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Berkeley, California
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BEVATRON ELECTRICAL SYSTEM CONTROLS, INTERLOCKS, AND WIRING RECORDS

Clarence A. Harris

July 31, 1962
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July 31, 1962

ABSTRACT

The electrical control system of the Bevatron is described. The system of prints, the complex of control and coax cables, and some of the general electrical control problems of nuclear accelerators are discussed.

The details of the electronic control chassis and components such as the RF tracking system are not covered in this report, although appropriate references are given where known.
BEVATRON ELECTRICAL SYSTEM CONTROLS, INTERLOCKS, AND WIRING RECORDS

Clarence A. Harris
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Berkeley, California

July 31, 1962

I. INTRODUCTION

During the past 17 years of particle accelerator operation at the Lawrence Radiation Laboratory, a specialized system of interconnecting electrical and electronic controls has been developed. This system of controls seems best suited to our type of operation, where the needs of the experimenter and/or the equipment may not be known until the final stages of construction. The method of interconnection provides for a minimum of duplicated effort when new conditions of control interlocking are met.

In Sect. II of this report we are concerned with the usual type of control and interlock used on the Bevatron. In Sect. III we deal with specialized signals and triggers that require coax cables. In Sect. IV we describe some of the specialized circuits required for Bevatron operation.
II. CONTROLS AND INTERLOCKS

The wiring system depends upon the standardization of many special control panels to give greater flexibility of interconnecting electronic controls and interlocks. Each standardized panel is composed of several similar units (i.e., relays, push buttons, indicator lights, etc.) mounted on a panel and wired to a terminal strip. These standard panels are then mounted in standard racks and wired by multiconductor cables to a central terminal board called a cross-connect. Several other multiconductor cables (trunk lines) are installed from the cross-connect to various parts of the project. These cable terminations act as collecting points for the various interlock features required.

The standard panels and trunk lines often may be installed before the details of the required control and interlocking are known. Then, when the final planning is complete, only cross-connect jumpers are needed to set up the circuits.

In this report we describe some of the details of this control system and how it applies to the Bevatron particle accelerator (see Ref. 1 for additional information as to how that system applies to circuits at the Livermore site of UCLR).

A. Standard Panels

We developed many types of standard panels to provide an efficient concentration of our equipment. Each standard panel consists of a grouping of similar components, compactly arranged and wired to a terminal strip on the chassis. Typical of standard panels are the following (see Appendices A, B, C, D):

- medium power relays - "A" Panel Print Z1012,
- low power control relays - "L" Panel Print Z2123,
- overcurrent relays - "AT3" Panel Print Z5551,
- and push buttons - "C4" Panel Print Z7073.

All standard panels that contain relays should have some type of surge suppressor, such as Federal 8A5-PS5, installed across the coils. This will increase the life of push buttons and relays used in control circuits.

Note that each standard panel carries with it some letter designation which defines a type of relay or component. This system is somewhat different from industrial practice, where such designation would indicate its function, such as "under voltage," "over current," etc.

B. Rack and Area Numbering

The Bevatron control system is based upon a positive identification of every connection on a terminal block; each terminal block has its own individual location number which may be used on a print. No unidentified splicing of wires is allowed.
In setting up this system for a large accelerator, such as the Bevatron, it is first necessary to allocate area letters for different parts of the building. If the accelerator is small and only a few racks of equipment are involved, this area designation would be omitted.

Some typical area designations of the Bevatron are:

- **C** = main control room,
- **D** = injector control racks,
- **H** = auxiliary racks above the main control room,
- **L** = general numbers assigned around the magnet,
- **N** = diffusion-pump controls,
- **R** = radio-frequency tracking equipment,
- **S** = motor generator room,
- **T** = pump room,

and

- **Y** = equipment in the experimental area.

The letter code designation should be easy to write (it will be written several thousand times) and not subject to confusion with other letters or numbers.

Each rack in a given area is assigned a number, such as D12 (D is area designation, and 12 is a rack in that area). These numbers are carefully registered so that the various coordinators working together will not duplicate them for different equipment. Numbers from 1 to 9 are always preceded by a zero, such as D02. The rack numbers are in sequence from left to right from the front of the racks.

Each 1.75-in. rack unit of every rack is assigned a number in sequence starting with 09 at the top. Numbers 01 to 08 are reserved for terminal blocks when used at the bottom of the racks. For convenience, every fifth rack unit is stenciled on the rack. These stenciled numbers start with space number 10 (see Fig. 1).

**C. Wire-Terminal Identification on Control Prints**

On a schematic wiring diagram an X indicates that there is either a solder or screw terminal junction at that point. For complete identification of the wire terminal, the number is written on a print adjacent to the X as shown in Fig. 2.

Points on the terminal strip are numbered from left to right or top to bottom as we look at the rear of the chassis. Coax patch panels are the only deviation from this sequence. The coax patch panel positions are numbered in sequence from left to right as we look at the front of the rack; this is done for the convenience of operators who use the panels from the front.

When a chassis is located in a rack at the Bevatron, it is customary for that chassis to be assigned a position number that is the same as the rack unit number at the bottom position of the chassis. This then makes it simpler to indicate where to install a given chassis; i.e., "Install chassis print number 6Y 7284 in position D0954."
Fig. 1. Rack space and block numbering.
Fig. 2. Typical terminal point identification and print references.
Where there are several terminal strips on the chassis, the individual strip will retain the terminal strip number as shown on the print for the chassis. The complete number for a given point on terminal strip No. 2 located on a chassis then becomes D0954-TS2-04. The TS2 number may be omitted if there is only one terminal strip on the chassis.

Note that in the LRL system we identify the terminal point by the physical location of the point. We do not identify by wire numbers which are the same at each end of the wire. We feel that our system of identification shows more clearly where the wires terminate. When these points are properly shown on a control schematic they indicate how and where the circuit may be broken for circuit analysis and for insertion of new control functions.

Terminal points on a print joined by a double line (see AX22-49 to AX22-50 in Fig. 2) are to be interpreted as two points that can not be disconnected from each other.

There are exceptions at this laboratory to the use of the double line on the print. At the 88-inch cyclotron and the Heavy Ion accelerator the double line is used to indicate the added cross-connect jumper. This use of the double line on the schematic diagrams clearly identifies the jumper. Some of the other projects do not try to identify the jumpers or the solid double tie; therefore, they do not use any double lines on the schematic diagrams.

D. Electronic Prints

Most of the prints produced for electronic equipment and controls are drawn primarily for the benefit of the electronics maintenance man. The prints are in a combination of schematic and block form showing the circuit functions rather than wiring diagrams.

The relay coils and their contacts are shown separately on a print to clearly show the circuit function. Care must be taken to add appropriate labels and cross-references on these items because the contacts and coils are separated, (see Figs. 2 and 3).

Everything possible should be shown on the print; e.g., warnings, information aids, operation procedures, etc. The coordinator is aware of these various items at the time the print is drawn; therefore, he should write them down and leave nothing to the imagination. This procedure will save the electronics maintenance man many hours of searching for information.

Neutral or common connections of relays, lights, etc., are usually common to several components. At times it would be inconvenient to show the complete neutral circuit on every print; therefore, certain simplifications are permitted. For example, it is general practice to show the circuit as if there were no common connections, because all the personnel involved should know that several standard panel relays may have a common circuit to the neutral return. The M panel or interlock lights are usually grouped, and the common connection would be shown as in Fig. 3.
Fig. 3. Simplified schematic and block diagram.
The prints showing the control and interlocking sequences used on the Bevatron are duplicated at three locations. The prints are marked with Roman numerals, I, II, and III for identification.

