMING CIRCUITS

7.1 INTRODUCTION

The fundamentals of amplitude analysis and time measurement in nuclear electronics have been dealt with in IAEA TECDOC-363 to which the reader is referred. Here we limit ourselves to a discussion of commercially available instruments from the viewpoint of maintenance and troubleshooting.

Apart from a few examples, discriminators are available just as part of single channel analyzers. The exceptions generally apply to instruments intended to accept pulses coming directly from photomultipliers in fast amplitude and time measurements. Although they are not referred to explicitly in what follows, the discussion is, in broad terms, also relevant to them.

To be useful in different applications, the output signal from a single channel analyzer frequently contains both amplitude and timing information. Circuits related to each one of these parameters are discussed below.

7.2 AN EXAMPLE: EDGE/CROSSOVER TIMING SCA, CANBERRA MODEL 2037A

A block diagram of the instrument is shown in Fig. 7.1.

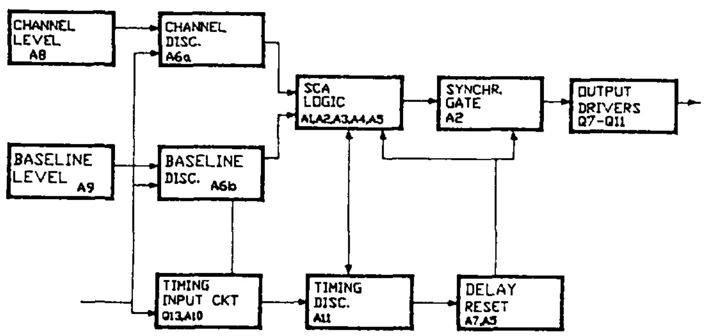


Fig. 7.1: Block diagram of timing SCA

The baseline and channel discriminators compare the input analog signal amplitude to the preset voltage levels V(E) and V(E + ΔE). The output of the discriminators is combined in the block labeled SCA logic to produce an output if the SCA conditions are satisfied (that is, if the baseline discriminator is triggered and the channel discriminator is not triggered). The output signal is delivered to the output drivers at an instant determined by the timing discriminator. A more detailed analysis of the various circuit blocks follows, together with troubleshooting guides.

7.2.1 Level Setting Circuitry

The comparison level for the baseline discriminator is set by the circuitry around A9, which is wired in a voltage follower configuration. From Fig. 7.2 you can see then that the input voltage to A9 (pin 3) comes from the NIM +24V supply; if this voltage changes, for example due to load changes in the NIM crate (see Chapter 5, Power Supplies), the output of A9 is bound to change.

To check whether the circuit is working properly, verify if the output voltage (pin 6) is equal to the input voltage (pin 3) at the extreme positions of the RV8 helipot range; the trim potentiometer RV5 should be adjusted so that at the lowest voltage in the range, the output voltage equals the voltage at pin 3; at the upper end of the range, RV6 should be adjusted so that the output voltage of A9 is +5V. If the circuit is not working properly, follow the procedures described in Chapter 6, (Preamplifiers, Amplifiers) to identify the fault.

The channel (window) comparison level is established by A8, which is wired as an amplifier of gain 2; the gain may be changed through the adjustment of RV2 by ±2%. Trim pot RV1 adjusts the offset voltage as in the circuit around A9. The voltage at the non-inverting input (pin 3) is very approximately given by $\frac{V(E) + V(E + \Delta E)}{2}$; thus at the output of A9 the voltage is $V(E) + V(E + \Delta E)$. You can see that the circuit around A8 allows one to move the channel up and down (by adjusting the baseline helipot) without changing its width. To check the circuit first set the baseline and channel helipots to zero; check if the input (pin 3) and the output are at the same voltage; if not, adjust RV1. Then turn the baseline helipot full scale (the output of A9 should have +5V); you should measure +5V on the output of A8, otherwise adjust RV2. Next, turn the channel helipot to full scale and the E range switch S2 to the 10V position; with the baseline helipot at zero, you should read 5V at the output of A8, otherwise adjust RV3. Next, with the same settings but with the range switch S2 in the 1V position, you should observe 0,5V at the output of A8, otherwise adjust RV4.

The above measurements should be done carefully and the corresponding adjustments, if necessary, should be made in the stated order.

We now refer to the level setting for the timing discriminator (A11). This level is derived from the baseline voltage follower; R16 connects the output of A9 to the base of emitter follower Q17 and to the "ideal diode" made up around A10. The non-inverting input of A10 is at about 200mV; pin 2 of A10 should have the same voltage if the feedback loop around the amplifier is closed. This will be so if diode D3 is conducting, a condition that is fulfilled whenever the output of A9 is above the value imposed at pin 3 of A10 by the R14, R15 divider network (≃ 200mV). You can check for the correct behaviour of this ideal diode by looking at the anode of D3 while the baseline helipot is increased from zero; while the output of A9 is below 200mV, A10 is saturated (output positive); above this value A10 enters the active region and the voltage at the anode of D3 is clamped to the 200mV value. Emitter follower Q17 drives this voltage to the timing comparator input if the leading edge triggering mode is selected. However, if the crossover mode is selected, this level setting circuitry is not used; the comparison level is then set at a value equal to the

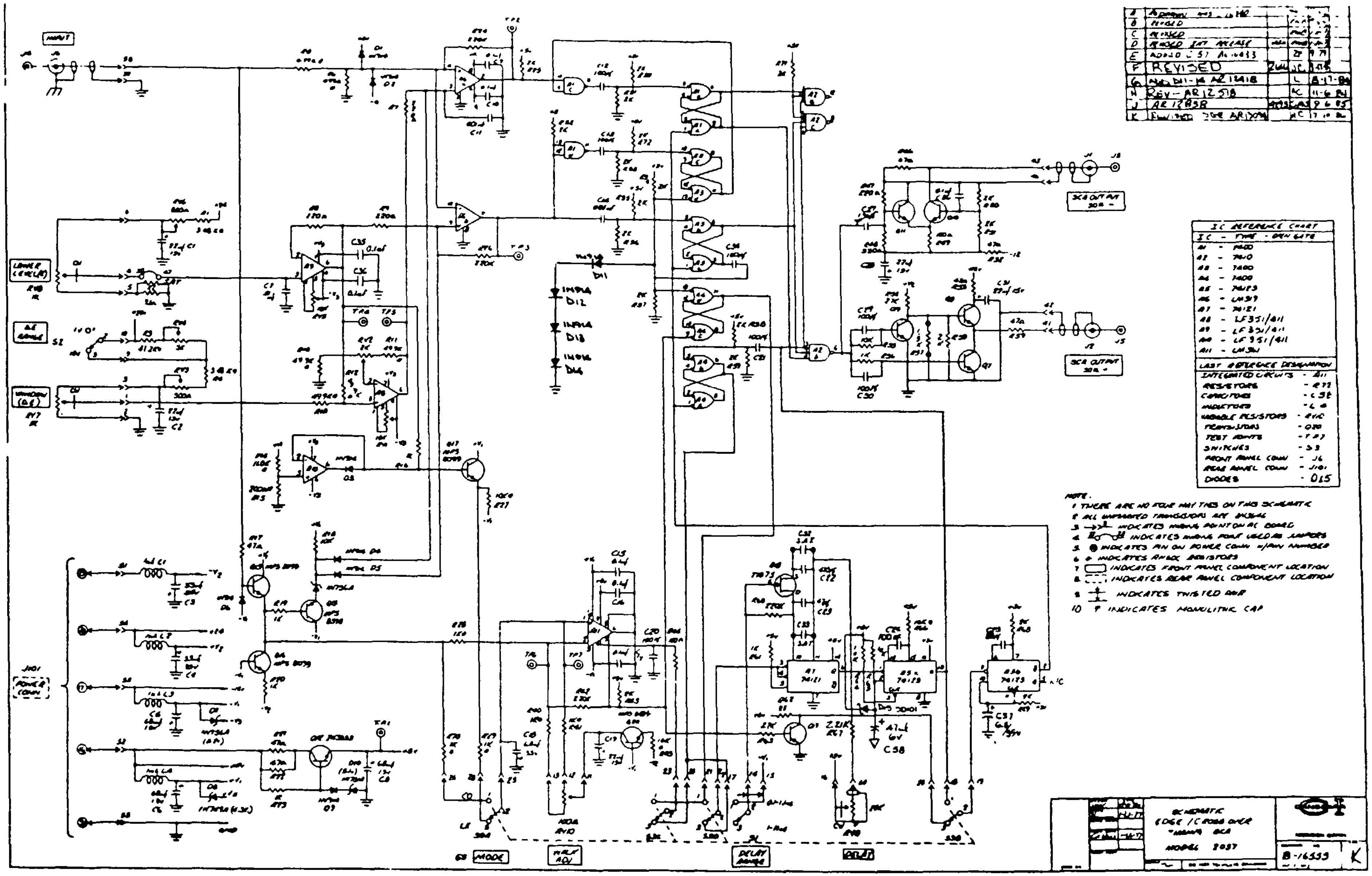


Fig. 7.2: Circuit diagram of a TSCA.

average voltage of the input line (that is, at the mean value of the output of the amplifier connected to the present instrument), see Fig. 7.3.

7.2.2 Analog Input and Discriminator Circuits

The input analog signal is divided by 2 before it is applied to the comparators A6a (channel) and A6b (baseline). The input is dc connected, and a first check can be made by applying a dc voltage to the input. For example, if the baseline helipot is set at half-scale position, the comparator should trip when the input voltage is approximately 5V.

The hysteresis of the comparator is fixed at roughly 5mV by the resistor network R26-R9. This may be checked by verifying that the voltage at pin 9 of A6b takes values differing 5mV from each other according to whether the output of the comparator is at logic 0 (≈ 0V) or at logic 1 (≈ 5V).

The comparator inputs are protected by diodes D1 and D2, and also by the circuit around Q15, which does not allow the input differential voltage to exceed the limits specified for the LM319 (± 5V). The protection circuit should be checked if the input analog signal fails to appear at the comparator.

The analog signal is applied at the inverting terminal of the timing comparator A11 through emitter follower Q13; Q16 works as a 10mA current source. The circuit up to the A11 inputs, when the crossover mode is selected, is shown in Fig. 7.3. Note that this mode of operation may be selected only if the input signal is bipolar.

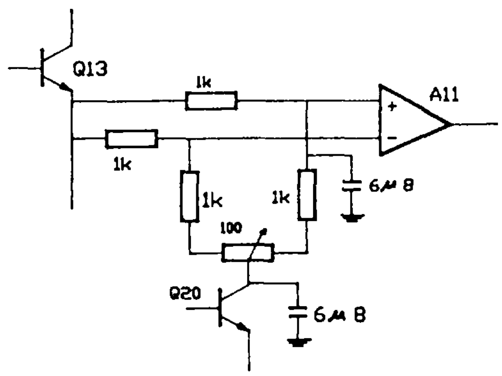


Fig. 7.3: Timing discriminator input circuit in crossover mode

In this mode of operation, the input analog signal and the comparison voltage level are both derived from the emitter of Q13; the comparison level is obtained by filtering the signal out with capacitor C18. Thus the comparison voltage follows eventual slow fluctuations of the analog input baseline voltage, as may be verified by applying a dc voltage at the input. Note that the 1mA current sink Q20 allows the differential dc level at the A11 inputs to be varied by 100mV through adjustment of RV10; this is easily checked with a multimeter if no input signals are present. This adjustment is intended to minimize the time walk; this parameter is discussed in detail in IAEA TECDOC-363.

The working condition of the comparators is easily checked. In the absence of input pulses, the output of the baseline discriminator (pin 7 of A6) should be at logic 1, and the output of the channel discriminator should be at logic 0. With a scope it should be observed that the outputs of the comparators go to the complementary logic state while the analog signal exceeds the respective comparison voltages.

7.2.3 The SCA Logic and Timing Circuits

The SCA logic is mainly based on RS latches made with gates included in A1, A3, A5, and on gate A2b. You may quickly perform a first check on these and the other latches present in the circuit by just observing if their outputs Q and $\overline{Q}$ are complementary, as they should be. The logic behaves in a somewhat different way according to whether the leading edge or the crossover mode is selected. We first refer to the leading edge mode operation, which may be checked as follows.

Apply pulses of about 5V amplitude and with a shape similar to 1us amplifier pulses. Set the baseline helipot to a level of about 4V, and the channel helipot to a channel width of 2V; only the baseline discriminator should be triggered by the input pulse. Look at the timing discriminator A11 output (pin 5); observe that it changes before the baseline discriminator output, because it is set to a trigger level of around 0,2V while the baseline discriminator level is set at about 4V. Note that for A11 to be triggered, it is necessary that pin 4 be at logic 1; the state at pin 4 is controlled by latch A4 pin 6.

You may now observe the actions initiated by the output pulse of A11. Through inverter Q19 it triggers monostable A5b; the complemented, roughly 0.1us wide output pulse of this monostable (pin 12) acts as a reset pulse; in particular, it resets the baseline latch (A3a,b). This may be observed at pin 6 of A3 which changes from logic 1 to 0; soon after, it is again set to 1 by the baseline discriminator signal. Note that the discriminator is reset at the beginning of the analysis cycle, not at the end. The monostable also resets latch A4a,b disabling the timing discriminator output; pin 6 of A4 then goes from logic 1 to 0, which causes the delay monostable A7 to be triggered. At the end of the delay period, 0.5us monostable A5a is triggered and its output pulse does two jobs: it triggers the SCA output circuits if pins 4 and 5 of A2b are at logic 1 (as they should be if the baseline latch was set by the baseline discriminator and the channel discriminator has not been triggered); and it sets latch A4a,b, enabling A11 for the next analysis cycle. You should also test the circuit response when the channel discriminator is triggered; in this case pin 4 of gate A2b should be at logic 0 and no SCA output pulse will be generated by the A5a monostable pulse.

The checking procedures just described are similar to the ones that may be applied to check the logic when the crossover mode is selected. In this mode, the output of A11 (pin 5) is at logic 1 when no input pulse is present. Note, in particular, that the SCA output signal is always synchronized with the timing discriminator output, and that it is delayed by A7 for a preset time interval relative to the A11 triggering time.

7.2.4 The Output Circuitry

The output pulses from this unit are intended to actuate the inputs of coincidence plug-in units or of time to amplitude converters. The output circuitry should be able to drive terminated 50Ω cable; discrete circuits are used here for this purpose. You should check if the positive-going pulse at the output connector J2 complies with TTL standards. Actually, from the circuit you should expect logic 0 to be less than 0,2V for currents as large as 50mA (Q7 and Q9 are saturated, Q8 is cut off), and logic 1 to be higher than 2.5V for currents larger than 50mA (Q7 and Q9 are cut off, Q8 acts as an emitter-follower).

The circuit for the negative-going NIM-pulse should sink a current of roughly 17mA; if this current flows through a 50-Ohm resistor, a signal of -0,8V develops; this signal is rather narrow due to the differentiating time constant of about 20ns at the circuit's input. If the discrete output circuits are suspected of malfunctioning, the techniques given in Chapter 6 for the troubleshooting of transistor circuits may be followed.

7.2.5 Constant Fraction Timing Discriminator

Another common method of obtaining accurate time marks, with a small amplitude dependent time walk, is the constant fraction method. A circuit example may be taken from Canberra's Model 2035A constant fraction timing SCA, see Fig. 7.4. The plug-in unit differs from the one previously discussed essentially in the All input circuits.

To check the circuit observe the input pulse at the emitter of Q13; at test point TP6, which is the negative input of All, the pulse occurs at the same time than at the emitter of Q13 and with approximately half amplitude. At test point TP7, which is the positive input of All, the pulse is delayed by 0.5, 2 or 10us according to the delay line selected, and its amplitude is reduced to about 1/3. The All timing comparator responds to the voltage difference between these two pulses, changing state when the difference crosses zero. As before, it may be seen that RV10 is a walk adjustment potentiometer. Note that when no input pulse is present, the output of All (pin 5) is at logic 1.

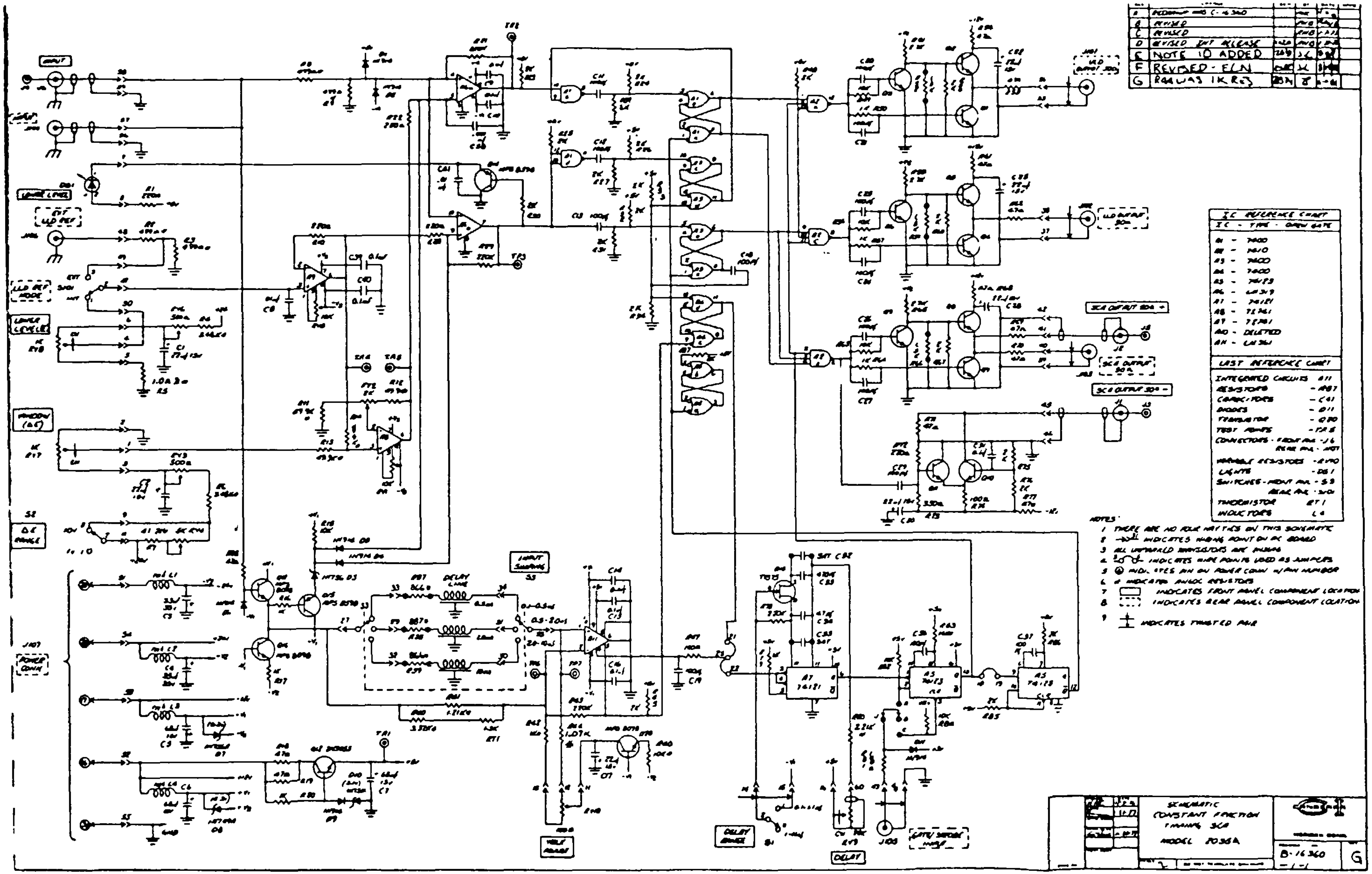


Fig. 7.4: Constant fraction timing circuitry

Chapter 8
SCALERS, TIMERS, RATEMETERS

8 SCALERS, TIMERS, RATEMETERS

8.1 TYPICAL STRUCTURES OF SCALERS, TIMERS AND RATEMETERS

To be able to service and repair scalers, timers and digital ratemeters, it is essential to correctly identify the different blocks in which the instrument may be logically divided, and to understand their interactions. To help in this procedure, a short description of typical structures is given below. A detailed description of examples of commercially available instruments completes this chapter.

8.1.1 Introduction

The general block diagram of a typical counter with preset count capabilities is shown in Fig. 8.1.

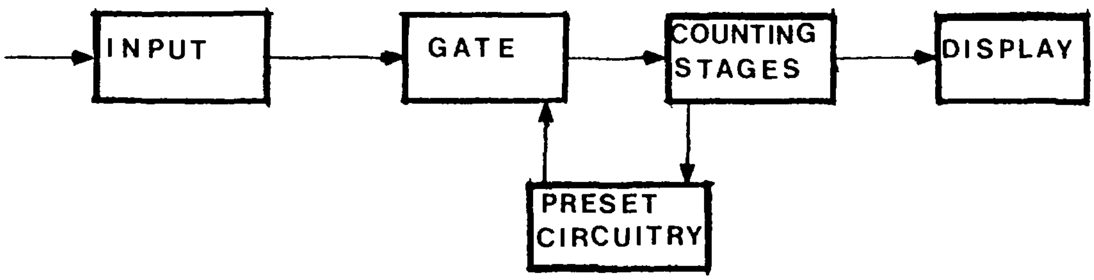


Fig. 8.1: Block diagram of a typical counter

The signal to be counted can, in general, be easily followed through its path in the counter, and defective ICs can be located without too much difficulty. Circuitry associated with preset count and gating is generally more difficult to troubleshoot because of interactions among several control signals.

As an example of faults which are hard to find, we may quote the spurious counts due to bad filtering by a defective capacitor.

8.1.2 Input circuits

Most input circuits accept NIM logic signals, positive and/or negative. Some counters have discriminator-type inputs, allowing analog signals of small amplitude to be counted.

One must check whether the input circuit passes the signals for counting in a proper way. In particular, this involves checking for triggering at the appropriate levels, and for multiple triggering due to cable reflections or other causes. NIM positive signals are frequently received at a 1k-Ohm impedance; significant reflections are absent provided the cables are not too long (and the signal is not too fast). NIM negative signals must be received in an impedance that closely matches the cable. Frequently, this impedance is made up of a resistor in series with the input impedance of a common base transistor; a significant impedance mismatch may indicate a defective transistor.

Discriminator-type input circuits most frequently use the 710 or other fast discriminator. Good power supply decoupling near the discriminator, and a not too small hysteresis, are needed to avoid multiple triggering.

8.1.3 Output Circuits

Output circuits are prone to be damaged by improper connections. Most frequently, however, they are just unable to cope with the demands put on them. For example, a TTL gate, or a CMOS driver, have a driving capability that can easily be exceeded. To drive a terminated 50-Ohm cable, one needs a transistorized output stage or a special integrated circuit. A check should be made to verify whether legal logic levels are being delivered.

Output connection to printers or equipment buses is addressed elsewhere.

8.1.4 Counting Gates

Counting gates are open/closed manually or by signal-levels and/or pulses. Debouncing of manual switches is mandatory; the corresponding circuitry is easily checked and the same is true for the latches associated with pulse control. These bistable elements are easily triggered by very short pulses; this may be a cause of trouble if decoupling is ineffective, or if glitches are allowed to occur and are not filtered out.

8.1.5 The Counting Stages

The counter generally provides several counting decades whose output is available in BCD format. Normally, only the first (faster) decade, or decades directly associated with some types of preset control, are of the synchronous type. Frequently, ICs with two decades are used, but LSI circuits with four or six decades are already present in various instruments.

Preset count is frequently limited to the combination pqx10^r where p.q and r represent decimal numbers. Generally it involves either a comparison of the BCD-coded numbers p and q with the contents of the sealer, or the zero detection in a count-down process of two decades previously loaded with contents p and q. Troubles may easily arise from glitches or spikes in the power lines.

8.1.6 Display Circuits

Seven-segment digits, implemented in LED or LCD arrays, are generally used in displays. In LED displays two multiplexed buses are typical, one from the decades to the BCD-to-7 segment decoder, another from the decoder to the digits. In LCD displays, all digits should be permanently activated; circuits including a 4-bit latch and a converter for each digit are generally used.

Scanning circuits are typically made out of a binary counter and a decoder (for example, an LS93 and an LS138) whose output lines successively activate the open collector or tri-state circuits that connect the various decades to the bus, and select the appropriate digit. Some LSI circuits, like the six decade 7301, already include the scanning circuits.

8.1.7 Time Generators

In timers or counter/timers, time marks are derived from the mains (typically at 1/100 or 1/120 second period) or, most frequently, from a crystal oscillator. These generally oscillate at a frequency of several MHz, which is suitably divided to give time marks either in a seconds or in a minutes scale. In preset type counter/timers, the preset count can be associated with either the counting events or the time marks.

8.1.8 Ratemeters

A typical digital ratemeter has a structure similar to that of a preset counter/timer. The integration period corresponds to a preset time; the displayed count, corresponding to the total count of the previous period, is updated once per period.

Analog ratemeters typically shape the input pulses in a well-defined form, and integrate them to have a voltage proportional to the incoming rate in either a linear or in a log scale.

8.2 TROUBLESHOOTING

The first step in troubleshooting is to establish the block diagram of the instrument and to identify the faulty block or blocks. This is generally easy for an absolute (no signal) failure, but may be rather tricky for the faults related to degraded performance (spurious counts, erroneous preset counting, etc.).

8.2.1 Checks at the Component Level

First check whether power arrives at the appropriate pin of the IC. The truth table of gates must be seen to be followed, otherwise the component is defective. A check should be made to verify if the voltage levels are well within the legal limits for the inputs and the outputs; this applies to all digital circuits. In latches and flip-flops, check if the Q and $\overline{Q}$ outputs are in fact complementary; in general, check the truth table of the component. If the component is supposed to behave in a dynamic way, like a LSI counter with multiplexed output, verify whether the scanning and related signals are being sent out.

Analog comparators and transistors are sometimes found, especially in input and output circuitry. Measurement of the voltage levels at the input and output will generally show whether a comparator is working properly. Transistors are easily checked as discussed elsewhere; frequently they will be either on or off, and the voltage levels they give to the following circuits should be seen to comply with the appropriate legal levels under the load conditions in which they are expected to operate.

Displays may easily give trouble. Frequently this is due to short circuits or misconnections in LED displays, and to improper contact in the conducting path (usually at the rubber/glass junction) of LCD displays. These are also prone to malfunction if excess humidity provides leaky paths for the segment voltages.

Faulty capacitors may be responsible for a total failure if they are short-circuited, or just to degrade performance of the instrument if they do not adequately by-pass spikes or glitches to ground (a much more difficult situation to troubleshoot).

8.2.2 Checks at the Block Level

The input block must be seen to give a single pulse for each pulse received, even if the pulse has a reasonable amount of noise; a pulse generator will help to determine the triggering threshold. If the input is supposed to work on analog signals, multiple triggering is more likely to occur with slower signals; a sine wave, with the negative half wave clipped to ground by a diode, is a suitable test signal. If multiple triggering occurs (with the threshold well above noise level), the hysteresis circuit of the comparator must be checked.

Pulse pair resolution is determined either by the input block or by the first counting circuit. If otherwise unavailable, a simple test instrument can be built around two 74LS221 integrated monostables and an OR gate, as shown in Fig. 8.2.

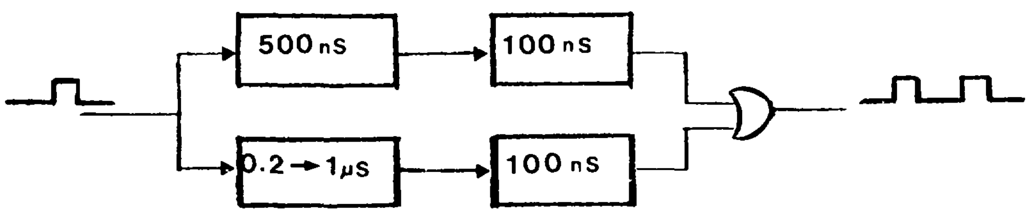


Fig. 8.2: Double pulse generator with adjustable separation between pulses

The functioning of the counting circuits can be easily checked if they consist of individually accessible decades or binary counters. When one is dealing with LSI counters, where the output lines are time-shared by several decades, the functioning of each decade may be observed by externally triggering a scope with the scanning clock signal.

Preset count circuitry may be checked starting from the storage of preset information, followed by observation of the count-down, or by examination of the comparator circuits that test when preset count is reached, according to the approach used in the instrument to implement the preset function.

8.3 TROUBLESHOOTING EXAMPLE: TIMER/SCALER, CANBERRA MODEL 2070

A block diagram of this timer/counter is shown in Fig. 8.3; some semiconductor components (not all) are indicated to help in identifying the blocks.

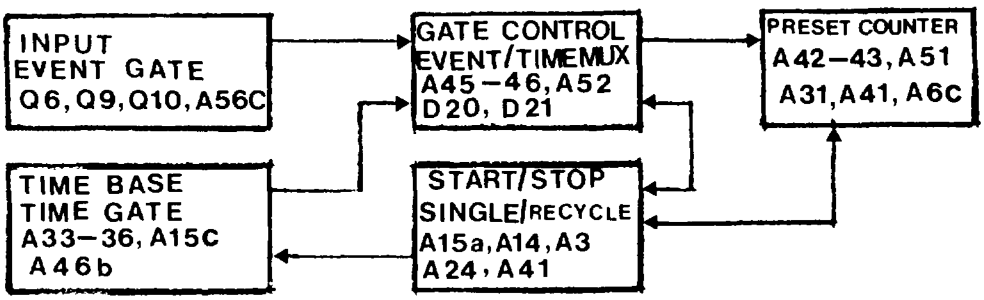


Fig. 8.3: Block diagram of Canberra 2070 timer/counter

8.3.1 Input and Event Gate

The dc voltage at the input is approximately 0V for it is imposed by Q9 whose base is at about 0,7V, as set by the diode connected transistor Q6. NIM positive logic pulses (actually, any positive pulse larger than about 0,7V) saturate Q10 and cut off Q9; NIM negative pulses do not affect Q10, but draw enough current through Q9 for a logic 0 voltage to be developed at the input of NAND gate A56c. Input pulses should appear at pin 8 of A56 if pin 9 is at logical 1; this level should appear if PRESET COUNTS mode is chosen (if not, check A15c for logic 0 at pin 10 and A52 for logic 1 at pin 2).

8.3.2 Time Generator and Time Mark Gate

Check the output of the 12 MHz generator and the divide by 12 IC (A33); the output of A33 is transmitted to the ck input (pin 5) of A35 if gate A13d is opened; this should occur if the external GATE input is left unconnected, and should stop if this input is grounded. The 1 MHz output of A33 is divided by 10 by A35, giving time marks spaced by 0,01s; A34 provides a division by 60, producing time marks separated by 0,01 min. A36 a and b, together with A46c, form a 2-to-1 multiplexer allowing the selection of the time scale by a switch. In TP8, a time mark wave should be seen of either 0.01 min or 0.01s (in the PRESET 0.01s or COUNTS position). A46b is the time base gate; the control input of this NOR gate (pin 6) is connected to the same line as the control input of the NAND event gate (pin 10 of A56), thus assuring that one, but only one, of these gates is always open.

8.3.3 Gate Control and Event/Time Multiplexer

The external GATE signal actuates through NOR gate A45c. If the gate is closed (logic 1 at pin 8), no time pulse will pass; again, the output (pin 10) will force multiplexing diode D20 into conduction, therefore fixing the output of the MUX (the common point of D20 and D21) to logic 0, and thus also disabling the counting of event pulses. If jumper A is moved to the B position, the external gate signal cannot disable counting.

The external gate also actuates on the time generator by closing A13d (provided jumper 5 is in the appropriate position); thus, time counting can be controlled in 1μs intervals.

Note that A45c is actuated through A45b, being open when the output of A45b is at logic 1; this requires pin 5 of A45b to be at logic 0 - a condition that is satisfied as discussed below.

8.3.4 Start/Stop and Enable Circuitry

The start signal, from the START input or from the manual switch, sets flip-flop A3. While the flip-flop is set, counting is enabled, except for an initial 10μs dead time period set by the A24 monostable to reset the A51 six decade counter. To allow a reset to follow quickly, the set signal should be narrow; this is accomplished in the manual starting mode by keeping pin 2 of A13 only momentarily at logic 0- only while R15 charges up C5. Through the output of A13a, the start signal triggers the 10us A24 monostable to clear the A51 counter and to enable the parallel load of the A42 and A43 down counters. Note that a 10μs dead time is thus introduced in the counting time.

The output of the A3 flip-flop is ANDed with the preset count signal (output of $\overline{\text{A6c}}$) in A14d, and wired-OR through this gate with the external $\overline{\text{ENABLE}}$ signal to control counting gate A45c through A45b. Note that the $\overline{\text{ENABLE}}$ port may be used as an output driven by open collector gate A14d.

The start signal line at the output of A14d is also used to keep the A35 and A34 time generator counters reset while the line is at logic 1 (counting not started); simultaneously, it also keeps the parallel load of the down counters enabled.

A2e and d form a falling edge triggered monostable that starts a counting cycle through A13a if D2 is moved to the Z position. This is necessary if one wants to allow counting to start at the falling edge of the external $\overline{\text{ENABLE}}$ signal.

The stop signal, either from the manual switch or the preset count output, resets the A3 flip-flop through the A15a gate; thus counting is disabled. When pin 11 of A14 goes to logic 1, the 10s monostable implemented in one-half of A24 is activated if the RECYCLE mode is selected. After the 10s delay, the 10 us A24 monostable is triggered to clear the A51 scaler and to parallel load the A42 and A43 counters, while the A3 flip-flop is set through A46d and A13a. This keeps the counter recycling with a 10s interval from the end of one counting period to the beginning of another.

8.3.5 The Counting and Preset Circuit

The preset count value takes the form pqx10^r where r is set to a value in the range 0 to 6, and pq is a two-digit number taking values from 0 to 99. This information is loaded in the down counters A42 (units) and A43 (tens). The power r is used to control the output of the six decade counter A51; if r = 0, the output has the same number of pulses as the input; in general, the output corresponds to a division by 10^r.

Pulses for the down counters come from the output of the decade divider A51 through gate A41d. This gate is enabled by the output of A41b while the preset count is not reached. When the preset value is reached, the output of A41 becomes 1 and through A28d and A6 stops the counting process. Capacitor C3 filters out eventual negative spikes that may trigger the following circuits. Gate A28d may be closed by A31, allowing the counter to be open indefinitely; A31, an 8-input NOR gate, closes A28d if the preset value to the down counters is zero.

8.4. TROUBLSHOOTING EXAMPLE: LCD DISPLAY OF DUAL COUNTER/TIMER, CANBERRA MODEL 2071

Here we just refer to the display section of this instrument, the block diagram (channel A) of which is presented in Fig. 8.4.

The 6-digit display can either show the contents of decades D5 to D0, or of decades D7 to D2, according to whether the contents of the most significant decades (D7, D6) is zero or non-zero; this is implemented by the scaling block. The contents of the various decades is transferred through a bus to the latch-decoder ICs associated with each digit; the latches are successively enabled by the strobe signals from A8, a counter that moves with the same clock (A32) that actuates the scanning circuits included in the LSI counter A54. The scan reset input of the LSI (pin 1) is used to assure the synchronism necessary for each digit to display the corresponding decade. The scan reset input signal can be made synchronous with the signal strobe 1, in which case the display shows decades D5 to D0; or with a signal that appears two scanning clock pulses before strobe 1, in which case the display shows decades D7 to D2. This scale selection is made through multiplexer A38, the address inputs of which are driven by the appropriate signal from the LSI scalers of channels A and B (through a flip-flop and a gate as shown in the block diagram).

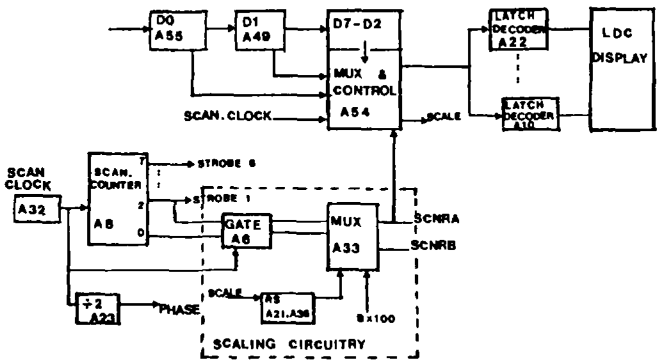


Fig. 8.4: Block diagram of the display section of dual counter (Canberra Model 2071)

A short guide to troubleshooting the main points of the display section of the instrument is given below.

8.4.1 Scanning Oscillator and Counter, Scaling Circuit

Check for the oscillator signal at the clock input of counter A8 (pin 14); if it is not there, check at the output of A32 (pin 3) where a rectangular wave with the high state twice the width of the low state should be seen. If the oscillator is working and no signal is present at the clock input of A8, go back to the oscillator through gates A15a and A12 (disconnect the daisy chain option if necessary). With the clock signal on, observe the outputs of A8; the outputs of A6 should be in the same state as the 0 and 2 output lines of A8. Observe the scanning reset of channel A (SCNRA signal at pin 13 of A38; check that it is synchronous with the strobe 1 signal (pin 3 of A8) if at least one of the decades D7 and D6 has non-zero contents, and that it is synchronous with pin 2 of A8 otherwise. If this is not the case, multiplexer A38 must be checked after verifying that it receives the correct signal from flip-flop A29 (through gate A36a).

8.4.2 Channel Data Multiplexer, Latches/Decades

The BCD-coded data from the decades of channels A and B is multiplexed by A37 to a bus connected to all the latch/decoder circuits. These are to be checked, including the operation with the phase signal (pin 6 of the latch/decoders) generated through

A23. The phase signal should be out of phase with the back-plane signal (pin 3 of A18) whenever a segment is to be ON, and in phase if it is to be off. If a segment is not ON while it is seen out of phase with the back-plane signal, it is possible that there is a misconnection, or a ground path, to inhibit the display of the segment; most often this occurs at the conducting rubber contact with the crystal. Otherwise, the display is defective.

8.5 TROUBLESHOOTING EXAMPLE: DIGITAL LINEAR RATEMETER, CANBERRA MODEL 2081

In this instrument the input signals are initially divided by 2 in a flip-flop, and further divided by a series of decade counters according to the range selected. It is the rate of the output signal from this block that is determined by the instrument. We just refer to the part of the instrument responsible for this determination, for the other one is just another example of a counter. The block diagram of this part is shown in Fig. 8.5; a short description of its operation follows.

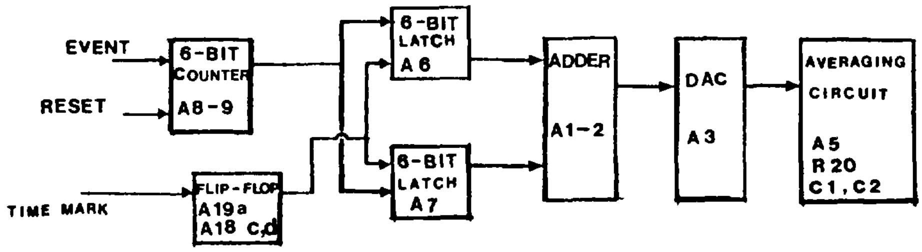


Fig. 8.5: Block diagram of part of digital linear ratemeter

Events are counted in the 6-bit counter during the interval between time marks (0.5s, or 5s in the lowest rate scale). At each time mark, the contents of the counter is transferred to either latch A or latch B, according to the state of the flip-flop; after transfer the counter is reset and a new cycle starts. The contents of the two latches, corresponding to successive time intervals, are added and the result is applied to the digital-to-analog converter. The output of the converter is read by a meter either directly or, in the lower ranges, after averaging.

8.5.1 Counter, Latches and Adder

Start by checking if the event signal is present at pin 5 of 4-bit counter A8. Reset pulses must be seen at pin 14 of A8, and pins 1 and 13 of 2-bit counter A9 (A8 and A9 form a 6-bit counter); these reset pulses are separated by 0.5s (5s in the 10 counts/sec range), and care must be taken if they are to be observed in a scope. Observe also the clock inputs of the A6 and A7 latches (pin 1): they must be complementary and change state at every time mark.

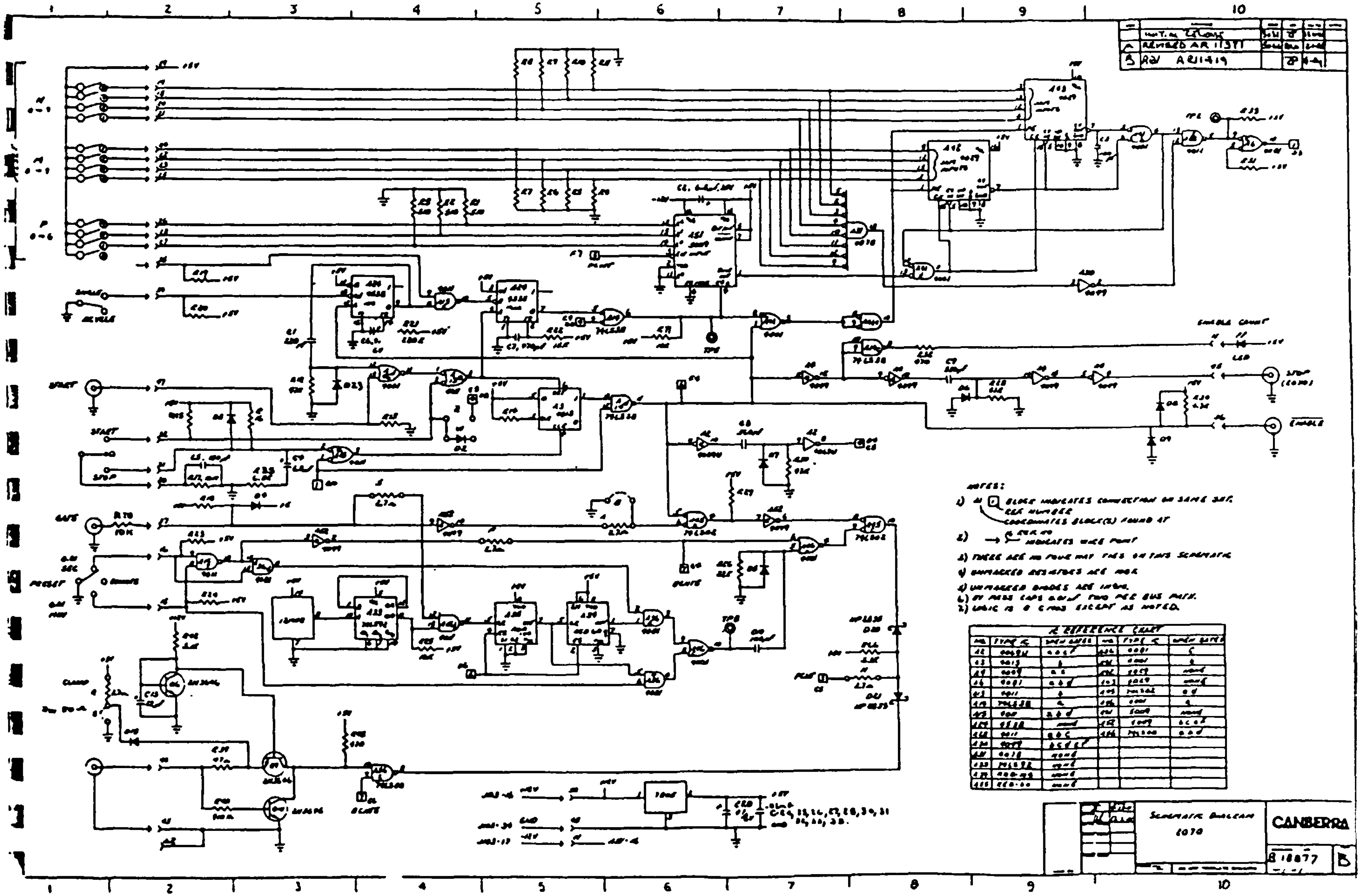
If the above signals are correct, check the behaviour of the A8 binary counter and of the A9 dual D flip-flop that works as a 2-bit binary counter. Observe if the latches A6 and A7 are correctly loaded; if this is felt to be difficult, observe a bit at a time or keep the rate constant and verify that the two latches have the same contents. The working condition of the adder is easily verified. [NOTE that the connections shown in the schematics from latch A6 to the adders A1, A2 are wrong.]

8.5.2 DAC and Averaging Circuit

Start by keeping a constant input to the DAC and check the operational amplifiers as discussed elsewhere in this manual. Then adjust the input pulse generator in such a way that the lowest seven input lines of the DAC are at logical 1. The panel meter should read full scale; adjust the offset potentiometer to compensate for small deviations. If adjustment cannot be obtained, measure the voltage at the output of A4, then reduce the pulse generator rate in a way that only the lowest six input lines of the DAC are at logic 1; the output voltage of A4 is now approximately one-half of the previous value, otherwise the DAC is not working properly. If it does, check the circuit around A5 and the meter.

To examine the behaviour of the averaging circuit (R20, C1 and C2), introduce a large step at the DAC input (for example, by stopping or changing the scale of the pulse generator), and observe the output of A5. It should move with a time constant of either 1.5s or 3s, according to the selected range.

Trouble can also come from the circuitry associated with the detection of overrange. Whenever the capacity of the 6-bit counter is exceeded, flip-flop A11 is set by a signal coming from monostable A12b; the output of the flip-flop sets the 2-bit counter A9 and parallel loads A8 to 0101; the content of the 6-bit counter is 110101. This is simultaneously transferred to latches A6 and A7, and added to apply 1101010 to the DAC (the LSB of the DAC is grounded), and the meter will be deflected almost full scale, until reset occurs (5 seconds later). A failure of the overflow flip-flop A11 may have various consequences, because of its many connections; for example, if pin i! of A11 stays at logic 0 (which is the state after overflow), counters A8 and A9 would be unable to count. A11 is reset by a signal from monostable A17b.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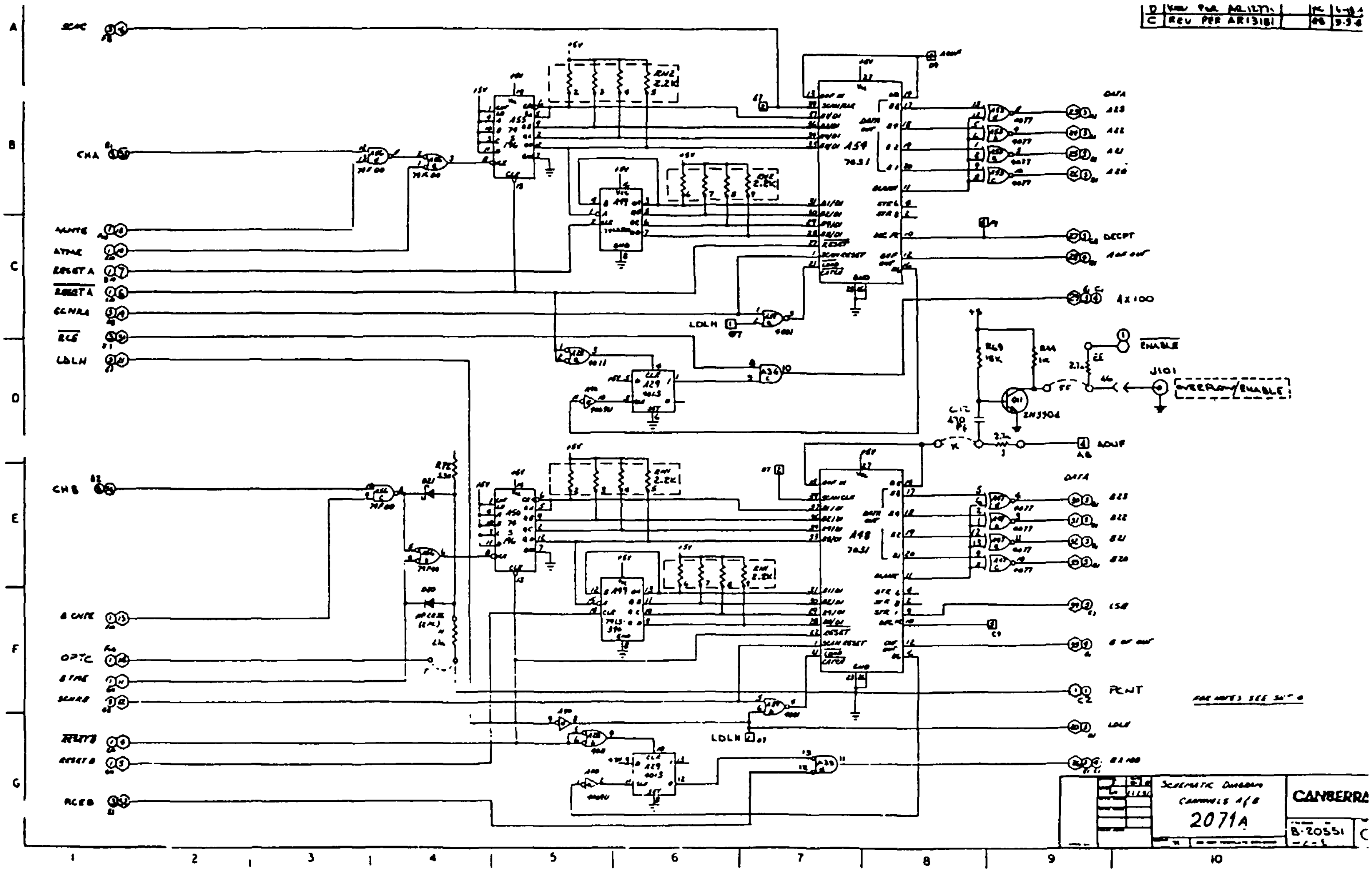
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CHB
LDLH
ENABLE
J101
OVERFLOW/ENABLE
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4x100
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PCNT
Schematic Diagram
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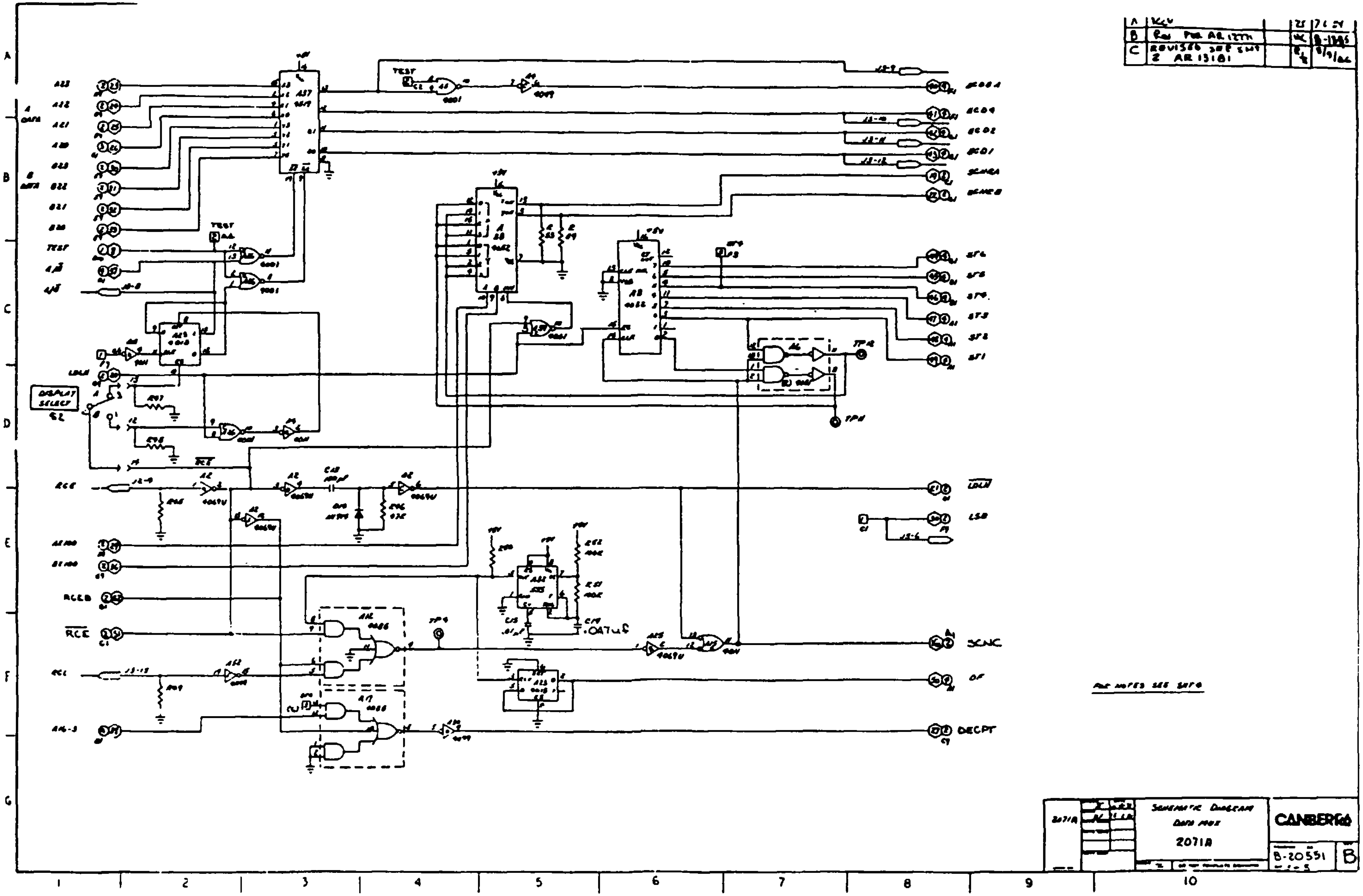
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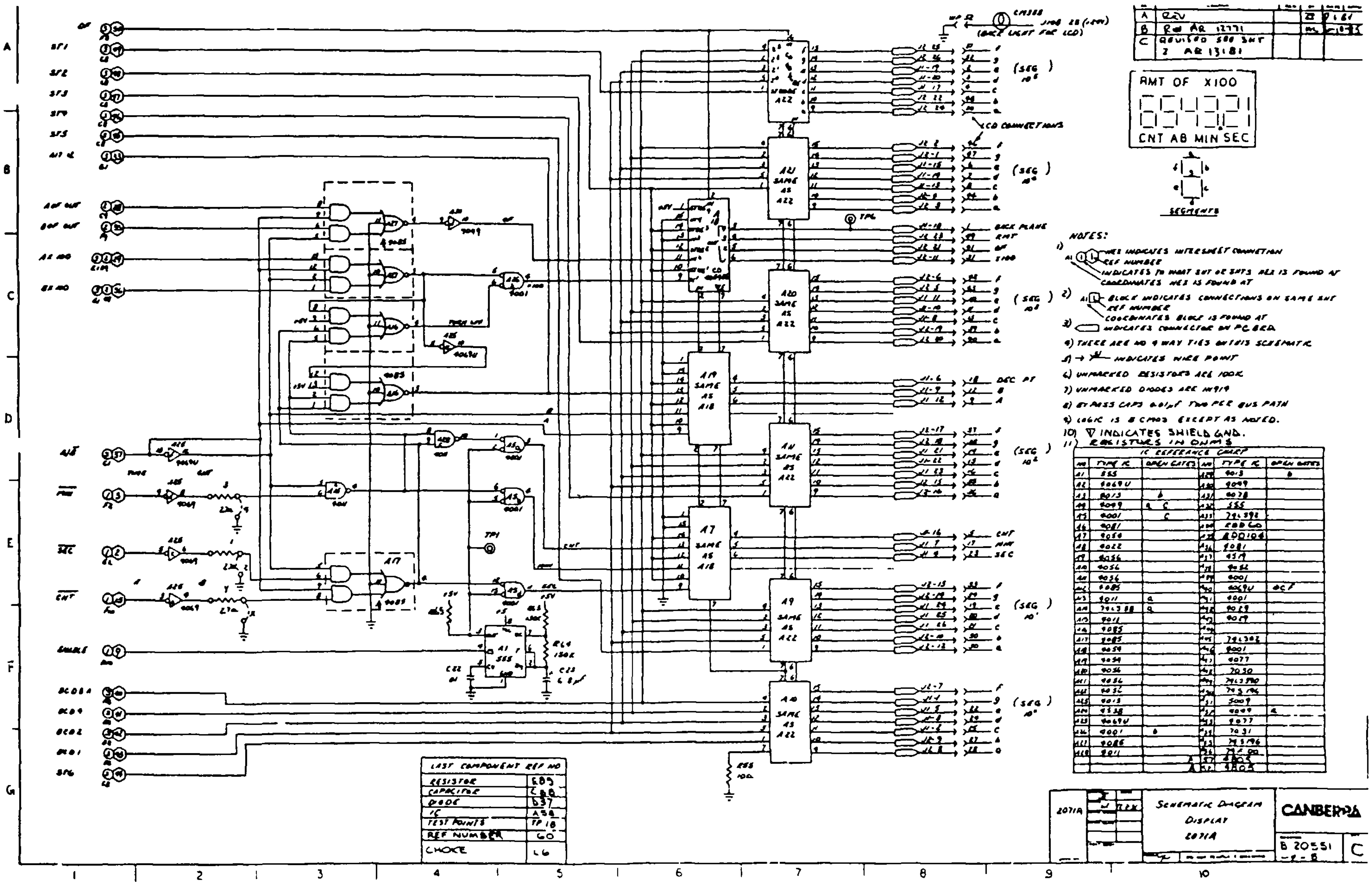
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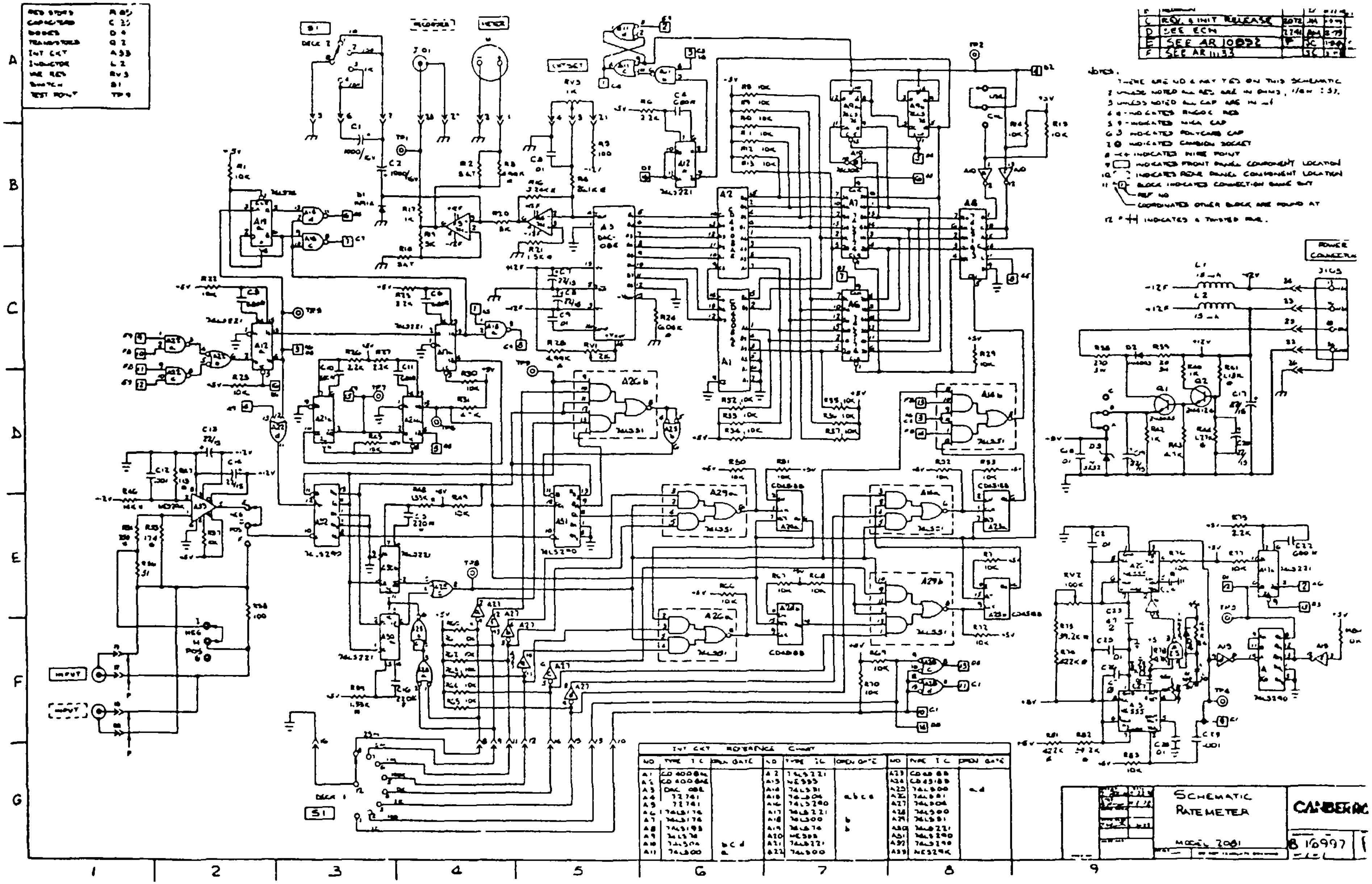
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METER

Chapter 9
MULTICHANNEL ANALYZERS

9 MULTICHANNEL ANALYZERS

9.1 INTRODUCTION

The most frequent task of a multichannel analyzer is to search for the pulse height distribution of the incoming pulses (pulse height analysis, PHA). In order to get the pulse height distribution or spectrum, the pulse height of each pulse is measured, and the result is expressed as a binary number. This is the task of the ADC unit. The measured binary number serves as an address to the random access memory (RAM) location. The contents of the called memory location is pushed into the ADDER where it is increased by one. The new number is returned to the same location. As a result of this procedure, the RAM can tell how many times a pulse of a given height has appeared during the measurement. The whole operation is controlled by the steering logic (Fig. 9.1).

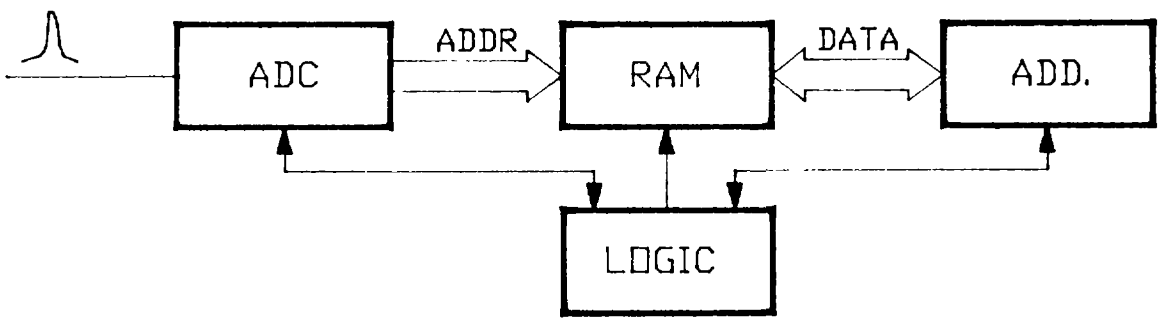


Fig. 9.1: Simplified MCA

During the measurement, or after it, results are either displayed by the CRT, and/or transmitted to a peripheral device, like printer or plotter. The display is always a part of the system while external units are connected according to our requirements. Communications with an external printer or plotter are realized either by the serial RS-232 interface or by the parallel Centronics. In order to perform the described tasks, a rather complicated system, composed of the analog part followed by the digital one, is used. In contemporary systems the digital part operation is steered by a microprocessor reading the operating instruction from a large ROM (Read Only Memory). The measured data are stored in the RAM. For the CRT display, a system similar to a television screen is used.

For effective repair you should become familiar with the multichannel analyzer operation. Troubleshooting instructions cannot describe every detail; some imagination is required.

Useful information on the operation of the multichannel analyzer can be obtained from the publication IAEA TECDOC-363, "Selected Topics in Nuclear Electronics", pages 117-168. The general instruction would be out of place here. Therefore, we will concentrate our attention on a typical MCA, Canberra 35 Plus (Fig. 9.2).

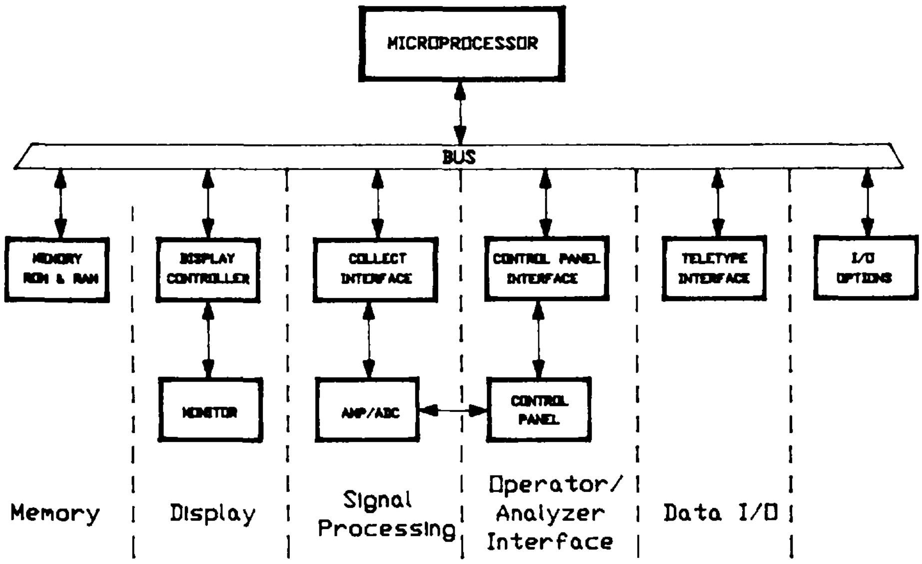


Fig. 9.2: Block Diagram of Series 35 Plus MCA

9.2 MCA TROUBLESHOOTING AT THE UNIT LEVEL

9.2.1 Low Voltage Power Supply

We have removed the top cover of a CANBERRA 35 Plus MCA. The location of individual printed boards is indicated in Fig. 9.3. If after 20 seconds the screen is still black, the power supply should be checked. On the power supply board are 5 LEDs in line, all lighting if supply voltages are present. This voltage can be measured between the ground at TP7 and TP1 to TP6.

GND = TP7	-12 = TP2
+ 5 = TP6	+15 = TP1
+12 = TP3	+24 = TP4
-12 = TP2	-24 = TP5

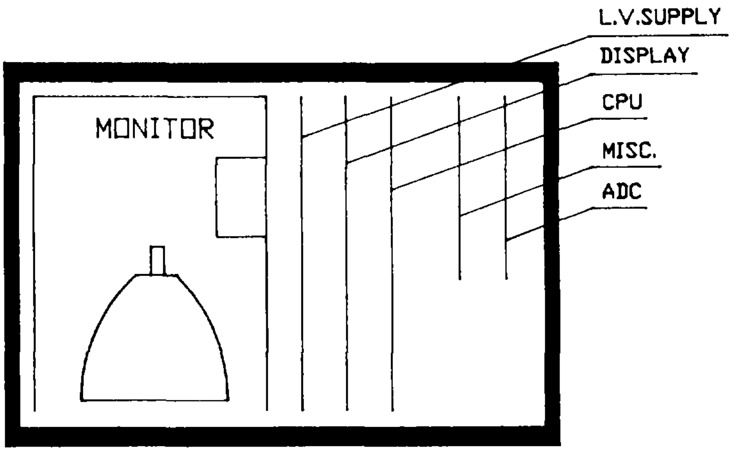


Fig. 9.3: Board locations

In the case of failure, follow the instructions given in Chapter 6, Section 6.14. Additional useful reading about this type of the power supply is given in the previously-mentioned IAEA TECDOC-363, Page 199.

If the screen is dark while voltages are adequate, the reason might be a bad monitor. Continue troubleshooting at MONITOR.

9.2.2 Central Processor Board

If a picture appears on the screen, we can check the CPU (Central Processor Unit) board. The analyzer has three built-in self-testing functions:

1. ROM test
2. RAM test
3. Alphanumeric generation test

To run a test you have to press YES to prepare the multichannel analyzer to accept your next command. Press the hidden key situated as shown in Fig. 9.4. You will hear a click, and the display shows:

DIAGNOSTICS: * CHECKSUM RAM CHAR

The CHECKSUM test can be run by pressing YES. After 12 seconds, the first result will appear on the screen as

A28 55E3

or similar.

The full test takes about one minute. The question marks following the chip label are displayed if either the corresponding IC is bad or not inserted:

A30 ????

The results of the test can be compared with the expected values given in Tables 9.1 and 9.2.

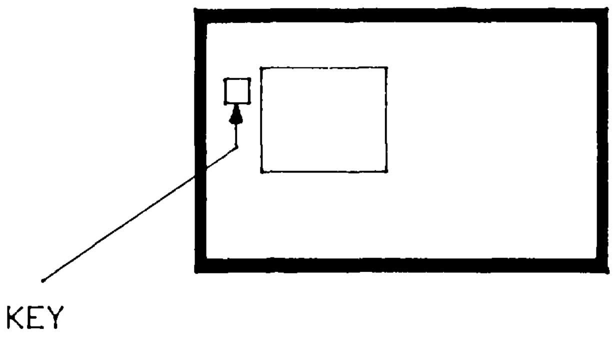


Fig. 9.4: The hidden key position

Selecting the RAM test programme causes the CPU to clear RAM and write known data into it; then the content of the memory is verified to see if the result is correct. The part of the RAM to be tested is selected by setting the MEMORY switch. If the VERTICAL RANGE switch is set to 1048K, the data pattern will appear as a ramp with a positive slope, and will be changed to a ramp with a negative slope.

TABLE 9.1: Series 35+ checksums for V-2.00

Chip Number	Option Number	ID Number	CHECKSUM	PROM TYPE
A28	BASIC	900069B	55E3	27128
A27	BASIC	900069B	85DD	27128
A31	BASIC	900070A	F89C	2716
A50	BASIC	900070A	0DD7	2716
A77	3541	900071A	D994	2716
A80	3541	900071A	03ED	2716
A64	3541	900071A	620D	2716
A77	3541N	900072A	D994	2716
A80	3541N	900072A	03ED	2716
A64	3541N	900072A	5616	2716
A77	3541C	900073A	D994	2716
A80	3541C	900073A	03ED	2716
A64	3541C	900073A	537D	2716
A30	3543	900074A	6552	2732A
A49	3543	900074A	9250	2732A
A53	3551	900076A	906F	2716
A53	3552A	900077A	3C86	2716
A53	3553	900078A	26E2	2716
A64	3554	900079A	EFEC	2716
A67	3571	900080A	1C5D	2716
A74	3571	900080A	4170	2716
A67	3572	900081A	6E3C	2716
A67	3573	900082A	8D9F	2716
A74	3573	900082A	FE2C	2716
A67	3573B	900083A	9548	2716
A74	3573B	900083A	9063	2716
A67	3574	900084A	5C88	2716
A52	3575	900097	D8E1	2732A
A63	3575	900097	4443	2732A
A64	3576	900098	9F32	2716

==

TABLE 9.2: Series 35+ checksums for V-1.00

Chip Number	Option Number	ID Number	CHECKSUM	PROM TYPE
A27	BASIC	900069	9306	27128
A28	BASIC	900069	EDAD	27128
A31	BASIC	900070	FCC2	2716
A50	BASIC	900070	230D	2716
A77	3541	900071	E700	2716
A80	3541	900071	0A44	2716
A64	3541	900071	620D	2716
A77	3541N	900072	E700	2716
A80	3541N	900072	0A44	2716
A64	3541N	900072	5616	2716
A77	3541C	900073	E700	2716
A80	3541C	900073	0A44	2716
A64	3541C	900073	537D	2716
A30	3543	900074	146D	2732
A63	3543	900074	AC02	2732
A30	3544	900075	1649	2732
A63	3544	900075	E64E	2732
A53	3551	900076	913C	2716
A53	3552A	900077	3FE8	2716
A53	3553	900078	2924	2716
A64	3554	900079	EF6C	2716
A67	3571	900080	2A0F	2716
A74	3571	900080	458D	2716
A67	3572	900081	7709	2716
A67	3573	900082	8012	2716
A74	3573	900082	E3CF	2716
A67	3573B	900083	8795	2716
A74	3573B	900083	7B70	2716
A67	3574	900084	5C95	2716

==

The following messages are expected as a result of testing:

RAM TESTED O.K., if good or
RAM FAILURE N, if bad
N indicates the failure type, and has the following meanings:
1Memory won't clear
2Memory integral incorrect positive slope
3Memory integral incorrect negative slope
4Flag bit incorrect

Selecting the CHAR test programme will cause the display to show two lines of the alphanumeric character across the bottom of the display.

By pressing the hidden key again, the diagnostic is finished.

If all three tests have been completed successfully, then we can assume that the CPU board is working properly.

9.2.3 Monitor

The MONITOR is a self-contained assembly, which includes the CRT and the necessary electronics to present a TV raster display. It should be considered as a replaceable component and is not intended to be repaired in the field. It accepts three signals:

- video, VID
- line synchronization, LSYNC, and
- field synchronization, FSYNC

Signals can be observed (Fig. 9.5) at the 10-pin connector as follows:

PIN 1 GND
PIN 6 LSYNC
PIN 7 + 15 V
PIN 8 VIDEO
PIN 9 FSYNC
PIN 10 VRTN (Video ground) PIN 10 is the lower one

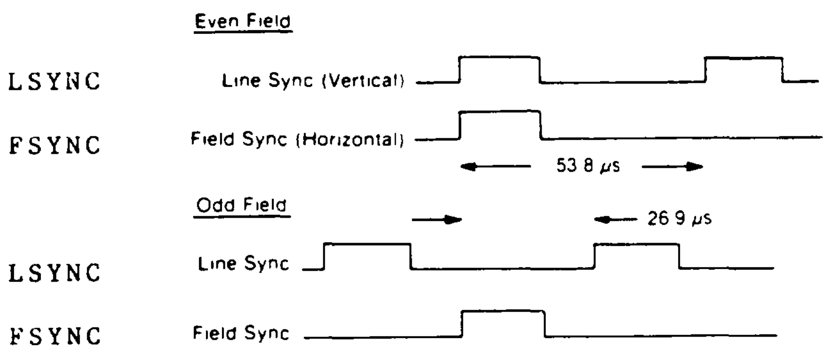


Fig. 9.5: Synchronizing signals

In the absence of any of these signals, the MONITOR screen will be black. Troubleshooting should be concentrated on the display board.

It is useful to know that the MCA is able to show the display field on the MONITOR with the LOW VOLTAGE POWER SUPPLY and DISPLAY BOARDs inserted, even if all the other boards removed.

9.2.4 Display Board

On the DISPLAY BOARD three signals for the MONITOR control are produced: LSYNC, FSYNC and VID as already mentioned.

The first two signals are used to control the MONITOR picture. Analogous to a TV monitor, a MCA display is an interlaced raster scan format. The major difference is that the CRT yoke is turned 90 degrees, causing the vertical field to force the beam to run fast from the bottom to the top of the screen, and slowly advancing from left to right making the first 256 runs before it returns to the left where it starts to make the second set of runs between the lines written during the first set (see Fig. 9.6).

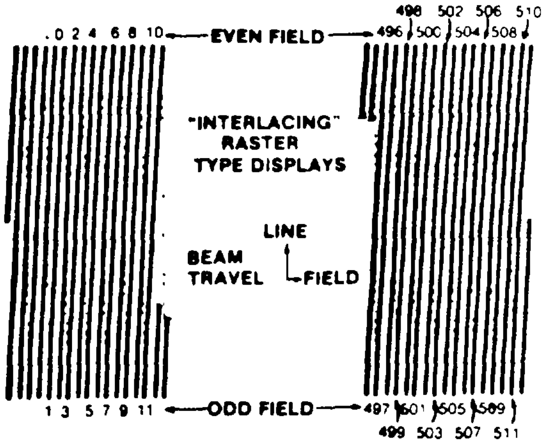


Fig. 9.6: Resultant "interlaced" frame obtained from odd and even field scan

During scanning, the electron beam striking the CRT screen should be properly intensified to draw the wanted pattern. This is done by applying the modulated VID signal to the CRT control electrode. The modulation information is gathered from different sources. Text is provided from ROM. Spectra representing points are contained in the RAM. Both information sources are on the CPU board. Fast operation is obtained through direct memory access (DMA) while the 8085 processor is in the HOLD state. See Fig. 9.7 for the connections between the DISPLAY UNIT and the remaining system. The dead time counter signal is produced on the DISPLAY board, using the LT line from the ADC board.

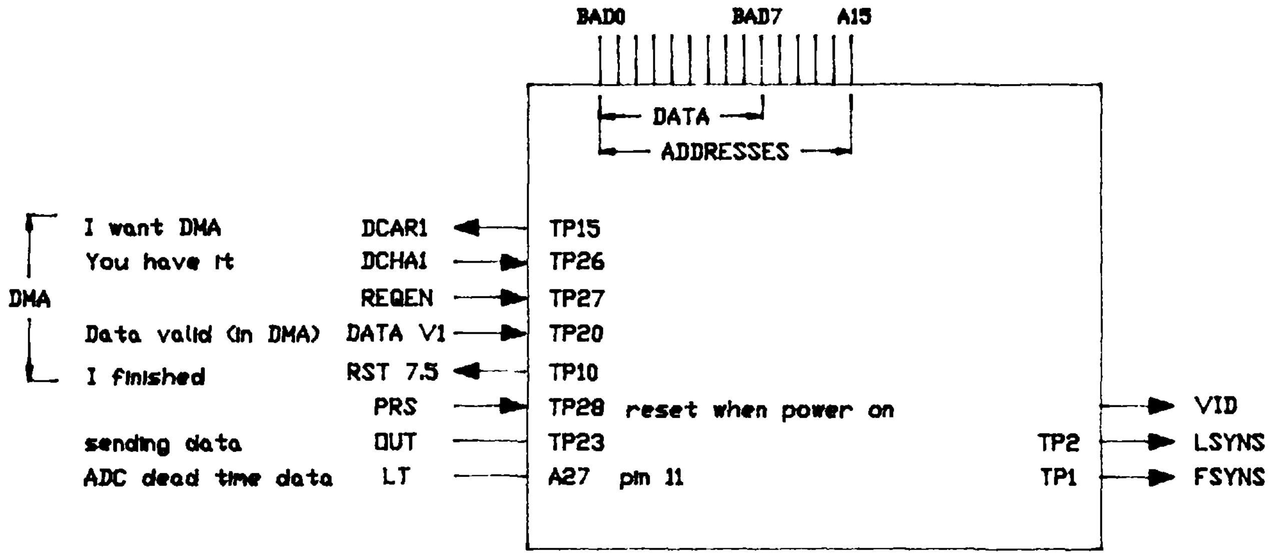


Fig. 9.7: Display board connections

9.2.5 Principles of the ADC Operation

ADC tells the height of the input pulse in a binary way. A simple example of the operation of a two- and four-channel converter is given in Fig. 9.8.

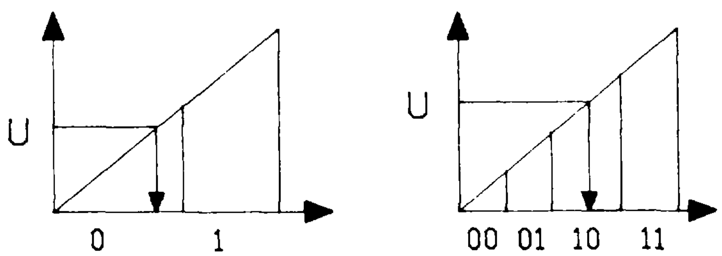


Fig. 9.8: Two- and four-channel pulse determination

In the first case the height of the input pulse U was grouped into channel 0 while in the second case the voltage was found in channel 10 (10 = 3, expressed decimally). However, to determine the pulse height more precisely, more channels are required. Contemporary multichannel analyzers have up to 16384 channels. To express this number in a binary way, 15 binary digits are required.

Conversion from the analog to the digital form takes some tens of microseconds. The conversion time of course depends on the conversion method. The widely adopted converters in nuclear instrumentation, for which the operating principles will be briefly described, are of the Wilkinson type.

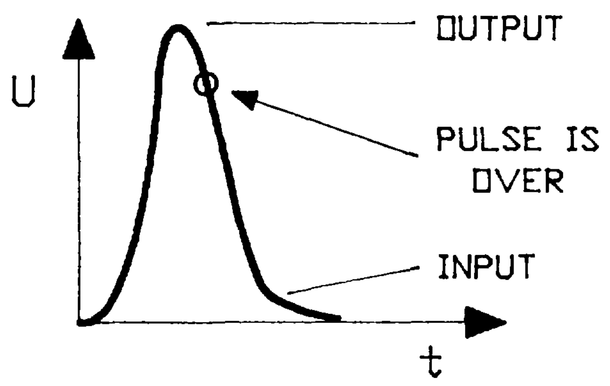


Fig. 9.9: What STRETCHER does

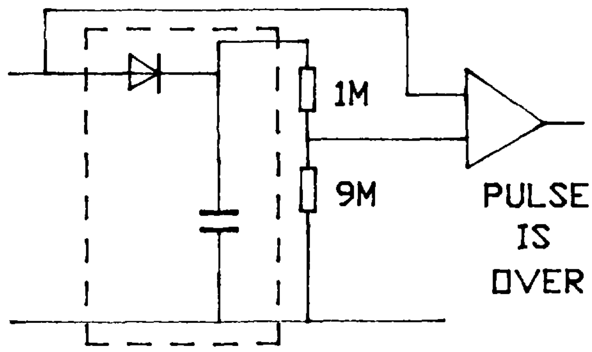


Fig. 9.10: Simple STRETCHER followed by 90% discr.

Gaussian pulses (Fig. 9.9) from amplifiers keep their maximum value only for a short moment. Therefore, for any precise determination, which is time consuming, their amplitude should be stored. This is done by using the special unit STRETCHER. The form of the obtained pulse is given in Fig. 9.9. Such operation can be realized by using the circuit given in Fig. 9.10. However, its properties are not adequate. The real stretcher has incorporated more than 20 20 transistors and a few integrated circuits.

Now the pulse is properly formed. Shall we start the measurement? Let us be sure that the peak is over. For this we wait that the instantaneous pulse value drops below 90% of its peak value which is stored in the capacitor. A discriminator comparing 90% of the stored voltage with the instantaneous signal value will tell us the right moment (Fig. 9.10) to start.

The height determination starts using the circuit shown in Fig. 9.13. When the constant current is applied to the capacitor, the voltage on it starts to go linearly to the zero (Fig. 9.11). During discharging, we count: one, two, three .... Counting is stopped when zero voltage is reached. The counting result is proportional to the pulse height. The analog to digital conversion has been performed. Really? No, the conversion procedure was over-simplified. There are a lot of tricks to squeeze out the 1/8000 accuracy using the analog computing technique. The signals in the typical ADC unit have to pass through more than 80 integrated circuits and 50 transistors.