Numerals I and II indicate prints showing the circuits as they are operating at any given time; but, in addition, these prints may show new circuits which have been requested and may even be partially installed. Numeral III indicates present circuits, new circuits which have been requested, and new circuits being worked on by the coordinator or engineer.

Each print has a special stamp on it to indicate the distribution of the print; i.e.,

IEM - Electronics maintenance,
IMG - Motor generator room,
II - Engineering file, Bldg. 64 Room 207,
and III - Coordinators file, Bldg. 64 Room 213.
(See also Appendix E.)

All shifts of electronic maintenance men must be kept up to date on all jobs that are in progress; the night shifts must know what changes in control circuitry occurred during the day shift. There are times when a job has been completed but there has not been time to bring the Number I print up to date. If the No. I file is not up to date the maintenance man may have to use the No. III copy. A special stamp is used on the outside of the print to inform the maintenance man whether there is a job in progress involving that print. It also gives the write up or work number of the job for reference.

The first number and letter of the print number designates the project or general classification of the print (Table I); the next three numbers are assigned serially, and the last number designates the size of the print (Table II). A letter following the print number indicates when the tracing has been revised.

A number and a letter (e.g., 2c) may be added after the normal print number (e.g., 5Z1814) to indicate a slight model change in a standard chassis, where it would not seem advisable to renumber entirely the modified chassis. See Appendix F for other numbering systems. The example number would then read 5Z1814-2c. The letter following the number indicates that the tracing has been brought up to date at a given time, and that there will be no chassis in operation wired for a print with an earlier letter change. There may be many chassis of each model in operation.

The control prints show the interconnection of one or more chassis and other controls. These control prints have area markings, similar to those on a road map, along the left side of the print to aid in referencing relay coils and contacts. A symbol [G] following a print number indicates the "G" area on the print.
Table I. Project classification.

<table>
<thead>
<tr>
<th>Project code</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>2L</td>
<td>184-inch cyclotron</td>
</tr>
<tr>
<td>3R, 4R</td>
<td>General building power</td>
</tr>
<tr>
<td>3S</td>
<td>Cloud chamber</td>
</tr>
<tr>
<td>4S</td>
<td>Bubble chamber</td>
</tr>
<tr>
<td>T</td>
<td>Counting equipment</td>
</tr>
<tr>
<td>2V</td>
<td>Synchrotron</td>
</tr>
<tr>
<td>3V, 4V</td>
<td>General and miscellaneous</td>
</tr>
<tr>
<td>7V</td>
<td>Data reduction and computer</td>
</tr>
<tr>
<td>6W, 8W</td>
<td>20-inch and 36-inch cyclotrons</td>
</tr>
<tr>
<td>1X, 2X</td>
<td>Counting equipment</td>
</tr>
<tr>
<td>3Y</td>
<td>Bevatron motor generator</td>
</tr>
<tr>
<td></td>
<td>Westinghouse prints</td>
</tr>
<tr>
<td>4Y, 5Y, 6Y, 7Y, 8Y, 9Y</td>
<td>Bevatron chassis and control</td>
</tr>
<tr>
<td>Z</td>
<td>Standard panels</td>
</tr>
<tr>
<td>3Z</td>
<td>Standard power supplies</td>
</tr>
<tr>
<td>5Z, 6Z</td>
<td>Standard equipment</td>
</tr>
<tr>
<td>9Z, 10Z</td>
<td>Standard parts</td>
</tr>
</tbody>
</table>

Table II. Print sizes.

<table>
<thead>
<tr>
<th>Print size code</th>
<th>Print dimensions (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sketch available; final print size not known</td>
</tr>
<tr>
<td>1</td>
<td>8 1/2 × 11</td>
</tr>
<tr>
<td>2</td>
<td>11 × 17</td>
</tr>
<tr>
<td>3</td>
<td>17 × 22</td>
</tr>
<tr>
<td>4</td>
<td>22 × 34</td>
</tr>
<tr>
<td>5</td>
<td>All larger prints</td>
</tr>
</tbody>
</table>
E. Write-Up Procedures and Records

The coordinator or engineer prepares the appropriate instructions on a special form when a change in an interlock function is required. (See Appendices G and H).

Copy III of the prints involved is marked in red and green by the coordinator, and appropriate records are made as work instructions or changes in the circuitry are designed. When the write-up is issued, copies I and II of the correct prints are marked up and identified with the serial number of the write-up (see Appendix I).

These markups are made with colored pencils; red obsoletes wiring and green shows the new circuit. Blue pencil shows the identification serial number of the work order or write-up.

If it will be a long time before a large job is to be completed, and there are many changes on a given print, it would lead to confusion in troubleshooting existing circuits if the prints were marked up in red and green at the beginning of the job. In this case a new print is issued showing the new circuit and both prints (new and old) are held in file with proper identification until the job is completed.

Copies of the write-up are given to the Electronics Installation group as instructions for the work. A copy of the write-up is also given to the Electronics Maintenance group so that they will know what changes are pending.

As the job proceeds, the Installation Shop keeps the Maintenance group informed when each section of the write-up is completed. In this way, the Maintenance group can keep abreast of any changes in the controls and at the same time shorten the time required to put a new circuit into operation.

When the prints become difficult to read because of many changes, and when all marked up circuits are completed, the tracings should be brought up to date and new prints issued.

The records to be kept of the control wiring or coax cables should be carefully analyzed. There should be a legitimate justification for every print or wire table which is to be maintained so that the work required to bring up the records and prints is not excessive or redundant.

Records must be kept so that it is easy to find spare wires in trunk lines, spare relays, spare controls and, last but not least, interlock lights. Visual inspection of a terminal strip, coax patch panel, or the spare spaces in a rack is not adequate investigation; there may be a pending write-up that uses the spares.

If records were kept only for locating spares, then no more than check marks would be required. The locating of spares is not the only reason for keeping records. If errors are made when various work is in progress, or when Electronics Maintenance is trouble-shooting a circuit, or in various stages of rewiring, the records eliminate a time-consuming search through the prints.
If wires or relays should accidentally be damaged mechanically or by fire, a quick glance through the record books should lead to the appropriate print references for faulted wires or defective relay contacts.

The records for wires and relays are more readily maintained in books and are normally available in the coordinator's office, where changes in these circuits should originate.

We have adopted the practice of keeping most records of coaxes as prints, which are located in the maintenance and coordinator's files.

The changes in the coax cables quite frequently originate on the job and are made by the maintenance man or coordinators in the field. The records are more apt to be kept up to date by having the record prints easily available.

The coax records usually consist of a coax-rack layout (see Appendix J), and one-line flow diagrams for triggers and signals that are routed throughout the building. Special symbols have been originated to minimize the amount of drawing required on prints. (See Appendix K for a typical diagram.)

F. Cross-Connects--Solder Type

We have found over a period of years that time and cost of installation may be reduced by bringing the wiring of all relays, push buttons, lights, etc., to one local area called the cross-connect. The required circuits are set up with short, expendable jumpers.

The Western Electric 80-point terminal block (No. 1) is used in the cross-connect, HX for H area, AX for A area, etc. (See Figs. 4, 5 and 6 for a typical installation.)

When the planning indicates that additional standard panels are required, a Job Order write-up is issued for installing these panels in the correct racks (see work order B06-03, Appendix L as an example). The write-up calls for a cable to be run from each panel to the cross-connect, and tied down as specified on the Job Order.