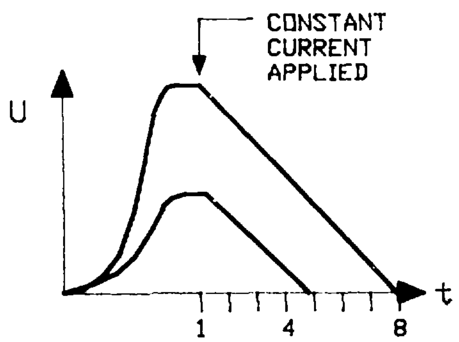


Fig. 9.11: Conversion

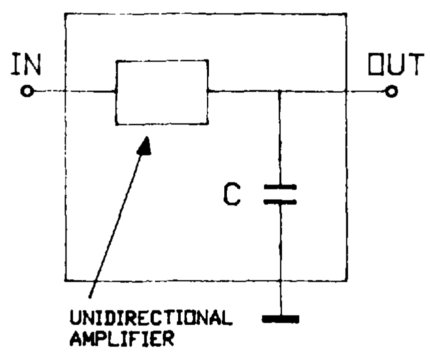


Fig. 9.12: STRETCHER

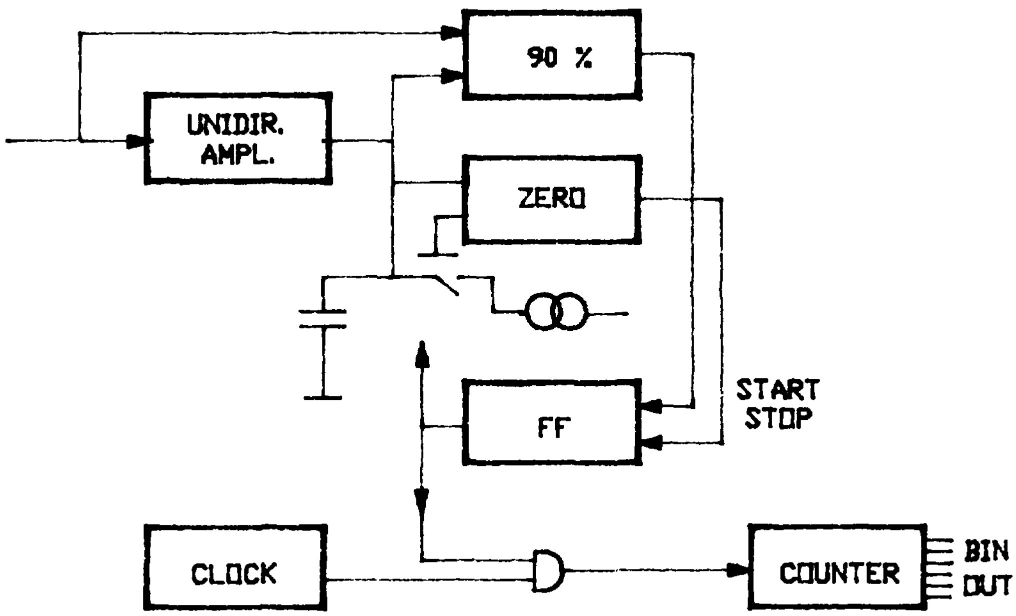


Fig. 9.13: Simplified ADC

9.3 CHECK AT THE UNITS LEVEL

9.3.1 ADC Board

An ADC board contains an amplifier and a ADC. As amplifier troubleshooting is not the aim of this chapter, explanation will be limited to ADC only. See Fig. 9.13 for the block diagram.

In principle, you can check the operation of the unit by using only the present instructions. However, it is strongly recommended also to consult CANBERRA SCHEMATICS SERIES 35 PLUS. The ADC board is given in 5 sheets.

Troubleshooting following the signal path is more difficult than in the previous cases. The separate blocks are interconnected with more than one line. Thicker lines indicate more than one signal going the same way. Arrows indicate the direction of the data flow.

The stretcher, for instance, accepts input signals, and its output is inspected by three blocks: stretcher/input interrogation logic, single channel analyzer and zero crossing discrimination.

In the case of proper input, well-defined output signals are also expected, assuming normal block operation. However, in the absence of the adequate control signals on lines DUMP, STRET OFF and RAMP ON, even a good block cannot work. All three control signals are coming from the CONTROL LOGIC block. This block makes its decisions by evaluating 14 input signals. A few of them depend again on the stretcher output signal. In this way we find ourselves inside a complicated feedback system.

The basic idea for such troubleshooting is to isolate separate blocks by fixing the auxiliary signals.

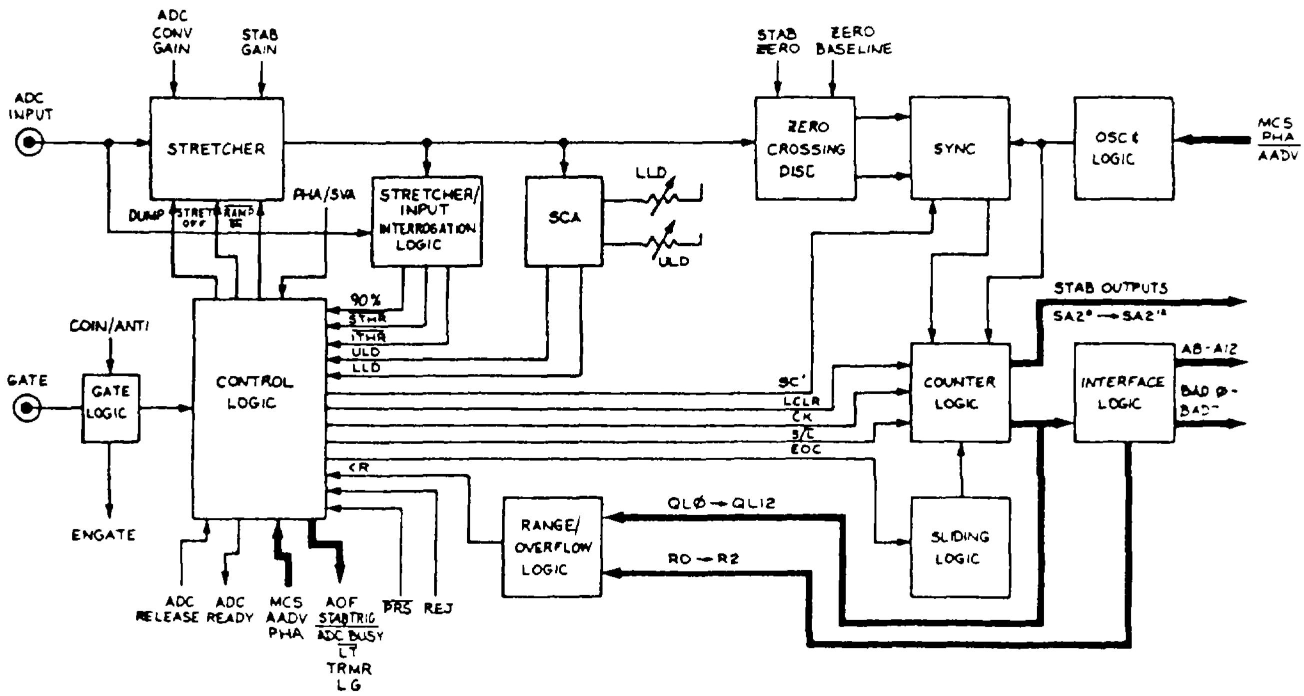


Fig. 9.14: Canberra 35+ ADC

To check the STRETCHER operation, for example, the STRET OFF signal must be low when the input pulse appears. If it is not low, we can simply push it down by grounding the STRET OFF line for a short moment. However, such an approach is not possible in many cases. The output of a TTL circuit cannot be connected to the +5 V without causing permanent damage.

We will start the ADC test by applying adequate pulses to the input. Pulses can come:

- from a pulser; recommended height 5 V, frequency - if changeable - the highest possible;

- from a pulse generator; the repetition rate is a few thousand per second, height is approximately 5 V, and the duration is a few microseconds;

- good pulses can be produced by applying rectangular signals to the input of any nuclear spectroscopy amplifier. Even the probe adjusting signal 0.3 V, 1 kHz, from the front plate connection of the TRIO oscilloscope, is suitable.

If such pulses are applied to the input and if the corresponding binary number appears at digital adders 74LS283 (A63, pins 4 - least significant bit 1, 13, 10; A65, pins 4, 1, 13, 10;

A64, pins 4, 1, 13, 10; and A63, pins 1 and 4 - most significant bit) we can assume that the ADC is working properly. In order to observe the binary output, the ADC board should be extracted and extended by using the extension card.

In the case of failure, the signal processing should be followed step by step.

1. Connect the oscilloscope probe to TP5 and clip the oscilloscope ground to TP9 to observe the input signal. Then repeat the observation moving the probe to the TP5. Note that the signal at TP5 follows the ascending side of the input pulse and remains constant after the peak has been reached. This is the indication that the stretcher works properly. If not, skip the next steps and go to 2.

   One or two microseconds later the discharge process starts. The slope of the linear approach to zero depends on the conversion gain. A few hundred milivolts below zero, conversion is stopped and the ramp returns to zero. The analog part of the conversion was successful.

   Note the case when the input signal exceeds the upper level discriminator (A28) setting. The control logic then sets DUMP to logic 1; Q24 and Q25 are both conducting and fast discharge follows. During the interval of the linear descent, the zero pulses from the 100 MHz clock are counted. The clock is running permanently. Its operation can be observed by connecting the oscilloscope to TP6 and using the corresponding ground TP7 to get a representative picture without superimposed oscillations. In the pulse analyze mode, clock pulses are passing NOR gates in A89. They can be observed at pin 6 and pin 11 of the before-mentioned circuit.

   When all the counting conditions have been met, the synchronizing unit is activated. The SYNC/ signal is delivered at pin 7, A83.

   Counting starts. The address counter consists of A79 through A82 and is configured as a 14-bit ripple counter. The 14th bit is used for under and overflow detection. During ramp-down sequence, the ramp counter and ramp current are enabled and synchronized to the 100 MHz clock. The resultant digital address in the address counter represents the magnitude of the ADC analog input. The counting can be followed from stage to stage if the input signal is high enough to activate the higher bits too and if the selected number of channels is sufficient. For instance, if the channel number was set to 512, then only the lower 9 bits will be active. Set the oscilloscope time base to smaller time/division values to display only a few periods of the observed signal.

   Then move the probe to pin 5, A82 and set time/division value to 1 or 2 microseconds per division. Now you can observe the full length of the pulse train which should follow the height of the input pulse.

When counting is finished, the resulting number is transferred into shift registers A85, A86, A87 and A88. Finally, the data are modified in four 4-bit adders A63, A64, A65 and A66. The binary number which was loaded into shift registers A85, A86, A87 and A88 from the sliding scale counter is now subtracted.

2. There is no signal at TP5. STRET OFF might be high. In this case the unidirectional amplifier charging C11 is disabled. To verify this possibility, join pin 9, A86 for a moment to the ground. If an adequate signal at TP5 appears, the fault is within the ADC board, control logic part. If the grounding does not restore normal operation, the unidirectional amplifier is bad. Check all transistors.

The next possibility is the voltage following the ascent side of the pulse, but not dropping back to zero. In this case, the discharging constant current source is not switched on, or the source is bad. RAMP ON signal (A29, pin 6) should be high during the discharge. If high state is revealed, then the current source is bad. Concentrate your observations on transistors Q20, Q21, Q22, Q23, Q26, Q27, Q28 and comparator A77 (LF411). If RAMP ON is low and discharging doesn't take place, the fault is probably in the control logic as before.

A good test to check a part of the discharging system is to use the fast discharger by injecting a bigger current through transistor Q29 controlled by transistor Q24. If the DUMP signal, which is normally low, can be made high by joining the corresponding gate output to 5V. However, by short-circuiting the emitter and collector of transistor Q29, the same effect is achieved.

The command to start conversion, i.e. to inject the discharging current into C11, is given by the discriminator A16 when the input signal has decreased to 90% of its amplitude.

Two additional tricks used during the conversion to improve accuracy will be described.

When constant current generator is connected to discharge the storing capacitor, the resulting ramp voltage might deviate from linearity because of the transient phenomena. Therefore, counting starts later. The lost time is compensated for by counting longer. Counting is stopped by the zero crossing discriminator which is actually set about 80 mV below the zero level. Instead of introducing the time delay T before counting, we can count from the very beginning, but setting the counter to the adequate negative value -N. Then after Nx clock period = T, the counter will be at zero. The loading, which is different for different conversion rates, is realized through the parallel input of counters.

The second trick is the use of the so-called sliding scale. Because of the interference of the surrounding digital circuits, the produced ramp voltage might be modulated. This would result in spectra deformation. The idea is to use in successive measurements different parts of the ramp voltage. Therefore, the binary counting system is additionally preloaded with 1, 2, 3 ..., up to 18. The resulting binary number would thus be too big by 1, 2, 3 .... To get the correct value, this number is subtracted in the adders A63, A64, A65 and A67. Subtraction is implemented by the addition of the two's complement.

Lines QL0 to QL12, with the signals representing the result of the conversion, have to be connected to the address-data bus (BAD0, BAD1, BAD2, BAD4, BAD6, BAD7, A8, A9, A10, A11, A12). The connection is done through three-state buffers A33 and A44 are used between.

9.4 CPU BOARD

9.4.1 Processor Description

The heart of the CPU board is the INTEL 8085 microprocessor with the pin assignment shown in Fig. 9.15. Because of the shared address and data pins, an additional latch must be added externally to create the normal 16-bit address and 8-bit data bus from the microprocessor AD0 - AD7 and A8 - A15 lines.

TABLE 9.3: Status signals

STATUS SIGNALS			
S0	S1	IO-M/	Type of Machine Cycle
1	1	0	Op Code Fetch (OF)
0	1	0	Memory Read (MR)
1	0	0	Memory Write (MW)
0	1	1	I/O Read (IOR)
1	0	1	I/O Write (IOW)
1	1,	1	Interrupt Acknowledge (INA)
0	1	0	Bus Idle

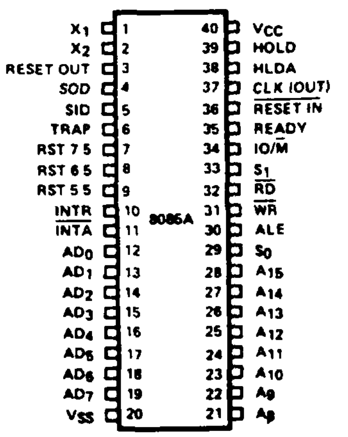


Fig. 9.15: 8085 microprocessor

ALE (Address Latch Enable) is used to load the low byte address to the external latch.

8085 needs a clock, therefore, an external clock signal of 6 MHz is applied to X1 while X2 is left floating.

The CPU board has a 12 MHz (A43) oscillator divided down to 6 MHz in 74LSD292 (A44). The buffered 6 MHz is the clock input to the 8085. The 8085 also divides this clock by two and outputs it as CLK signal.

To execute an instruction, the 8085 divides the operation into machine cycles. An instruction might take from one to five machine cycles. In each machine cycle there are three to six time states T (see Fig. 9.16). Each T-state consists of one clock period.

The activity of 8085 within each machine cycle is:

T1	Output an address
T2	Switch A/D from address to data IN/OUT
T3	Hold data stable
T4, T5	Internal operating time for 8085

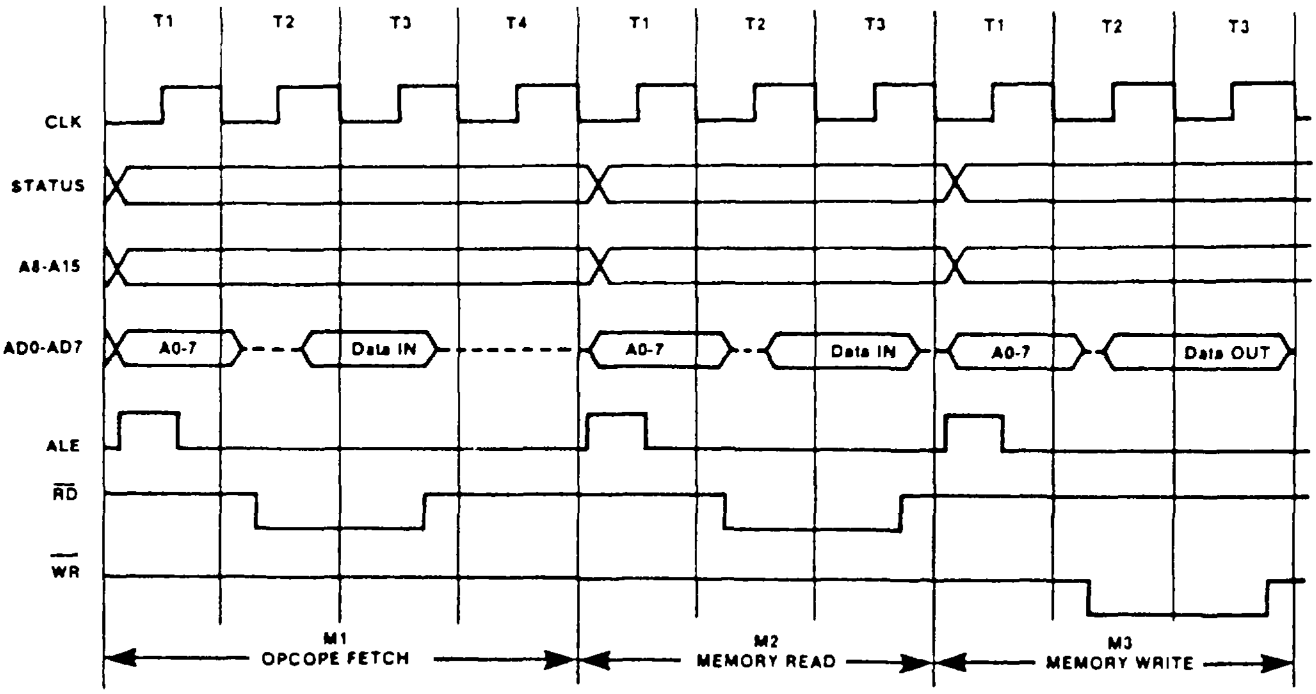


Fig. 9.16: 8085 timing

What is going on in the processor can be learned from status signals.

$\overline{\text{RESET IN}}$ sets the programme counter to zero and resets all flags; it initializes the microprocessor.

RESET OUT indicates that CPU is being reset. This signal can serve as the system reset.

$\overline{RD}$, $\overline{WR}$. The behaviour is evident from Fig. 9.16. The shown pulses are sent out.

HOLD input when driven high tri-states the address and data lines as well as $\overline{RD}$, $\overline{WR}$ and IO/$\overline{M}$ line. Internal processing can continue.

HLDA is an output indicating that the HOLD command has been accepted.

TRAP interrupt is edge and level sensitive and must remain at a high level until it is acknowledged. It is non-maskable (there is no software way to avoid it when the signal is applied to the input). When the interrupt occurs, the address is branched to 24H.

RST 7.5, RST 6.5, RST 5.5. These three inputs have the same timing as INTR except they cause an internal restart to be automatically inserted. The resulting addresses are 3CH, 34H and 23H respectively.

INTR, interrupt request, has a similar effect as TRAP and RST, with the return address depending on the instruction read by the CPU when interrupt is acknowledged.

NOTE: We only discussed the function of the pins used in the described application of 8085

9.5 GENERAL STRUCTURE OF THE CPU BOARD

Microprocessor 8085 has to be supported with some additional units to form the complete computer system. However, because of the request for direct memory access, more than minimum additional circuits were added. See Fig. 9.17 for the block diagram of the CPU board. The complete schematics of the CPU board are covered by 6 sheets:

1. RAM organization
2. ROM organization
3. Cursor-motion controlling system
4. 8085 processor with bus lines and status decoder
5. Direct memory access controller; central clock unit
6. Remote control interface

9.6 8085 COMMUNICATION

To check the 8085 operation starts with 6 MHz clock inspection. The indirect test is done by observation of the 1 MHz clock derived from 6 MHz clock at test point TP8. Another indirect test is to observe CK signal of 3 MHz leaving the 8085 at TP10. However, for the direct check, your probe should be attached to pin 1 of 8085 (big chip, A45 position).

The 8085 system bus is created by using A40 and A47 (8282, INTEL production, similar to 74LS374, but different pin configuration to latch the 16-bit addresses). Latch is performed using the $\overline{A}$ signal derived from the ALE microprocessor output ($\overline{A}$ signal can be observed at TP11). See Fig. 9.18 for the block diagram.

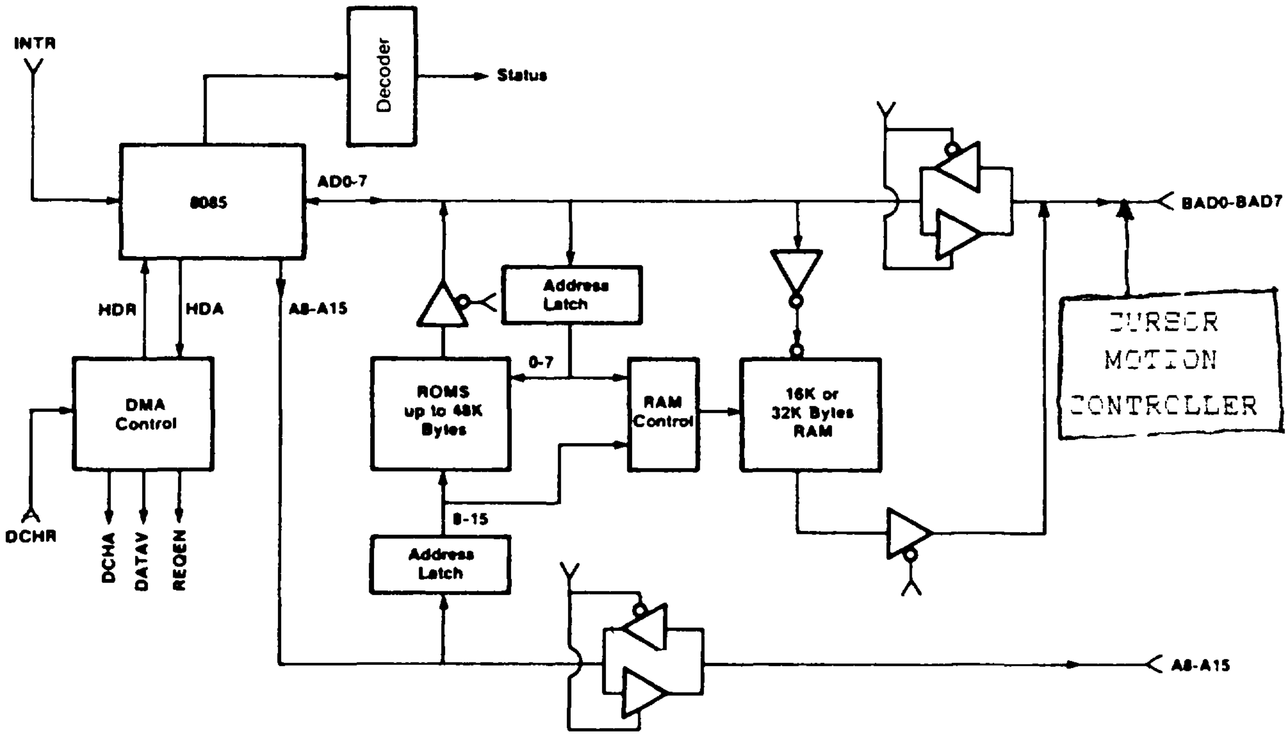


Fig. 9.17: CPU board structure

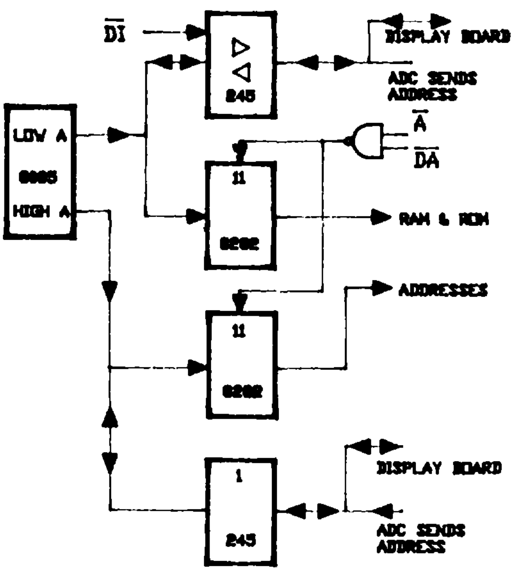


Fig. 9.18: 8085 system bus and data flow

Bidirectional data flow is provided using the 3-state bidirectional drivers 74LS245 (A61 and A62). A61 output is enabled by RDROM signal (observe TP17) and the direction is selected by DI (available at pin 1, A61).

The A61 data flow direction is selected by a signal which can be observed at TP15. Three-state operation is not used, i.e. pin 19 is grounded.

The status decoder A39 produces the input/output control signals:

$\overline{WM}$, at TP9

$\overline{RM}$, at TP13

$\overline{OE}$, at TP12

and a few others.

When working with the slow input or output devices, a WAIT state should be inserted into the normal instruction cycle. The READY input is suitable for this, controlled by A25 and A26.

After the direct memory access request, the normal microprocessor operation should be restored. This is done using RST 7.5 and RST 5.5 input lines of 8085.

The general power failure is indicated by a LOW on $\overline{PWRF}$ line. After the inversion in A60, the TRAP input (highest priority) is activated.

9.7 ROM OPERATION

ROM organization is given in Fig. 9.19. The ROM circuit is divided into four banks of 16k x 8 bits for a total programme memory of 64 kbytes. This is also the normal addressing space of 8085. Because we also need RAM for data storage, the programme-controlled bank switch was introduced.

The signals BK1 and BK2 are stored in latch A11. Tri-state driver A48 is enabled if BK1 is low or address bit A14 is low. Driver A29 is enabled if BK1 is high and if the address bit A14 is high. Signal BK2 is gated with address bits A14, A13, and A12 in a 74LS10 (location A10) to determine which ROM output is passed through driver A48. The selection of the separate ROM chips is realized through 3 to 8 line decoders 74LS138 (A14 and A78).

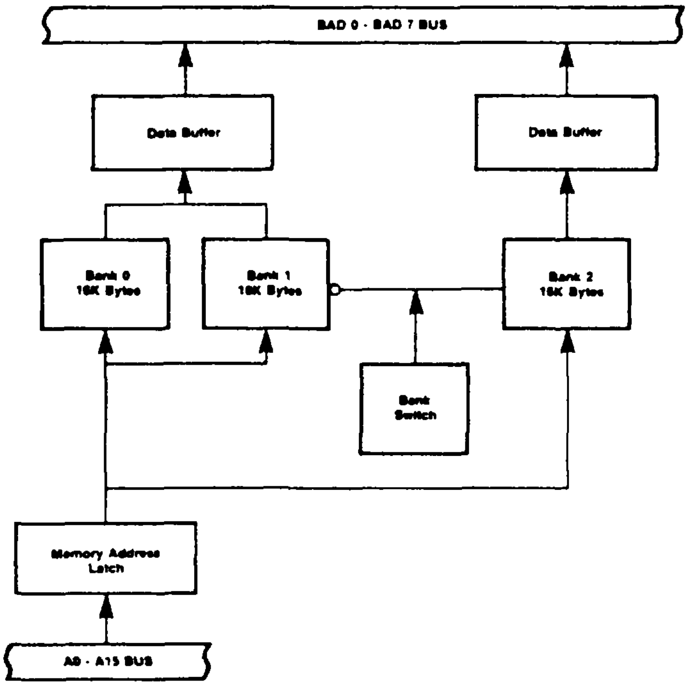


Fig. 9.19: ROM organization

9.8 RAM OPERATION

RAM consists of four static RAM chips, 8k x 8-bit each. Because of the low power consumption, memory chips can be powered from the built-in rechargeable battery for up to 30 days.

The data exchange goes through three-state bidirectional transceiver 74LS244 (A65, A72). The data from the upper four lines between transceiver and RAM can be stored in latch 74LS373 (A75) in order to avoid false data registration in some phases of the programme.

Read or write access to RAM is determined by $\overline{WT}$ signal, pin 27. The same signal is used to control A65.

Addressing is achieved through 14 address lines. Lines A0 to A9 are directly connected to RAM chips. They come from latches 8282, sheet 4. Signals P0, P1, P2 and P3 indirectly involved in the addressing are generated by the programmable chip A26, sheet 5. It accepts the address lines from A10 to A15 from circuit A47 and provides outputs with respect to the memory organization.

Three of the generated lines P0, P2 and P3 are used as the remaining three address lines.

P1 line together with the latched A12 and A15 address line is applied to A62, 3 to 8 lines decoder. Output pins 4, 5, 6, and 7 of A62 are used to enable RAM chips.

The battery charger (sheet 5) connects the rechargeable NiCd battery to the 5 V source when power is applied. If 5 V is present, the current to the base of Q4 keeps it conducting. The resulting current sinking from the Q5 emitter into the Q4 collector through R61 also makes Q5 conducting.

9.9 DIRECT MEMORY ACCESS

Direct memory access (DMA) is used to allow high speed data exchange between RAM and an external device. The operation of the system under the DMA conditions is shown in Fig. 9.20. The controller (see sheet 5 for schematics) provides three operating modes: Read, Write and Read-Modify-Write (R-M-W).

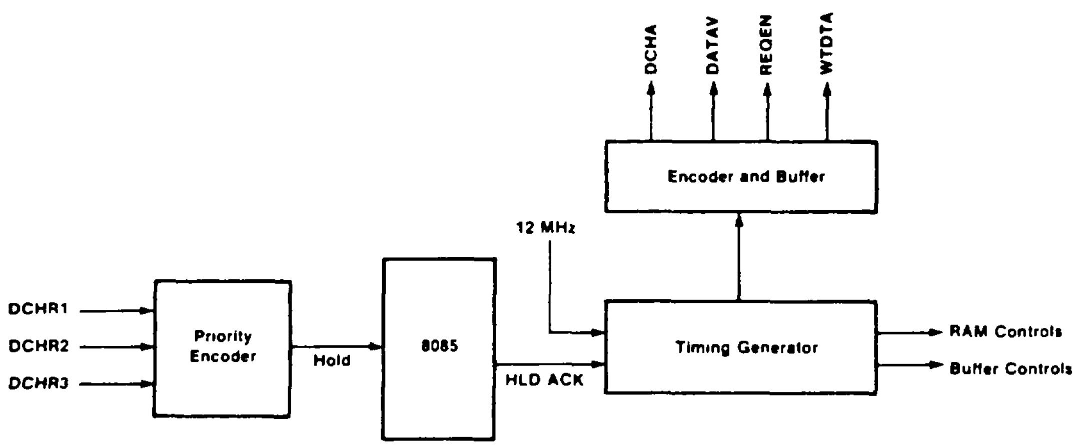


Fig. 9.20: DMA realization

The controller can accept three direct memory access requests DCHR1, DCHR2, coming either from the Display Board or from Collecting Interface/Miscellaneous Boards. The third one, DCH3, might be used by the boards inserted into the option board slot.

In combination with the clock signals, the DMA request is confirmed through the DCHA1 line (TP2) and through the DCHA2 line (TP3). These signals are sent back to the DMA requesting units. Simultaneously, the microprocessor address and data lines are tri-stated through the hold command HDRII.

When 8085 acknowledges the HOLD command, it generates the HDAI signal. This signal starts the operation of the timing generator. In the timing generator (A34 and A3), followed by some logic (A2, A7, A18), different DMA cycles are composed. See Fig. 9.21 and Fig. 9.22 for the generated signals.

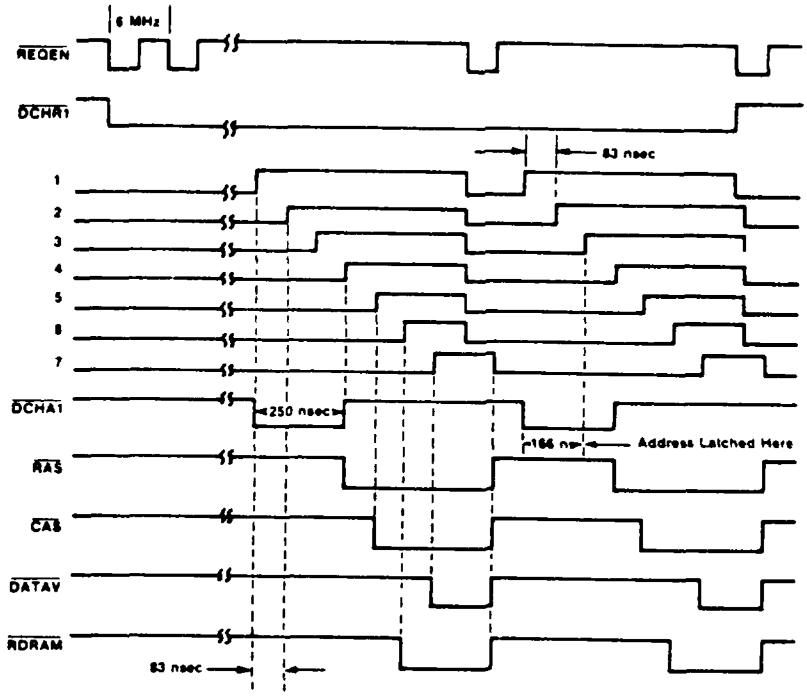


Fig. 9.21: DMA Read Timing

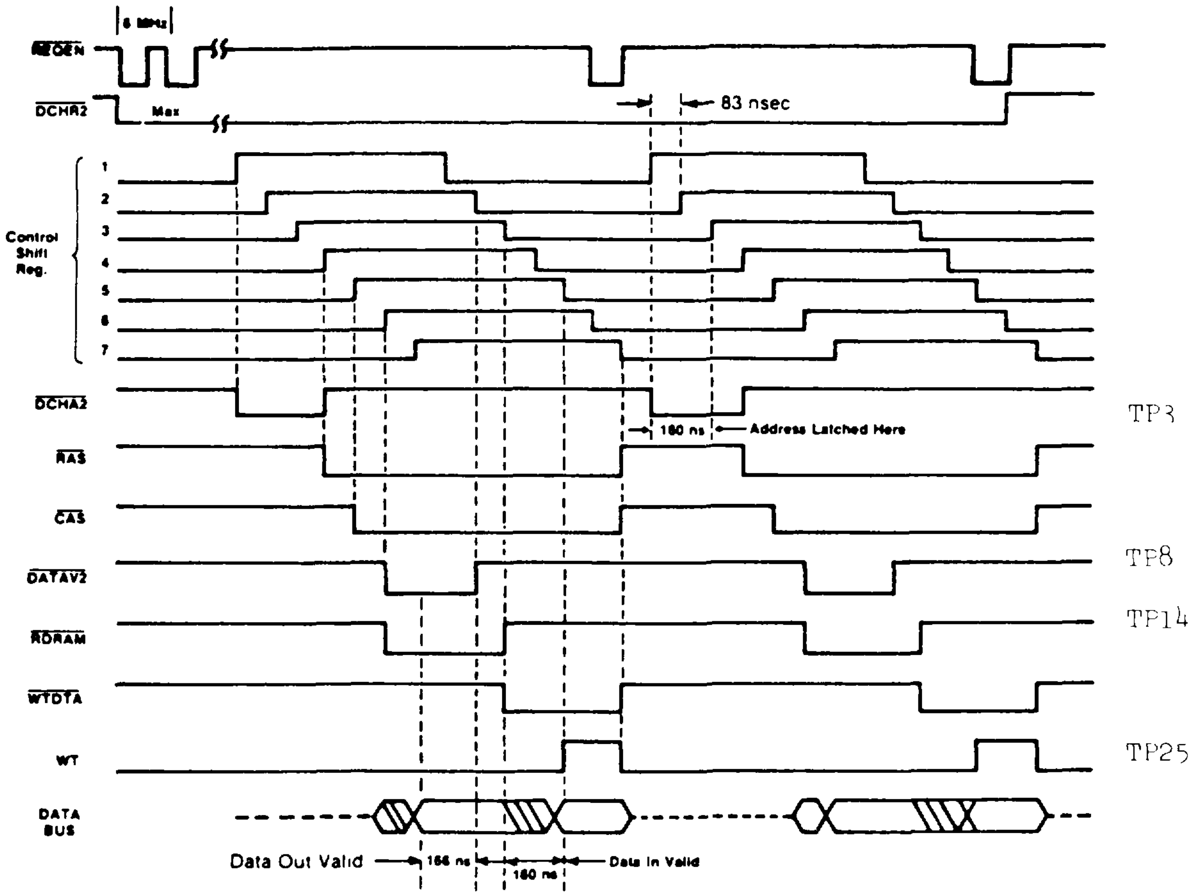


Fig. 9.22: DMA Read-Modify-Write Timing

9.10 CURSOR CONTROL

The aim of this circuit given in sheet 3, CPU board, is to control the cursor position. Its implementation into the board can be seen from Fig. 9.23.

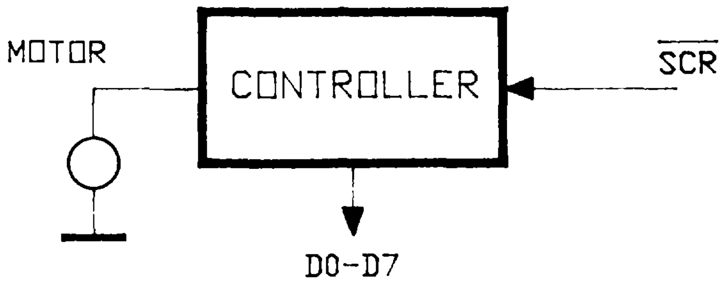


Fig. 9.23: Cursor controller connections

The command, in the form of a binary number, to move the cursor is given to the CPU through the three-state latch A81 (74LS373). The latch receives data from two bidirectional four-bit counters A82 and A83 (74LS191), which are periodically scanned for the data. Counters count pulses from the VFC (Voltage to Frequency Converter) A84 (4151). VFC driving voltage is provided by a DC motor serving as a generator when rotated. Negative or positive voltage applied to the operational amplifier connected as a rectifier causes the generation of the clock signal at the output of VFC. The same frequency results for the left and for the right motion. An additional comparator A86 (LM 311) senses the polarity of the generated voltage and selects the counting direction: up or down.

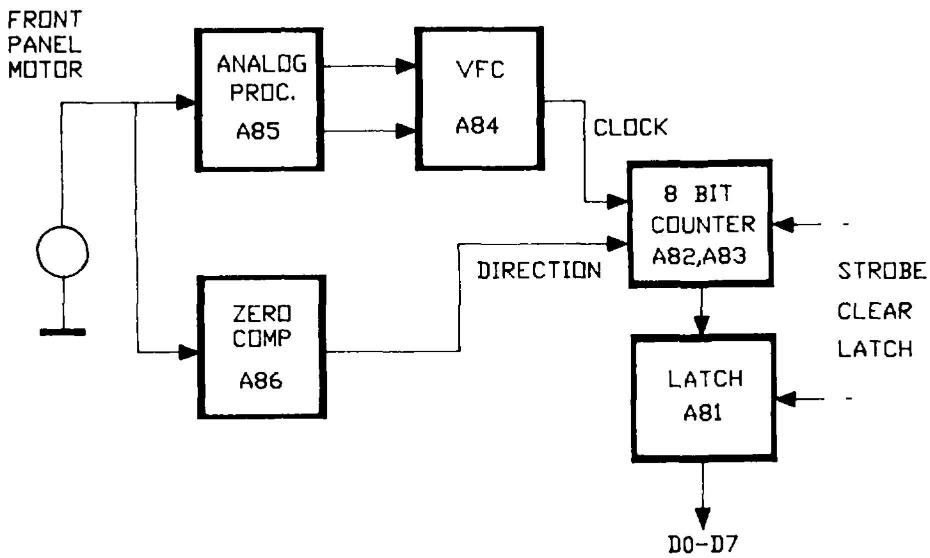


Fig. 9.24: Cursor controller block diagram

Some Troubleshooting hints follow:

1. Check the voltage, magnitude and the polarity at pin 3, A86 to the ground.

2. Is there a change in the polarity of the A86 output signal at pin 7 when rotating left and right?

3. Can you observe the rectangular signal at pin 3, A84?

4. Are there strobe pulses of negative polarity at pin 1, A81 and pin 11, A82 and pin 11, A83?

5. Are counters A82 and A83 connected serially into 8-bit binary counter active? Can you observe the rectangular signal at pin 9, and at the higher bits, when you rotate the motor rapidly?

9.11 DISPLAY BOARD - WHAT IT DOES

The task of the display board is to control the monitor and provide the information to be displayed on its screen.

Using the built-in clock, two digital signals, LSYNC and FSYNC, are derived to synchronize the monitor.

The display board also looks into the RAM using the direct memory access DMA to get the number of the stored counts in different channels. These data are combined with the information about the MCA working conditions which have to be displayed in text form in the lower part of the screen. For this task, the display board is instructed which letter should be sent to MONITOR through the character video line CVID.

Also, the dead time determination runs in parallel. Data about the analog to digital converter activity obtained from the ADC unit in analog form are converted into the digital one. The result is put on the internal data bus. The dead time indicator scale pattern is also taken from the ROM as a separate contribution to the screen picture.

Data from different sources are composed together into the video signal, which is used for the CRT beam modulation.

The display board containing more than 100 integrated circuits is too complex to be presented here, even in block diagram form. Therefore, the partial block diagrams will be given in the following chapters.

9.11.1 CRT Synchronizer

The final product of the CRT synchronizer is FSYNC and LSYNC signals. However, auxiliary signals defining the writing across selected parts of the screen, like GT1, GT2, CHEN and others, are also generated. See Fig. 9.25 for the screen structure.

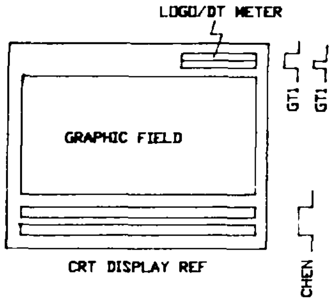


Fig. 9.25: Screen fields

All signals are derived from the basic clock of 14.90 MHz generated by the crystal oscillator. After the division by two, the DTCK signal (Fig. 9.26), available at TP6, is obtained (dead time clock). Presetable counter A12 (74LS161) produces the cell clock signal (TP7).

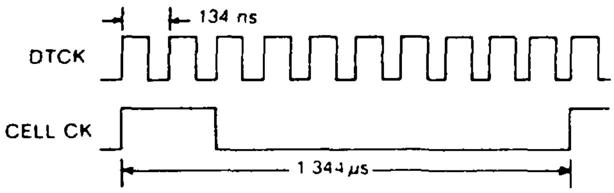


Fig. 9.26: Clocks

Through the further division by counters A10 and A11, and using the data from ROM (IM 5610), the line synchronization trigger LST is formed. Passing through uni-vibrator A16 (74LS221), the line synchronizing signal LSYNC can be inspected at TP2. After inversion in A92 (74LS37), it leaves the board as $\overline{\text{LSYNC}}$.

In another binary counter group A25, A26 and A27 (74LS161A all), the CELCK signal is divided by 547. Under the name FST, it triggers two serial connected uni-vibrators in A15 (74LS221). The resulting signal FSYNC can be controlled at TP1. The signal leaves the DISPLAY BOARD as $\overline{\text{FSYNC}}$ after the inversion in A92.

Inside the CRT synchronizer unit, some additional control signals, like GT1, GT2 (dead time meter gate), CHEN (character gate), DGT (data gate), and SDMA (start direct memory access) are also derived. As inputs to A9, ROM IM 5610, signals from VERTICAL CELL COUNTER (A10, A11) are taken.

A further division of the field synchronizing signal provides a 2.1 Hz blink frequency for flashing messages. There is no test point for it; it appears at pin 6, A29.

9.11.2 Dead Time Indicator

The task of this unit schematically presented in Fig. 9.27, right part, is the determination of the ADC dead time and the generation of signals to show the result on the CRT screen.

The circuit measuring the percentage of the dead time, and helping to present it, is given in sheet 8, DISPLAY BOARD.

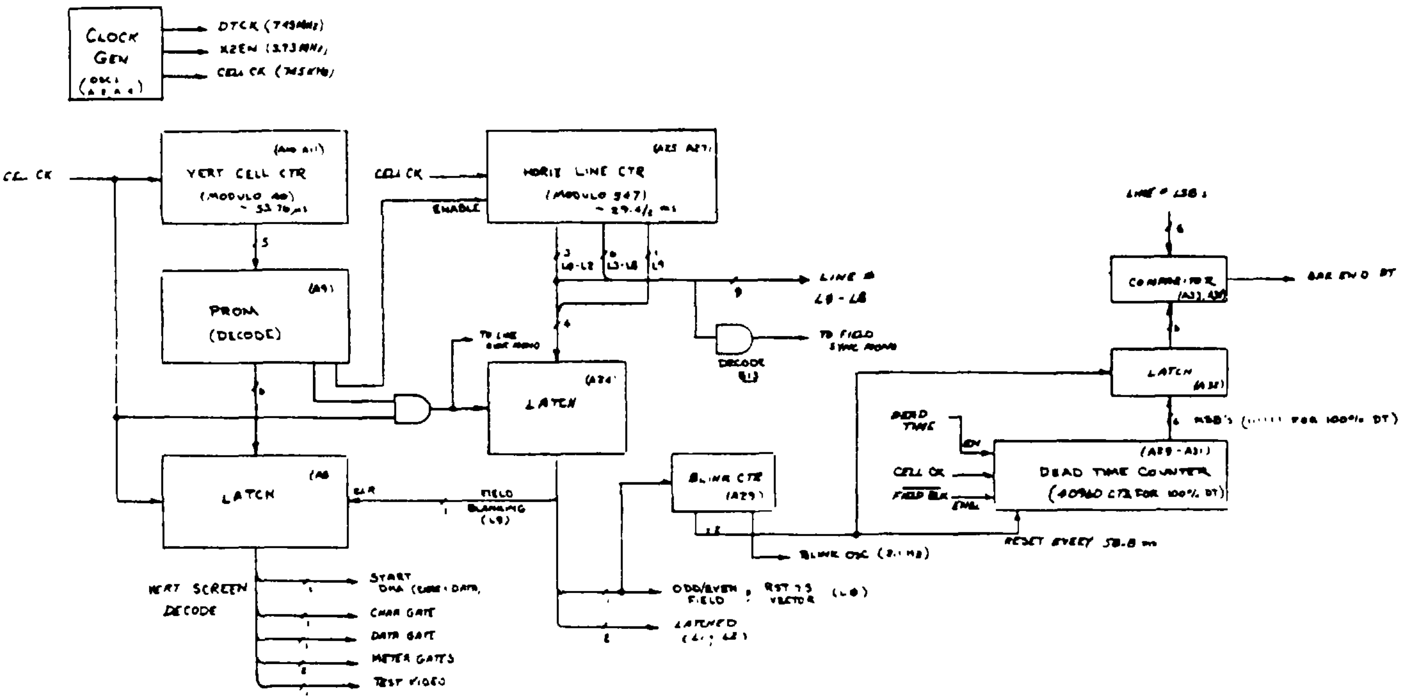


Fig. 9.27: Synchronizers and timers

Cell clock CELCK (TP7) is counted in the decade counter A30 during the intervals when ADC is busy. For adequate gating, the LT signal coming from the ADC board is used, A97, pin 13. The counting proceeds in dual binary counters A29 and A31. Collect time of subsequent runs are two frame periods, which amount to 58.8 ms. In this way 4096 counts are collected each time if the ADC would be busy all the time, i.e. if the dead time percentage is 100. Only the most significant 6 digits of the obtained result are used for the indication. If the dead time is smaller, the number of the collected counts is proportionally smaller.

The obtained resulting number stored in latch A32 is compared with the six lower bits L0, L1, L2, L3, L4 and L5 of HORIZONTAL LINE COUNTER in the 6-bit digital comparator A33, A31. The result of comparison (A34, pin 7) tells which of both numbers is bigger. If this signal would be used for the CRT beam intensification, then the pattern of 8 vertical bright raws would be seen over the full screen. The width of the raws would be dead time dependent, but the full screen is taken for presentation.

Additional logic is introduced to limit the picture size. The pattern is activated only in the sixth row by applying L6, L7 and L8 to the NAND gate A28. The height is defined by the GT1 signal derived in the CRT SYNCHRONIZER applied to the same gate.

9.11.3 Data Point Video

During the scanning of the display field, the properly timed burst signals are required to draw the pattern. One of these beam intensifying signals makes the picture of the spectrum within the graphic field. It is produced inside the data point video section (sheet 2 and 3 of the DISPLAY BOARD documentation). Start at sheet 2 and find the local bus lines AD0 to AD7.

From the local data bus, 20-bit data about the memory content are locked in A86, A88 and A89 at 0 to 1 transition of the BYT1CLC (TP29), BYT2CLC (TP24) and BYT3CLC (TP25). For further processing, only 8 of 20 bits are selected because of the limited display possibilities (Fig. 9.28).

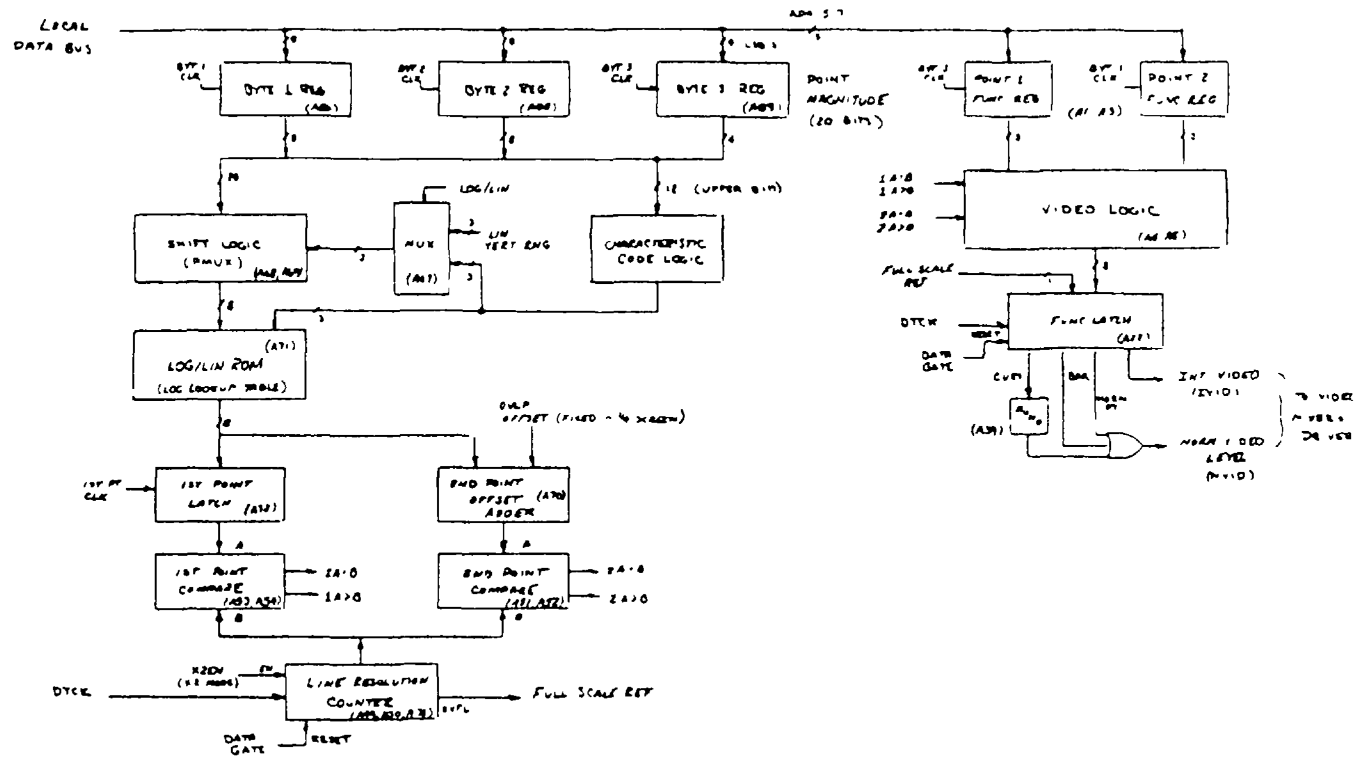


Fig. 9.28: Data point video

Selection is done by multiplexer (A68, A69), which is controlled by another multiplexer A67. Multiplexer A67 allows the selection of linear or logarithmic display, and the selection of the vertical scale. The conversion to logarithmic format is performed in ROM A71, and the result is stored in latch A72 (drawn in sheet 3, top).

Simultaneously, the counting of DTCK clock signal (TP6) in 8 bits line resolution counter A49, A50 starts. The line resolution counter is periodically cleared by DGT (TP16). During counting, the electron beam in the CRT climbs up along the line. At the moment when the content of the LINE RESOLUTION COUNTER is equal to the channel content number stored in A72, the 8-bit binary comparator A53, A54 delivers the pulse at the output A=B (A54, pin 6). This pulse is used to intensify the electron beam at the proper time.

In this way a bright point appears on the CRT screen at the position whose height is proportional to the number of counts stored in the channel.

The signal A > B generated in the same digital comparator tells when the number of the stored counts is smaller than the current LINE RESOLUTION COUNTER content. The A > B signal can be used to bright the bar between zero line and the spectrum point when this is required.

Check the graphic field contribution to the video display at TP13.

Notice: to realize the overlap-function, the 4-bit adder A70 (74LS283) and the comparators A52/A53 are used. To achieve this mode, a constant offset of 64 is added to RAM contents. This results in a second graphic display 25% lifted.

9.11.4 Status Register and Data Video

Status information is needed to provide the display logic with system variables such as vertical scale, expand, range, etc. Therefore, at the end of each monitor frame, an interrupt is introduced through the line RST 7.5. Programme jumps to sub-routine updating the status register. Related schematics are at sheet 5. The block diagram is shown in Fig. 9.29.

Inside the display board its own data-address bus is created. The three-state buffer A100 takes data from BAD0 to BAD7 lines and repeats them as AD0 to AD7. Enable of A100 is controlled by CHEN (A10, pin 1 or pin 19). Lines A8 to A15 are reproduced at outputs of A80, also the three-state output buffer. Three lines, BA8, BA9 and BA10, demultiplexed in 3 to 8 demultiplexer A78 are used to produce the strobe signals R0, R1, R2 and R4. Multiplexer A78 is enabled by OUT (output request generated within the CPU board). OUT can be checked at TP23. By these signals applied to four 8-bit latches A101, A103, A84 and A102, four bytes of the information can be stored. R4 is used to enter the data into A60, the dual flip-flop.

Through some additional processing in two multiplexers A83 and A65, the complete display status is created. From the latched data you can learn what is the memory range (M0, M1, M2), or the display mode, or similar.

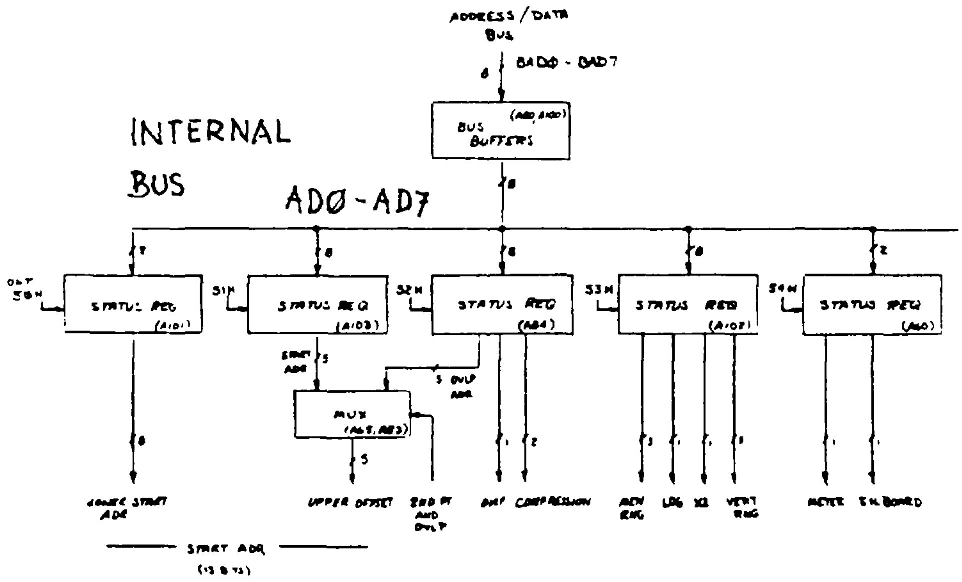


Fig. 9.29: Status register

9.11.5 Character Display and Video Mixer

Characters are displayed in the dot matrix form, 5 x 7 in our case. The character cell size is bigger; 8 x 10 dots (Fig. 9.30).

Characters to be displayed are accepted from the local data bus (Fig. 9.32) during the direct memory access (DMA) cycle and loaded into the 8-bit character latch A91 (sheet 4) followed by another 8-bit latch. In this way a two-byte fast memory is created. When the second character is accepted immediately after the first one, the first character is transferred into latch A90 (Fig. 9.32).

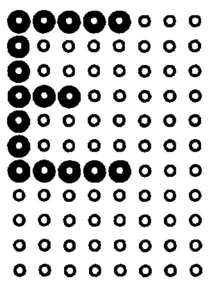


Fig. 9.30: Matrix representation

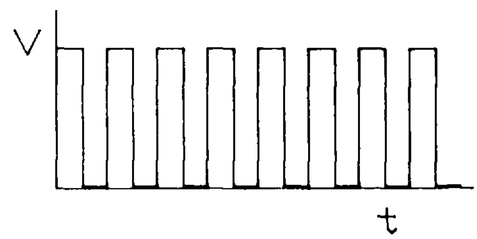


Fig. 9.31: Video signal drawing the first line of E

Having the character code at outputs (A1 to A6) of the ROM A108, the output corresponding to the vertical line pattern of the required character appears at B1 to B8. To reproduce E, for example, the thicker points should be brightened. When the beam runs from bottom to top of the screen and arrives at the letter E, the pattern 1111111 should appear at the ROM output. Then two 4-bit shift registers A106 and A107 are loaded with B1 to B8 data. The pattern is then pushed out in the serial form corresponding to the first vertical line of the loaded character (TP30), and the command shown in Fig. 9.31 is delivered at the CVID line.

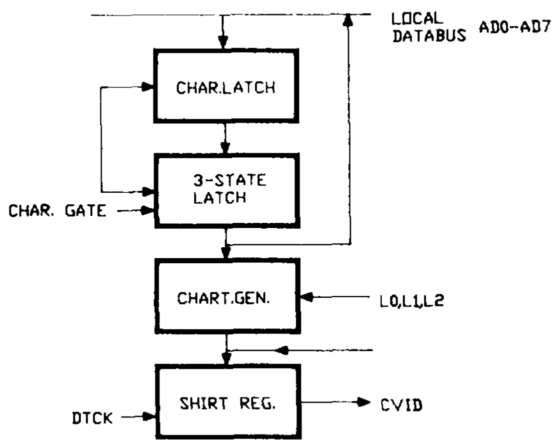


Fig. 9.32: Character display block diagram

After this, the second character is pushed down from A91 to A90 to draw the pattern of the upper character line. Only the first line of both characters was used. Therefore, we don't need to change them yet but we have to keep them. The lower character stored in A90 is returned to A91 to be used again in the next vertical line. After using all eight lines of both characters, A91 and A90 are reloaded. However, to write the second vertical line of the same character the L0, L1 and L2 addresses are increased for one.

Signals CCK (character clock, TP17) and CHEN (character enable) ensure proper timing in data handling. BOSC makes characters blink.

Video mixer, sheet 4, DISPLAY BOARD, accepts three separate TTL signals (CVID, NVID and IVID) and mixes them into video signal VID (pin 8, 10 pins line connector, MONITOR input; use also video ground, pin 10) serving for the CRT beam modulation in MONITOR. The contribution of each signal in the composed signal is determined by potentiometers as follows:

CVID, (TP30) drawing characters is set by RV 5;
NVID, (TP13) used for the normal spectrum representation is set by RV3; and
IVID, (location A20, pin 4) used for the intensified lines like the integrated areas as set by RV4.

Check also the auxiliary DC voltage at outputs 1, 8 and 14 of quad operational amplifier A111.

Observe signals at collectors of Q6, Q5 and Q4. They should follow the corresponding TTL input signals but the amplitude of signals depends on the RV3, RV4 and RV5 settings.

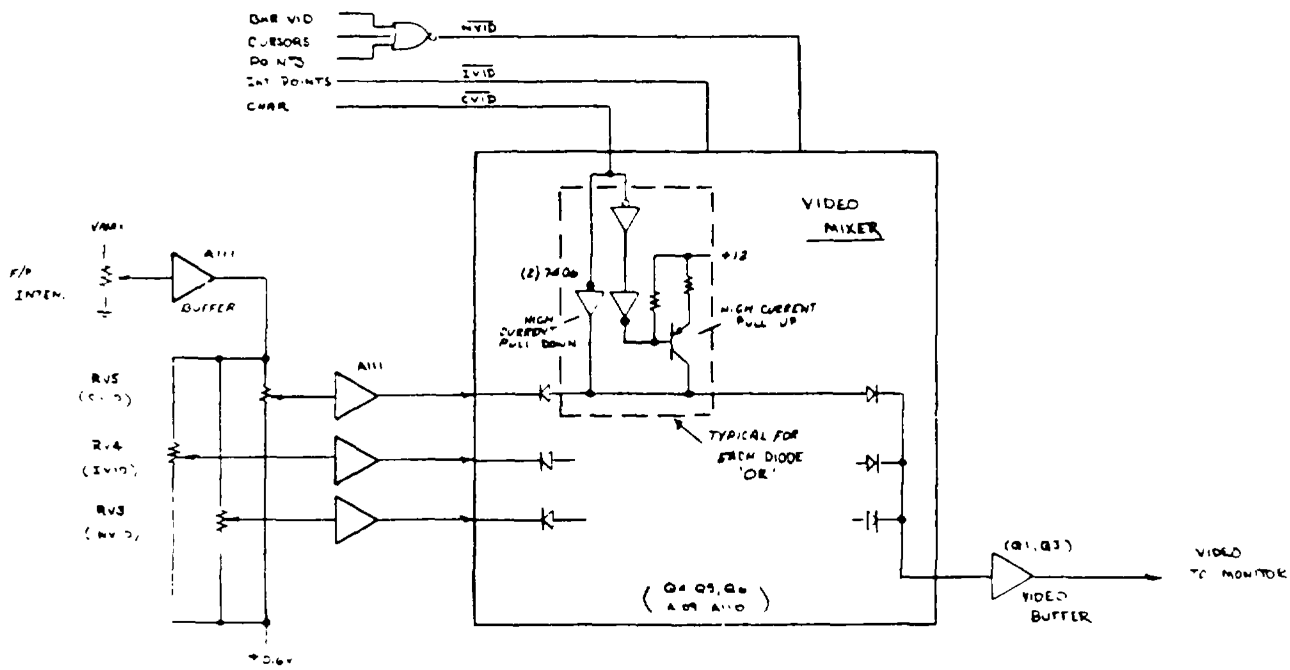


Fig. 9.33: VIDEO mixer

9.11.6 Direct Memory Access Logic and Address Generator

The direct memory access (DMA) is used to keep the CRT display refreshed and updated with real time data collection and text. This is done once per each Monitor vertical line, during the flyback.

DMA logic generates write and read commands and asks the 8085 to relinquish bus control.

DMA address generator determines the memory address from which data should be taken.

The circuit block diagram is given in Fig. 9.34 while the corresponding detailed schematic is at sheet 6 and 7.

DMA request is sent to the priority encoder (sheet 5) residing at the CPU board. The DMA request signal DCHR1 can be checked at TP15. Simultaneously the memory address from which the information should be provided is set at the MUX (A81, A63, A98 and A99) output. The signal DCHA1 confirming that the DMA request has been accepted and executed is returned after 1 us. DCHA1 is at TP26.

The content of the selected memory location appears on the system bus and the local bus. The content is locked in BYTE 1 register (Fig. 9.28, top left) by the BYTE 1 CLK (TP29).

The next memory address is set and the content from the corresponding memory location is latched in the BYTE 2 register. Check TP24 for BYTE 2 CLK.

The action is repeated to get the data BYTE 3. Check TP25 for BYTE 3 CLK.

To run 3-stage ring counter A96, A95 some activity at TP20 (DATA V1) and CNDMA (pin 5, A74) should be revealed.

For the character loading into 2-byte memory (A91, A90, sheet 4) signals CCK (TP 17) and CHLD (A26, pin 13) are used.

During data handling the proper RAM and ROM addresses have to be set. See Table 9.4 for the required combinations. The corresponding schematics are shown in sheet 7.

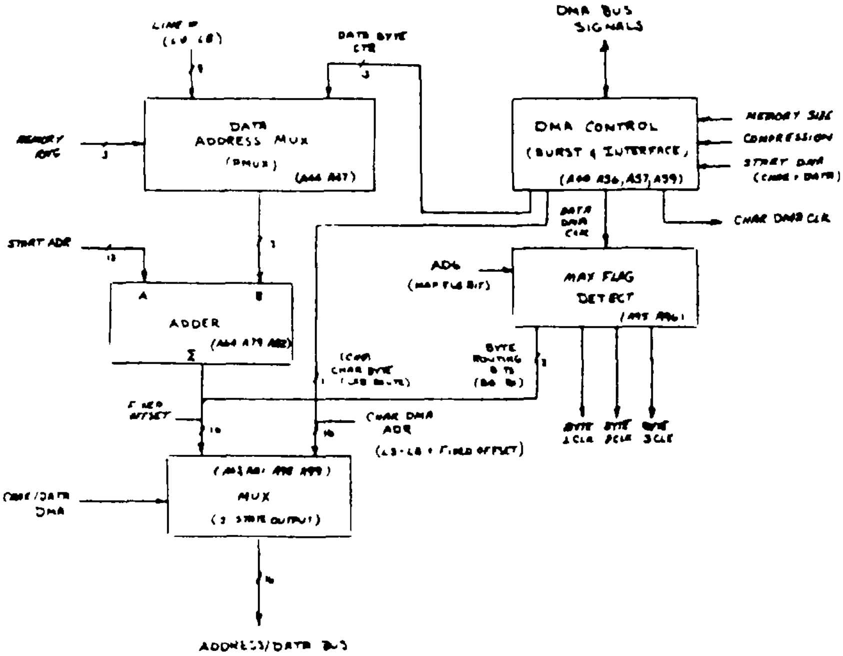


Fig. 9.34: DMA

TABLE 9.4: DMA addresses

MEMORY SIZE	A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
8K	D0	D1	0	D2	L0	L1	L2	L3	L4	L5	L6	L7	L8	B0	B1	1
4K	D0	D1	D2	L0	L1	L2	L3	L4	L5	L6	L7	L8	0	B0	B1	1
2K	D0	D1	L0	L1	L2	L3	L4	L5	L6	L7	L8	0	0	B0	B1	1
1K	D0	L0	L1	L2	L3	L4	L5	L6	L7	L8	0	0	0	B0	B1	1
512	L0	L1	L2	L3	L4	L5	L6	L7	L8	0	0	0	0	B0	B1	1
256	L1	L2	L3	L4	L5	L6	L7	L8	0	0	0	0	0	B0	B1	1
128	L2	L3	L4	L5	L6	L7	L8	0	0	0	0	0	0	B0	B1	1
CHAR	CH0	L3	L4	L5	L6	L7	L8	0	0	0	0	0	0	1	1	1

9.12 MISCELLANEOUS BOARD

The miscellaneous board is responsible for various activities such as communication with the keyboard and communication with external units through the serial interface RS-232 or TTY.

However, the most important task is the mathematical operation during the pulse height analysis (PHA). As it has been previously mentioned, the ADC board presents the height of the input pulse in the binary code. This binary number is the address of the memory cell (RAM, residing at the CPU board) in which the content should be incremented by 1.

9.12.1 Collect Part

This addition is performed on the miscellaneous board within the part schematically given in sheet 4 and 5. See Fig. 9.35 for the block diagram.

Buffered lines BAD0 to BAD7 (sheet 4) are seen as DD0 to DD7 at A-side of the bidirectional buffer A81 (74LS245). Data flow direction is determined by signal at pin 1, A81. When data is present-indicated by DATA-V2 (sheet 5) - it is latched into A37 an 8-bit latch 74LS273. Outputs of A37 are connected to A-inputs of 8-bit summer A25, A38 (two 74LS283 connected serially). In the PHA (PHA line, pin 2, A47, high) mode, the addition of "1" is achieved by applying high state to the carry input (pin 7, A38) from flip-flop A7 while B-inputs are grounded.

The number of counts for each channel are contained in three bytes. See APPENDIX for details.

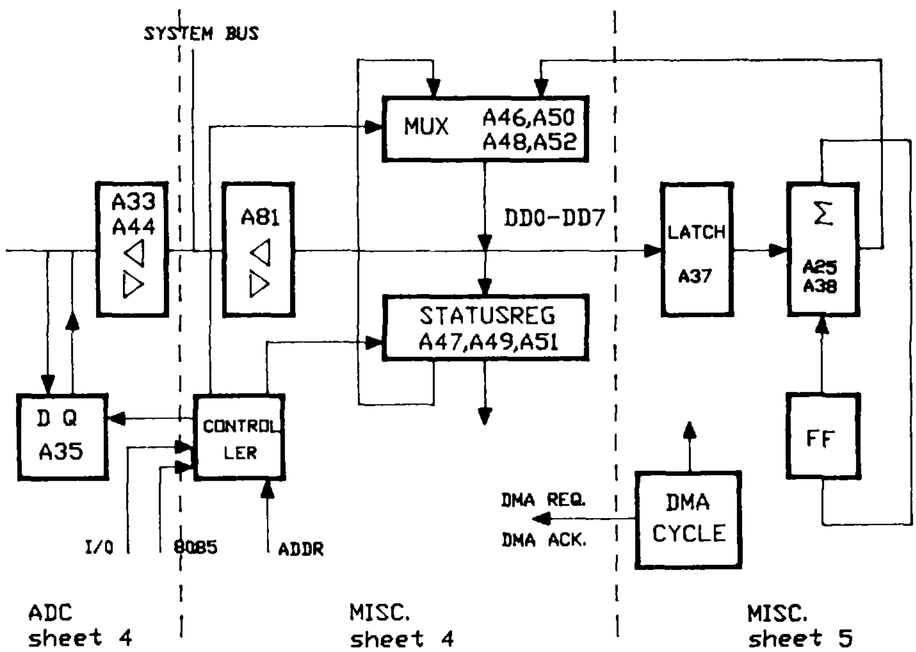


Fig. 9.35: Collect part of the Miscellaneous Board

In the first step, "1" is added to BYTE 1. The result is put in the flip-flop A7. The modified BYTE 1 is returned to the same memory cell through demultiplexers A50, A52 (sheet 4) and the bidirectional buffer A81.

Next, BYTE 2 is inserted and the procedure is repeated.

Then BYTE 3 is treated. However, only four LSB are a part of the number represented by BYTE 1, BYTE 2 and BYTE 3. Therefore, by applying BYTE 3 signal to the gate A12 and A24, the sumation is limited to four LSB only.

If during the processing of BYTE 1 or BYTE 2 carry is not produced, further sumation is meaningless and is stopped.

When the DMA cycle is over, HOLD command is removed and 8085 is returned to the normal operation through line RST 5.5.

All commands controlling the data flow and the described arithmetic are generated by the circuit containing A10, A5, A6, A7, A8, A12, A24 and A65 (situated in sheet 5, left down).

We have assumed up to now that BYTE 1, BYTE 2 and BYTE 3 are available. However, for proper selection the adequate address should be given to RAM.

The position of BYTE 1, BYTE 2 and BYTE 3 within the RAM is given in Fig. 9.36. For proper addressing, the address line A15 should be 1 all the time when communicating with RAM (ROM is addressed by A15 = 0). A13 and A14 have to be set according to Table 9.5.

TABLE 9.5

	A15	A14	A13	A12 ....A0
BYTE 1	1	0	0	determined by base address and range
BYTE 2	1	0	1	determined by base address and range
BYTE 3	1	1	0	determined by base address and range

The above-mentioned address lines are controlled by flip-flops A13 through three-state buffer A65 (74LS367, sheet 5). During the DMA-cycle the CPU data bus is tri-stated and external users have direct access to the RAM. Check TP5 for A13 by using DCHA2 as the trigger. The end of the DMA cycle is indicated by DMEND signal from monostable A5 and triggered by the signal that can be observed at TP4.

Until now we have talked about the ADC-gain of 8291 channels. Frequently we use less channels to have the possibility for registering several spectra. In such cases the starting address also depends on the base address. For available base addresses and their coding, see Table 9.6. The current base address is kept within the miscellaneous board.

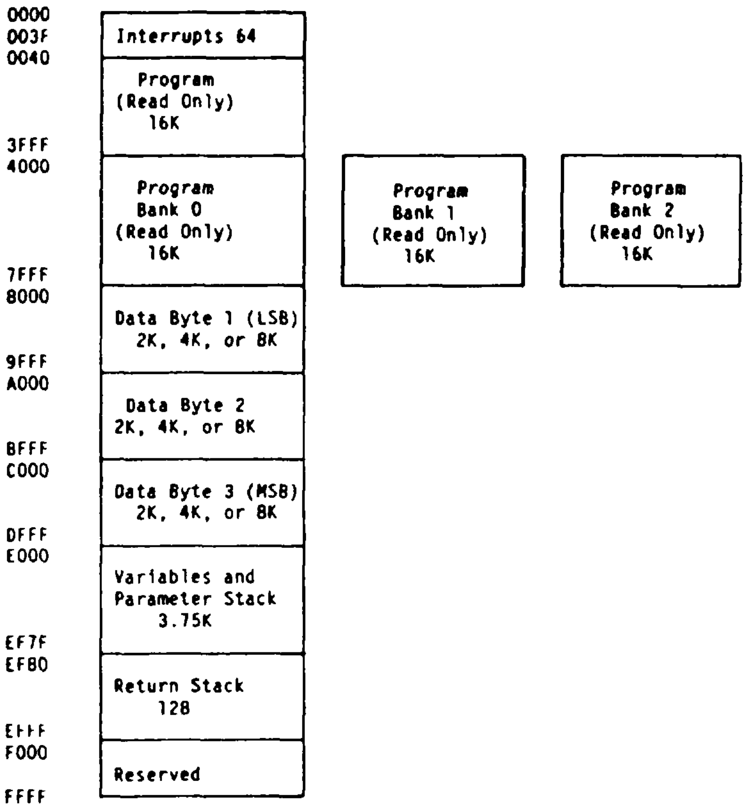


Fig. 9.36: Memory map

TABLE 9.6

B4	B3	B2	B1	B0	Base
0	0	0	0	0	0
0	0	0	0	0	256
0	0	0	1	0	512
0	0	0	1	1	768
0	0	1	0	0	1024
0	1	0	0	0	2048
0	1	1	0	0	3072
1	0	0	0	0	4096
1	1	0	0	0	6144

TABLE 9.7

R2	R1	R0	Range
0	0	0	256
0	0	1	512
0	1	0	1024
0	1	1	2048
1	0	0	4096
1	0	1	8192

For a proper display, the memory address should not run higher than the starting address plus the number of channels. The number of channels is also kept within the miscellaneous board under the name range. See Table 9.7 for the coding. The range code is used by the limit logic on sheet 4 (A44, A55, A56 and A57) to prevent the ADC from generating an address larger than the memory assigned to it.

Where to find, and how to use the base address and the range code?

Miscellaneous board (sheet 4) contains its own status register. You can find latches A47, A49 and A51 (74LS273, 74LS174, 74LS273) providing 22-bit data storage. The last, 8-bit latch 74LS273 also controlled by the miscellaneous board is moved into the ADC board (sheet 4, A35). The lowest 5 bits are the base address while the three highest bits represent range code (R0, R1, R2).

In A47, A49 and A51, information is stored about the current operating mode (PHA, MCS) and other system variables. This information can be sent to DD0 to DD7 lines through the three-state multiplexers 74LS257 (A46, A47, A48, A50). Such configuration is called I/O port in the computer language.

Data are written into output latches with signals delivered at outputs of A62 (two-to-four line decoder) and activated by the 8085 OUT command (pin 5, A63). Data from ports are read when the 8085 IN signal is given (pin 9, A63). The port addresses are transmitted through lines BA8, BA9, BA12, BA13, BA14 and BA15. Output lines PO3 (output) and PI3 (input) control the port in ADC.

APPENDIX 1

To count up to 2^{20} counts each channel has to be three bytes long. The four highest bits of the third byte, not used for channel content, provide the information about the special treatment for this channel:

bit 21, if set, the corresponding point is intensified;

bit 22, if set, the bar is displayed instead of the point;

bit 23, if set, indicates the channel with the biggest content;

bit 24, if set, channel is within the region of interest.

Chapter 10
INTERFACES

10 INTERFACES

10.1 GENERAL

All information delivered in the following chapters assumes some basic knowledge of interfaces and of Personal Computers (PC). It is devoted entirely to problems you will be faced with when selecting interfaces or working with them.

The three major groups of interfaces which will be covered are:

(i) Standard Interface Used for Data Communication

- the serial interface RS232 C/V24
- the parallel interface Centronics

(ii) Standard Interface Used for Remote Control of Instruments

- the IEC 625 (IEEE-488, GPIB) interface

(iii) Non-Standard Interface for Remote Control of Peripherals

- I/O ports
- Motor control

10.2 SELECTION OF INTERFACE

Whenever you have to select an interface, ask yourself a few questions.

a. What is available at my laboratory?

b. Who is going to be the controller (master) of my system?

- Is it a PC?
- Is it a special dedicated device which only provides data like a multichannel analyzer (MCA), scaler/timer, digital multimeter (DVM)?

c. What am I going to connect (slave)?

- Is it a data communication device like a printer or a terminal?
- Am I going to control different instruments like DVMs, scaler/timers, MCAs?
- Do I have to control peripherals such as sample changers or motors?

d. Are interfaces already available in the master?

- If "YES", can I use them for the job I am going to do?
- If "NO", what is available from the company or on the market?

e. Is an interface already available in the device (the slave) I am going to connect?

f. If interfaces are available in both the master and the slave, are they compatible?

ATTENTION:	Make your decisions very carefully; you will have less trouble later on.

10.3 SERIAL INTERFACE RS-232C/V24

The application of the RS-232 interface is widespread in mainframes, minicomputers, microcomputers, printers and all types of terminals. It is used for a SERIAL BINARY DATA INTERCHANGE between two devices. The basic principles of the standard are implemented in such devices; however, various options may occur from device to device. These variations become extremely significant when interfacing different combinations of computers, printers and terminals. A general rule may be established as follows.

NOTE:	When connecting between devices, make sure that an output signal goes to an input signal and vice versa.

First of all, terms which are used for this interface must be explained:

DTE - DATA TERMINAL EQUIPMENT like computers, terminals or printers

DCE - DATA COMMUNICATION EQUIPMENT like modems

As one can see from above, two different types of devices exist which can be connected together. The first case to connect a DTE to a DCE should not create any problem; you simply connect them straight through. This is because each output pin on a DTE has a corresponding input pin on the DCE. Signal flow is shown from the DTE side.

PC-Pin (DTE)		Lead name (abbreviation)		Modem-Pin (DCE)
1	<--------	Protective Ground (PG)	---------->	1
2	-------->	Transmitted Data (TD)	----------->	2
3	<--------	Received Data (RD)	<--------------	3
4	-------->	Request to Send (RTS)	----------->	4
5	<--------	Clear to Send (CTS)	<-------------	5
6	<--------	Data Set Ready (DSR)	<------------	6
7	<--------	Signal Ground (SG)	-------------->	7
8	<--------	Data Carrier Detect (DCD)	<-------	8
20	-------->	Data Terminal Ready (DTR)	------->	20

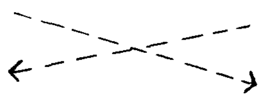
The second case to connect two devices from the same type, namely two DTE's together, can bring you into trouble. Therefore, let's do it step by step. The kind of cable we have to use is called a "NULL MODEM CABLE."

GROUND: connect them straight through

Function	PC1-Pin (DTE)		PC2-Pin (DTE)	Function
PG	1	<----------->	1	PG (Protective Ground)
SG	7	<----------->	7	SG (Signal Ground)

DATA LEADS: Pin 2 is used for transmitted data and pin 3 for received data. Data are transmitted over pin 2 from one machine and received on pin 3 at the other. To allow for proper data transmission and reception at both machines, cross pin 2 on one end with pin 3 on the other end.

Function	PC1-Pin (DTE)		PC2-Pin (DTE)	Function
PG	1	<----------->	1	PG (Protective Ground)
SG	7	<----------->	7	SG (Signal Ground)
TD	2		2	TD (Transmit Data)
RD	3		3	RD (Receive Data)



Data terminal equipment (DTE)-provided signals are all that are present in a null-modem cable. This limitation forces us to provide DCE signals with available DTE signals. Specifically, the DTE signals (RTS and DTR) must be used to provide or emulate the DCE-provided signals (DSR, CTS and DCD). Data Terminal Ready (DTR) pin 20 is ordinarily provided by the DTE to indicate that power is on at the terminal. For an indication that the line is established, the DCE normally gives a signal on pin 6 Data Set Ready (DSR). As long as DSR is on, one can assume that DCE is available for data transmission. If pin 6 is not present, the line or connection is not available. To emulate DSR (pin 6) at both ends, we strap the DTR signal (pin 20) at one device across to pin 6 on the other device. The same strapping is done in the other direction. By strapping pin 20 across to pin 6, whenever DTR is high (the machine power is on), the other end will get indication that the transmission line is available. If power is off, the other end will not have DSR, indicating that the communication path is not established.

Function	PC1-Pin (DTE)		PC2-Pin (DTE)	Function
PG	1	<----------->	1	PG (Protective Ground)
SG	7	<----------->	7	SG (Signal Ground)
TD	2		2	TD (Transmit Data)
RD	3		3	RD (Receive Data)
DSR	6		6	DSR (Data Set Ready)
DTR	20		20	DTR (Data Terminal Ready)

The other element of the control function on the interface is path control. Request To Send (RTS) pin 4 is normally generated by the DTE. For data transmission to be allowed, Clear To Send (CTS) pin 5 must be received by the same DTE. So we loop the RTS signal back to the originating DTE by wiring it back to pin 5 (CTS). Whenever the DTE - for example PC1 - raises RTS, it immediately receives a CTS signal indicating that data transmission is now possible. As for the need of the receiving device to have an indication that data will be arriving, we must provide for Data Carrier Detect (DCD) pin 8 to be derived from the same source, RTS. Thus we also connect RTS (pin 4) at the originating DTE (PC1) to the Carrier Detect lead (pin 8) from receiving device. By making these cross connections, not only will a CTS signal be given, but when RTS is raised, the other end will also receive its DCD signal, indicating that data transmission is possible. Repeat these connections at both DTE's to allow two-way transmission.

Function	PC1-Pin (DTE)		PC2-Pin (DTE)	Function
PG	1	<----------->	1	PG (Protective Ground)
SG	7	<----------->	7	SG (Signal Ground)
TD	2		2	TD (Transmit Data)
RD	3		3	RD (Receive Data)
DSR	6		6	DSR (Data Set Ready)
DTR	20		20	DTR (Data Terminal Ready)
RTS	4		4	RTS (Request To Send)
CTS	5		5	CTS (Clear To Send)
DCD	8		8	DCD (Data Carrier Detect)

The path control requirements have been met in the null-modem cable. As we have mentioned above, two different types of devices (DTE and DCE) are existing, so we have to ASCERTAIN THE "SEX" OF THE EQUIPMENT before we can connect them together.

The best way to determine whether an equipment using RS-232 ports is configured to emulate DTE- or DCE-provided signals, is to review the device documents. Consult the user's manual for this information. If documentation is not available, a break-out box may be used to determine which leads are provided by a device. For specifications of a break-out box, see Chapter 3, Section 3.2.17.

Connect the break-out box to the RS-232 port and make sure that the device is powered and the port in question is active or enabled. The LED's on the box should display which leads are being generated from the device. From this display a determination can generally be made as to whether the device is emulating DCE or DTE; green LED's indicate negative voltage, red LED's indicate positive voltage.

REMEMBER: RS-232 output levels for

LOGIC 0 (SPACE) between +5V to +15V

LOGIC 1 (MARK) between -5V to -15V

RS-232 input levels for

LOGIC 0 (SPACE) between +3V to +15V

LOGIC 1 (MARK) between -3V to -15V

INPUTS are ENABLED when positive, DISABLED when negative
OUTPUTS are ASSERTED when positive, FALSE when negative

We will ascertain the "SEX" of the computer first. If the PC is a DTE device, pin 2 should be the transmitter, and its negative voltage will illuminate the green LED. The receiver terminal, if left unconnected, may illuminate an LED if a pull-up resistor is present. If pin 20, Data Terminal Ready, or pin 4, Request To Send, is on, the port is more likely emulating Data Terminal Equipment and is expecting to be connected to a modem or a device emulating DCE signals. On the other hand, if the display shows that signals such as Clear To Send (pin 5), Data Set Ready (pin 6), or Data Carrier Detect (pin 8) are present, the port is probably emulating DCE and will allow a straight-through cable to be used when connecting a terminal configured as DTE, as if connecting to a modem.

If you don't have a break-out box, the levels can also be determined by an oscilloscope or a DVM.

If you want you can build up a LED Voltage Detector by yourself to test your interface pin by pin (Fig. 10.1).