Each terminal point on the L panel or on other standard panels is connected to two adjacent points on the left side of the cross-connect block. This method allows only one jumper wire per point on the right side, which simplifies the installation, checking, and troubleshooting of a circuit. The coordinator makes up two sets of record sheets; one set is grouped in the wire table book, Appendix M, and indicates where control units are used. The other set is assembled in the cross-connect book (Appendix N) where we show the wire-jumper interconnections of the relays and other control equipment by the numbers on the right side. At this time the neutrals of the relays are tied down and no future write-up should disturb the neutral because the neutral is common to several relays which may be used on different circuits.
Fig. 4. Trunk lines and equipment side of cross-connect blocks.
Fig. 5. Jumper side of the cross-connect blocks.
Fig. 6. View of Bevatron main cross-connect rack.
At times, many wires must be brought into the cross-connect from some remote spot. These wires are used to connect door interlocks and other control equipment interlocks to appropriate circuits. In this case a 52-point block is located somewhere near the point of origin of the interlocks and assigned some number consistent with its location in the building. A 52-conductor No. 16 AWG cable is then connected from the terminal block to the left side of the cross-connect blocks, and it is quite common, although not required, to tie these trunk lines to single points instead of double points.

For convenience in locating the neutral power terminals, several of the lower connections of each vertical row of cross-connect blocks are tied to the neutral of the power system.

The wires on the left side of the block are considered permanent and are formed and dressed up accordingly (see Fig. 4).

The interconnection cross-connects, on the right side of the block, are not permanent and may be changed. Therefore, although care is taken when installing the cross-connects, they are not expected to look as neat as those on the left (see Figs. 5 and 6).

The wire used for cross-connects is No. 18 glass-braid-covered rockbestos stranded wire. This rockbestos covering provides good fire protection on the cross-connect board. All cross-connects are soldered.

The multiconductor cable used to connect standard panels at remote junctions to the cross-connects is No. 16 TW solid wire. Color coding is preferred but optional.

The Bevatron has required about 19,000 ft of 52-conductor cable, 7,000 ft of 32-conductor cable, and 27,000 ft of 12-conductor No. 16 cable to give the required flexibility in the control system. (See Fig. 7 for the general routing of these cables.)

G. Cross-Connects--Taper-Pin Type

The application of taper pins to the cross-connect blocks has been considered for some time. Taper pins seem to offer many advantages in making the cross-connect system more reliable because:

(1) It is easier to wire check circuits because pins may be withdrawn to break up the circuit.

(2) Circuit changes would be easier to make with less hazard to adjacent contacts. There would be no problem of small wires or dripping solder causing short circuits.

(3) Terminal point density is higher; 2400 double points per rack for the old system, 3500 for taper pins.

(4) Circuits may be temporarily "buggered" or by-passed without the danger of clip leads causing shorts.
<table>
<thead>
<tr>
<th>Average length of run (ft)</th>
<th>Number of No. 16 control wires</th>
<th>Feet</th>
<th>No. 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>470</td>
<td>312</td>
<td>100</td>
<td>5000</td>
</tr>
<tr>
<td>582</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>2840</td>
<td></td>
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<tr>
<td>266</td>
<td>368</td>
<td></td>
<td></td>
</tr>
<tr>
<td>423</td>
<td>72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>352</td>
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<td></td>
</tr>
<tr>
<td>348</td>
<td>102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>468</td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>302</td>
<td>416</td>
<td>100</td>
<td>1200</td>
</tr>
<tr>
<td>300</td>
<td>104</td>
<td>20</td>
<td>1648</td>
</tr>
<tr>
<td>550</td>
<td>170</td>
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<td>600</td>
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<tr>
<td>300</td>
<td>300</td>
<td>25</td>
<td>700</td>
</tr>
<tr>
<td>220</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>3300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7. Bevatron control cables.
(5) To alter circuits after the first installation, the cost per cross-connect should be about 50% less with taper pins.

Our early investigation of this type of block indicated that the initial cost would be prohibitive, but through the efforts of G. V. Wilson and the aid of Reynolds Industries, Inc., of Santa Monica, California, a special taper pin block part No. R-101467 and fanning strip was developed. The Lawrence Radiation Laboratory identification of this block is 9Z3163.

We estimate that the original installation will cost about 70 cents per double point; this includes racks, blocks, trunk line termination and cross-connects. This installation cost is about the same for either the solder terminals or the taper pins.

The advantages of taper pins over solder connections make the taper-pin system more desirable, especially for altering circuits.

Figures 8, 9 and 10 show a typical installation of taper pins as applied at the 88-inch Cyclotron.

H. New Auxiliary Relay Panel

In the past we have added new auxiliary-control relay L panels by installing relay panels in a sub-rack, then connecting a trunk line from the panels to the cross-connect.

See Figures 11 and 12 for two new types of relay panels (LA, LB). These were developed for both the solder-type and the taper-pin type cross connect. These panels are mounted in the group of cross-connect blocks and eliminate the need for a trunk line. Plug-in relays are used to give further flexibility in replacement.

I. Power System

Several types of 60 cps ac-power sources are used to power the various pieces of equipment required for an accelerator. The nominal voltages, which depend upon the total power required, are,

1. 12 kV 3 phase from motor generator (MG) sets, 1.5 MW and up,
2. 2400 V, 3 phase for MG sets, 1/2 to 2 MW,
3. 480 V, 3 phase for smaller MG sets, motors, vacuum system, and miscellaneous auxiliary power supplies,
4. 240 V, 3 phase, 120 V, 1 phase for general accelerator power, and
5. 120/208 3 phase, 4 wire for general building lights and convenience outlets.

It is a firm rule that the control power used on cross-connects shall be phased so that no voltage greater than 120-V ac exists between any two points. It is established practice that no circuits shall appear on the cross-connect that might be damaged by an accidental short circuit involving 120-V ac.
Fig. 8. Front of taper-pin cross-connect rack.
Fig. 9. Rear of taper-pin cross-connect rack, close-up.
Fig. 10. Rear of taper-pin cross-connect rack.
Fig. 11. LA plug-in relay panel for solder type cross-connects.
Fig. 12. LB plug-in relay panel for taper pins.
The No. 16-wire control wiring into cross-connects shall at no time be protected with a breaker larger than 10 A.

A 240-V, 3-phase delta bank is used for accelerator auxiliaries. The midpoint of one side of the delta between phases A and C is grounded as a power neutral. This system then gives 120 V for neutral to the A and C phase, as well as 240-V, 3-phase power. The A phase to neutral is always used for the control wiring that goes through cross-connects.

Whenever the 120-V control power originates from a small control transformer that is connected to a 480- or 240-V power circuit, the transformer is connected to the A and C phases. The 120-V side shall be phased the same as neutral to A phase of the control power used in other cross-connects.

The C phase to neutral should be used for single phase, 120-V auxiliary power to balance the total KVA used from the A and C phases. This power is not carried through the cross-connect terminals but is connected through the blocks at the bottom of the standard racks, and is used to feed such items as oscilloscopes and power supplies.

Westinghouse E frame breakers (15 to 50 A), in a standard O panel, are used to distribute power. Either single or 3-phase breakers are used and connected to the supply buses, BA panel, as required. (See Fig. 13.)

The load side of each O panel breaker is usually connected to the left side of one of the 12-point terminal blocks at the bottom of a standard rack with No. 10 wire. This allows a good wiring form to the breakers and leaves any wiring mess at the bottom of the racks. Most control power is fed from Heineman 5- or 10-A breakers in a P2 panel. Typically, when control power is required from a power circuit, the line side of a P2 panel breaker is connected to the load side of the A phase of the O panel used in the power circuit. This procedure then sets up a circuit similar to that shown on Fig. 3.