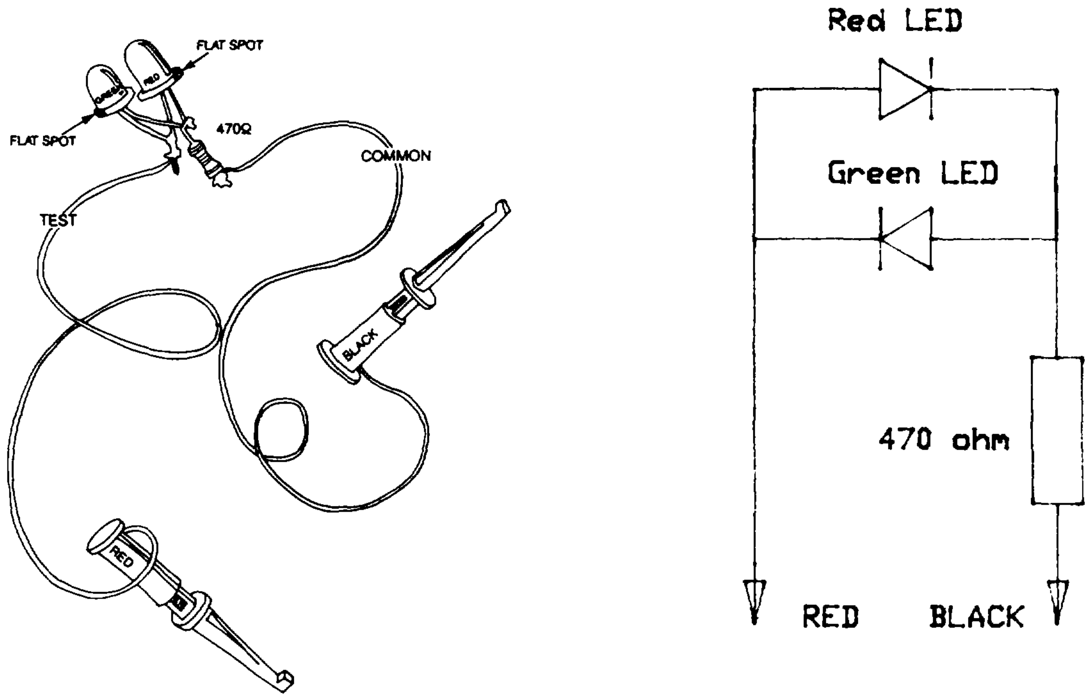


Fig. 10.1: Simple LED voltage detector

To avoid confusion, it is best to use charts to show the status of the seven pins. For example, use NEG for negative, POS for positive. Inactive pins that illuminate neither LED should not be left blank - otherwise you may not know if you have already tested the pin. Instead, use an X to represent any undefined logic state. Beside each number is the abbreviation of its name as well as an O for output and I for input. When the connector is charted, you'll have a good idea of what control logic is being used. Two examples, one for a DTE and one for a DCE, are given.

DTE:

Pin	I/O	Volts
2 TD	O	NEG
3 RD	I	X
4 RTS	O	POS
5 CTS	I	X
6 DSR	I	X
8 DCD	I	X
20 DTR	O	POS

DCE:

Pin	I/O	Volts
2 TD	I	X
3 RD	O	NEG
4 RTS	I	X
5 CTS	O	POS
6 DSR	O	X
8 DCD	O	X
20 DTR	I	X

The important factor is that all requirements of the ports, with regard to pins' being on or off, must be met.

You can easily test how the control inputs are working. If you apply a negative voltage (< -3V) to DSR (pin 6) of the DTE, you disable it. The cable between the devices to be connected is important for successful implementation. However, after a cable has been built or supplied, a number of other items must be compared and set properly before the interfacing will be complete.

Following, you will find a checklist for options generally found on computers and peripherals.

Item	Options
Speed	75 bps to 19,200 bps
Flow control	ETX/ACK, XON/XOFF, Hardware
Parity	Odd, Even, None
character length	5, 6, 7, 8 bits
# of stop bits	1, 1.5, 2
Mode	Simplex, Half-Full duplex
Echoplex	Yes, No
Line feeds	0, 1, 2, CR implies LF, LF implies CR
Transmission mode	Asynchronous, Synchronous
Polarity	Positive, Negative

In summary, all items should be checked for proper optioning to permit successful installation. Both devices have to be SETUP to match each other. For example, if one device is set to 4800 bps, the other one has to be set to the same baudrate. The same has to be done with all other items listed above. In most cases these changes can be done either by DIP-switches located on the interface board or by software in a PC.

Let us have a closer look at the basic hardware of such an interface. Normally you have data on a parallel data bus, in most cases 8-bits wide. This data has now to be converted into a serial one, which is done in a so-called USART (Universal Synchronous Asynchronous Receiver Transmitter). This circuit also takes care about the hardware handshaking lines as shown in Fig. 10.2.

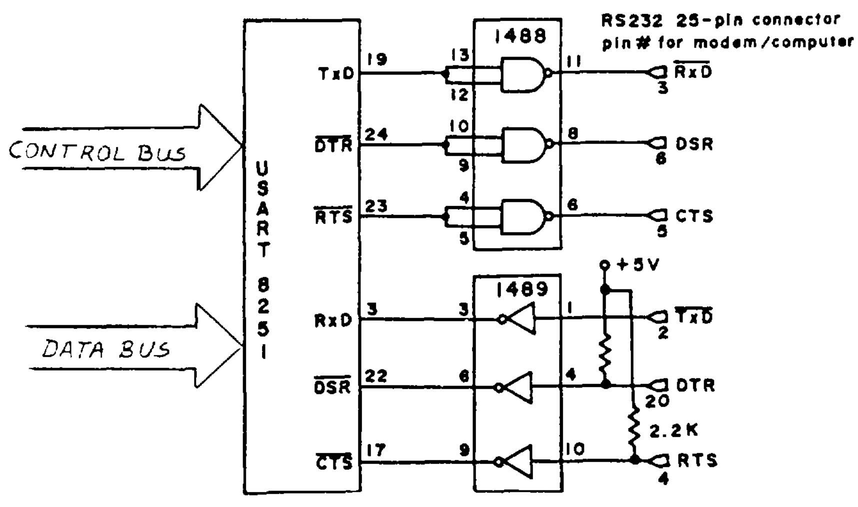


Fig. 10.2: Parallel to serial conversion with a USART

Computer RS-232 interface supports via USART (Fig. 10.2), DTR, DSR, RTS and CTS control lines. The 25-pin connector pins are labeled from the terminal's point of view, while the inverted computer labels appear on the USART. Note that this interface works with or without the control protocol, since the input handshake lines are pulled up. Most of the interfaces work in this way, so you only need to define pins 2 and 3. But don't forget to connect the ground pins 1 and 7.

Fig. 10.3 shows the widely used TTL to RS-232 converters. The receiver includes a hysteresis input to reduce its noise sensitivity. The +/- supply voltage for the 1488 does not have to be symmetric. Positive voltage can range from +7V to +15V and the negative from -3 to -15v.

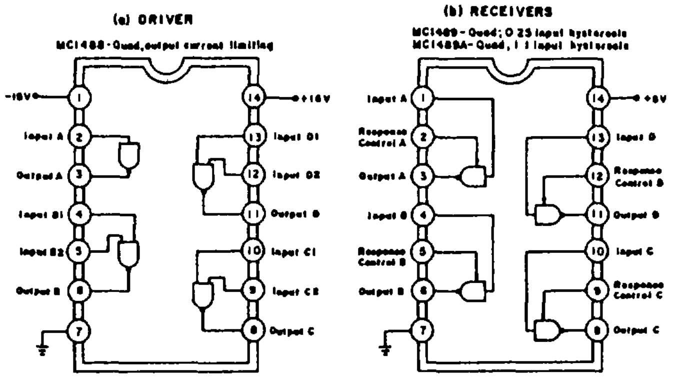


Fig. 10.3: Pin-out of RS-232 drivers and receivers

As a typical example, we will take the interface board of a MCA 35+ from Canberra. Fig. 10.4 shows you the circuit diagram where A69 is the USART, A57 is the transmitter, and A67 is the receiver.

One typical example is to connect a MCA like Canberra 35+ to a PC, in our case an IBM-compatible.

The MCA is set as DCE, the PC as a DTE. In this case you can use a cable which is connected straight through.

PC	Pin		Pin	MCA	
TD	2	--->	2	RD	
RD	3	<---	3	TD	
CTS	5	<---	5	DTR	
DSR	6	<---	6	DSR	> pulled to +5V through 3k
DCD	8	<---	8	DCD	

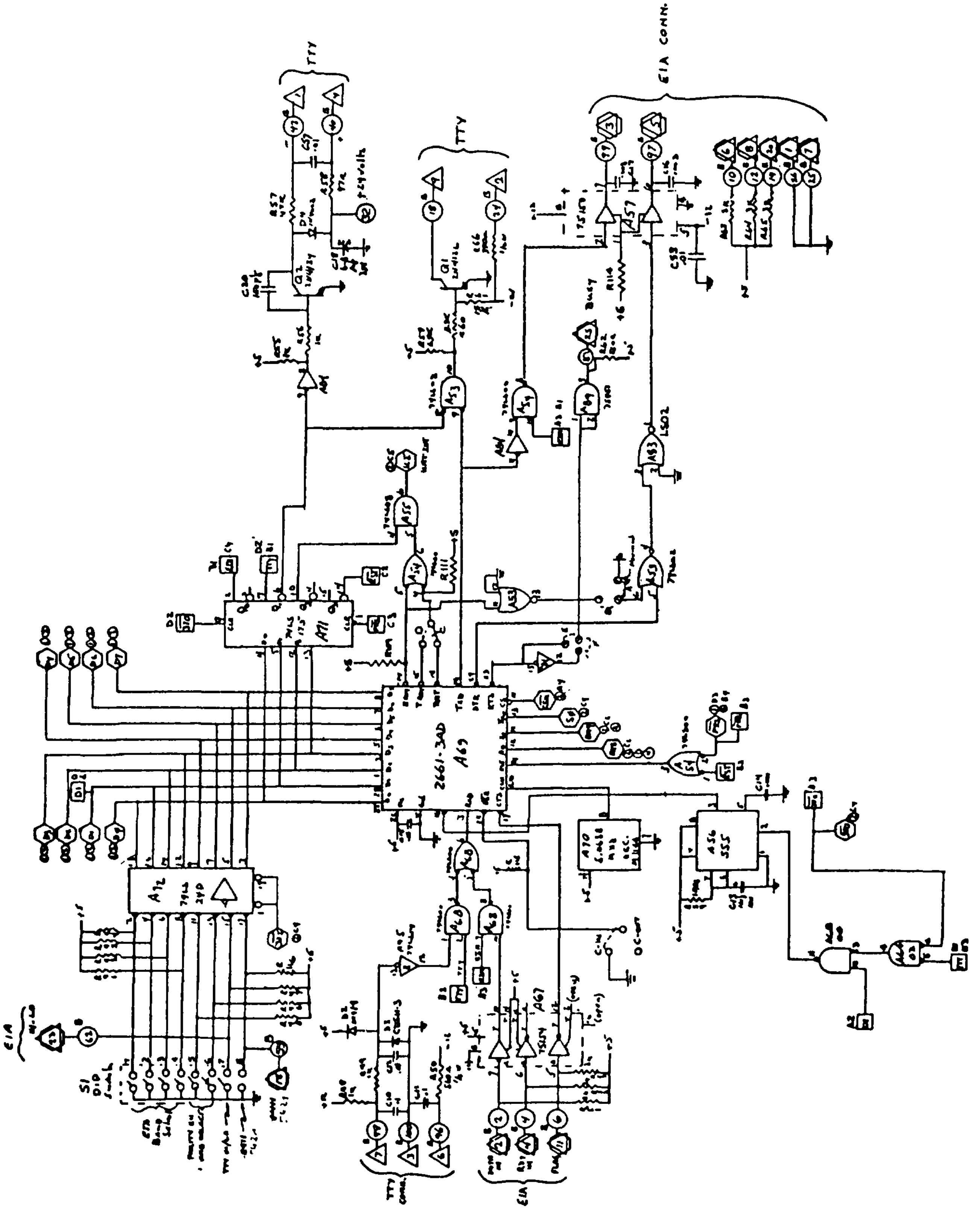


Fig. 10.4: Interface circuit diagram for the RS-232 port of a MCA 35+

> **ATTENTION:** Don't connect Pin 20; it can damage your driver in the PC!

Next you have to provide the options in your computer to the setup chosen on the serial interface in the MCA. You will find a detailed description on the setup of the interface board in the Operators Manual of the MCA. Take care: you cannot exceed a baudrate higher than 4800 bps, because no handshake is supported.

Some hints if you run into trouble when installing your interface are presented in Table 10.1.

TABLE 10.1: Partial list of problems with an RS-232 interface

Symptom	Equipment	Cause/Remedy
No data is being displayed or printed	Terminal or printer	Check to be sure that power is on. Ensure that device is in on-line mode. RS-232 requirements may not be satisfied.
		Polarity of signals could be improperly set. Both devices should have the same setting. Speed of ports may not be set the same. Big difference in baudrates.
		Device controller or driver circuits may be defective.
		Cables may not be plugged snuggly into port or may be broken.
	Printer	Possibly out of paper.
		Printer lid, if raised, may inhibit further printing.
		Computer or terminal port to which printer is attached may be incorrectly configured as DCE or DTE; verify this. Printer ribbon may be defective or worn out; replace it.
		Computer port driving the printer may not be enabled, check address of the port.

Garbled or lost data	Terminal, printer or computer	Port speeds may not be consistent. Cable could be faulty. Character length could be wrong. Flow control may not be occurring. Parity may be improperly set. Cable too long or too high capacity for selected Baudrate --> max. length 15 m!
Communication line cannot be established or maintained	Terminal, printer or computer	Power may be off on the device. This would disable DTR (pin 20) which should not allow the connection to be made. Device or port must be in on-line mode to keep DTR on and maintain the line. Duplex should be the same at each end. Computer at the far end may automatically disconnect if it determines that the call is being made by an invalid user. Cable between the devices may be faulty or not properly wired.
Improper spacing Double spacing	Terminal or printer	Line feeds; see if computer outputs a line feed with each carriage return. If so, option for zero line feeds at the device or option the computer to only output a carriage return.
No spacing	Terminal or printer	Computer is only outputting a carriage return, while the device is not adding a line feed. Option either the computer or the device to add a line feed with each carriage return.

==

If you look with an oscilloscope to the transmitted or received signals, don't expect very fast leading or trailing edges.

10.4 PARALLEL INTERFACE CENTRONICS

This type of interface is mostly used to connect printers to a PC. Synchronization is done by STROBE pulses supplied by the transmitting device, in our case the PC. Handshaking takes place through ACKNLG or BUSY signals. Data and all interface control signals are compatible with TTL level. Both the rise and fall times of each signal must be less than 0.2 us. As to the wiring for the interface, be sure to use a twisted pair cable for each signal and never fail to complete connection on the Return side. To prevent noise effectively, these cables should be shielded and connected to the chassis of the host computer and the printer respectively. Interface cables should be kept as short as possible to avoid problems (max. length 4m).

Most of the input and output drivers are very sensitive against connecting devices together while power is applied. They may be damaged.

Below you will find the pin assignment and description of signals, seen from the printer side, in our case an EPSON.

Signal Pin No.	Return Pin No.	Signal	Direction	Description
1	19	$\overline{\text{STROBE}}$	In	Used to strobe (Latch) data in. A pulse > 0.5 us at receiving terminal is required.
2-9	20-27	DATA 1-8	In	Eight TTL-compatible data lines. Each has its own signal ground return for use with twisted pair cables.
10	28	$\overline{\text{ACKNLG}}$	Out	Output pulsed low for approx. 12 us and indicates that data has been received and that the printer is ready to accept more data.
11	29	BUSY	Out	"HIGH" indicates that the printer cannot receive data. The signal becomes "HIGH" in the following cases: during data entry, during printing operation, in OFF-LINE state, during printer error status.
12	30	PE	Out	A "HIGH" signals that the printer is out of paper.
13		SLCT OUT	Out	A "HIGH" signals that the printer is in the selected state, in most printers pulled up to +5V through 3k3.
14	--	$\overline{\text{AUTO FEED XT}}$	Out	When this input is low, the paper is automatically fed one line after printing.
15	--	NC	---	Not used.
16	--	OV	In	Logic ground level.

17	--	GND	Out	Printer chassis ground. Normally isolated from logic ground.
18	--	NC	---	Not used.
19-30	--	GND	In	Twisted-pair return signal ground level.
31	--	$\overline{\text{INIT}}$	In	When this input is "LOW" the printer controller is reset to its initial state and the print buffer is cleared. A pulse of > 50us is required.
32	--	$\overline{\text{ERROR}}$	Out	This output goes "LOW" when the printer is in PAPER END state, OFF-LINE state, or ERROR state.
33	--	GND	In	Same as pin 19 to 30.
34	--	NC	---	Not used.
35	--	ON	Out	Pulled up to +5V through 3k to indicate the +5V supply.
36	--	$\overline{\text{SLCT}}$	In	Data entry to printer is only possible when this signal is "LOW".

If you are going to make your own cable to connect a printer to an IBM-compatible PC, be careful. You will find instead of a 36-pin connector, a 25-pin one, similar to the one used for RS-232. The circuit diagram (Fig. 10.5) will help you to find the right signals on the PC board. At the same time, it will show you how a parallel interface is built up. The 8-bit databus is connected over tri-state-driver circuits direct to the connector. To transmit data U18, U4, U11 and U16 are used. To receive data U9, U16, U8 and U1 are used.

The following timing diagram (Fig. 10.5) shows you the relation between STROBE, DATA, ACKNLG and BUSY SIGNAL. You can check it with a normal dual beam oscilloscope. As mentioned before, it is very important that rise and fall times of each signal must be less than 0.2 us.

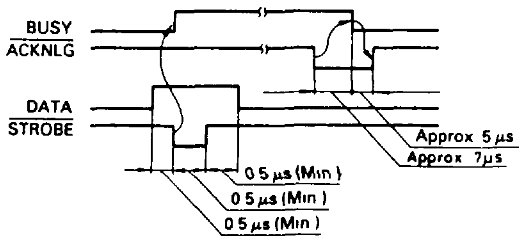


Fig. 10.5: Parallel interface timing

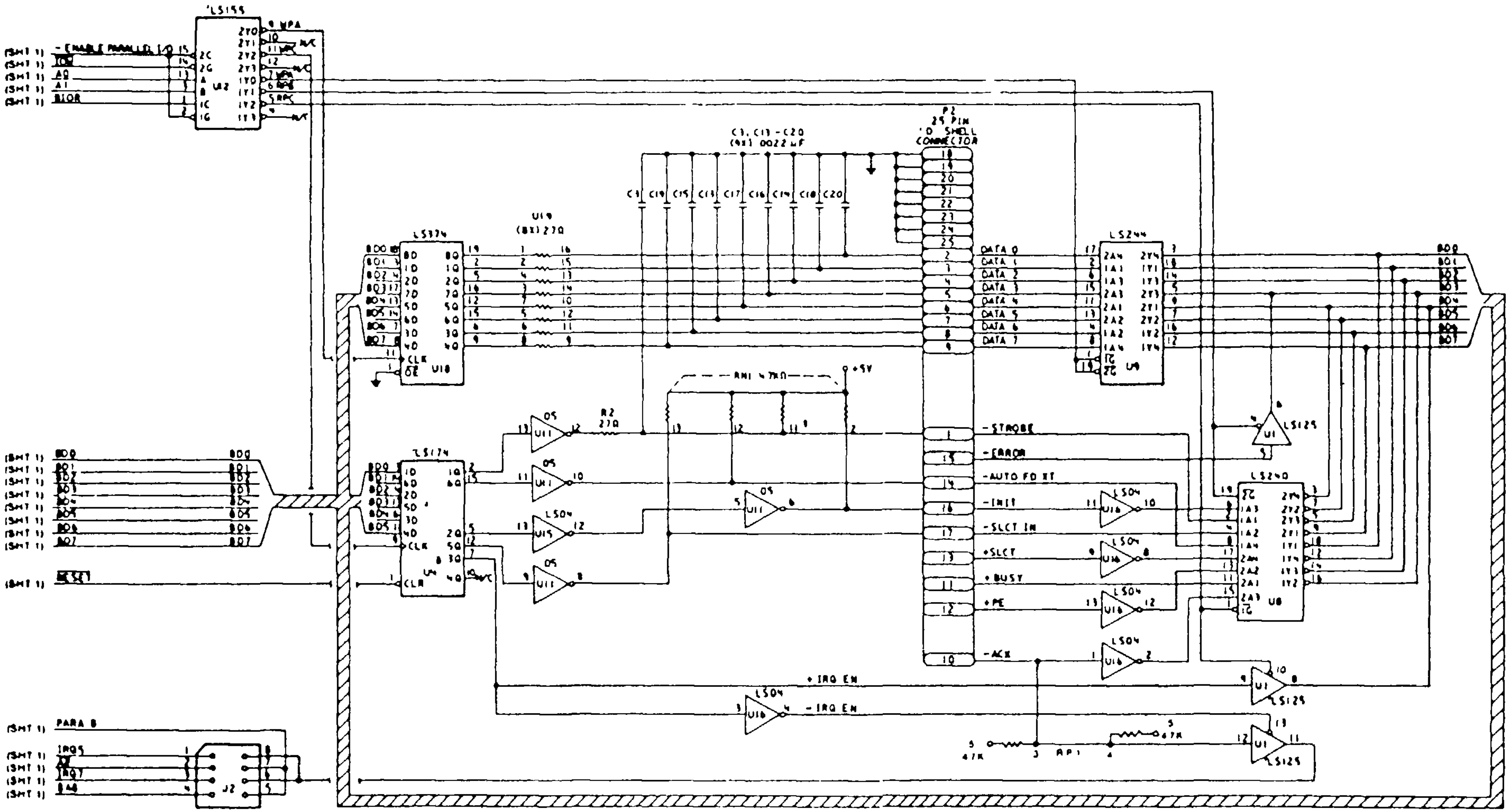


Fig. 10.6: IBM parallel interface

In Table 10.2 are some useful hints for troubleshooting. The device which is connected will be in our case a printer.

TABLE 10.2: Partial list of problems with a Centronics parallel interface

Symptom	Cause/Remedy
No data is being printed	Check to be sure power is on. Ensure the device is in on-line mode. Check all signals according to the above specifications. Computer port driving the printer may not be enabled; check the address of the board. Refer to PC manual. Printer lid, if raised, may inhibit further printing. Printer ribbon may be defective or worn, replace it.
Garbled data	Cable could be faulty. Timing of $\overline{STROBE}$ signal incorrect, too early or too late. Cable too long --> max. length 4m.
Communication line cannot be established or maintained	Power may be off on the printer. Cable between the devices may be faulty or not properly wired.

For a detailed printer description, refer to the printer manual.

10.5 IEC 625 (IEEE-488, GPIB) INTERFACE

The general purpose interface bus (GPIB) is a link or network by which system units communicate with each other. It is widely used for automation in measurement and control applications. The bus allows the connection of up to 15 devices to a system. Each system participant performs at least one of three roles:

CONTROLLER,
TALKER, or
LISTENER

A CONTROLLER manages the bus communication primarily by directing or commanding which device (TALKER) is to send data to other devices, or to receive data from other devices (LISTENER) during an operational sequence. A controller can be interrupted and it can command devices to interact directly among themselves.

The GPIB consists of 16 lines which are grouped into three sets according to function:

8 lines used for data (bit parallel, byte serial, data transfer)

3 lines used for control (provide a data transfer handshake compatibility with both slow and fast devices)

5 lines used for general management (allows initialization, interrupts, and special controls)

All instruments are connected in parallel to the bus of such a system via special cables.

The pin assignment and description of signals is presented below:

Pin No.	Signal	Description	
1	DIO 1	Data bit 1 (lowest)	Lines are also used to transmit commands. When ATTENTION (ATN) = 1, data on the lines interpreted as command. When ATN=0, data are interpreted as data.
2	DIO 2	Data bit 2	
3	DIO 3	Data bit 3	
4	DIO 4	Data bit 4	
13	DIO 5	Data bit 5	
14	DIO 6	Data bit 6	
15	DIO 7	Data bit 7	
16	DIO 8	Data bit 8 (highest)	
17	REN	Remote Enable: will be activated when system is active	
5	EOI	End or Identify: EOI=1, ATN=0 -> last byte of a datablock EOI=1, ATN=1 -> parallel poll	
9	IFC	Interface Clear: Resets the whole system	
10	SRQ	Service Request: has same priority for all instruments in a system. Is active whenever an instrument requests a service. Controller will interrupt and start with a serial poll to determine and satisfy the requestor.	
11	ATN	Attention: ATN = 0 Data is transmitted ATN = 1 Commands transmitted	
6	DAV	Data Valid: indicates the data on the bus is valid	
7	NRFD	Not Ready For Data: is sent from the instruments to indicate that they are not ready to accept data	

8	NDAC	No Data Accepted:	is sent from the instruments that valid data on the data-bus have not been overtaken yet.
12	SHIELD		
18-23	GND		
24	LOGIC GND		

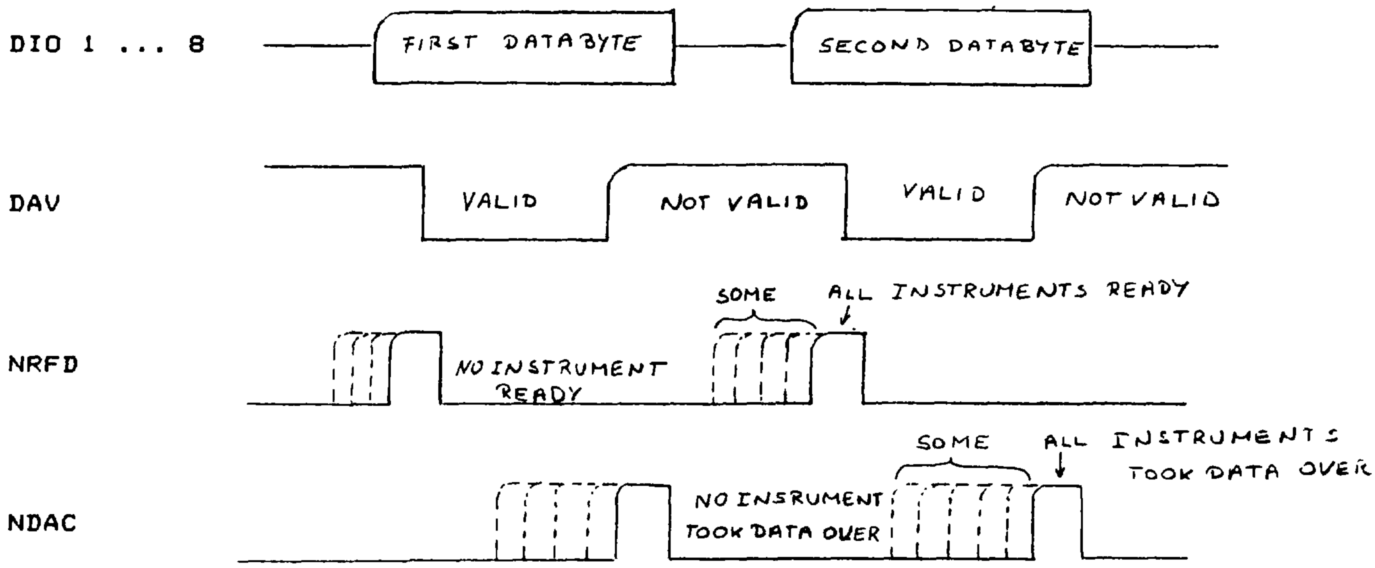


Fig. 10.7: Timing diagram for handshake

As an example, we will take the Canberra counter/timer 2071 with the installed GPIB-option (see Fig. 10.8). Before you can operate the scaler in a GPIB system, you have to configure the interface through eight DIP-switches.

The first five switches from the top are used to set the units' GPIB address. The address is the sum of all switches in the ON position. DON'T select an address already used in your system. Also, address 31 is illegal; it is reserved for the GPIB command UNTALK.

The sixth switch is TALK ONLY.

At this point you have to decide whether your scaler works with or without a controller. The TALK ONLY mode is used to transfer data from a single module to a single peripheral listener device, such as a GPIB-printer. If the TALK ONLY switch is off, the controller must assert REN (REMOTE ENABLE) during the entire communication.

The seventh switch is RECYCLE. In the ON position, the unit will clear after readout and start counting again. In the OFF position, the unit is in the single cycle mode.

The eighth switch is FF/CR. In the FF position, the message unit delimiter is sent out as an ASCII Form Feed. In the CR position, it is sent out as a Carriage Return. The choice of the delimiter depends upon the peripheral device being used.

Let us take a closer look at the interaction with a controller:

A typical counting sequence would begin with the operator pressing start on the Counter. After reaching preset, the Counter will generate a SRQ (Service Request) via ECOL (END COLLECT) from counter/timer. The controller would then, via Serial Poll, determine the device requiring readout. During this polling sequence, the controller will assign each of the devices to be polled a Talk address, and then the device will put out a STATUS-byte. In our case, the Counter is the requester and would output the Status 42H and remove its service request. If it would not have been the requesting device, it would output a Status 00. The controller completes the serial poll mode by doing a Serial Poll Disable (SPD). If the Counter is the only possible source of the Service Request, the controller can respond immediately by reading the data from the module, which also clears its Service Request. To read data from the Counter, the controller responds to the Service Request through the Ready For Data (RFD) line via the Acceptor Handshake. Read Clock Enable (RCE) is active once MY TALK ADDRESS and Read Clock (RCL) is sent to the counter to clock the bytes from the counters during S3 (output sequencer). After each LSB (Least Significant Byte), the output sequencer activates S4 to gate the message unit delimiter to the bus (separates counter outputs). After S4 of last counter S5 became active and gates ASCII Line Feed and EOI to the bus (End Message). Afterwards LB (Last Byte) is active and terminates the TALK MODE.

Following you will find a Block Diagram (Fig. 10.8), a Circuit Diagram (Fig. 10.9) and a description of the signals (Table 10.3).

Troubleshooting in such a system is limited because of its complexity. First, in many interfaces you will find large scale integrated circuits which support you with all signals used for the GPIB. Most of them are set up and programmed via software. Second, without a logic analyzer, you are in great difficulty. Timing relations among the signals are essential, and they can only be analyzed by using such an instrument.

So what to do if your GPIB system doesn't work, and you don't have a logic analyzer? Let's go step by step:

1. Look to see if power is applied to all of your devices connected to the GPIB.

2. Check if the interface cables are in good condition and plugged in correctly.

3. Check the addresses to which each device in the system is set; don't use the addresses twice.

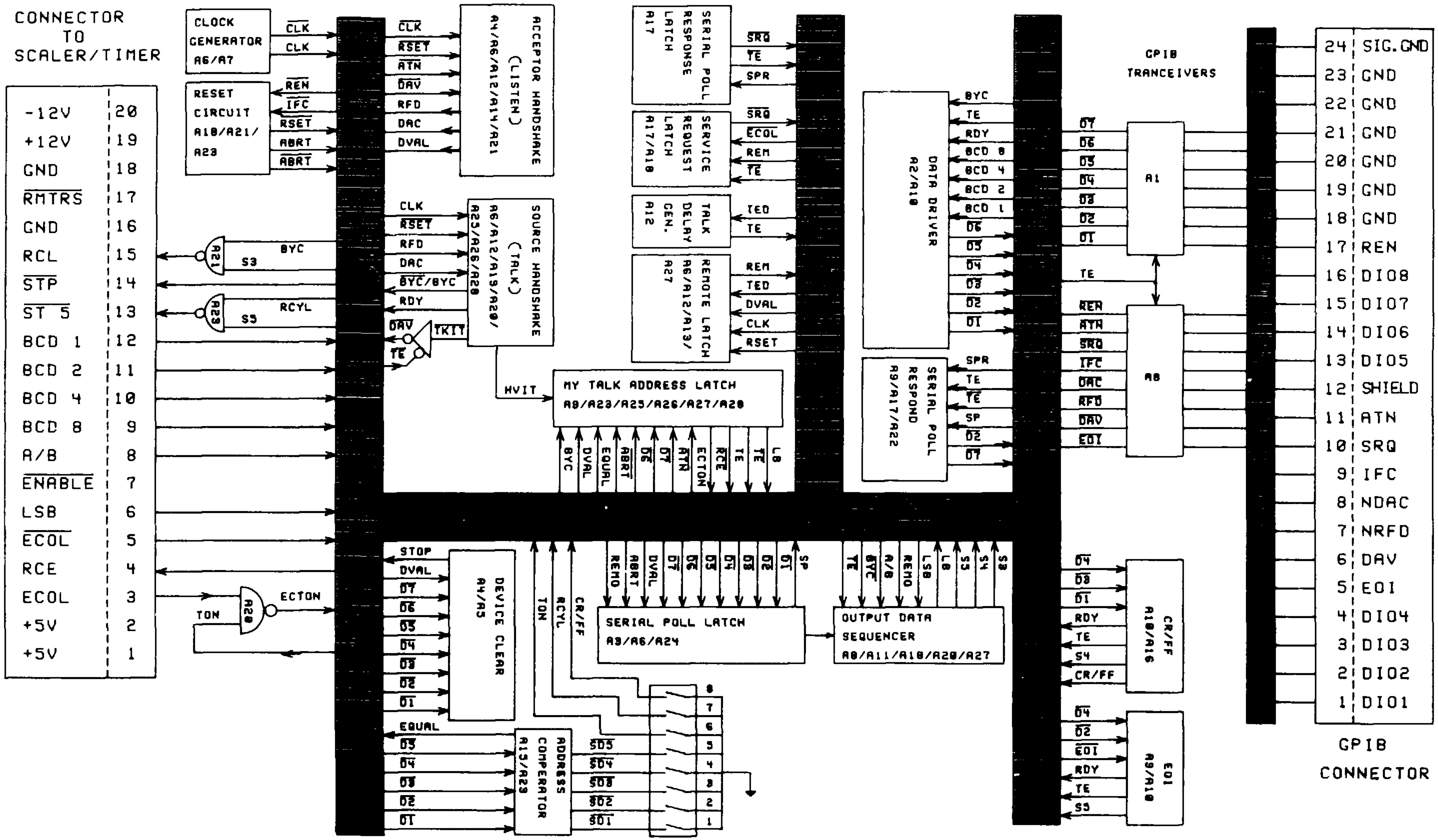


Fig. 10.8: Block diagram of GPIB interface for Canberra counter 2071

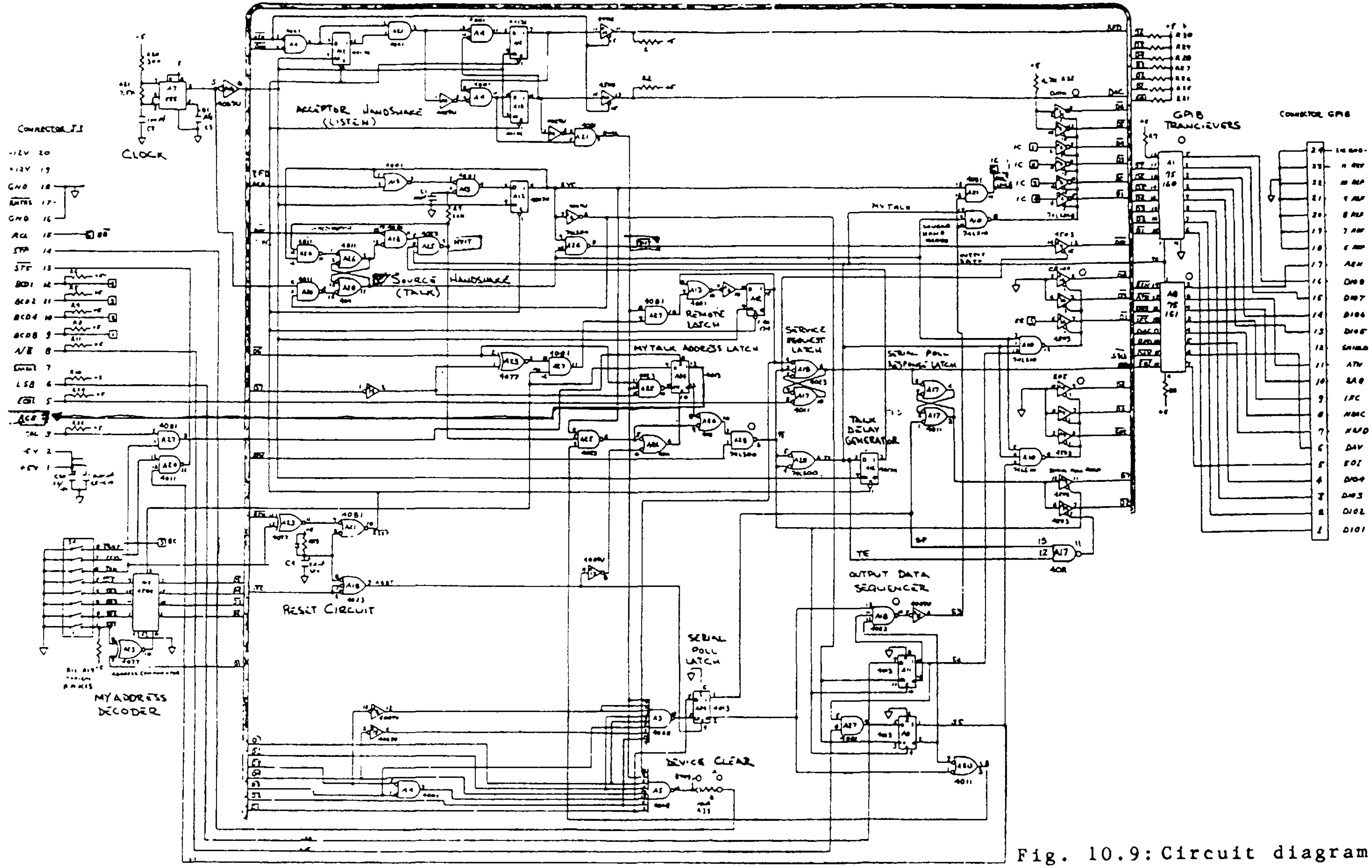


Fig. 10.9: Circuit diagram of GPIB interfacing for Canberra counter 2071

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TABLE 10.3: GPIB option functional description

The following twelve functions, identifiable on the GPIB interface schematic, are described in terms of the function inputs and outputs with brief descriptions of the output functions.