The load sides of several P2 breakers are connected to the left side of solder-type or to the rear of taper-pin type cross-connect blocks. This provides a convenient way of obtaining small amounts of control power at the cross connect for a new control circuit.

Normally there are seven 12-point GE terminal blocks (No. 642248-G12, type EB-5) at the bottom of each standard rack for wiring circuits up to 35 A, 3 phase, 240 V. These are numbered 01, 02, 03, 04, 06, 07 and 08, and follow the rack number. In general, block No. 05, lower left, is a solid copper block with screw terminals and is connected to the neutral of the power source. When it is necessary to run several No. 16 wires from a rack to cross-connect for miscellaneous controls, one or two of the GE strips may be removed and 32- or 52-point terminal strip (Western Electric No. 31-D) substituted. (See Fig. 1.)

When planning the power distribution to accelerator auxiliaries, scopes and miscellaneous chassis, consideration should be given to turning off all this power with one push button. Single phase, 120-V power is usually distributed by installing plug strips in the rear of each rack that may contain chassis. Special convenience outlets are installed in the front of racks that
Fig. 13. O panel rear view.
may feed temporary chassis or maintenance oscilloscopes. These plug strips and outlets are tied to P2 panels having ac power controlled by a suitable ac contactor; the contactor is controlled by a push button on the main control desk. This permits the operator to turn off all the equipment that would otherwise be left on but not used. It is understood that some power must be left on 24 hours a day and, therefore, would not pass through these specially controlled panels.

J. Portable Power Supplies

Portable power supplies may be used to energize the various auxiliary magnets required to separate and focus the secondary charged-particle beams from the Bevatron. Some of the dc power is supplied by installed cables from motor generator sets to multiple dc-outlet cans distributed throughout the experimental area.

Recently though, we have exhausted the possible space for MG set installations. We are now adding mag-amp and silicon controlled rectifiers for dc power. The supplies are considered portable.

Four-hundred amp plugs for 480-V, 3-phase power are being installed to supply power for the power supplies. There will be 33 of these plugs installed throughout the experimental area, making a total available power of 3,000 kVA. Several 60-A, 480-V plugs are also being installed.

More details regarding the dc power for auxiliary magnets can be found in reference 3.

K. Common Neutral Control System and dc Control

A control-power neutral system is set up and interconnected to provide a common neutral at all points in the building where it may be required. The neutral system is connected to the building ground system near the transformer location. This system allows a 120-V ac control circuit to proceed as a single No. 16 wire circuit from a breaker in one area through several interlock functions to a relay or light whose neutral is tied down at some other place in the building.

A single-wire ac-control circuit is satisfactory for wires less than 600-ft long between interlock functions. For circuits more than 600-ft long, the capacitive reactance between the wires in a multiconductor cable is low enough that it may cause trouble. The ac voltage from energized circuits will be coupled into circuits that should be dead. The practice of putting 3-W interlock lights after each control function to indicate its function tends to hold the shunt-load impedance low enough to minimize the series capacitance coupling. Because of this coupling, neon indicators without a shunt load are not satisfactory for the interlock chain lights.

If the size of the project requires control circuits longer than 600 ft, it would be advisable to evaluate the problem by making a special test using a typical control circuit on a sample cable or using 24- to 36-V dc for control. One pair of No. 22 wire used for each function would be economical for these longer circuits. The use of dc voltage would allow simple multiplexing of controls by the utilization of diodes and voltage-sensitive circuits.
III. COAXIAL CABLE SIGNALS

A. Historical

Early in the design of the Bevatron, it was recognized that coax cables carrying triggers and signals would play an important part in control. Tests indicated that a single coax grounded at different parts of the building might show stray signals as great as 3 V. It did not seem feasible to use insulated oscilloscopes in the Main Control room to view the multitude of signals planned, especially since dual-beam scopes were planned to conserve space.

It was found that signals remote from the Control room could be observed if two coax cables were used to transmit the signal and if a differential input were used on the oscilloscope. (See Fig. 14.) The noise level of these differential signals is about 1 mV.

Some signals, such as those from the rf tracking system, are sensitive to stray noises introduced into the circuit by the monitoring systems. These signals are viewed in the Main Control room on insulated scopes. Because the scopes are insulated, a single coax may be used to transmit the signal. The noise level of these signals on the oscilloscope is about 10 mV. The capacity to ground of the power transformer in the oscilloscope at the Main Control area can introduce noise in the shield of the cable; this transformer capacity may produce a noise signal on the oscilloscope but it does not necessarily affect the circuit being monitored.

The RG-62U coax cable is used for the majority of signals to be monitored; RG-62U has a copper-weld center conductor which is magnetic. Care should be taken to eliminate the possibility of noise generation when the cable is in a varying magnetic field. The more critical signals are sent over RG-9/U or Amphenol No. 21406 which is RG-63/U with two separately insulated shields. Most of the coax cables are of a permanent nature; therefore, Amphenol connectors in the 83 series were used. This plug is a rugged device and more economical than the quick-connect plugs.

A system of coax-cable trunk lines was installed that enabled signals and operational triggers from most parts of the building and from critical operations of the Bevatron to be monitored in the Main Control room. It was especially important to route signals from high radiation areas to the Main Control room.

The coax cables were brought to a group of racks near the control desk and are readily available for changes. Double-pole relays were installed in the same racks and are controlled by push buttons located near the appropriate oscilloscopes. This way, different signals could be set up at the main coax patch panel and easily viewed at the control desk by push button control. The differential input to the scopes required two relays for each signal to be monitored; shields and center conductors were switched.
Fig. 14. Differential input to oscilloscope to eliminate ground signals.
B. New Concept

As time passed and more signals were added to the monitoring complex, the original neat installation grew out of bounds and became an uncoordinated mess of coax cables. Temporary circuits for special experiments were mixed in with what should be permanent cables. Errors were made, and occasionally time was lost because of the confusion. A change in concept was in order! The new concept would relocate all permanent operational cables on new racks (C31 to C35) to the rear of the present exposed patch panels (C20-21).

The existing racks, C20 and C21, would be reserved mainly for signals to and from the experimental areas. The front patches of these racks would be considered temporary for a given experiment and a minimum of records would be kept for them.

Many trunk lines would be added to the experimental area. Some of these lines would carry a selection of standard timing signals to be available to the experimenters without having to make special arrangements for the signals.

The timing signals or pips are approx 50 V X 10 μsec triggers. Many transistorized isolation amplifiers were added so that trouble or short circuits put on a line by one experimenter would not affect the use of the signal by others.

The unused coax cables from the experimental area terminate on the patch panel C20-21 in the Main Control room. Appropriate trunk lines are available in the same racks to allow signals to be routed to the Main Control desk. Numerous other signals are available in these racks that can be patched out to the experimenters if required.

Several Tektronix 531 oscilloscopes are available in the Main Control room racks C83-85. These are to be used for special operational monitoring such as signals from the experimenters and for special beam control conditions.

We do not intend to describe the reasons for all the signals presented, but instead to give a general feeling of the complexity required to satisfactorily operate an accelerator such as the Bevatron.

C. Experimental Area and Signals

The experimental area covers about 28,000 ft² of floor space. Seven racks are located throughout this space so that any experimenter would not have to go more than 50 ft to obtain necessary signals to run his experiment. Each of the racks has ten different timing signals permanently patched to it. In addition there are eight RG 62/U and two No. 21406 double-shielded cables to carry special signals that may be required between the experimenter and the Main Control room.

In addition to coax signals, these racks are used for the termination of 32 conductor trunk lines to the main cross-connect. These wires
carry the various signals used for special beam programming features that are available.

Power at 480-V 3-phase, 240-V 3-phase, and 120-V 1-phase is available at these racks for use by the experimenters.

D. Construction Problems

Since coax patch panel space is at a premium in the Main Control room, we decided to use a panel that would hold 15 coax connectors horizontally across a 19-in. panel. We decided to stay with the 83 series connectors where possible, because they are far cheaper and more rugged than most of the smaller plugs.

When the 83 series connectors are spaced for 15 across the panel there is not enough room for T connectors, so a special H fitting was developed to connect two coaxes, one above the other. (See Figure 15.) This fitting is easily fabricated and installed in the panel. It allows a cable to be plugged into the rear and provides for one tap in the rear and two on the front of the panel. Two hundred and fifty of these connectors were required for the installation of the new system of cables.

E. Scope Signals

The original relays had given some contact problems for low voltage signals; we therefore decided to eliminate the separate relay panels where possible and to do most of the switching by using push buttons near the scopes. At the same time, we would increase the number of circuits to the scopes to 15 signals per beam. A compact 24-in. panel was developed (see Figs 16 and 17) that would accept a total of 30 differential signals, (+A, -B for each signal), 15 signals for each of two beams.

For this application it would have been impossible to bring 64 (60 input and 4 output) of RG-62/U cables to 83 series plugs on such a small panel; consequently, we turned to the use of Microdot miniature cables and Microdot miniature fittings.

Some compromises were made when it was required to tie these push button signal panels into the main coax patch panel. Many of the signals for the scopes in racks C07 and C08 would be used for signals showing the target positions. Since these signals all originate in adjacent areas, just a few -B signal cables were required to give the required differential signals.

To save cables and terminations, a special -B signal panel was installed near the scopes, thus saving many feet of cable and connectors on the main patch panel.

All of the +A input cables, and some of the -B connectors from the signal panels, were routed to the main patch panel to give flexibility for future signals.

A special fitting was designed to change from the Microdot cable to the 83 series connectors at the main patch panel.
Fig. 15. Special coax H fitting for a patch panel.
Fig. 16. Bottom view of oscilloscope signal switching panel.
Fig. 17. Top-rear view of oscilloscope signal switching panel.
To eliminate cross coupling of signals in the push-button panel because of contact capacitances, each signal was attenuated by a factor of 10 with a compensated divider network before the switch; the original signal is thereby isolated for other purposes. The switch then shorts out all the signals except for the one that is being looked at.

Direct current was used for the push-button lights, Model 17000, Switch-Craft, Inc. The light, though dim, is sufficient for reading labels and brightens when a button is pushed. See Figs. 18 and 19 for a rear and front view of the push-button stations after installation.

F. Oscilloscope Triggers

With 15 signals available for each beam of the dual-beam oscilloscopes (Tektronics 502), it was required to have several different triggers available for the sweep of the oscilloscopes.

A push-button panel, similar to the scope signal push-button panel, was used for the triggers.

Again, to save the number of cables between the scopes and the main patch panel a special trigger patch panel was built to the rear of the scopes. (See Fig. 20.) All of the triggers to be used were brought to this patch panel where they were then patched to the trigger push-button panel for each scope. Each scope then has the capabilities of 15 different triggers.

Locating the trigger selecting patch panel in the rear of the racks should not be a hardship since the patches would seldom require changing.

G. General Oscilloscope Monitoring

The four, two-beam scopes in rack C07 and C08 (Fig. 19) are equipped with the push buttons for signals as described above. These scopes monitor the target position signals and a few other signals that may be viewed from time to time. Care must be taken with these scopes when calibration of the signal is required, since there is a 10 to 1 divider in the push-button panel.

The two scopes in rack C09 are for the injector system and are normally left on one set of signals. Push-button control panels are provided above the scopes to select the signals to be displayed. These control panels energize relays at the injector in order to select signals. The power to the relays also simultaneously controls the position of beam interceptor cups, if they are required to monitor the beam at various positions in the injector system.

The scopes in rack C10 have no push-button controls for their signals because these scopes are used almost exclusively to monitor magnet voltage and current. A small patch-panel above the scopes allows special signals to be brought over from the main coax patch panel.

The three Tektronics 531 scopes in racks C11 and C12 are connected into the rf tracking and beam monitoring signals, and they aid in obtaining the best operating conditions of the Bevatron.
Fig. 18. Rear view of coax signal switching panel after installation.
Fig. 19. Main control room oscilloscopes.
Fig. 20. Special micro-dot cable trigger selector panel.
IV. SPECIALIZED CONTROL CIRCUITS

A. Smoke Detectors and Explosive Gas Alarms

We need smoke detectors and explosive gas alarms for the many pieces of electronic equipment, motors and oil-filled machines that are located in high-radiation areas.

During liquid-nitrogen trap-filling times—about every two hours—a general inspection is made of these remote areas. Even with these frequent inspections there is always the threat of a fire that would prove disastrous if not detected early.

Because we desire immediate warning of such a fire, the best type of detector seemed to be combustible product detection. We installed a detection system produced by Pyr-A-Larm, which seems to be the system best suited for our purpose.

In the event of a detected danger, a steady blast on the Klaxon alarm is sounded in the Main Magnet room. There are also area indicator signals visible to the operator.

Several fire or emergency reporting stations are located in the experimental area. These stations are phones in red colored boxes that automatically turn in a local fire alarm when taken off their hook. The Control Room operator is then in communication with the person turning in the emergency alarm.

Liquid hydrogen and propane are used in some of the secondary beam targets and particle detectors. These two gases cause two different hazards in the experimental area. Propane is heavy and may settle in trenches, pits, and similar depressions. Heavy concentrations of this gas could not only cause asphyxiation but also present an explosion hazard. Proper forced ventilation should be provided. Hydrogen, being light, presents explosion hazards in the vicinity of and above those devices using the liquid hydrogen. Extreme care is taken in using these gases, and most industrial precautions are taken. A special committee has been formed that must approve all uses of these gases.

Permanently located tubes have been run into various parts of the building where the gases may be used; there are, however, provisions to extend these tubes close to the source of the gas when necessary. An explosive gas sampler, located in the experimental area, draws a continuous sample through all the tubes, and samples each tube in its turn every four minutes. If an explosive mixture is detected, an alarm is given in the Main Control room. The alarm is a modulated blast on a second klaxon horn.

B. General Alarms

Alarm panels are mounted in the Main Control room to alert the operators when any abnormal condition exists that needs attention.

Some of the conditions that give alarms are

(1) building water and air pressures,
(2) cooling water pressures and temperatures,
(3) magnet cooling and temperatures, and
(4) vacuum system pressures.

The alarms are operated from the general 120-V ac auxiliary power, and the functions are normally connected through contacts that are closed for normal operating conditions. When the contacts open, an alarm bell rings and a light flashes signaling the faulty condition. A button is provided for silencing the bell, but the light remains steady until the condition is remedied. The flashing light then indicates a new incoming alarm even when several other alarm conditions are already indicated on the panel.

Our present alarm system resets automatically when the condition clears; it does not maintain a signal to indicate which alarm circuit was in trouble. We are now considering an alarm panel (X4) designed by J. Shand that will maintain a signal even after the condition that sets off an alarm clears. The operator may reset the indication when he so desires after the trouble is remedied (see Figs. 21 and 22, and Appendix O).