1) Acceptor handshake timing

Inputs		
CK	CLOCK	FROM INTERNAL CLOCK
RSET	RESET	FROM RESET LOGIC
DAV	DATA VALID	BUS GENERATED
ATN	ATTENTION	BUS GENERATED
Outputs		
RFD	READY FOR DATA	ACTIVE WHEN READY TO RECEIVE THE NEXT BYTE FROM THE BUS
DAC	DATA ACCEPT	ACTIVE AFTER DECODED BYTE HAS BEEN ACCEPTED BY THE MODULE
DVAL	DATA VALID	ACTIVE FOR ONE CLOCK PERIOD DURING STABLE AND VALID DATA STROBES ALL MODULE DECODERS AND LATCHES

2) Source handshake timing

Inputs		
CK	CLOCK	FROM INTERNAL CLOCK
RSET	RESET	FROM RESET LOGIC
DAC	DATA ACCEPT	BUS GENERATED
RFD	READY FOR DATA	BUS GENERATED
TE	TALK ENABLE	FROM TALK DELAY GENERATOR
TED	TALK ENABLE DELAY	FROM TALK DELAY GENERATOR
S3	STATE 3	FROM OUTPUT DATA SEQUENCER
Outputs		
BYC	BYTE CLOCK	GENERATED TO SYNCHRONIZE INTERNAL CIRCUITS ON EACH OUTPUT BYTE
RDY	READY	INACTIVE DURING THE PERIOD WHEN STATE AND BYTE CHANGES ARE OCCURRING GOES INACTIVE ON DAC ACTIVE ON THE RISING EDGE OF NEXT CK AFTER BYC GOES INACTIVE
TKIT	TAKE IT	GENERATES DATA VALID TO THE BUS GOES ACTIVE AFTER A DELAY TIME (ALLOWING DATA TO SETTLE) AND RFD INACTIVE AFTER DAC
HVIT	HAVE IT	ACTIVE INDICATED BYTE RECEIVED ON THE BUS GENERATED BY DAC AND VALID TO THE END OF BYC FORCED BY TE TED OR RDY TO PREVENT BYC
RCL	READ CLOCK	SENT TO COUNTER TO CLOCK THE BYTES FROM THE COUNTERS IN S3 DATA CHANGES TO NEXT LSB ON THE FALLING EDGE OF RCL

3) Talk Delay Generator

Inputs		
CK	CLOCK	FROM INTERNAL CLOCK
ATN	ATTENTION	BUS GENERATED
MTA	MY TALK ADDRESS	FROM MY TALK ADDRESS LATCH
Outputs		
TE	TALK ENABLE	ACTIVE FOR TALK STATE
TED	TALK ENABLE DELAY (A12 2)	SYNCHRONIZES BUS TO INTERNAL CLOCK FOR CORRECT TIMING

4) My Talk Address Latch

Inputs		
MA	MY ADDRESS	FROM MY ADDRESS DECODER
D7 D6	DATA 7 6	BUS GENERATED (10)
DVAL	DATA VALID	FROM ACCEPTOR HANDSHAKE TIMING
BYC	BYTE CLOCK	FROM SOURCE HANDSHAKE TIMING
HVIT	HAVE IT	FROM SOURCE HANDSHAKE TIMING
LB	LAST BYTE	FROM OUTPUT DATA SEQUENCER
ABRT	ABORT	FROM RESET CIRCUIT
TON	TALK ONLY MODE	S20-6
ECOL	END OF COLLECT	FROM COUNTER BOARD
Outputs		
RCE	READ CLOCK ENABLE	OUTPUT TO COUNTER BOARD TO ENABLE RCL
MTA	MY TALK ADDRESS	ACTIVE AFTER BUS COMMAND MTA INACTIVE AFTER DTA OR UNT BUS COMMANDS CLEARED ON LB AND HVIT

5) My Address Decoder

Inputs		
D1 D5	DATA 1 5	BUS GENERATED
S20 1	ADDRESS	BUS ADDRESS SELECT SWITCHES
S20 5	SWITCHES	BINARY WEIGHTED 1 to 16 NOTE All switches on (address 31) is not allowed
Outputs		
MA	MY ADDRESS	ACTIVE FOR (D1/ D5) - (S20-1 TO S20 5)

6) Serial Poll Mode Latch

Inputs		
D1 D7/	DATA 1 7	BUS GENERATED
DVAL	DATA VALID	FROM ACCEPTOR HANDSHAKE TIMING
ABRT	ABORT	FROM RESET CIRCUIT
Outputs		
SPM	SERIAL POLL MODE	ACTIVE AFTER SPE COMMAND FROM THE BUS D7 D2 001100 AND D1 01 INACTIVE AFTER SPD COMMAND — D7 D2 001100 AND D1 0

7) Service Request Logic

Inputs		
REM	REMOTE	FROM REMOTE LATCH
SPM	SERIAL POLL MODE	FROM SERIAL POLL MODE LATCH
TE	TALK ENABLE	FROM TALK DELAY GENERATOR
ECOL	END OF COLLECT	FROM COUNTER BOARD FOR ANY STOP COLLECT
Outputs		
SRQ/	SERVICE REQUEST	ACTIVE AFTER EOC UNTIL TE IN REMOTE ONLY
SPR	SERIAL POLL RESPONSE	ACTIVE IF SPM PRIOR TO TE AND SRQ TO GATE SERIAL POLL RESPONSE TO THE BUS

8) Output Data Sequencer and Gating

Inputs		
TE/	TALK ENABLE	FROM TALK DELAY GENERATOR
TKIT/	TAKE IT	FROM SOURCE HANDSHAKE TIMING
SPR/	SERIAL POLL RESPONSE	FROM SERVICE REQUEST LOGIC
SPM/	SERIAL POLL MODE	FROM SERIAL POLL MODE LATCH
BYC/	BYTE CLOCK	FROM SOURCE HANDSHAKE TIMING
RDY	READY	FROM SOURCE HANDSHAKE TIMING
RCYL	RECYCLE	RECYCLE MODE SELECTED S20 7
CR/FF	ASCII CR OR FF	SELECTS EITHER CARRIAGE RETURN OR FORM FEED AS A MESSAGE UNIT DELIMITER S20-8
LSB	LEAST SIGNIFICANT BYTE	ACTIVE DURING AN LSB FROM THE COUNTER BOARD
A + B/	CTR A and Bnot	ACTIVE HIGH WHEN THE FIRST COUNTER IS BEING SENT AND LOW FOR OTHER COUNTERS CHANGES ON THE FALLING EDGE OF LSB
BCD1	BINARY	FROM THE COUNTER BOARD
BCD2	CODED	DURING DATA OUTPUT CONTAIN THE
BCD4	DIGITS	COUNT DATA SYNCHRONIZED TO BYC
BCD8		SENT MOST SIGNIFICANT DIGIT FIRST
Outputs		
S3	STATE 3	ACTIVE FOR ALL STATES EXCEPT SPM S4 OR S5 GATES BCD DATA WITH ASCII HEADER (3X HEX) IF RDY AND TE TO THE BUS
S4	STATE 4	ACTIVE AFTER LSB TO GATE MESSAGE UNIT DELIMITER TO THE BUS (SEPARATES COUNTER OUTPUTS)
S5/	STATE 5	ACTIVE AFTER S4 OF LAST COUNTER OUTPUT GATES ASCII LINE FEED AND EOI TO THE BUS (END MESSAGE)
LB	LAST BYTE	ACTIVE AT THE END OF OUTPUT TO TERMINATE TALK MODE
EOI	END OR IDENTIFY	DRIVES BUS COMMAND LINE EOI (END MESSAGE)
STS/	RESTARTS	PULSE SENT TO THE COUNTER BOARD DURING STATE 5 IF RECYCLE IS SELECTED

9) Device Clear

Inputs		
DVAL	DATA VALID	FROM ACCEPTOR HANDSHAKE TIMING
REM	REMOTE	FROM REMOTE LATCH
D1 D7	DATA 1 7	BUS GENERATED
Outputs		
DCL	DEVICE CLEAR	WHEN ENABLED SENDS A STOP PULSE TO THE COUNTER ON A DCL COMMAND FROM THE BUS D7 D1 (0010100)

10) Remote Latch

Inputs		
CK	CLOCK	FROM INTERNAL CLOCK
RSET	RESET	FROM RESET CIRCUIT
MA	MY ADDRESS	FROM MY ADDRESS DECODER
DVAL	DATA VALID	FROM ACCEPTOR HANDSHAKE TIMING
D6/ D7	DATA 6- 7	BUS GENERATED D7 D6 (10 OR 01)
Outputs		
REM	REMOTE	ACTIVE AFTER HAVING RECEIVED MY LISTEN OR MY TALK ADDRESS FROM THE BUS INACTIVE AFTER RSET

11) Reset Circuit

Inputs		
	POWER ON	ACTIVE AT POWER ON
IFC/	INTERFACE CLEAR	BUS GENERATED
TON	TALK ONLY	FROM S20-6
REN/	REMOTE ENABLE	BUS GENERATED
Outputs		
ABRT	ABORT	ACTIVE AT POWER ON OR DURING IFC CLEARS MY TALK ADDRESS AND SERIAL POLL MODE LATCHES
RSET/	RESET	ACTIVE AT POWER ON OR DURING REN RESETS ALL HANDSHAKE CIRCUITS AND THE REMOTE LATCH IF TON SELECTED MONITORS REN TO PREVENT BUS CONFLICT WITH AN ACTIVE CONTROLLER

12) Internal Clock

THE CLOCK CIRCUIT GENERATES THE TIMING FOR PROPER OPERATION OF INTERNAL AND EXTERNAL CIRCUIT REQUIREMENTS
Positive Interval — GREATER THAN 3 μsec
Negative Interval — GREATER THAN 1 μsec

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4. If everything was correct, disconnect all devices and try it with a single one.

5. If you don't have success, try another cable, another unit.

6. If after all these tests your controller still does not work, open it and check if the board is installed properly.

7. Measure the supply voltage of the board.

8. Take an oscilloscope and check the signals (TTL-level).

9. If no signals after the GPIB-transceivers appear, check if signals appear before the transceivers - if not, your controller is faulty.

For further diagnostic tips, see Table 10.4.

TABLE 10.4: List of problems typical for a GPIB interface

Symptom	Cause/Remedy
Device receives wrong commands, transmits wrong results or status information, cannot be addressed.	One or more datalines, NRFD, NDAC interrupted or tied too low (bad bus transceiver)
Controller doesn't receive Service Request	SRQ interrupted
Continuously receives Service Request	SRQ tied too low
Device cannot be programmed	ATN interrupted
Device cannot receive commands	ATN tied too low
No remote control	REN interrupted
No parallel poll possible	EOI interrupted
Cancels receiving after first received data block	EOI tied too low
Bus blocked	DAV interrupted

10.6 I/O PORTS

Most microcomputers incorporate some form of parallel input/output (PIO) facility. While an increasing number of microprocessors provide this as a built-in facility, parallel I/O invariably takes the form of one, or more, LSI devices known as a peripheral interface adaptor (PIA). Such devices generally provide separate 8-bit ports, in which 8-bit lines can be configured, under software control, as input or output.

The interface from the PIA to the CPU usually consists of eight data lines, two or more address lines, and different control lines like Chip Select ($\overline{CS}$), Read ($\overline{RD}$), and Write ($\overline{WR}$). The data lines are, of course, bidirectional whereas the address and control lines are unidirectional and form a subset of the system. The PIA thus appears as a number of specific memory or I/O addresses which may be selected by appropriate software instructions. The PIA also utilizes the CPU control bus when, for example, a $\overline{RD}$ and $\overline{WR}$ signal is used to determine the direction of the data flow from/to the PIA. In addition, bidirectional buffers are used to interface the peripheral lines to the PIA. These buffers are generally TTL-compatible and provide limited current drive capability, typically in the order of 1mA.

As a typical example for a PIA we will take the 8255, which is also called programmable peripheral interface (PPI), see Fig. 10.10.

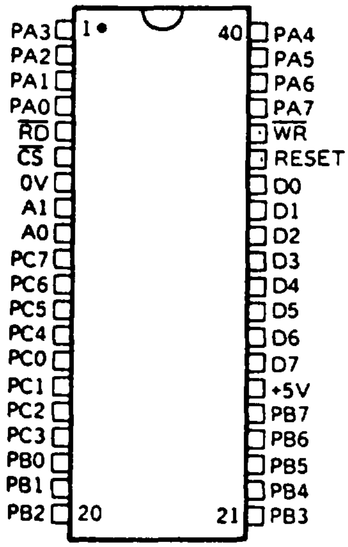


Fig. 10.10: Pin-out of 8255 programmable peripheral interface

As an example of the use of PIA devices, we will consider the operation of a keyboard decoding arrangement, see Fig. 10.11. On most computers, the keyboard consists of a matrix of 60 or more switches, with the possible addition of further switches reserved for specific functions. The key matrix is arranged in eight columns and sixteen rows. Ports A and B are configured as inputs while port C is configured as an output. Note that only half of port C is utilized and that the four output lines are taken to a four-to-sixteen line decoder. This device effectively scans the keyboard rows, addressing each in turn as the binary count on port C is cycled through its sixteen states under software control. This process is repeated every 10ms and an appropriate interrupt is generated when a key is pressed. This interrupt is done by a return signal appearing on a column line. Note that special function keys, such as "SHIFT" and "CONTROL" do not form part of the matrix. These higher priority keys are treated separately as direct inputs to port A.

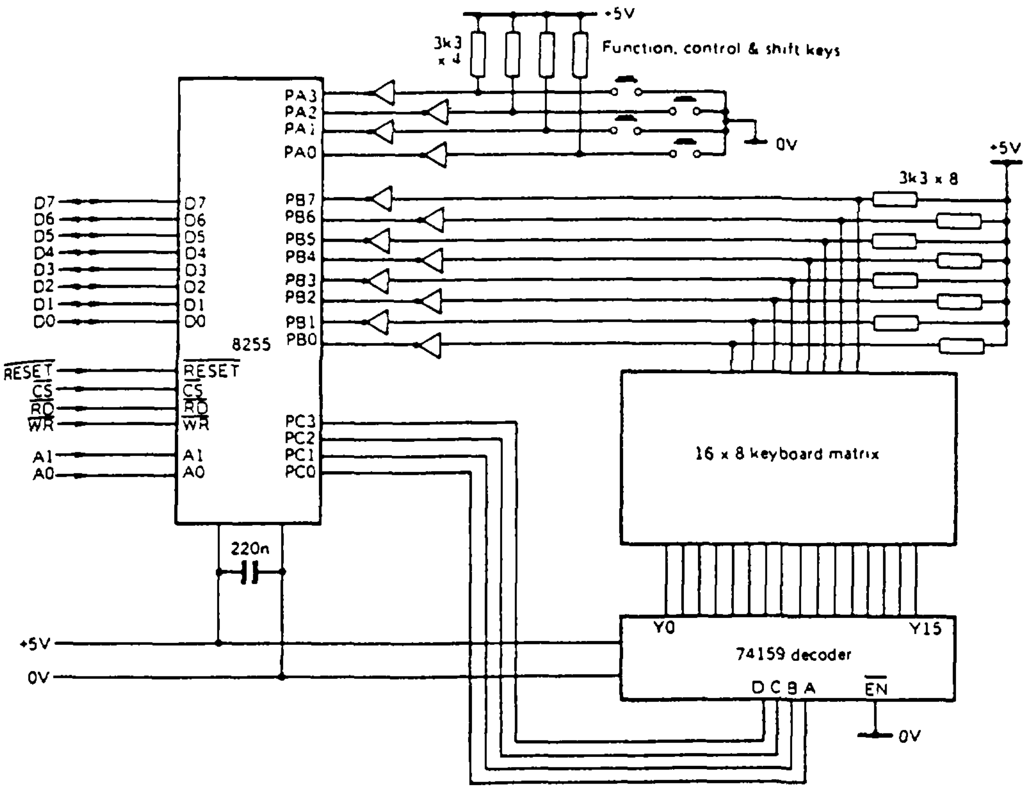


Fig. 10.11: Keyboard coding arrangement using a 8255 PPI

Now let us assume that there is something wrong with your keyboard interface; how do you start troubleshooting. First, try to find out if only one of a group of keys is not working or if the whole keyboard is not working. This may be seen by pressing related keys in the keyboard. If your whole keyboard is not working, check the supply voltage.

Take an oscilloscope and have a look if scan pulses appear on PC0 to PC3. If they do, look at the decoder output to see if this is working. Pulses should appear on lines 0 to 15. Next check if the pulses are connected through to the inverters and PB0 to PB7 by pressing the related keys. Check the special function keys at PA0 to PA3.

If you find that up to now everything works correctly, you can assume that your controller is defective. But before changing it, make some more tests on the bus side of the controller.

If you find that on the peripheral device the keyboard works properly and that writing to the PIA is correct, then there may be something wrong with the read control line. If $\overline{RD}$ appears as well, we may think in two alternatives: first the PIA is bad, second it was wrongly initialized so that the ports are not set properly. Maybe your software is causing the trouble. So write a small test programme which initializes the PIA and so that you can test each PIA line separately.

10.7 STEPPER-MOTOR DRIVE

Frequently, an interface application will require that the PC controls the motion of an object. A device that is often used to power or move a shaft in precise increments, directions and speeds is a stepper motor. Here we consider two approaches to this problem. The first uses the stepper motor, a device whose angle of rotation is known reliably from the pulses which have been sent to it. Once calibrated and initialized, no feedback of the rotor's position is necessary, unless the speed demanded is too high or the torque required is too great. Running a motor this way without feedback is called OPEN LOOP. The second method uses feedback, is a CLOSED LOOP approach, and is called a servo system. The servo system can respond more quickly and accurately than the open-loop stepper motor system and is relatively insensitive to hardware variations. However, it requires position sensors as well as more complicated drive electronics to ensure stability.

Next we have to distinguish between two different ways of driving the motor. The first method is to implement the stepping sequence by hardware. We have only to send output strobes, and a signal for direction pulses for the coils of the motor are generated by the hardware. The hardware implementation has the advantage of relieving the CPU from dedicated timing loops; also it is safe even if the CPU crashes. The CPU only has to know when to send the next pulse. This is mostly done on an interrupt driven basis.

The second method to drive stepper motors is completely handled from the CPU by I/O Ports (PIA) and current drivers. The CPU has to provide, via software, the correct phases for appropriate lengths of time.

A typical example for the second method using an OPEN LOOP system is shown in Fig. 10.12.

Troubleshooting in such a system is very simple. You can only check if power is applied to the drivers and if pulses are coming out of the PIA and passed through the drivers. If there are no output pulses provided by the PIA, refer to Section 10.6.

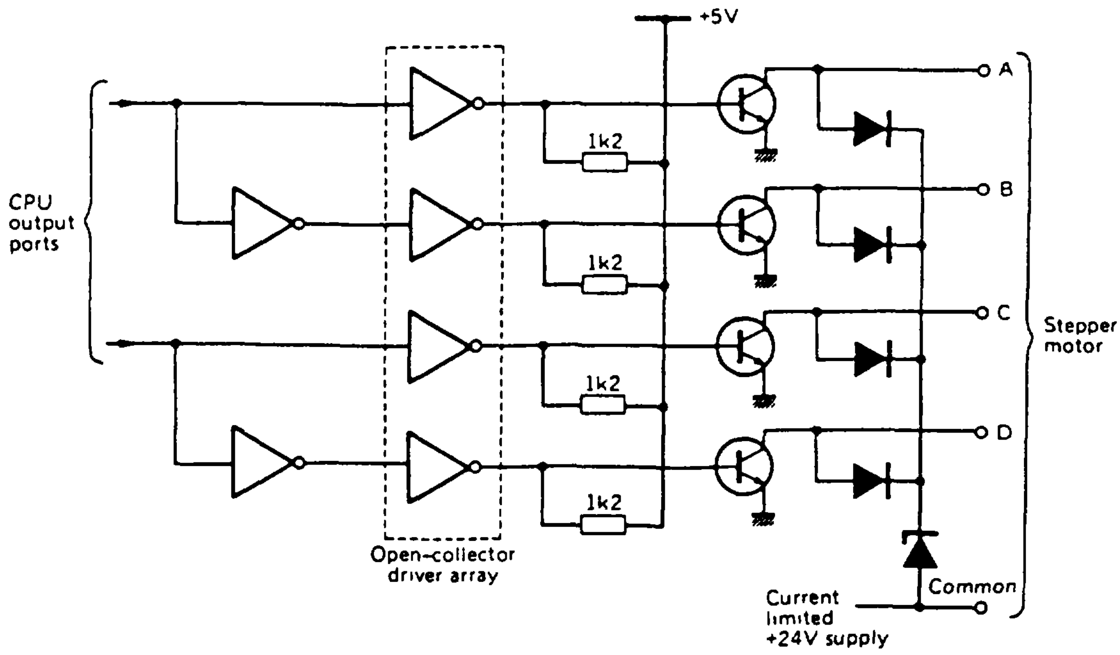


Fig. 10.12: Open loop transistor driving circuit for 4-phase stepper motor

In the other case, a CLOSED LOOP system, things become more complicated. A simple CLOSED LOOP system is represented in Fig. 10.13.

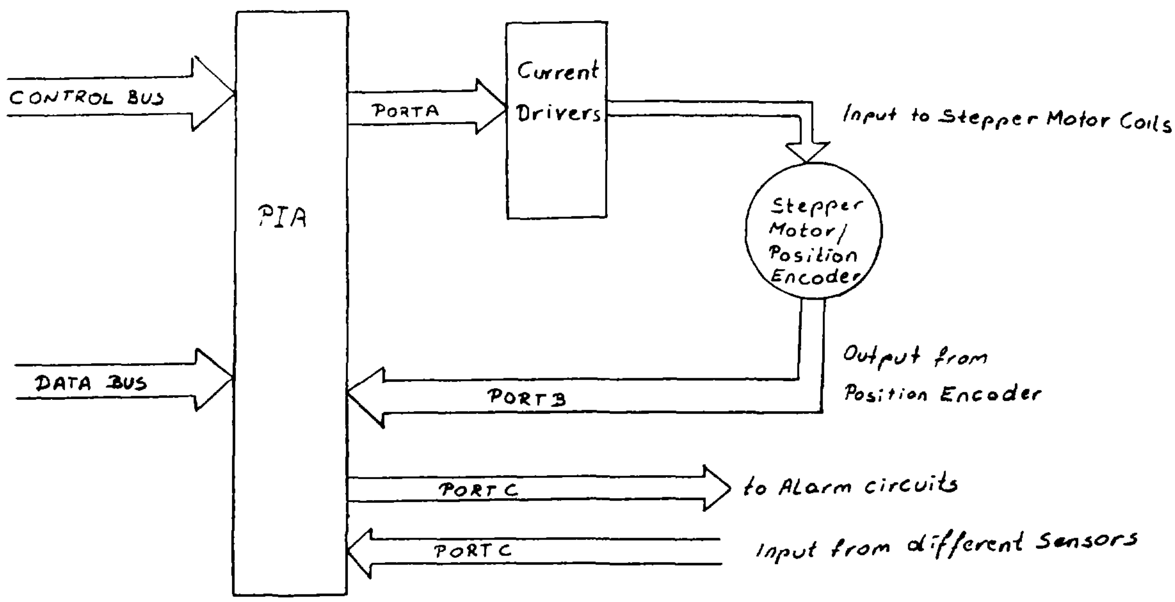


Fig. 10.13: Closed loop stepper motor driver with position encoder

There are two possible faults. The first is the driving circuit, as described before. The second is the position encoder which indicates the momentary position of your driven system. It strongly depends on the encoder which kinds of signal are fed back to your controlling device.

If you find out during troubleshooting that the driving circuit works correctly but the position is incorrect, you have to check the feedback loop. Depending on the position of the encoder in use, check if the output signals are correct.

10.8 CONCLUSION

Dealing with interfaces, especially if they don't work, can be a tough job. Nevertheless, you have to do it; a few additional tips for troubleshooting are listed below.

1. Never start your job before you have read the operating manuals; a lot of problems result from a wrong setup and operation.

2. Before you start troubleshooting on boards, study the circuit diagrams; if they confuse you, try to draw functional block diagrams for it makes your job easier.

3. Write down everything you are doing; maybe the next day you won't remember what you did.

4. Follow the signals from the destination to the source.

5. Make timing diagrams to learn how signals are related together.

6. If possible try to implement your own simple test software to perform step-by-step testing. It makes everything more transparent.

Chapter 11
DEDICATED INSTRUMENTS

11 DEDICATED INSTRUMENTS

Previous chapters are devoted to the instruments that are used in nuclear research laboratories: NIM modules and MCA. Two examples of the instruments used in other applications are described below.

11.1 SURVEY METER

11.1.1 Fields of Application

Ionizing radiation dose-rate meters, or simply survey meters, are the most important measuring instruments in radiation safety. We have no sensory organ to guide us on the intensity of ionizing radiations present in our environment due to natural or artificial sources. Without proper measuring systems one might be exposed to health deteriorating radiation levels.

Survey meters are used in radioactive-ore prospecting as well. If the instrument is not functioning according to specification, the ore may not be located, and the natural resource would remain hidden.

It is important to realize that if the survey meter is not functioning properly, we might be harmed by radiation or loose ore fields. The problem is that sometimes the fault develops very slowly, without dramatic signs. The repair staff and the user should know how to check the performance of the survey meter to overcome the hazards to health and property.

11.1.2 Controls, Turning On and Quick Functional Checks

On most survey meters a single multi-function rotary switch is used to:

- turn on and turn off the instrument, battery checking is the first position after the switched-off state;

- control the measuring range selection.

Some designs have ZERO-SETTING and CALIBRATION controls as well.

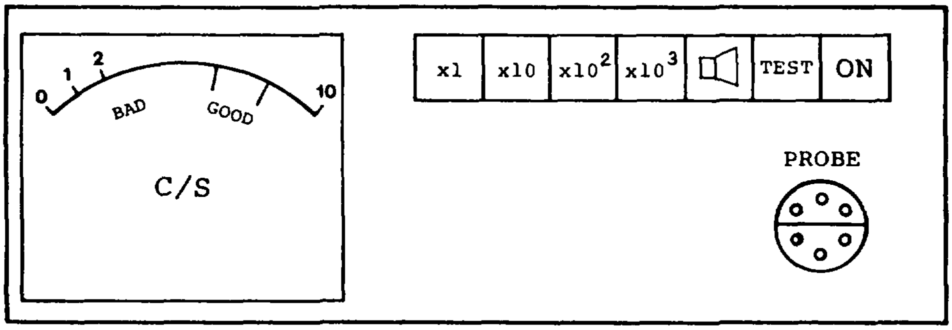


Fig. 11.1: Front panel of a typical radiation monitor

In ore prospecting, the use of energy-selective measuring channels is rather common. The front panel of a typical survey meter with a scintillation detector is shown in Fig. 11.2.

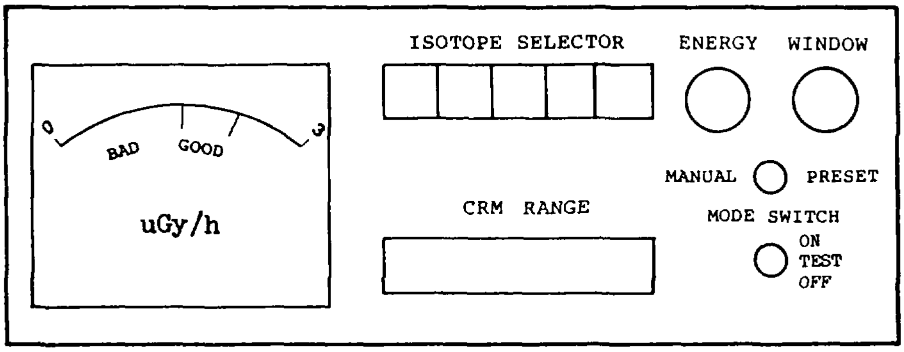


Fig. 11.2: Front panel of a typical survey-meter

Controls for the energy and the intensity range setting are common with the single channel analyzers. The radiation intensity can be read from either a moving-coil meter or a digital display.

The first step of the quick functional test is the same for both design variants: the instrument should be turned into the battery checking position. The indication should be: BATTERY OK, or similar. If this is not so, one should use the STOCK FAULT LIST given in section 11.5.

If the BATTERY OK condition was indicated, the second step can be started by following the calibration instructions of the manual: adjusting the controls to the appropriate ranges after the instrument was zeroed. Then the calibrating radioactive source of the unit should be put before the detector at a given distance. The readings should match with those given in the calibration certificate of the unit. If this is not so, one should use the STOCK FAULT LIST in section 11.5.

What should you do if you have no calibration instructions or data on expected readings?

1. If the instrument arrived without any such data and instructions, you should inform the supplier and ask for replacement under the warranty.

2. If the instrument has already been with you for a long time, you must set up your own testing facility. For this you need a small activity, Cs-137 or Sr-90 radioactive source. You must have information on the present activity or the source, which should preferably be between 15-150kBq, or according to the Radiation Safety Regulations of your area. If you know the activity of the source and its distance to the detector, the dose-rate can be calculated with acceptable accuracy for such types of quick tests.

3. The dose-rate readings should match the calculated values with less than +/- 50% difference.

4. This checking, however, is a very rough functional one, indicating only that the instrument is operating, so could not substitute the calibration of the instrument in your National Metrological Institute or equivalent.

5. If your instrument was recently calibrated in the National Metrological Institute, it is a good practice to take readings in standardized geometry with your own reference source, and to use this data in future quick functional tests. If you can cover more intensity ranges, the better. Your "work investment" will pay off in reduced troubleshooting time.

11.1.3 Operating Principles of Systems with Various Detectors

All survey meters have an ionizing radiation detector and circuits to convert the detector-signal-carried information into dose-rate information and a display unit. The survey meters are battery-operated, portable units. With a few exceptions, they contain DC/DC converters for the detector supply, as well as for the low voltage.

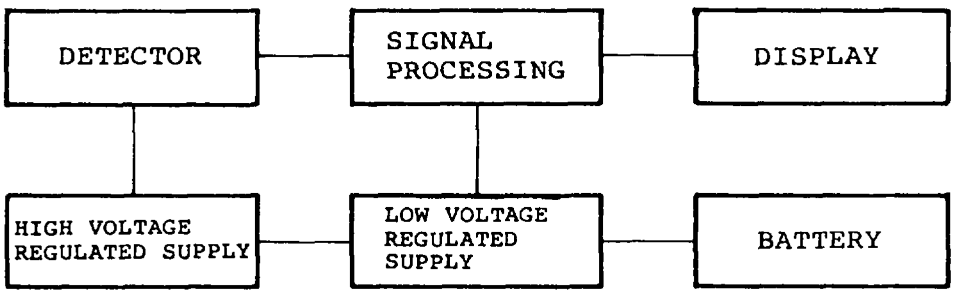


Fig. 11.3: Block diagram of a survey meter

11.1.3.1 Dose-rate meter with ionization chamber detector (Fig. 11.4)

In this system a DC/DC converter supplies a few hundred volts for the ionization chamber. In most cases, the low voltage electrode of the chamber is connected to a differential amplifier with FET inputs. The phase-inverted output of this amplifier is fed back to the common point of the chamber and the input of the amplifier through a very high ohm value, specially designed and manufactured resistor. Such a circuit configuration can convert very little current into voltage. The differential amplifier improves the temperature stability characteristics of the system. By changing the value of the feedback resistor, the current-to-voltage conversion rate changes as well; the smaller the resistor value, the smaller will be the voltage output of the amplifier for the same current. Sometimes the output of the amplifier drives the moving-coil meter directly; in some other designs an additional bridge circuit serves the same purpose. Linear and logarithmic scale versions are available to display the dose-rate. The ZERO-SETTING control potentiometer acts on the non-inverting input of the differential amplifier. In some designs a low pass filter smooths the movement of the moving coil meter, and other circuits protect it from overloading.

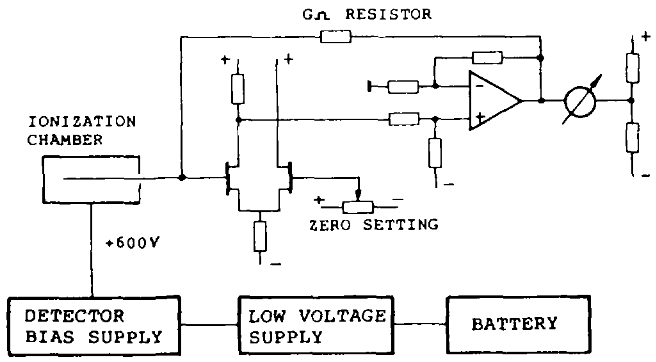


Fig. 11.4: Diagram of a survey meter with ionization chamber

11.1.3.2 <u>Survey meter with Geiger-Mueller tube (Fig. 11.5)</u>

A DC/DC converter supplies the Geiger-Mueller tube with its operating voltage. On the load resistor of the tube, voltage pulses are developed for each ionizing interaction if the appropriate "dead-time" has elapsed since the previous detection. The pulses need to be standardized in amplitude and length, and monostable circuits are used for this purpose. In some designs, the pulse length determining components (R or C) are modified on different dose-rate ranges, so the signals after integration can directly drive the moving-coil meter resulting in a linear dose-rate scale. In some systems after the integrating amplifier, a logarithmic amplifier is employed to give a three - four decade display span. In order to improve the shock resistance of the system in new designs, they often use digital counters with timers instead of the moving-coil meter.

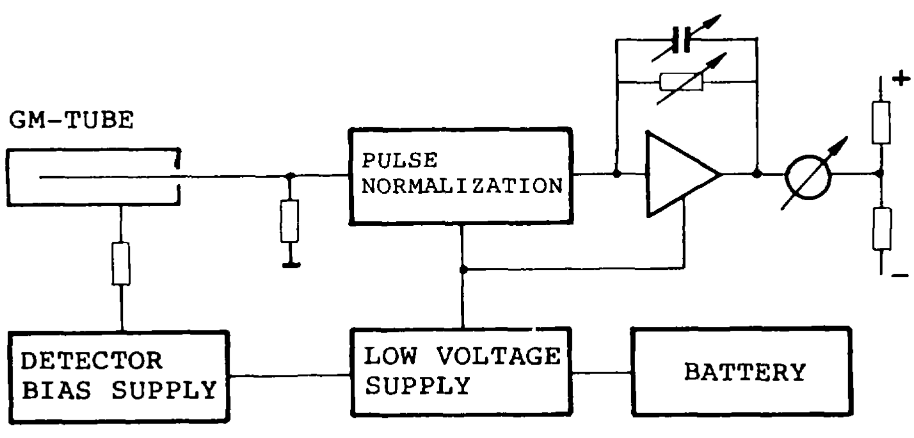


Fig. 11.5: Main components of a G.-M. counter

11.1.3.3 Survey meter with scintillation detectors

A DC/DC converter supplies the photomultiplier with the necessary voltage. The current output of the photomultiplier is a function of the interacting particle energy. In very wide energy range, the current pulses ar e integrated and converted to voltage signals to drive the moving-coil meters. Such systems are often combined with logarithmic amplifiers to cover many magnitudes in dose-rates.

In ore prospecting, clinical and industrial applications, another popular version consists of a complete single channel analyzer with either a counting rate meter or a scaler/timer, sometimes with a digital ratemeter.

11.1.3.4 Survey meter with semiconductor detectors

A DC/DC converter supplies the detector voltage. The signals, after linear amplification, are passed to various pulse-shaping and modifying circuits. In most versions multi-range counting rate-meters develop the driving signal for the moving-coil type display meter.

In some advanced neutron dose-rate meters, the energy dependent Quality Factor weighing is done with a microprocessor and an analog-to-digital converter system.

11.1.4 Diagnostic Procedures

11.1.4.1 Health safety hazards

In all survey meters DC/DC converters are used to supply the detector voltage. The charge on the filtering capacitors might not be lethal in passing through the person touching it, but unintentional muscle contractions might cause serious damage.

The diodes in high voltage power supplies are of good quality; the reverse currents are rather low, and due to this, even after tens of minutes, enough charge might remain to give a painful "kick". All instruments arriving for repair should be carefully checked for the "bleeder resistors" presence, having the role of automatically discharging the high voltage capacitors.

Survey meters are often used in areas where they might be exposed to radiological contaminations. It is very important to check all units entering the workshop for this, and all repair work should be done only on radiologically safe instruments.

11.1.4.2 High value components safety

It is very important to inform the repair staff on the proper handling and testing of the valuable, hard-to-replace components.

The most often destroyed components during repair of survey meters are the following:

- FETs, due to electrical discharge;
- photomultipliers, due to exposure to daylight when HV is on.

11.1.4.3 Preparation of the survey meter for diagnostic procedures

The instrument should be checked for nuclear safety, and then for electrical safety; it should enter the repair workshop only if both conditions were properly tested and documented. One can save quite a lot of problems in the case of a lethal accident if it can be proved that such precautions were taken.

The instrument should be properly cleaned before the repair work starts because if dirt can move from one place to another during the repair of an ionization chamber system, such instabilities might develop which are rather hard to trace later.

Under tropical conditions, it is a good general practice to "dry out" the units before starting the repairs. This can be done very efficiently by attaching a de-humidifier to a box, wardrobe, etc. with closely fitting doors. After 48 hours, most of the humidity would be removed from the instruments.

If you have to open the instrument, you are kindly requested to make note of the following suggestions:

1. Remove batteries from the instrument before starting.
2. Try to locate the minimum number of screws, etc. necessary to gain access to the inside of the instrument.
3. Mark the screw, etc. locations with a washable marker pen in sequence as you remove them.
4. Put all removed screws in a box or tray in the same sequence as the marked areas. Never leave screws just on the table.
5. If you have to remove many screws and there is no space to do proper markings, make sketches.

It is a justified question, "Why should one put so much energy into such a simple, routine activity?". It could happen that you will be able to continue this very repair only months from now; it could be that you will remember all screw positions, their lengths in different locations, etc., but what happens if you don't? It could happen that somebody else might finish the job because you were promoted or something. You will find it worthwhile in the long run to follow the given suggestions.

11.1.4.4 Recommended test instruments

It is a statistically proven fact that 35% of the faults in survey meters could be located with visual inspection, smelling and touching. Please try to rely on your senses before you start using sophisticated instruments.

The first item needed in survey meter repairs is the radioactive test source. This should be matched to the nature of the survey meter. For example, if you have to repair a neutron dose-rate meter, you must have access to a neutron source during some phase of your work, but please remember that all nuclear detector signals can also be simulated by electrical or electronic means.

It is important that users of radioactive sources should be trained on proper handling and storage of these. The simple rules are the following:

1. If the source is not in use, it should be in its container. Try to reduce exposure to yourself and to others.

2. Never touch the source with your hands. This even applies for the less than 37 kBq activity source.

3. If you use a radioactive source, do not allow smoking or eating in that room.

4. You should strictly follow local Radiation Safety rules; wear the film badge or other personal dose-meter, etc.

The next instrument that you will need is a multimeter, preferably with a minimum 20 kohm/volt input resistance with proper connecting cables.

If you have an adjustable low voltage power supply, it could be advantageous to use this instead of batteries, but this is not essential.

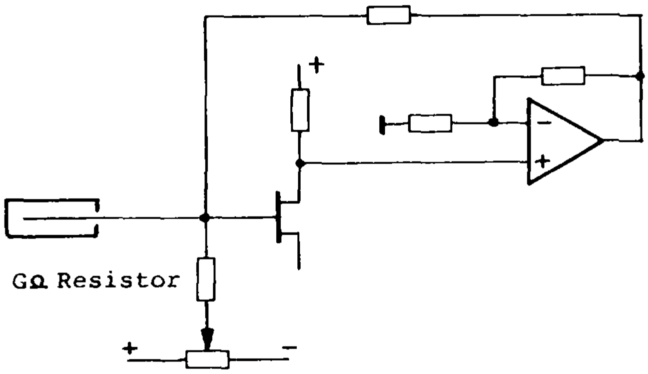
It is a good practice to measure the current uptake, so you should have an ammeter, preferably a fused one.

To check the operation of the DC/DC converters or the pulses from the Geiger-Mueller tubes, scintillation detectors, an oscilloscope will be necessary with a minimum 3 MHz bandwidth and 50 mV/division sensitivity. A standard probe with a minimum 1 MOhm input resistance is enough for most of the tests; however, 1:10 range extender might ease the work.

With the exception of the ionization chamber system, electrical pulses carry the information. You can simulate these with pulses from a generator, having the means to adjust the rate, width and amplitude. So you must have a pulse generator with maximum +/- 10 volts of adjustable amplitude, from 5 microsec to 10 msec width, and a repetition rate of between 10 Hz and 10 kHz.

For the calibration of the counting-rate meters, one should have a scaler with a reasonably accurate time base. The mains frequency in most countries is not suitable for this purpose.

In repair of ionization chamber systems, a 10 kOhm multi-turn potentiometer with micro-dial can be a useful repair aid to simulate the detector, as shown in Fig. 11.6.



MULTI-TURN POTENTIOMETER USED IN TESTING

Fig. 11.6: The technique of electronically simulating a radiation detector

In testing DC/DC converter transformer shorts, the ohm meter could give information only on very crude faults. A more sensitive approach is when the ohm meter is connected into the collector circuit of a transistor (minimum beta - 45) in series with the primary of the transformer under testing. The secondary should be in the base circuit to form a "blocking oscillator", as shown in Fig. 11.7. Note the correct coil connection directions symbolized with the dots.

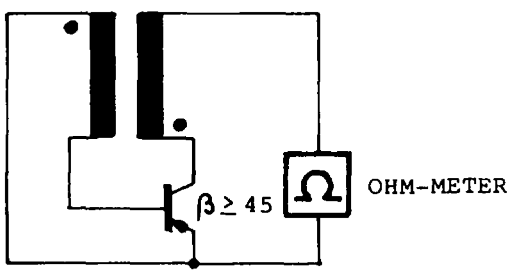


Fig. 11.7: A simple tester for DC/DC converters

11.1.4.5 <u>Identification of the key points, signal simulation</u>

DC voltage measurements, or pulse shape observations in the key points, aid the repair efficiency, the quick diagnosis of the fault.

If the battery of the survey meter is bad, no functions could be expected from it. So the first key test point is the battery output. In most systems there is a possibility to do this checking with the built-in battery tester.

If the DC/DC converter is faulty, the detector will not operate properly. The second key test point is collector of the transistor driving the step-up transformers primary coil.

The third key test point is the DC output of the DC/DC converter. Special care should be taken with this voltage measurement, because the internal resistance of this point is rather high.

The fourth key point should give information on whether the detector is functioning or not. The best point to check for this is the output of the first active component. In the case of the ionization chamber, a DC level change should be present at this point if a radioactive source - 15 to 150 kBq activity - is moved slowly to the detector and away from it. The pulse rate should change as a function of the source to detector distance in other systems.

The fifth key test point should give information on the output signal of the display driver, and the sixth should be the presence of the display itself.

There is a possibility to introduce simulated signals or voltage levels to each key test point with proper care and this way one can test the functions of the circuit after that point.

For example, instead of the batteries, one can give power from a regulated power supply. The same applies for the DC/DC converters case: if there is no detector voltage, from outside one should give the necessary voltage after the original supply was disconnected from the detector. From a pulse generator, detector signals can be simulated to drive further circuit sections.

11.1.4.6 Identification of key points if circuit diagram is not available

It is easy to find the battery connectors, this is the first key point for testing. For the second key point, one should search near the transformer. The third test point could be located by searching for a filter capacitor with a few hundred volts rating. The fourth test point should be near the signal entry; one should search for active components outputs.

One may save much time during future repairs if all identified points are documented, even if only a rough sketch. It is important to save such documents and to make a note in the instruments log-book that such drawing already exists.

11.1.4.7 Expected normal voltages, currents and pulse shapes at key points

On the first test point, the voltage should correspond to the number of cells in the unit. If the batteries are new and their short circuit current is over 1 amper, there should be not more than 10% drop if the instrument is switched on. Higher current uptake is often the sign of non-functioning DC/DC converter.

At the second test point, a periodical signal should be present; the amplitude depends on the type of the converter.

The third test point is the DC output of the converter. In most instruments, voltage muliplier circuits are used. If there is no DC output on the last stage of the multiplier, it is worthwhile to test the other stages, because often only the last diode fails.

Typical DC/DC converter output voltages are the following:

- ionization chambers	200 - 600 volts
- Geiger-Mueller tubes	350 - 1200 volts
- scintillation detectors	600 - 1000 volts
- semiconductor detectors	60 - 400 volts

When the internal resistance of the converters is in the 100 kOhm - 1 MOhm range, the readings on a low internal impedance voltmeter will be correspondingly lower, so care should be taken in their evaluation.

On the fourth test point, a DC level change is expected if the intensity of the radiation changes. In all other systems pulses should be present on this output if the detector and the first stage operates in response to the radiation.

The signals from a Geiger-Mueller tube are many microseconds long, while the scintillator signals are only some microseconds in width. The amplitudes range from a few tens of millivolts to volts.

If the fifth test point is the output of a counting rate meter, a DC level change should be the response when the radioactive source to detector distance is changed. The deflection of the moving-coil meter should change in the same way.

If a digital display is used in the survey meter, the checking should follow the instructions given in the scaler section of this manual.

11.1.4.8 Diagnostic tests in the M.I.P. 10 polyradiametre

The M.I.P. 10 is a portable, battery- or mains-operated survey meter, equipped with various types of nuclear radiation detectors. It can be used as a dose-rate monitor, if calibrated.

(i) Controls and display

The picture of the front panel is shown in Fig. 11.8. A main switch, battery test, loud speaker on-off, and four counting rate-meter range selector push buttons, form the controls of the instrument. The moving coil type display has two scales: one for the battery condition indication and the other for the CRM readout.