Any alarm system depending upon ac power for the alarm issues false information should there be a loss of power to the alarm panel. Consequently, we have an additional alarm function that takes its power from the dc batteries of the PAX phone system. This additional alarm is sounded if the ac power to the main power panel or any sub-alarm panel is interrupted. The operator then knows that the main alarms are out of commission.

C. Stray Currents in the Building

Any varying magnetic field will induce voltages in anything that may be present as a conductor and encloses the changing magnetic field.

Recently 6-in. aluminum pipes were added around the periphery of the Bevatron building to carry additional cooling water for the auxiliary magnets. To minimize corrosion problems the aluminum pipes were not grounded.

After some time this pipe accidentally became grounded near the water towers; this left the other end of the pipe with an induced voltage of about 3.2 V whenever the main Bevatron magnet was pulsed. This occurred even though the maximum stray field was only approximately 100 G. The free end of the pipe was in the hydrogen hazard area of the 72-in. bubble chamber. When this end of the pipe was also accidentally grounded, about 200 A flowed causing considerable sparking in a hazardous area.

The final solution to this problem was to ground the aluminum pipe at every possible location; even so, some sections still carry about 200 A every time the magnet pulses. Apparently this current is relatively harmless, since it exists where there is plenty of cooling available.

In the meantime, the pipes are periodically inspected for corrosion from the interaction of aluminum with copper pipe.
Fig. 21. X4 alarm panel front view.
Fig. 22. X4 alarm panel rear view.
D. Beam Operation Indicator

Some of the other buildings such as the chemistry building at the Lawrence Radiation Laboratory have low-level counting experimenters in progress. The accuracy of the recorded data can be modified because of the stray radiation from the Bevatron. To aid the experimenters, a counter turn-off gate is generated at the Bevatron for the duration of the acceleration cycle when all other conditions are set up for particle acceleration. This gate can be used to turn off the counters for those special experiments where the radiation flux from the Bevatron is significant. Originally this gate was sent out as a radiated rf signal on 166 Mc with appropriate receivers where required.

This system proved unreliable and has led to a far simpler method of disseminating this signal throughout the project.

There is a common set of public-address-system wires available in all buildings at the Laboratory. By using appropriate isolation transformers out of the amplifiers it is possible to bias these wires with respect to ground by the gate signal to provide an easily available method of gating required counters everywhere on the Project. The public telephone system has spare pairs available in all the buildings that would also be usable for such a gating system. The charge for the use of these lines would be very reasonable.

E. Illuminated Signs

In the Bevatron there are many occasions when lights are required for warning personnel of particular hazards. Simple flashing lights are not sufficient since there are so many different hazards. We now have a sign that combines flashing lights and illuminated wording that should indicate clearly what hazard exists (see Fig. 23).

F. Flip Targets and Travel Targets

The Bevatron operation requires rapidly moving targets that are timed to intercept the accelerated proton beam at the energy required by the physics experiment. The operation of these targets is controlled by two coils in the main magnetic field and mechanically coupled with a pentagraph mechanism to the target lifting device. These coils are displaced 90° from each other on the axis of rotation of the coils. One coil is energized to drive the target into the raised position; the impedance of the second coil is controlled to act as a dynamic brake to limit the accelerating forces on the target.

Time delay and gate chassis are used to control the precise time that a target is energized and raised into position. The time delay section is used to time precisely when the target starts to rise; the gate length is used to adjust the time that the target stays in the raised position. Sometimes the adjustments of the target timing and rf beam tracking are made to intercept only part of the accelerated beam. This adjustment allows more than one experimenter to use a particular Bevatron beam pulse, and is particularly useful when each experimenter cannot use the total number of accelerated protons in each Bevatron beam pulse.
Fig. 23. Illuminated warning light.
The position of the target (down, in flight, or in the raised position) is displayed as a signal on an oscilloscope. Microswitches mounted on the target assembly provide the signals for the position indications.

The location of a target in the Bevatron magnet must be changed from time to time to accommodate the requirements of different physics experiments. This relocation of the target has in the past required a vacuum shutdown. Someone must then go in between the pole tips of the magnet and physically move the targets. It is expected that after January, 1963, the Bevatron beam will be so intense that it would not be feasible to go into the magnet gap to change targets. The induced radiation in the iron of the magnet would require a long delay before a person would be allowed to make the change.

It was because of the induced radioactivity in the iron of the magnet and the time lost to pump the tank to operating pressures that the design of a travel target was undertaken.

A track system has now been designed that will allow positioning of a target from the main control room. This system also will incorporate an air lock so that targets can be withdrawn from the main vacuum tank without letting the tank to air. The installation of this travel target system has been completed.

Kenneth Stone (Mechanical Engineer), Robert Force (electrical Engineer), and Felix Caldera (Electronics Coordinator) are responsible for the design and installation of the target control system. A detailed report of this system is not now available.

G. External Beam Magnets and Control

At the beginning of the Bevatron acceleration cycle large radial and vertical oscillations cause the orbit of particles to take up most of the available volume in the tank. When the particles are near their final energy these oscillations have damped down to about 1/6 of their original vertical magnitude and 1/12 of their original horizontal magnitude with a resultant decrease in the cross section of the tank required.

A stationary magnet designed to provide the necessary radial force to eject the proton beam at final energy would have to have a large gap and throat in order that it not intercept the beam at low energy. It would be necessary to pulse the magnetic field of a stationary magnet in a very short time if the extraction of the beam were to be successful. The combined problems of a large magnet and pulsed field make this method of beam extraction rather impractical.

The method of beam extraction to be used on the Bevatron is known as the Piccioni type (see Ref. 5). A thin target is brought into position and the beam allowed to pass through it; in so doing the beam loses a small amount of energy. This decreased energy beam then travels on a smaller radius orbit with a large radial oscillation. The first of two internal sets of magnets is placed downstream from the target on the inner radius so that the perturbed beam will pass between their gaps. This first set, a bending magnet M1 and a quadrupole singlet Q1, is located in the east tangent tank and bends the beam further inward.
The beam then enters the second set of internal magnets, M2 and Q2, located in the south tangent tank. This set of magnets is larger than M1 and Q1 and bends the beam toward the outer radius of the machine where it emerges from the Bevatron through a thin window of 0.020-in. Al.

A third set of magnets, M3 and Q3, is located on the outside platform of the west tangent tank. They give the external beam a further outward deflection so that the beam will leave the shielding wall in the desired location. Doublet quadrupole Q3 focuses the beam to two points just outside the shielding wall.

Magnets M1, Q1, M2 and Q2 cannot be left in a fixed position. These magnets must be out of the way of the injected beam and then, just before they are used, moved into position near the envelope of the high-energy beam.

Magnets M1 and Q1 weigh 300 lb and 40 lb. They require peak power of 100 kW and 45 kW respectively; the power supplies for these magnets are rated at 185 kW and 78 kW peak power.

Magnets M2 and Q2 weigh 4500 lb and 400 lb. They require a peak power of 180 kW and 65 kW, respectively; the power supplies are rated at 260 kW and 105 kW peak power.

These magnets are moved into position with two sets of high-pressure oil-operated plunging systems. There are two classes of motion involved: one a fast drive--30 in. of travel in 0.75 seconds--to move the magnets from their retracted positions to a position near the beam at high energy; the second a slow speed drive--2 inches in one second--to keep the magnet near the envelope of the beam as it slowly contracts in the later stages of acceleration. This slow motion is applied only to M1 and Q1.

The linear motion of these two systems is controlled by a predetermined program that uses mechanical-servo valves in a high-pressure oil system.

The magnets were designed to be as small as possible to minimize the amount of mass that had to be moved (plunged). The magnet cooling requirements are based upon pulsing the magnetic field. The duty factor used is about 50%. The pulsed operation is obtained with magamp controlled rectifiers which are shunted with 10% power transistors for fast response.

The external deflection system is designed to extract a beam at any energy from 3.0 BeV to about 6.3 BeV. For this range of energy it is required that the currents in all three sets of magnets be programmed or otherwise controlled to within about 0.1% during each pulse. Then, experimenters requiring a different energy of beam could share the beam during a single Bevatron pulse; this, of course, assumes that each experimenter does not require all of the available beam.

The precise control of the current in the deflecting magnets could not be done with the magamp regulators alone. The magamp regulators are used for a first order program; further accuracy is obtained by the use of transistor regulators that bleed a maximum of about 10% of the magnet current through a load in parallel with the magnets. The internal impedance of
the power supplies has been made high enough for these shunt regulators to function properly. M3 and Q3 Magnets will use silicon controlled rectifiers.

Each of the magnets (seven in all) will be powered with its own regulated power supply. The precise control of the current will be made with a curve corrector that allows the current in each magnet to be independently programed.

The precise position of the plunging magnets relative to time is controlled by an open-loop system. It is thought that this open-loop system will be stable enough once it is adjusted. The plunging magnet monitoring has been so constructed to make this a closed-loop system if required.

The successful operation of the external-beam program has depended upon many persons. The design parameters have been set up by Dr. W. A. Wenzel. The mechanical engineering has been headed by Jack Gunn. The electrical engineering has been led by Pierre Pellissier and Terry Jackson, and the electronics coordination by Chester Pike and Jack Kelso.

H. Communications

The local communications within the Bevatron are handled in several different ways depending upon the requirements.

We have installed a 50-line PAX (Public Automatic Exchange by Automatic Electric) dial-telephone system that is connected to all major parts of the building and to special equipment. This is powered by a 24-V storage battery which allows communication in case of building power failure.

A transistorized public-address system is used for general paging and is operated from the PAX storage battery. For emergency operation it is vitally important to have good communications throughout the building.

The PAX system also has facilities for a conference call line and right-of-way phones. In addition to the above, there are other systems that provide local area paging and direct communication between experimenters and the Main Control room. Another system of general intercom is provided so that experimenters can plug headsets into a generally available system of boxes, thus releasing the PAX line finders where direct communication is used for an extended time.

I. Cranes

In buildings such as ours it is sometimes convenient to control the cranes from a position on the ground. High radiation in the upper part of the building is one reason. Also, in the case of a short lift, it takes less time to make a lift than it does to get a man up to the crane cab.

One of the cranes in the circular part of the building has a pendant control. When the crane is operated from the cab the pendant is lifted clear of all obstructions. The crane in the annex of Bldg. 51 is also equipped with a pendant control as well as a radio link so that the crane may be guided from the ground over obstructions too high for pendant control.
J. Magnetic Field and Vacuum Tank Problems

A magnet with a varying magnetic field must have many insulated joints to prevent excessive eddy currents. Small loops near the main accelerating gap of only a few tens of amps will disturb the accelerated beam.

In the case of the Bevatron vacuum tank there are many places where it would require the failure of only four insulated joints to cause several thousand amps to flow. See Appendix P for the radial-bar and corner-bar short-circuit calculations; this is only a typical example, as there are other types of construction shorts that can cause similarly high short-circuit currents.

The quality of these insulated joints is not high; in fact we are forced to run with several of these joints shorted because of the effort required to get to and repair them.

We have installed a continuously operating ohmmeter alarm system to monitor about 120 of these critical joints on each quadrant. The magnet pulsing is interrupted if enough joints short out to cause all four alarm lights to come on...

Because filings and other metallic debris can cause these shorts we are especially cautious about clean housekeeping during the progress of any work in the building. See Appendix Q for special instruction for work in the vacuum tank proper.

K. Pole Face Windings

There are 21 windings on the tips of the Bevatron magnet. Each winding is run circumferentially to the magnet and located every 3 in. radially across the tips.

At present, currents are caused to flow in the pole face windings in a self-energized way. The various currents are adjusted to modify the slope of the magnetic field vs the radius of the Bevatron magnet. These adjustments are required for the Bevatron beam to better utilize the radial width of the magnet.

In the near future a new method will be used to power these windings. The new system will use an external power supply with adjustable resistors and inductances to better isolate the influence of the current in one winding upon the currents in other windings:

A special set of pickup loops and equipment is used to measure the slope of magnetic field \( n = \frac{dB}{dr} \) when adjusting these currents.

Some of these windings will also be used with a transistorized power amplifier to minimize the magnetic-field ripple in the center of the gap. (A future report will describe this system.)

These systems that control currents or feed additional power into the pole face windings must incorporate a means of limiting the current in case of a ground fault. Also if there is an indication of ground current the Bevatron magnet must be stopped from pulsing and the additional power sources to the magnet turned off.
In addition to the above soft ground protection and alarm circuits there are relays in series with the grounding circuits of the pole tips and waterfalls. The later relays are called serious short alarms and are located in the boxes with the ohmmeter alarm system for the vacuum skins. The serious short alarms also stop the Bevatron magnet pulsing and turn off any power sources that can feed power into the gap of the main magnet.

L. Special Power Supply Specifications

The "General Specifications for Power Supply Equipment" are included in Appendix R. These specifications apply to the major points to be considered when purchasing any power supply; an additional set of specifications are required to detail the specific power-supply requirements and other important considerations. The following list enumerates some of these further considerations:

1. When specifying the required input voltage be sure to specify the maximum line-to-line short-circuit current available or expected. This influences the required interrupting capacity of the power line breaker and magnetic contactors.

2. When specifying the input power circuit be sure to consider the use of a line disconnect that can be locked off with a key.

3. When specifying the output voltage of the power supply be sure to specify the voltage insulation level required of the secondary voltage. At times it is required to have voltage to ground insulation many times greater than the output voltage of the power supply. Never should the secondary windings and circuitry have a rated voltage insulation level of less than 600 V to ground.

Power supplies purchased for a research laboratory are quite frequently used for purposes other than the original design. A minor addition to the original specifications may add little if any to the cost of the power supply but may be very important under some other design use.

4. Transformer primary and secondary shields can be very important. The presence of the primary shield may eliminate unwanted 60 cps and higher harmonic signals from secondary circuits. These voltages capacitively coupled from the primary windings to an isolated secondary circuit can be very annoying and sometimes disastrous to low voltage transistor circuits and high-gain amplifiers.

Secondary shields are especially important when secondary circuits are biased at voltages greater than the primary voltage. If this secondary-bias voltage is susceptible to transient sparking these transient voltages may be coupled capacitively or magnetically to the primary circuits.

For the original use of a new power supply we may not require these shields but later we may require their presence. The cost of putting both shields in at the beginning will usually be very small.

5. The use of reverse polarity diodes may seem desirable to save construction problems, but we are trying to eliminate them because they increase the stocks required for repairs. The reverse diodes are normally not well identified as such and can cause error when we replace a faulty diode.
(6) We have found frequently that the lifting rig of the power supplies designed for oil filling on the customer's premises may not be designed to lift the power supply including the added weight of the oil. This should be carefully noted when specifying this type of equipment. We always want to be able to safely move a power supply without draining the oil.