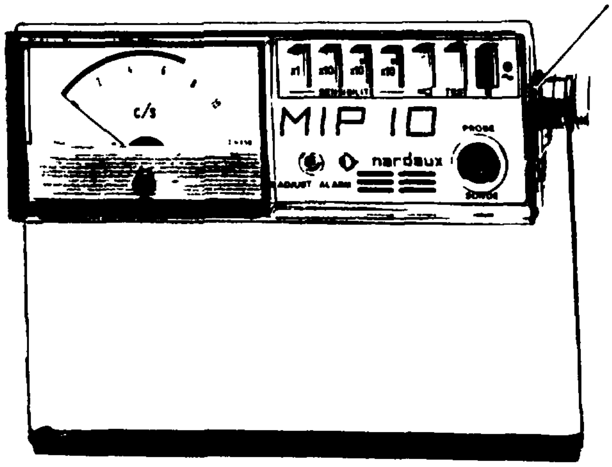


Fig. 11.8: Front panel of a typical survey meter

(ii) Connections

The detector socket is on the front panel; line voltage, recorder and scaler outputs are on the rear side with the mains fuse.

(iii) Battery operation

Eight 1.5 volt batteries can be loaded into the battery compartment. In an optional variant, a rechargeable Ni-Cd supply is available with a drip charging feature. The wiring diagrams of the two variants are shown in Fig. 11.9.

The first key test point is the battery voltage between pin 1 and 11. This can be tested with the built-in TEST push-button. If new batteries were put into the instrument and the TEST gives no indication to the moving-coil meter, the S1e switch has to be tested for continuity. Sometimes corroded battery compartment contacts create problems; they must be cleaned or replaced as needed. By regular bi-monthly battery compartment check-ups, such failures could be eliminated.

In case of the Ni-Cd battery option, one might expect to find an indication on the display if the batteries are already charged. After a long unused period they might be discharged. If the DS1 LED lights up after the mains is connected, it proves that the cord, connector, fuse and the transformer are functioning.

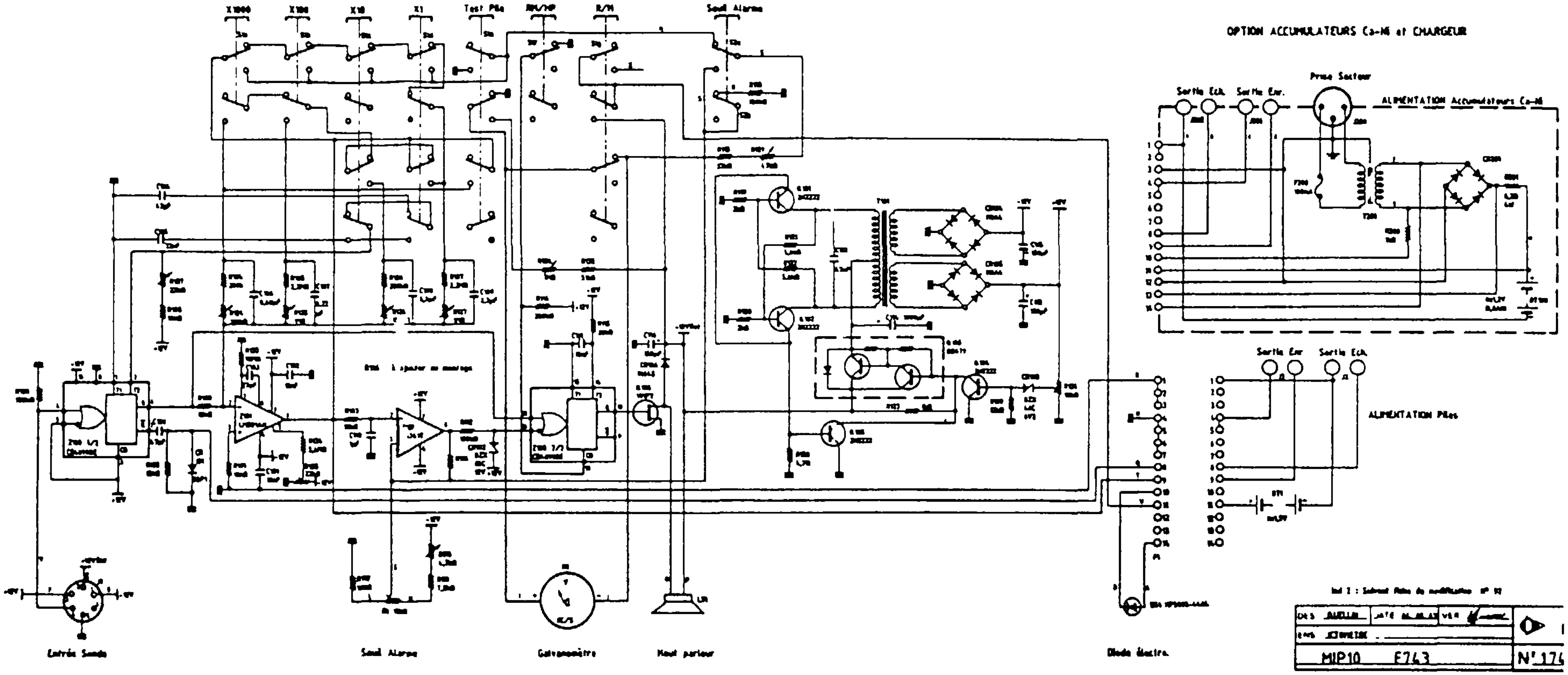


Fig. 11.9: Wiring diagram of a survey meter

If the fuse is blown out, one should suspect first the Ni-Cd batteries for short circuit and the CR201 rectifier. The test should be repeated with the 14-pin socket detached if they prove to be good, because then the short circuit is further away from the battery.

It is good to know that the Ni-Cd accumulators have a limited life, which might be reduced by neglecting the periodical chargings. A Ni-Cd cell still working after four years is of an exceptional, non-standard quality.

(iv) The first DC/DC converter

The voltage from the batteries or from the accumulator changes during use. To overcome this, a regulated power supply feeds the circuits with +/- 12 volts.

A self-starting power oscillator (Q101, Q102) drives the T101 transformer. If the emitter current of these transistors exceeds a certain limit, the Q105 transistor pulls to ground the base of the series control power transistor (Q103). The central tap of the transformer is connected to the emitter of Q103 while its collector is on the positive pole of the battery. The base potential of this emitter-follower is driven by Q104. The base of Q104 is connected to the rectified output signal of the transformer through the R131 potentiometer and the reference diode CR103 to form an adjustable, feedback-controlled, regulated voltage circuit.

If the output voltage is not +/- 12 volts, the fault causing it should be determined and eliminated.

Let us suppose that the symptom is no voltage on the +/- 12 volts rail. First the detector should be detached from the central unit. If the voltage appears, then the problem is in the removed section. If the voltage does not appear, a quick way to locate the fault could be done by separating the central tap of the transformer from the emitter of Q103, and with an ohm-meter check for shorted collector-emitter condition in Q101 and Q102. If there is no short circuit one should apply 4 to 8 volts through a fused ammeter for a short time. If the oscillator starts operation and the current is less than 50 mA, a volt meter should be attached to the collector of Q104. This point should be near to battery voltage if the R131 potentiometer is grounding its base and it should start conducting if the potentiometer is put into the other end position. If no change could be observed, all components should be checked one by one and the bad ones must be replaced.

It might happen that the oscillator will not start because either CR104 or CR105 has a short circuit; this could be checked by disconnecting them from the circuit.

Another reason could be a short circuit in the transformer. This can be checked for with the previously described "blocking oscillator" test.

Q103 can be replaced with two transistors in Darlington connection.

(v) The Geiger-Mueller probe

The circuit diagram is illustrated in Fig. 11.10. The detector voltage is developed in the DC/DC converter on the left. A blocking oscillator composed of Q105 and Q106 generates the detector voltage, which is doubled with the use of CR105 and CR106 and the capacitor C103. The high voltage is filtered by C104 and C105. A fraction of the high-voltage is fed back to the Q101, Q102 composed differential amplifier. There are two non-common circuit elements: the CR101 and the CR103; they are current sources composed of two transistors in Darlington connection. After Q103, emitter follower output of the long-tailed pair is further amplified by Q104.

If there is no detector voltage, first the blocking oscillator should be tested for operation. If the base of Q102 is driven from outside with a variable voltage from a helical potentiometers wiper, the operation of the amplifier stages could be easily checked.

The secondary winding of such transformers is rather vulnerable if it is exposed to humid climate. They often develop short circuits within the secondary. Local repair is possible if proper interlayer insulation could be secured combined with vacuum impregnation.

If R110, the 22 MOhm value feedback resistor, fails to conduct, a dangerous situation might develop. The missing feedback voltage forces the circuit to increase the output, so a higher than normal voltage will soon be established on C105 and the Geiger-Mueller tube will "behave" accordingly.

The reverse leakage current of the CR106 can be 30-100 mA only, so a dangerous charge might remain on the C105 capacitor for a long time after the instrument was switched off; the 0.01 J energy kick can hurt.

Care should be taken to check the presence and good condition of the feedback resistor before starting the repairs.

The Geiger-Mueller tube is in the center; on its right side a pulse shaping circuit can be found. If the Geiger-Mueller tube is triggered, a positive pulse will appear on R204, limited to battery voltage amplitude by CR201 clamping diode. The pulse is differentiated by C201-R204 before it enters Z201, a monostable multivibrator, generating equal amplitude and length pulses. After further amplification in Q202, the signal leaves the sonde through emitter follower Q201.

The connecting cable is rather critical in portable instruments. It should be checked thoroughly for continuity and wear. It is better to replace the worn cable before a fault develops.

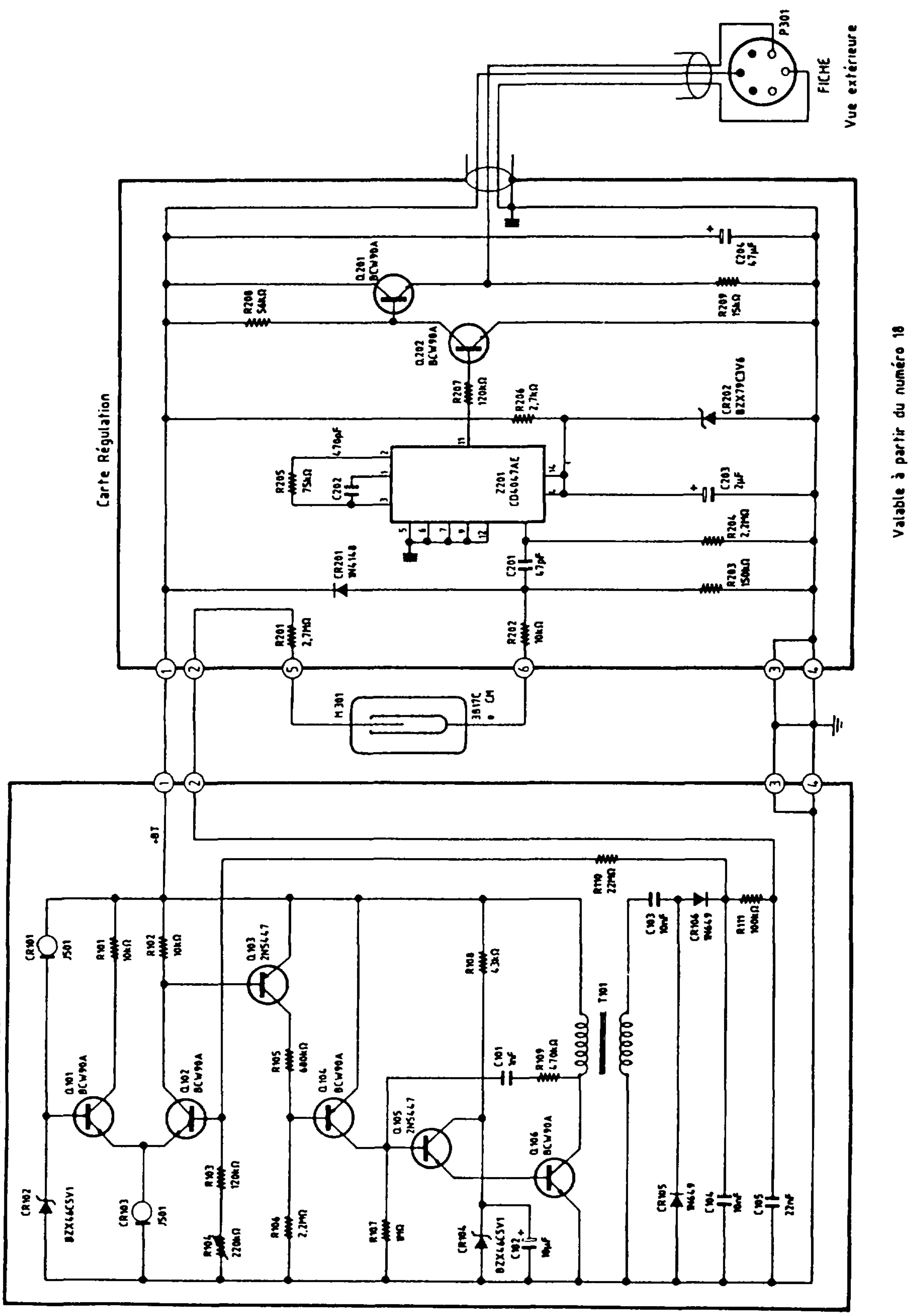


Fig. 11.10: Circuit diagram of a G.-M. probe

The Geiger-Mueller tube signals should never be checked on the tube itself because the capacitive load of the test probe increases the peak current and reduces the expected life span of the tube. A suitable point is on C201. If the tube is not functioning, the sonde can be tested further with a pulse generator from C201.

(vi) The scintillation detector probe

The circuit diagram of this probe is illustrated in Fig. 11.11. The high voltage DC/DC converter is on the upper half of the drawing. An audio frequency oscillator composed of three NOR circuits drives the base of Q102. The step-up transformer T1 is in the collector circuit of Q102, which is fed by the emitter follower Q101.

On the secondary side of the step-up transformer a ten-stage voltage multiplier operates delivering approximately + 1000 volts, if 10 volts are present on the base of the Q101 emitter follower.

The feedback loop is closed through the 100 MOhm value R201 resistor driving the inverting input of the Z201 operational amplifier, which is connected to the base of the Q101 emitter follower.

Dangerously high voltage can develop in the circuit if the 100 MOhm R201 resistor is broken. It is easy to test the circuit by breaking the B - B connecting line and introducing a variable DC voltage to R108. This way the oscillator and the power-stage and the voltage multiplier can be tested separately.

The operational amplifier can be tested if the feedback loop is opened at A - A and a variable DC voltage is injected to the junction of R202 and R206 through a 100 kOhm resistor. If the voltage input is changed, the output should suddenly change in the reverse direction when the operational amplifier is good.

The output signal from the photo-multiplier is fed through junction G to the amplifier section consisting of a buffer IC (Z203), a level discriminator IC (Z202), and the output amplifier composed of Q201 at TP1 on the emitter of Q204.

By the adjustment of the potentiometer R215, the triggering level could be set.

Testing of the scintillation detector is done with a small 15 - 150 kBq activity radioactive source, preferably a Cs-137 one. If the detector operates, a few microseconds long, a few hundred millivolt and positive amplitude signals should be observable on TP1 while the source is a few centimeters from the detector and the detector voltage, etc. is on.

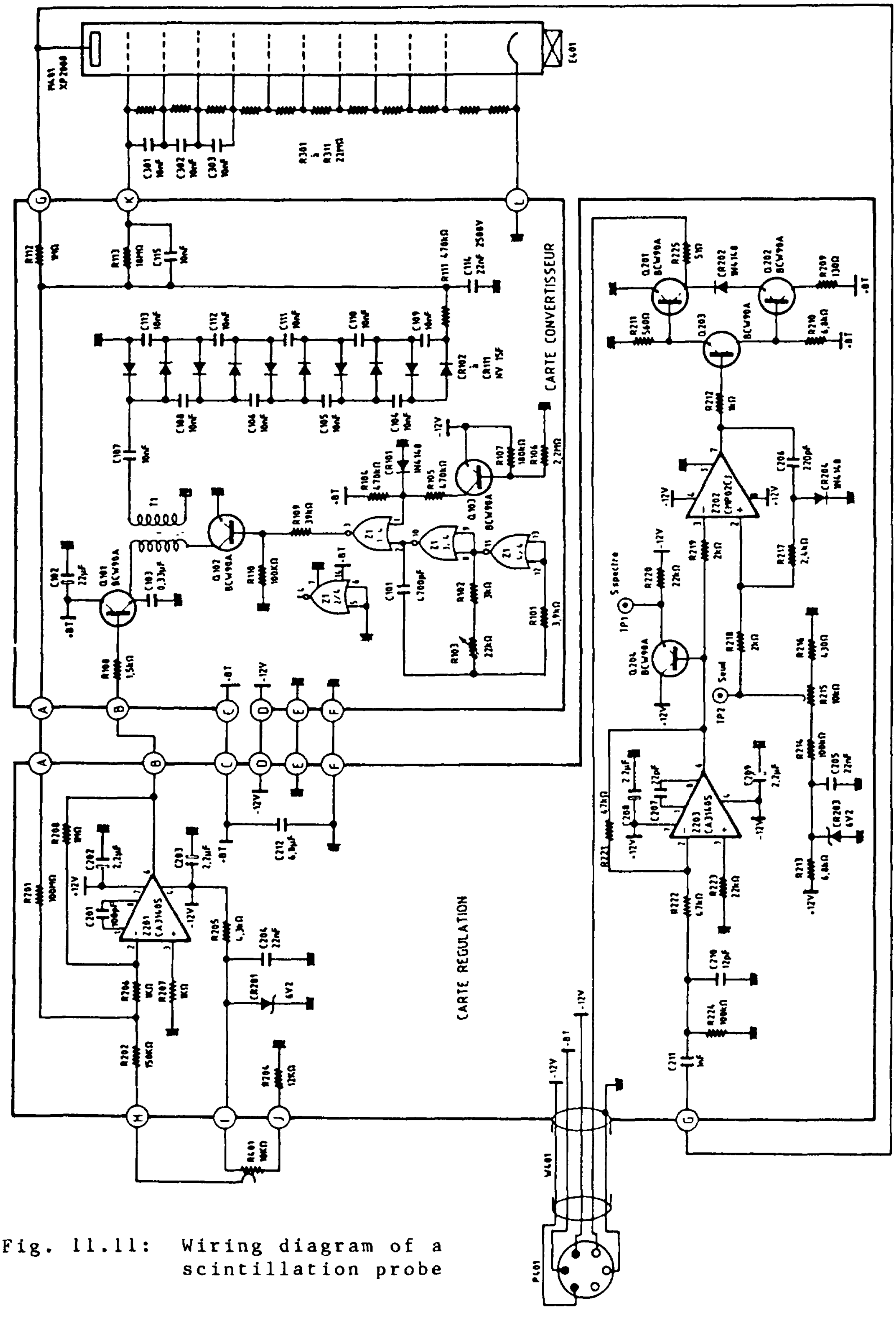


Fig. 11.11: Wiring diagram of a scintillation probe

If there are no output signals, the detector should be disconnected from C211 at G point and a signal from a pulse generator should be injected to test the circuit. If the amplifiers are good, the photo-multipliers dynode resistor chain should be tested for continuity, preferably with the high-voltage "on" and by stepping from dynode to dynode.

In some versions the photo-multiplier is not in a light-tight case after the cover of the probe is removed. Under such conditions the photo-multiplier should be removed from its socket before the resistor chain testing, otherwise the photo-cathode might be seriously damaged. For further instructions please look at the section on Detectors in this manual.

(vii) The ratemeter and the alarm circuit

These parts of the circuit are shown in Fig. 11.12. The signals from the probes are first passed into a Schmidt-trigger (Z100) to remove the effects of the cable. Both the signals from the Geiger-Mueller tube and the scintillation detector are standardized to equal length and amplitude in the probes so the counting-rate meter is a simple integrator (Z101) with varying time constants in the feedback loop in various ranges (R104-C106, R105-C107, R106-C108, R107-C109). The output signal of Z102 drives the moving-coil type display meter (M1) through resistors R113 and R129 serving for full-scale adjustment.

The alarm circuit starts to operate above a level which can be set with the R1 potentiometer. Checking can be done by injecting a variable voltage through a 10 kOhm resistor to the inverting input of Z102; if the operational amplifier output does not change, it must be replaced.

The second half of the Z100 generates the alarm signal frequency and Q106 is the power stage driving the loud-speaker LS1.

11.1.5 Stock Faults in Various Systems and Repairs

Symptom	Cause	Action
New dry batteries Test: no indication	corroded contacts	clean, if needed replace
	faulty switch	clean, if needed replace
	meter or R113 bad	repair or replace
	short circuit	determine location, repair
Test: low voltage	short circuit	determine location, repair
	R129 misadjusted	readjust R129
	corroded contacts	clean, if needed replace

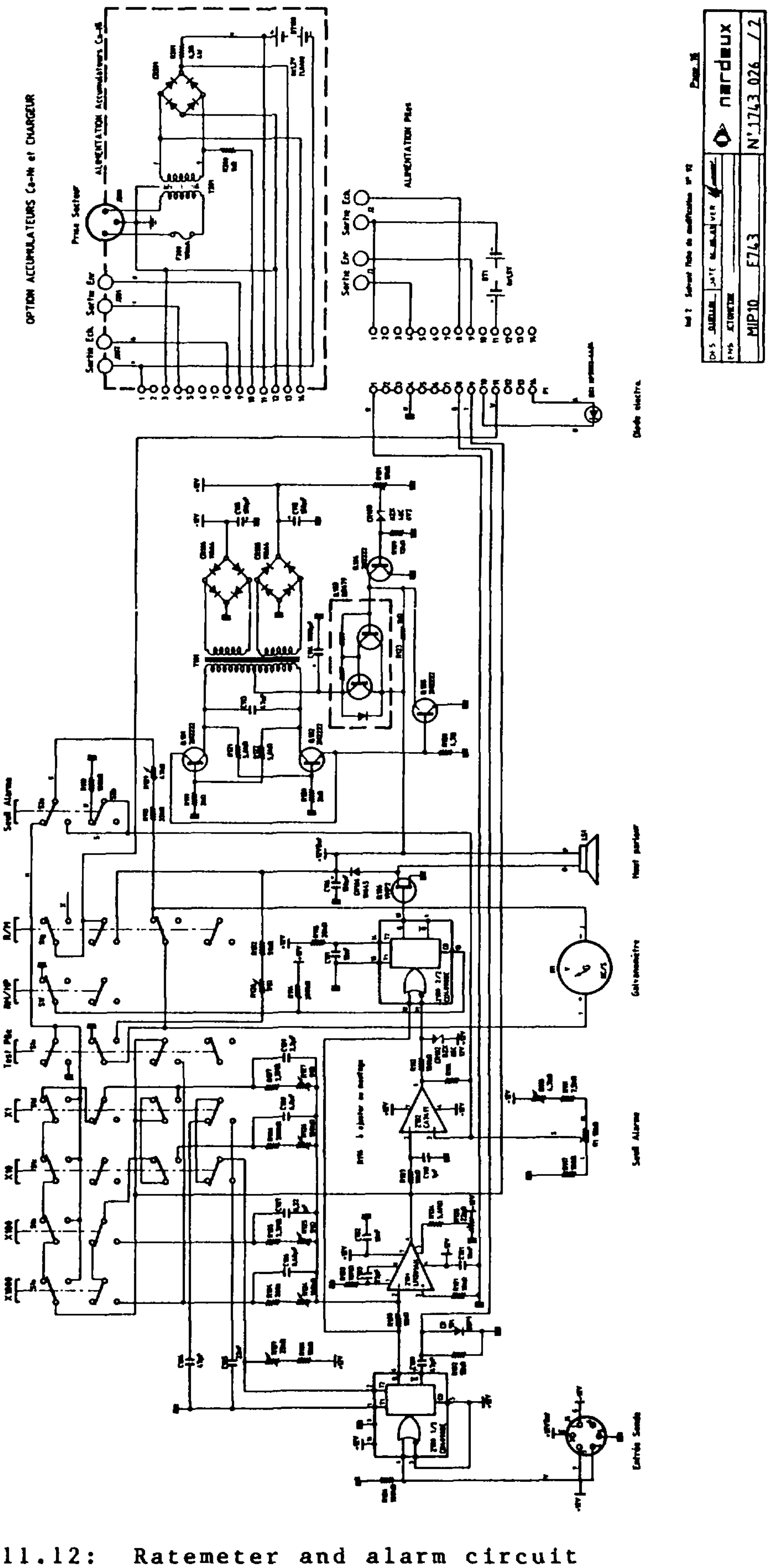


Fig. 11.12: Ratemeter and alarm circuit

Ni-Cd accumulator: low voltage	charger fuse bad	determine why, replace
	cell bad	replace
	rectifier bad	replace
	short circuit	determine location, repair
No +/- 12 volts	oscillator bad	replace bad component
	regulator bad	replace bad component
	Q105 short, C115 bad	replace bad component
	transformer bad	repair
	rectifier bad	replace
More than 12 volts	R131 broken	replace
	CR103 broken	replace
	Q103 short	replace
Less than 12 volts	R131 misadjusted	readjust
	short circuit	determine location, repair
Geiger-Mueller sonde, No 12 volts	broken cable	repair, replace
	bad connector	repair, replace
	short circuit	locate, repair
No detector supply	blocking osc. bad	locate and replace
	short CR105	replace component
	broken C103, CR106 R111	replace component
	short in transformer	repair, replace
	broken coil	repair, replace
	bad regulator	locate, replace
Detector supply high	broken R110	replace
	R104 misadjusted	readjust
No signal with source	bad M301 tube	test, replace
	bad Z201	test, replace

Signal too short	bad C201,C202,R205	replace bad components
	bad cable, connector	replace, repair
Pulse rate higher than reference value with standard source and geometry	radiological contamination	decontaminate
	too high detector voltage	repair DC/DC converter
	faulty tube	replace
	fault in main unit	locate, repair
Pulse rate lower than reference with standard source and geometry	too low detector voltage	repair DC/DC converter
	increased "dead-time" Fault in main unit	replace G.-M. tube locate, repair
Scintillation sonde no low voltage	broken cable	repair, replace
	bad connector, contact	repair
No detector voltage	oscillator bad	locate, repair
	T1 bad	repair or replace
	Q101 or Q102 bad	replace
	Z201 bad	replace
	R401 or CR201 bad	replace
Detector voltage high	broken R201	replace
	bad Z201	replace
Detector voltage low	R401 badly adjusted	readjust
	short in T1	replace or repair
	diode short in voltage multiplier CR102-111	locate, replace
	capacitor short in voltage multiplier	locate, replace

No scintillation detector output signal with standard source in reference position (TP 1)	dynode resistor chain element broken	locate, replace
	photo-multiplier bad	check, replace
	Z203 or Q204 bad	replace
	C211 broken	replace
Pulse rate higher than normal in reference condition	radiological contamination	decontaminate
	noise pick-up from DC/DC converter	locate bad capacitor, (C102, C212, C208, C209) replace
	noisy photomultiplier	replace
	corona discharge on high voltage component	locate, repair
	humidity caused high leakage current	dry system
	increased background in workshop	locate, remove open source if possible
Pulse rate lower than normal in reference condition	high-voltage too low	Readjust or locate cause and repair
	deteriorated scintillator	replace
	R222 broken	
	C301-303 broken	replace
Main unit, counting rate meter not functioning in reference mode	no signal from sonde cable is bad	repair or replace
	connector is bad	repair or replace
	Z100 bad	replace
	Z101, range switches R104-106, R124-127 or C106-109 bad	locate, repair or replace
Counting rate meter calibration bad in single range	bad adjustment or faulty R-C components in integrator loop	locate, replace

Alarm system not functioning	bad Z202	replace
	bad Z100 2/2 or C111, R115	replace
	bad Q106 or loud-speaker	

11.1.6 Quality Control of the Repaired Instrument

The repaired instrument should be tested with the reference source of the workshop in a standardized geometry, that is, the same distance between the detector and source and same relative position. A simple approach is to mark on plywood the outline of the detector and the location of the source with its identification number. During all measurements this set-up should be used. It is very important to record the results and to compare them to previous tests.

It is good practice to record the power uptake of the unit during tests, which helps later on with diagnosis. An increasing current uptake compared to previous measurements could be the sign of an insulation deterioration due to moisture accumulation in the DC/DC converter transformer. In an early stage often a simple drying might save the instrument from a total breakdown.

During the reference measurements all other radioactive test sources should be removed from the standard geometry area to secure a normal radiation background level. It is a good practice to do such measurements a minimum of 1,5 meters above the floor, preferably on a plywood platform hanging from the ceiling in a dedicated area of the workshop.

11.1.6.2 Dose-rate calibration

The dose-rate calibration of the survey meters could be checked if the activity of the test source is known, using the following relationship:

dose-rate/hour [R/h] = K * A [Curie]/R2 [m]

where K, the dose-rate constant of the used test source
A, the activity of the test source in Curies
R, the source detector distance.

Such check-up tests could not substitute the periodical calibration of the survey meter by the National Metrological Institute. The expected accuracy of such check-ups is better than +/- 20%.

11.1.6.3 Marginal testing

It is important to know whether the battery test green and red areas are valid or not. Sometimes the series resistor of the moving coil meter changes its value and batteries might be thought to be good even when they are already bad.

To test the validity of the indication, the survey meter should be connected to a variable power supply and the voltage should be reduced until the measured intensity drops by 10%. Then the supply voltage should be increased with one volt and the series resistor of the moving coil meter should be adjusted to the border of the green and red areas. This test should be done once yearly BEFORE the calibration in the National Metrological Institute.

11.1.6.4 Stability testing

All instruments should be tested for stable operation after repairs, for a minimum of six hours. This test should be carried out with a regulated power supply, delivering the nominal voltage expectable from the dry batteries, for example 8*1,5 volts in the case of the M.I.P. 10 survey meter.

The intensity should be adjusted to give an 80% deflection on the meter. Readings should be taken in every half hour time and a graph should be plotted from the results. If the readings change with more than +/- 20% during the day, the cause should be traced and repaired.

Care should be taken with the scintillation detectors during such measurements; they should not be exposed to direct sunlight or to the cold air stream from an air-conditioner. It is good practice to monitor the temperature on the spot of the measurement.

11.1.7 Preventive Maintenance

11.1.7.1 Recommended periodical check-ups

The batteries and the condition of the battery compartment contacts should be checked monthly. The instrument should be tested under reference conditions a minimum of twice yearly.

11.1.7.2 Preservation technologies

Scintillation detector probes should not be exposed to over 50 degrees Centigrade because the photocathode might deteriorate. Never leave the scintillation detector, for example, in a car with closed windows. The mechanical construction might survive high accelerations, but this should be avoided if possible.

The high voltage DC/DC converters are vulnerable to moisture; try to store the instruments in dry areas when not in use. If silica-gel cartridges are in the instrument, their condition should be checked with a periodicity based on observations.

11.1.7.3 Log keeping

Keep a log-book and introduce all findings and activities (repair, battery replacement, calibration, etc.) into it. Evaluate the entries yearly and try to improve your work by making use of the observations.

11.1.8 Instrument Selection, Parts Replacement

Try to standardize the survey meters, reduce the brands. The fewer types, the easier it is to organize the spare supplies and the repair.

Check the high voltage DC/DC converter transformers; if they are not the hermetically sealed type, order one replacement and for each ten units one more additionally.

If you have good workshop facilities, you might try to make the transformer. If you do not have data on the number of turns, measure the weight of the coils and the diameter of the wire; from these two pieces of information one can estimate the turn ratios. The insulation is about 10% of the available area, and the copper could not be more than 40% there.

If you have to replace a diode in the voltage multiplier and you do not have the same type, it is better to replace all with the same type.

11.2 RECTILINEAR SCANNER

11.2.1 Field of Application

Medical rectilinear scanners are used to map-up the distribution of radioactive tracers that were introduced into the body for diagnostic purposes. The output information from the scanner is the scintigram, a one-by-one image of the investigated organ with colour-coded representation of the local radioisotope concentration. The areas with highest radioactive isotope concentrations are displayed with red iso-intensity areas, in most system 8 - 12 different intensity levels could be visualized by this imaging technology. The pictures are used to evaluate the extent of the organ tissues participating in the normal metabolism and the locations of the already damaged areas. The scintigrams are used in diagnosis, in therapy planning, and in therapy evaluation.

This imaging technology is non-invasive and very important because it can provide information on such soft tissue organs which could not be easily accessed by x-ray or ultra-sound.

11.2.2 Operating Principle

In the medical scanners, one or more nuclear detectors are moved on a meander path above and sometimes under the investigated organ. The nuclear detector or detectors are in special lead shields with apertures in the direction of the isotope distribution providing high directional sensitivity (see Fig. 11.13).

Single-channel pulse-height analyzers are connected to the detectors, with the windows on the photopeak of the radioactive isotope, which was introduced into the body for investigation.

Counting rate meters are driving the display system which moves together with the detector above the scintigram paper. The measured counting rate drives the intensity-to-colour information converter, consisting of a multi-coloured typewriter ribbon positioned by a servo-system under an electromagnet controlled hammer called the "tapper". In multi-detector systems, each detector has a separate display unit.

As the measured intensity changes, various coloured portions of the tape will be put under the tapper by the servo. Since the detector and the tapper move together, if the tapper hits on the ribbon, the colour mark on the scintigram will correspond to the measured intensity.

As the detector moves above the selected area of interest, it collects the radiation intensity data along its path displayed in colour code, with a display determined by the time-constant of the counting rate meter.

The fidelity of the image will be a function of the statistics. If the detected number of pulses per square centimeter are low, the related statistical fluctuation will be high, so a longer time constant is needed to smooth it out. For a good quality image, 600 pulse/square cm must be obtained, therefore the detector speed should be adjusted to meet this requirement. The scanning speed should be fairly stable, easily adjustable within 30 - 500 cm/min range. The detector in the lead shield is over 60 kgs in most designs so a powerful motor system is needed to move it "line-wise" and "step-wise". The "line" direction is perpendicular to the spinal-chord, in some systems they call it the X axis, and the step direction as the Y axis.

Scanning is a series of information gathering processes, which is rather slow. Taking one view often requires over 20 minutes, but less time is needed to complete the scintigram if the scanned area is smaller. The programming of the scanning area is done with the LIMIT SWITCHes on the X and Y axis. After completion of each line detected by the LIMIT SWITCH, a step-wise detector motion takes place and the line scanning direction is reversed.

It is important to know that if the activity administered to the patient is greater, the scanning time is shorter. Another important feature of the technique is that if the patient moves during the imaging, the picture will be blurred and then it should be repeated. If the channel is not on the photo-peak, the image will have poor geometrical resolution with low diagnostic value.

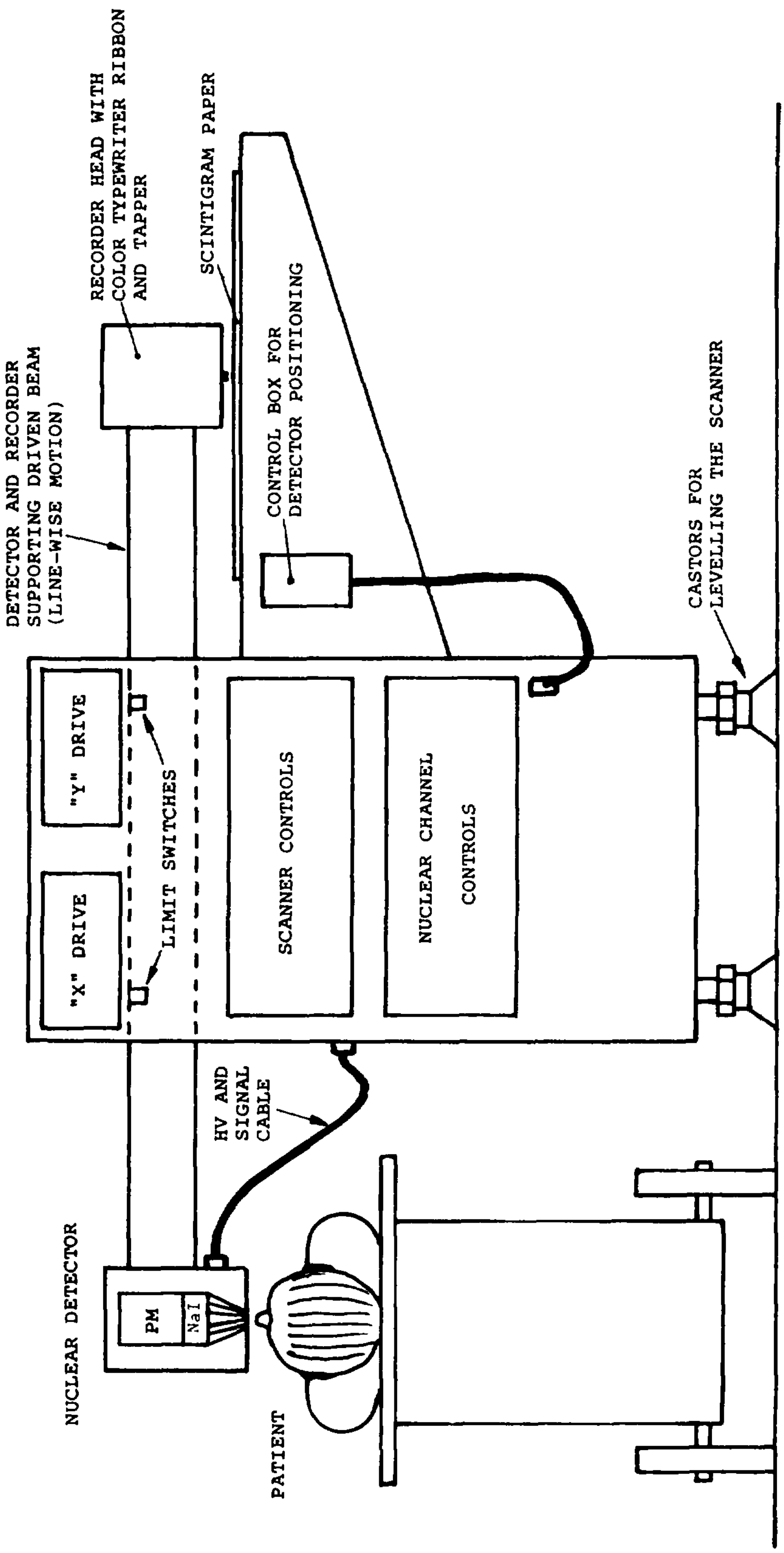


Fig. 11.13: Main mechanical elements of a medical scanner

11.2.3 Controls, Turning-On and Quick Checks

The nuclear channels are controlled by the ISOTOPE SELECTOR (see Fig. 11.14); this switch or push-button adjusts the energy and window settings optimal for the isotope used. If they are not periodically checked for accuracy, poor pictures might result. In most systems, MANUAL ENERGY and WINDOW controls are also available. If the manual and the preset adjustments give different results, it's time for readjustment and calibration.

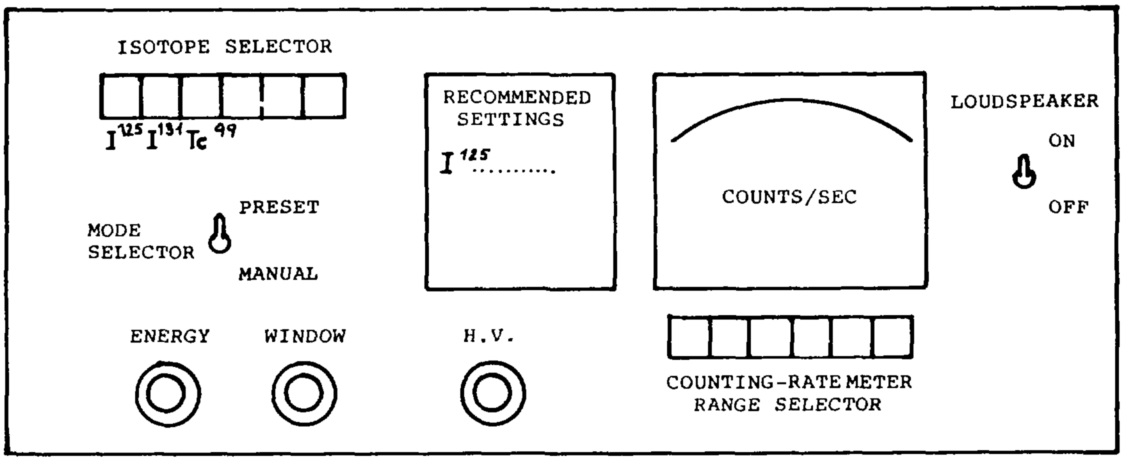


Fig. 11.14: Nuclear channel controls

The counting-rate meter range adjustment is conventional. If a radioactive source is introduced into the field of view of the detector and the corresponding preset or manual energy and window selection was done, the display meter should indicate changing values as the source is moved under the detector.

An example of the front panel of a scanner control is shown in Fig. 11.15.

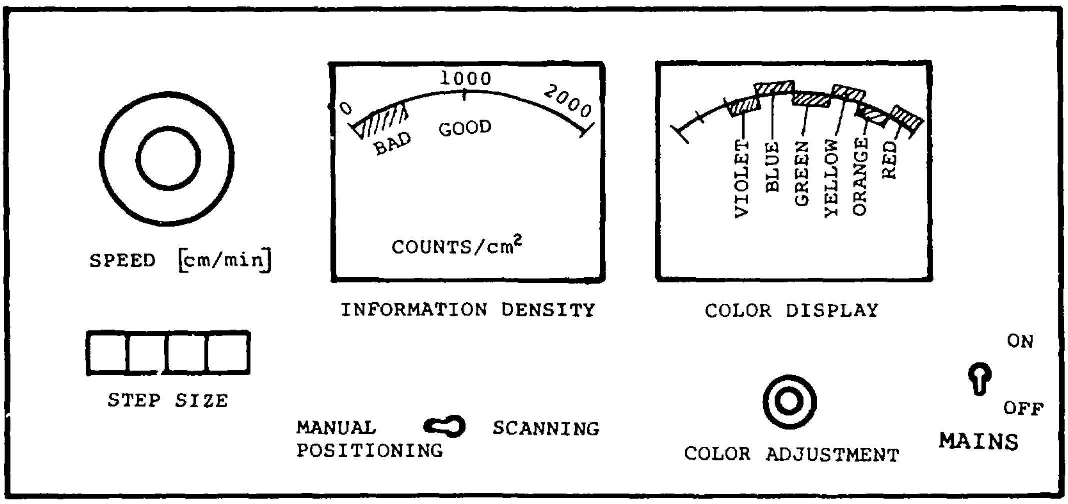


Fig. 11.15: Scanner controls

The activity-to-colour servo should follow the movement of the display meter as the source is moved under the detector.

The next test is concerned with the X-Y movements of the detector. First the LIMIT or LIMIT SWITCHes should be set for a short, few centimeter long line length, with full-size step-wise motion and the scanning should be started with the START switch in the lowest SPEED range. The scanner should start meandering within the preset borders.

The speed should be adjusted for higher and higher speeds up to the maximum. Take care, because if the limit switch is bad, the detector might try to run away, breaking parts of the mechanical system; this is why the border control checking is recommended on the lowest speed range.

If the system is already moving, a small source, a so-called "phantom-organ", should be put under the detector and imaging should be attempted. Here one should follow the recommended setting-up procedure described in the manual. First position the detector above the source and adjust the CALIBRATION control to get the display meter pointer to reach the red colour zone, representing the highest activity zone on the scintigram. The speed should be set to get the recommended 600 counts/square centimeter information density. An image of the source should result from this activity similar to those which were taken previously under reference conditions.

The detector and source distance is critical in imaging; the best resolution could be obtained from the "focal plane" of the multihole diaphragm before the scintillator. The optimal imaging distance is given on the diaphragm.

Each scanner has some means for the detector positioning. This function is used during the setting-up adjustment. By looking on the counting-rate meter or listening to a variable frequency loudspeaker sound, controlled by the radiation intensity, the operator should search for the area with maximum isotope concentration. This manual mode can be used to test the safety switches on the border of the maximum scannable area. If the detector is not stopped there automatically, the drive mechanism can be harmed.

A block schematic of a typical scanner can be found in Fig. 11.16.

11.2.4 Troubleshooting and Stock Faults

11.2.4.1 Power supplies

In most systems separate low-voltage regulated power supplies are used for the nuclear channel and for the detector motors. A DC/DC converter feeds the scintillation detector, which receives power from the nuclear channels voltage regulator. The trouble-shooting procedure is similar to all scintillation detector high-voltage power supplies.

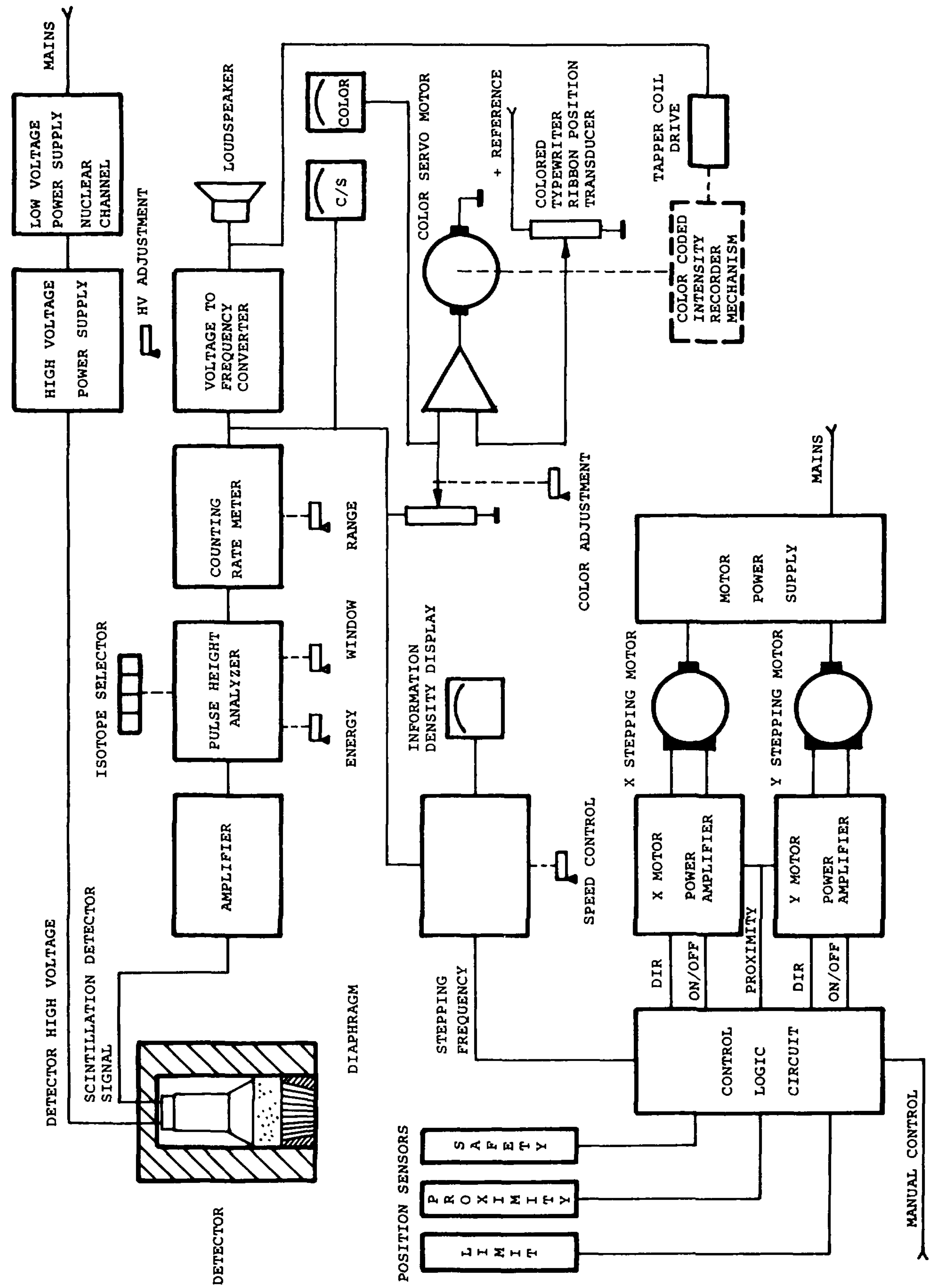


Fig. 11.16: Block schematic of a typical scanner

The regulated voltage supplies of the X-Y motors are rather simple; their rated output is between 150-300 VA. They are designed to deliver ample power to start moving the detector by the stepping motors. The speed regulation is accomplished by changing the frequency of the steps. The rotation direction is changed by altering the phase relations in the control coils of the motors.

The high power semi-conductors might fail more often if the ventillation of the heatsinks are obstructed or high voltage transients are present on the supply lines. This often happens in hospitals where the cables are heavily overloaded and the wire connections are corroded. An AC voltage stabilizer can improve the situation for the scanner.

There is only one simple rule in power diode replacement, the symmetry should be conserved in the rectifier, that is if the same diode which failed is not available, both diodes should be replaced with properly rated ones.

11.2.4.2 Scintillation detector

All troubleshooting recommendations given for scintillation detectors in this manual are valid for the detectors of the scanners as well. But there are certain stock faults which are not common in other applications.

Detector cable. They are exposed to cylical bendings and movements after accomplishment of each scanning line; this can amount to 10.000 cycles/week and two million cycles/year. Most cables are worn out in 3-4 years. The cable deterioration is slow; sometimes noises appear without any apparent reason, only in certain areas of the scintigram even without any isotope. If such effect appears, it is a sure sign that the cable is deteriorating.

Contamination of the detector. Under clinical conditions it could happen that the detector surface is contaminated by the patient. This can be prevented by enclosing the detector in an easily replaceable plastic sheet or bag.

Scintillation detector stability. If the gain of the photomultiplier changes during the imaging, it could happen that a fraction of the photopeak information will be lost. On the scintigram it might look as if certain organ areas had lower metabolic functions. It is easy to test the system by attaching a small radioactive source to the detector and keeping the scanner record the measured intensity in this fixed geometry. A good scanner should not drift in one hour more than ten percent in recorded intensity.

11.2.4.3 Pulse-height analyzer

All recommendations given for pulse-height analyzer trouble-shooting are valid for the scanners as well; there is, however, one additional uncommon stock fault.

Isotope selector drift. Most scanners have certain preset channels for the most often used isotopes. The adjusting elements might change their value due to environmental effects. It is important to check the accuracy of the preset channel positions periodically by comparing the manually adjusted photopeak counting rates to the preset channel results. If they differ by more than 10%, readjustment is indicated.

11.2.4.4 Counting-rate meter

The counting-rate meters drive the intensity-to-colour code converter in the display system. The linearity of the conversion is critical and since it can lead to false medical diagnosis, it has to be checked periodically. The procedure is rather simple. One should measure the frequency of a pulse generator which drives the pulse-height analyzer. A graph should be plotted on input frequency vs. displayed value relation. Action should be taken if the integral non-linearity exceeds +/- 5%.

A pulse generator is an essential instrument in the diagnosis of counting-rate meter faults.

11.2.4.5 Colour adjustment potentiometer

The most often used control element of the scanner is the potentiometer between the counting-rate meters output and the input of the intensity-to-colour converter servo circuit. It must be adjusted so that the maximum activity area should appear in red colour on the scintigram. An early sign of wear of this potentiometer is if the colors are changing while the count-rate remains constant during tests with a source fixed to the detector.

11.2.4.6 Intensity-to-colour code converter servo

The circuit diagram and mechanical construction of a typical converter is shown in Fig. 11.17. In its simplest version the position of the coloured typewriter ribbon under the tapper is sensed by a potentiometer, mechanically attached to a DC motor. The non-inverting input of the operational amplifier is connected to the source of the intensity information, that is, to the counting-rate meter output through the colour adjustment potentiometer. The inverting input is connected to the moving contact of the potentiometer, while one end is on ground and the other on a reference DC voltage level. The DC motor is connected with such polarity to give negative feedback, that is, the voltage from the potentiometer compensates the input voltage and the motor rotates until the error signal is minimized.

The most critical part is the potentiometer. They wear out after 10 million turns, so their expected life is 3-4 years in a nuclear medicine unit with 5.000 imagings per year.

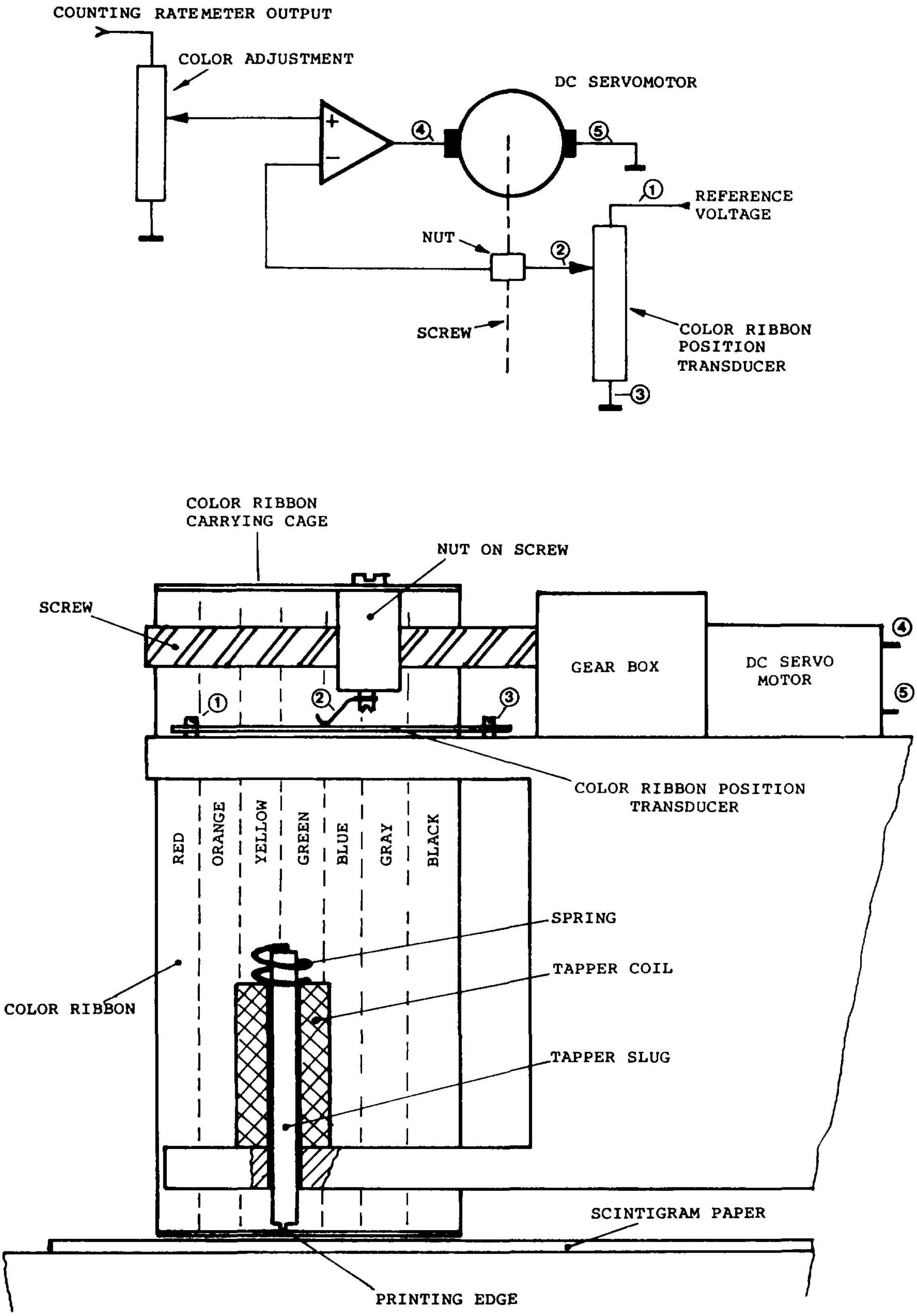


Fig. 11.17: Circuit diagram and mechanical construction of a typical converter

Wear could be one reason for the component deterioration, but under-used potentiometers can develop noises under tropical conditions as well. However, they are reduced to a normal level after a few hours of operation.

11.2.4.7 Control logic

The movement of the detector is under the control of the scanners logic system. Its main functions are the sensing of the position of the scanning area determining boarder limit switches, the position of the border limit proximity switches and the safety limit switches, and to control the stepping motors accordingly.

Some situations and actions:

- scanning line-wise border switch activated:

  step-wise motion starts, after this new line scanning starts with reversed direction.

- step-wise border switch activated:

  scanning is finished, all motors are stopped.

- border limit proximity switch activated:

  motor torque is reduced, breaking action starts before scanning direction is reversed, this action is important otherwise the mechanical system is exposed to heavy strain.

- safety limit switch activated:

  further motion in same direction is inhibited.

Under the manual detector positioning mode, only the safety limit switches are active in protecting the mechanical system.

11.2.4.8 Stepping motor control circuits

The block diagram of the circuit is illustrated in Fig. 11.18. The step frequency selection is done by the SPEED control switch. In a phase splitter, double phase signals are generated from the step frequency signals to feed the rotation direction control circuit together with the line-wise border limit switch information.

Whenever a border limit switch is activated, the bi-stable multivibrator, sensing it, changes the phase of the triggering pulse to the triac which drives the rotation direction control coil of the motor.

The motor torque is always reduced to zero before the rotation direction is reversed by modulating the "firing angle" under the control of the limit proximity switch.

The step-wise motion is under the control of a preset counter, programmed by the step-length switch.

In manual mode all rotation direction orders are controlled by the manual switches and the motors move only while they are pushed and only the safety logic can inhibit them.

All repair activities should start with the checking of the safety switches, because if they are shorted, the mechanical system will not stop on the borders, and if the torque limiters are bad, expensive damages can be expected. For this reason, it is a good practice to put the detector into the center of the scanning area during the initial part of the testing.

If triacs should be replaced, the rule is to change them in pairs. Use fuses to protect them during first trials after replacement.

11.2.4.9 Alignment of the mechanical system

The detectors are rather heavy and the mechanical system can operate properly only if the beam supporting the heavy lead shield is accurately leveled. The mechanical system wears out quickly without this precaution. It is important to check the leveling of the scanner after transportation.

11.2.5 Quality Control of the Repaired Instrument

Recommendations of the IAEA TECDOC-317 on "Quality Control of Nuclear Medical Instruments" should be followed.

11.2.6 Preventive Maintenance

Recommendations given to the Nuclear Medical Pilot Laboratories should be followed, that is:

- instruments should be protected from environmental effects like dust, moisture condensation, excessive line voltage fluctuations, and transients;

- instruments should be covered after use;

- rarely used instruments should be turned on periodically and mechanically operated to prevent rusting, and to dry out;

- lubrication and safety check-ups should be according to the manual;

- only trained operators should use the instrument;

- a log book should be kept on use and repairs, reference tests and their results should be attached to the book.

Chapter 12
RADIATION DETECTORS

12 RADIATION DETECTORS

This chapter presents a description of difficulties with the detectors most frequently used in advanced nuclear spectrometry. Although a detector is directly, and sometimes inseparably, connected to electronics, discussions on the behaviour and faults of electronic parts is avoided; for this the reader should refer to Chapters 5 and 11. Furthermore, attention is devoted entirely to the high resolution detectors; simple detectors, such as Geiger-Mueller or scintillation, are described in Chapter 11. Accordingly, the chapter starts with the high-resolution x-ray and gamma-ray detectors.

12.1 HIGH RESOLUTION X-RAY AND GAMMA DETECTORS

Today, we find on the market the following types of high resolution detectors:

Coaxial pure germanium detector, p-type	for gamma
Planar pure germanium detector	x-rays
Coaxial pure germanium detector, n-type	x-rays and gamma
Si(Li) detector	x-rays
Pure Si(Li) detector	x-rays
Surface barrier detector	alpha and beta

The Ge(Li) detector, which started the revolution in the field of high resolution spectroscopy, is not produced anymore by the respected manufacturer of semiconductor detectors.

12.1.1 Selection of a High Resolution Detector

When ordering a germanium detector for gamma rays, one must specify:

1. Resolution (an average detector will have resolution 1.8 keV).
2. Efficiency (varies from 8 to 40%).
3. Type of cryostat, i.e. the size of the dewar, and the position of the dipstick.

> NOTE: The price of a Ge detector steeply increases with the size (efficiency) and with improved resolution.
>
> NOTE: A detector with a vertical dipstick is the most common type. Other shapes of the dipstick are for special applications.

For a pure planar germanium detector, we must define:

1. Thickness of the detector
2. Area of the detector, in square mm
3. Resolution, in keV
4. Size of the dewar and type of the dipstick

> NOTE: Planar Ge detectors are used in measurement of x-rays with energy above 20 keV. Due to intense escape peaks, they cause difficulties in interpretation of complex spectra.

When buying a Si(Li) detector, we must determine:

1. Resolution of the detector, in keV (an average detector has 180 eV)
2. Area, in square mm (the usual sizes are 30 and 80 sqmm)
3. Type of cryostat and dipstick
4. Type of preamplifier (optical or resistive feedback)

12.1.2 Installation and Testing of a High Resolution Detector

The high resolution solid state detectors are shipped together with the dewar, but without liquid nitrogen, except if the customer specifies otherwise. A pure germanium detector and a modern Si(Li) detector can be stored for years at room temperature, without loosing their characteristics.

Before put into operation, the dewar of such a detector must be filled with liquid nitrogen, and the detector cooled for a period of 4 to 6 hours. The manual of the detector specifies the minimum time for cooling, and it is advisable to adhere to the recommendations of the manufacturers.

With each solid state detector, the customer receives a certificate describing the properties of the detector, and the conditions under which these characteristics have been determined. An example of the certificate (in this case, for a Si(Li) detector) is given in Fig. 12.1. When determining the features of the detector, one must try to reproduce as close as possible the measuring conditions given in the certificate.

A general observation is that the manufacturers are rather conservative with the specifications presented in the certificate. With careful adjustment of electronics and correct measuring procedures, the value given by the manufacturer can as a rule be easily achieved and surpassed. Before you start to write angry letters to the company that supplied the detector about dissatisfactory performance of their detector, be sure about your electronics setup, grounding and overall conditions in your laboratory. For example, high humidity in the laboratory can easily deteriorate the resolution of a Ge detector that needs 5000V+ as the bias voltage.

Section 6
DETECTOR SPECIFICATIONS AND PERFORMANCE DATA
(REAR ENVELOPE)

6.1 SPECIFICATIONS

Serial Number b 86151

The purchase specifications and therefore the warranted performance of this detector are as follows :

Model 7229P-7500-1320

Rel. Efficiency 13 %

Resolution 2.0 keV (FWHM) at 1.33 MeV
keV (FWTM)

keV (FWHM) at 122 keV
keV (FWTM)

Peak/Compton : 1

Cryostat Description Vertical dipstick, type 7500

6.2 PHYSICAL/PERFORMANCE DATA

Date

Actual performance of this detector when tested is given below.

Geometry Coaxial one open end, closed end facing window.

Diameter 48 mm

Length 35 mm

Active area facing window 18.1 cm^2

Distance from window 5 mm

ELECTRICAL CHARACTERISTICS

Depletion Voltage (+)4000 Vdc.

Recommended Bias Voltage (+)4500 Vdc.

Leakage Current at Recommended Bias .01 nA

Preamplifier Test Point Voltage at Recommended Bias - 2.3 Vdc.

RESOLUTION AND EFFICIENCY *

Isotope	Co^{57}	Co^{60}		
Energy(keV)	122	1332		
FWHM(keV)	.836	1.79		
FWTM(keV)		3.34		
Peak/Compton		42.4 : 1		
Efficiency(%)		13.0		

* All measurements performed at 4 microseconds shaping time

Fig. 12.1: The certificate for a Si(Li) x-ray detector

12.1.3 Germanium Gamma-Ray Detector

The International Electrotechnical Commission published detailed instructions for testing of semiconductor detectors. For gamma-ray detectors, the IEC Publication 656 (1979), "Test Procedures for High-Purity Germanium Detectors for X and Gamma Radiation" can be ordered from the Bureau Central de la Commission Electrotechnique Internationale, 1, rue de Varembe, Geneve, Suisse.

12.1.3.1 Determination of resolution

Resolution of a gamma-ray semiconductor detector is defined as the full-width-at-half-maximum (FWHM) of the peak that corresponds to the gamma-rays from Co-60 at the energy of 1.3MeV.

The measurement is simple: place a suitable Co-60 calibration source at a distance of 25 mm from the face of the detector. The counting rate of the detector should be at least 1000 counts/s. The resolution of a detector depends on the counting rate; with a higher counting rate, the resolution decreases. The commercial companies make their measurements for the certificate at a counting rate very close to the nominal 1000 counts/s.

Using a spectroscopy amplifier with carefully adjusted pole-zero cancellation and a good multichannel analyzer, collect a spectrum of Co-60. In the central channel of the 1.3 MeV peak, at least 10,000 counts should be collected.

With a modern multichannel analyzer, the FWHM can be determined by the firmware of the instrument. Otherwise, you can do it approximately on the monitor of the MCA, or precisely by plotting the part of the spectrum with the 1.3 MeV peak, and determining the FWHM from the plot.

Put all the conditions of the measurement and the results in a log book, together with the copy of the certificate.

12.1.3.2 Efficiency determination

Efficiency is a very important property of a high resolution gamma ray detector. The Ge detector efficiency is defined as the net area under the Co-60 peak at the energy of 1.3 MeV, compared to the net area under the same peak measured with a 3x3 inch NaI detector. The efficiency is given in %.

Place a Co-60 calibration source at a distance of 25 cm from the surface of the 3x3 inch NaI detector, take the spectrum and determine the area under the 1.3 MeV peak. Repeat the measurement with the Ge detector under identical geometry. The ratio of the intensities gives you the efficiency:

$$eff = \frac{I(Ge)}{I(NaI)} \times 100$$

Some other very important information that tells us about the quality of the detector, is the dependence of the efficiency on the energy of the detected gamma rays. A number of methods have been designed for accurate measurement of this property, and computer programs are available for evaluation of measurements. The simplest methods involve the use of a set of calibrated gamma sources. For details see "A Guide and Instruction for Determining Gamma-Ray Emission Rates with Germanium Detector Systems", by K. Debertin, May 1985.

12.1.4 Si(Li) and Planar Ge Detector

They are for high resolution x-ray spectrometry. From the outside, there is only one essential observable difference, compared to the gamma-ray Ge detectors: on the top of the detector cap we find a berillium window. It represents a barrier that separates the vacuum inside the detector from the atmospheric pressure outside, and does not permit light to fall on the detector. It does not stop x-rays appreciably, except if they are of very low energy, say, below 4 keV.

A newly received x-ray detector should be tested for its performance immediately upon arrival. After cooling it with the liquid nitrogen for several hours, the tests can start.

12.1.4.1 Connections and initial tests

The x-ray solid state detectors use two types of preamplifier: with resistive feedback, or with optical feedback. Most of the contemporary Si(Li) detectors use the optical feedback because this permits them to obtain better resolution. The one honourable exception are the detectors produced by ORTEC, using resistive feedback.

Let us consider the case of a preamplifier with optical feedback. After connecting the high voltage (SHV connectors, usually a RG59 cable; observe the polarity, in most cases a negative voltage is applied!), use a BNC cable to display the output (sometimes called ENERGY) from the preamplifier in an oscilloscope. Before the high voltage is applied, the oscilloscope (try to use the amplification on the vertical scale that gives 5 V/cm, and a time constant of the sweep of 100ms) will show that there is some negative voltage (about 12V) on the output. This you can see if you switch the oscilloscope from DC to GROUND operation. Slowly start to increase the voltage, say about 100 V per second. If you stop for a moment at 300 V, you will see on the oscilloscope the picture as shown in Fig. 12.2. After a few seconds, the sawtooth shape of the signal will become stretched out (Fig. 12.3), until you see only a straight line. Now, the voltage can be increased to the prescribed value.

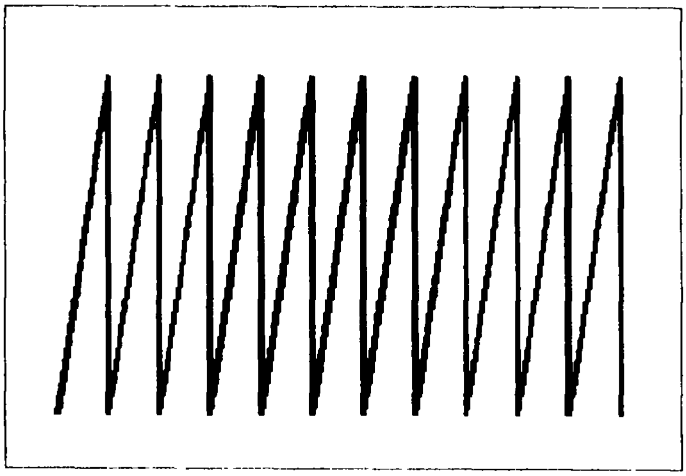


Fig. 12.2: Scope shows sawtooth shapes when high voltage is applied to an optical feedback preamplifier

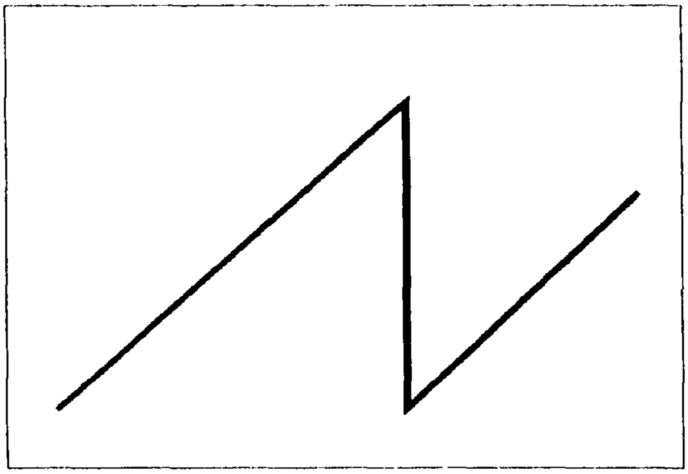


Fig. 12.3: In a short time, the shape changes to a low frequency saw

It is time to put a radioactive calibration source on the detector. It is preferable to use a Fe-59 source, emitting x-rays of 5,9 keV. If you do not have a calibration source, use an excitation source in a suitable holder, and place a sample that contains mainly iron, in the position of the sample, on top of the holder.

If the counting rate is high, the sawtooth will appear again. Increase the sweep frequency and the vertical amplification of the oscilloscope, and you will observe the steps on the increasing line of the sweep, Fig 12.4.

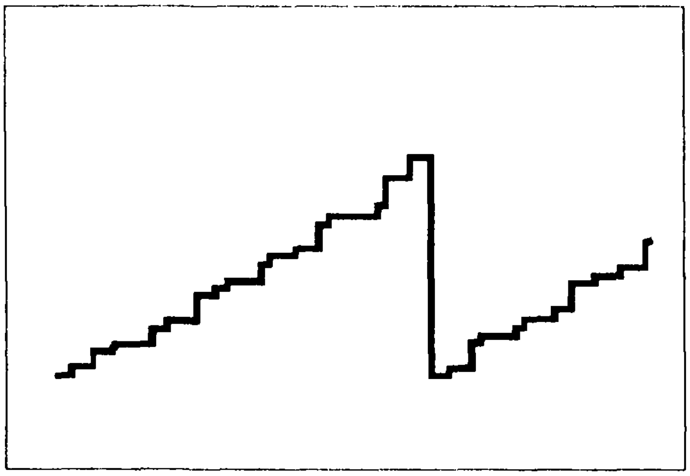


Fig. 12.4: Shape of the preamplifier output with x-rays coming into the detector

The detector and the preamplifier are working.

12.1.4.2 Resolution

After connecting the preamplifier to the main amplifier, and this to the multichannel analyzer, adjust the amplification of the main amplifier so that the 5.9 keV peak will be registered in channel 300 or there about. Use long shaping time (try to match the specification on the certificate!), say 16 microseconds, and the amplification about 300.

Make the energy calibration of the MCA using two calibration x-ray sources, or two different pure metals on top of the holder with the excitation source. One of the two should be the Fe-59 source. Collect sufficient counts in the peak to obtain good statistics. Determine the FWHM of the k-alpha (the largest) of the Fe-59 radioisotope peaks. The FWHM value of the 5.9 keV peak, in eV, is the resolution of the detector, as given in the certificate. If no Fe-55 calibration source is available, you can use an excitation source, and an iron sample. Although the resolution is determined at 5.9 keV (the Mn K-alpha line), the value obtained with the iron target (6.4keV for the K-alpha line) will be a good approximation.

12.1.4.3 Efficiency

Determining the efficiency of the x-ray detector as the function of x-ray energy is a tedious and long procedure (see for example the IEC Publication 759, "Standard Test Procedures for Semicondictor X-Ray Energy Spectrometer". Around 10 keV, a Si(Li) detector efficiency is 100%, falling to zero at 2 keV, and decreasing less radically on the high energy side.

12.1.5 Maintenance of High Resolution Detectors

In addition to all the established routines for the proper handling of nuclear instruments, some specific precautions should be applied to the solid state detectors that operate at low temperatures.

All modern, high resolution solid state detectors can be stored at room temperature. In your laboratory, you might still have an old Ge(Li) detector, or a Si(Li), manufactured before 1982. These detectors have to be kept at a low temperature at all times.

How do we know when the level of the liquid nitrogen in the dewar is too low? One can buy some level measuring devices (or, as an electronics man, you can design one yourself). More simple is to put the dewar with the detector on a bathroom scale, and determine how heavy the system is with, and without liquid nitrogen.

In many laboratories, the dewar is refilled by a rather dangerous procedure of taking the detector from the dewar, filling the liquid nitrogen by pouring it in the dewar, and reinstalling the detector. If you are a very careful and rather strong man, this technique works. But it is much more advisable, practical and safe to acquire a transport dewar with a filling attachment (see Fig. 12.5).

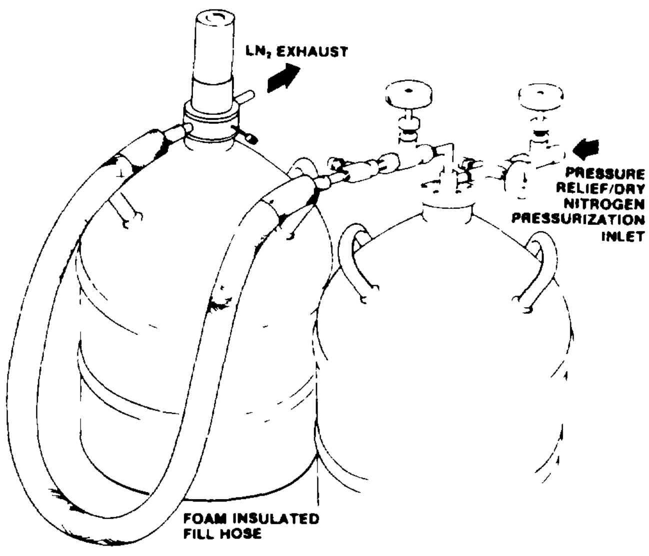


Fig. 12.5: The nitrogen transfer device

The detector cap is connected to the dipstick with a flange, see Fig 12.6. An O-ring takes care of vacuum tightness of the joint. Be careful not to pour liquid nitrogen on the flange. The cooling will make the rubbery material of the O-ring brittle, and a vacuum leak will develop. Some manufacturers use metal rings; they are safe as far as the cooling is concerned, but are difficult to replace.

By mishandling, liquid nitrogen can be poured on the flange. While this is bad, it is not necessarily a catastrophy. Tighten the screws holding the bottom and top flange together; you might be lucky, and the O-ring can be squeezed enough to still hold the vacuum.

It is a recommended policy to keep the detector in liquid nitrogen all the time. The shortage of liquid nitrogen might force you to let the detector warm up. If this happens, let it warm up all the way, i.e. let it spend a day or two at room temperature before it is cooled again.

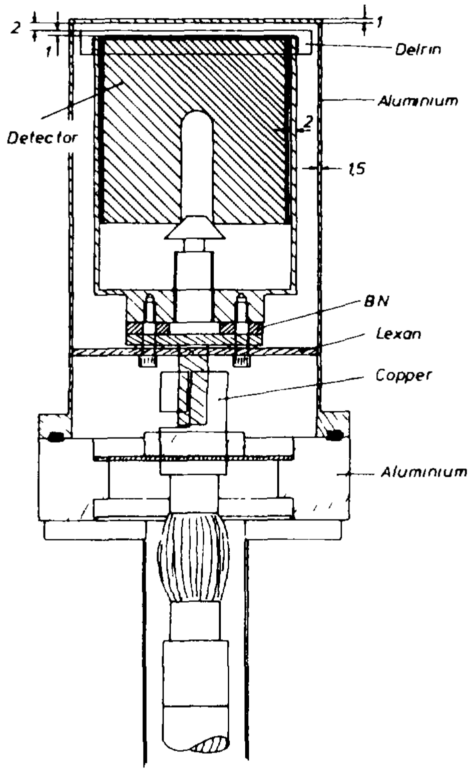


Fig. 12.6: The inner life of a semiconductor detector. Note the flange with an O-ring.

High resolution detectors are sensitive to mechanical shocks. Be very careful when moving them. A special feature of these detectors is microfony. Mechanical vibrations or accustic signals will be transferred to the detector, and undesirable noise will be produced. Different precautions can be taken to avoid these effects:

- place the dewar of the detector on a soft, rubbery mat;

- put sound-absorbing material around the detector cap;

- put some fine sand in the bottom of the dewar, to a level that the end of the dipstick will be inserted in the sand; this prevents bubbles from forming on the surface of the dipstick end.

With the Si(Li) detectors, the berillium window is the most sensitive part. It can be easily broken; high humidity will cause corrosion resulting in the appearance of microscopic vacuum leaks. When not in use, the detector should be protected with the plastic cap. If stored for a longer period, the detector top should be covered with a plastic sheet, with some silica gel to avoid high humidity.

12.1.6 Troubleshooting of Ge and Si(Li) Detectors

The semiconductor high-resolution detectors are normally bought together with the preamplifier. The properties of the detector (and with them its price) are defined for the combination detector+preamplifier+dipstick. With some detectors, the preamplifier can be ordered separately as a replacement, to be installed locally.

There are several possible combinations and configurations, and each should be treated in a separate way:

(i) The ORTEC detectors are recognized by their shape: the preamplifier is integrated in the cylinder of the detector head, see Fig. 12.7. This streamlined solution is practical for some measurements where the detector must be inserted in a measuring chamber, and the protruding preamplifier is an obstacle. These detectors are somewhat more difficult to service and repair.

(ii) A widely accepted configuration is shown in Fig. 12.8. Here, the preamplifier is located in a separate box that is attached to the dipstick. Such a preamplifier can contain the input stage, with the FET at room temperature: this solution is sometimes applied to the gamma-ray detectors. In most cases, the protruding box does not contain the input stage; this is somewhere inside the detector cap, with the FET at low temperature.

Suppose that you have a gamma-ray detector, with a preamplifier outside the detector cap. Something seems to be wrong with it. Basically, there are two possibe types of defects, mechanical and electronic. The defects and their symptoms are listed in Table 12.1

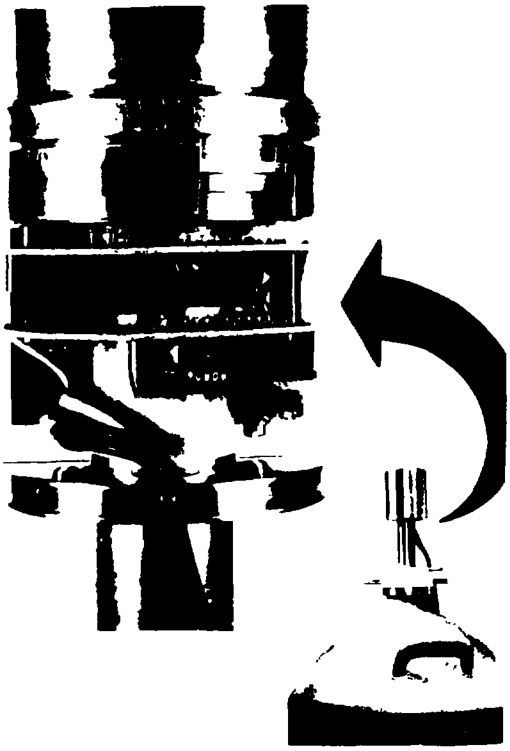


Fig. 12.7: Streamlined detector-preamplifier setup

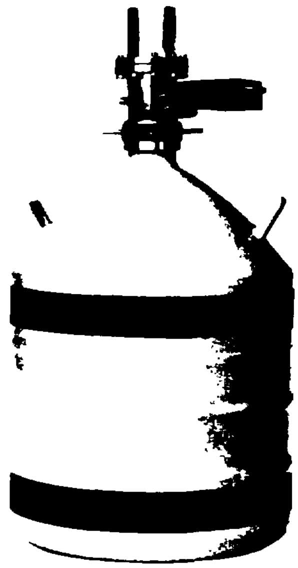


Fig. 12.8: Preamplifier outside

TABLE 12.1: Defects and how they are recognized

(a) Mechanical defects:	
- the vacuum inside the detector cryostat is bad	- moisture or ice accumulated at the neck of the cryotat
- the detector is broken	- no signal at the output when gamma source is close
- the wires inside the detector heads are broken	- no signal with source or with pulser
(b) Electronic faults	
- input FET is defective	- no output signal, with test signal on the input
- deteriorated resolution	- either damaged detector or moisture accumulation in the preamplifier
- bad efficiency (x-ray)	- dirty Be window or detector crystal surface

There are some actions that you can implement to repair a defective or improperly operating detector. But there are a number of faults when the detector must be returned to the factory for repair. Let us analyze some typical cases.

(i) When touching the detector cap, it feels very cold; moisture or ice accumulate at the point closest to the dewar. This is a sure sign that the vacuum inside the detector cryostat is bad. If you have a good vacuum laboratory, with a pumping system and a He leak detector, you can find the leaking spot, and repair it. Then you pump the cryostat for several hours, at the same time heating the bottom part of the cryostat, and the protruding dipstick to 80 or 100 degrees C. Without the proper vacuum equipment, the detector should be returned to the manufacturer's service laboratory.

> ATTENTION: Do not apply high voltage to a detector which shows signs of a bad vacuum inside the cryostat. Some detectors (but not all) have a temperature-sensitive switch inside the cryostst that prevents the application of high voltage to a detector that is not sufficiently cooled.

(ii) The most obvious loss of vacuum happens if the Be window on an x-ray detector breaks. Immediately switch off high voltage, cover the detector with a tight plastic cap, and remove the detector with cryostat from the dewar. If you are fast, the detector crystal itself can be saved, and the costs of repair will be only for mounting a new Be window. Without vacuum but with high voltage on, the detector will heat up, the Li will drift out of the detector, and you will have to buy a new one.

(iii) If the detector is properly cooled, and yet there is no signal at the preamplifier output, there are several possible reasons:

- you forgot to put a calibration source in front of the detector;
- the high voltage is not provided; check the operation of the bias supply and the connections
- the low voltage power supply (usually +/- 24 V) is not in order; check the outputs of the preamplifier connector (mounted on the main amplifier backplane) and the connecting leads;
- the preamplifier is defective; closely inspect the printed board in the preamplifier and all connections;

- the inaccessible parts of the detector (the crystal itself or cooled FET) are faulty; in this case, without a well equipped vacuum laboratory, you can do very little.

(iv) The detector resolution has deteriorated. The most frequent reason is the humidity and the condensed water in the preamplifier. Use a hairdryer to remove moisture. A second possible cause is dirt on some components of the preamplifier, or on the connector pins protruding from the cooled part of the cryostat. Clean them, preferably with methane, but at least with a dry and clean cotton buds. Pay special attention to the high voltage filter in the preamplifier, usually made of two highohmic resistors and two high voltage capacitors.

The test input on the preamplifier box is connected to the detector crystal via the high voltage supply lead. Using a pulser, or a pulse generator, you can inject the signals through the detector diode to the FET. If there are signals on the output of the preamplifier, you can conclude that the FET is working, and that the high voltage lead to the detector crystal is not interrupted. If the x- or gamma-rays are still not detectable, you can conclude, with a high probability, that the detector itself is faulty.

NOTE: Modern high resolution semiconductor detectors are good and reliable instruments. If operated with proper care, they will last for many years. Even the old detectors can be trusted; fifteen-year-old Ge(Li) detectors that still operate with full original specifications are not unusual. In most cases, it is a human error that kills a detector. Handle these detectors with care, and you will not need the above troubleshooting advice.