(7) When water-cooled solid-state diodes are used they should be mounted in water-cooled blocks so that an individual diode may be easily removed without interrupting the water flow. The water flow passages in the cooled blocks should be so arranged that they can be cleaned with a wire brush if required.

(8) Most power supplies that have short-circuit secondary currents of 50 A or more are designed with some sort of high-impedance ground-current circuit that limits peak current in case of a secondary fault to ground. Overcurrent relays are installed in this circuit to turn off the power supply. Unless specifically permitted, the secondary circuits so isolated should have no other components, such as capacitors, connected from the secondary circuits to the frame ground.

(9) The layout of parts to facilitate maintenance procedures and identification is very important. One should not have to dismantle many components to change a single small part.

(10) Power supplies that are considered portable and are connected with 240 V or 480 V plugs carrying 100 A or more should be equipped with interlocks that prevent the plug from being withdrawn when load current is flowing. Whenever possible the interlocks should disconnect the power source to the plug when the cable plug is partially withdrawn.

(11) It is sometimes necessary to use jumper cables and plugs to interconnect chassis or other larger racks. To make it easier to stock spares, the following precautions should be seriously considered:

(a) The plugs should be wired 1-to-1 or A-to-A and not mixed up.

(b) The plugs on each end of the cable should be of the same type and number of pins, with male and female plugs on the respective ends of the cable.

(c) All pins in the plug should be wired in the cable with no pins left blank.

(d) There should be no wires in the cable plugs to create a short between pins. If parallel wires are required, make these jumpers in the chassis or racks involved.

(12) Be complete when specifying the rating of the output of a power supply. For instance, when a power supply is rated for an output of 0 to 100 V at 100 A it might imply that the intended load is a constant current device. The power supply might be designed to deliver 100 A at 1 V but could not be lowered to 1 V at a load current of only 10 A. Extreme care must be taken to fully outline the intended use of the power supply.
(13) The wiring in electronic equipment should have fire retardant insulation. Some hookup wires have a nylon abrasion coating that makes even PVC wire very inflammable.

(14) We prefer bunched tinned wire to solid wire; it forms like solid wire but is resistant to nicking the same as stranded wire.

The items above and some of those in the general specifications, Appendices R, S, T, U, V and W may seem redundant or unnecessary, but they are an outgrowth of our various sad experiences with manufacturers of electronic equipment. We feel these are serious points to be included in specifications if we want to have a minimum of difficulty in misinterpretations of our requirements.
ACKNOWLEDGMENT

The control circuits as described herein are obviously the results of ideas and suggestions from many persons and have evolved over several years.

The following persons have each in some way contributed to the present system: Charles Park, James Shand, Warren Dexter, Gerald Wilson, Marion Jones, Henry Cutler, Jack Kelso, Felix Caldera, Warren Howe, Frank Haubrock, Paul Breitenbach, Harold Vogel, Wesley Rutz, Don Milberger, and many more.

REFERENCES


V. APPENDICES
WIRE #16 FLAMEOL

REAR VIEW

FOR ASSEMBLY SEE Dwg. Z1004
SUPERSEDES Dwg. C1001

SUPERSEDED BY Z3901

8 1/4 PANEL

22 AMP CONTACTOR (3 UNITS)

SCHEMATIC

REV. & REDRAWN

ARCHIT. 1/1/44 Z1012 C
Panel at 10 1/2"
IAC overcurrent relay panel
drawout type
two units
with instantaneous trip

Wire #16 Flamenol

Drawing list
Z5551 schematic
Z5534 panel details 1 req'd.
Z5562 T.S. Mtg. Bracket 1 req'd.

Note: Connections as originally purchased & changed as shown.

Material

APPENDIX C: STANDARD AT 2 PANEL

MUB-1422
APPE N DIX D, STANDARD C (4) PANEL
APPENDIX E. BEVATRON PRINT FILES
(See example sheet next page)

File I 51 EM Located in Bldg 51 Rm 16
File I MG Located in Bldg 51 MG Rm
File II Located in Bldg 64 Rm 207
File III Located in Bldg 64 Rm 213

(1) File III is available in Bldg 90 for engineers and coordinators. Any engineering changes or short-form write-up changes to these prints are to be circled and marked 90C-1, 90C-2, etc., instead of the familiar EOC-1, etc. The first three columns of the stamp on the front of the print are to be filled with the 90C-Number, the number of times that the change appears on the print and the date and initials of the person who originated the change. See last sheet of this note for examples. The change is then to be listed on the clip board which will be kept near the file so that the change can be transferred to other copies of the print. In the case of "long-form" write-ups, prints listed are to be designated BC instead of present BD and File I copies will be marked up immediately, instead of waiting for completion of work. (Long-form write-ups do not need to be indicated on the clip board.)

(2) File II is available in Bldg 64 for use of engineers, coordinators and maintenance men. Any engineering changes or short-form write-up changes are to be marked 64C-1, etc., and indicated on a clip board. Long-form write-ups will follow the same pattern as for File III prints.

(3) File I 51 EM is found in Rm 16, Bldg 51; prints in this file will be marked up to show expected long-form write-ups immediately instead of at the conclusion of work on the write-up. When print is marked up, the first three boxes of the stamp on the outside of the print and the column headed "conveyed by" will duplicate the information in these columns on the File II and File III prints. The column headed "Date Completed" is to be filled out by EM to indicate the actual date on which E.I. completed work on a long-form write-up; for engineering changes or EM changes this column is to carry the date on which the change was made, or crossed out if time is not important. Field changes which are originated on File I prints either by EM personnel, engineers or coordinators are to be marked EMC-1 the same as at present, and indicated on clip board.

(4) File I MG will be found in the Bldg 51 MG Control Room. Long-form write-up procedure will follow the same pattern as File I EM. Field changes are to be marked MGC-1, etc., to differentiate them from those originated elsewhere. To expedite this system change, File I prints are now being marked up to show all current information on the File II prints.

(5) When a write-up is complete and the date completed column of the EM print is filled, the information must be transferred to the File I and File II prints.
### APPENDIX E. EXAMPLE SHEET

#### FILE II OR FILE III - TYPICAL

<table>
<thead>
<tr>
<th>Write up No. eng. change</th>
<th>Times shown</th>
<th>Changed by</th>
<th>Date completed</th>
<th>Conveyed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>B6-47</td>
<td>2</td>
<td>6-8-60 C. J.</td>
<td>6-17-60</td>
<td>6-10-60 A.R.</td>
</tr>
<tr>
<td>90C-1</td>
<td>1</td>
<td>6-17-60 C. J.</td>
<td>6-21-60</td>
<td>6-18-60 A.R.</td>
</tr>
<tr>
<td>B7-62</td>
<td>3</td>
<td>6-19-60 C. O. P.</td>
<td>6-20-60</td>
<td></td>
</tr>
<tr>
<td>64C-1</td>
<td>1</td>
<td>6-24-60 C. O. P.</td>
<td>6-23-60</td>
<td>6-23-60 A.R.</td>
</tr>
<tr>
<td>EMC-1</td>
<td>1</td>
<td>6-23-60 C. O. P.</td>
<td>6-25-60</td>
<td>6-25-60 A.R.</td>
</tr>
<tr>
<td>MGC-1</td>
<td>2</td>
<td>6-25-60 C. W. P.</td>
<td>6-26-60</td>
<td>6-26-60 A.R.</td>
</tr>
</tbody>
</table>

Typical changes from Bldg. 90 on File III Prints

Typical changes from Bldg. 64 on File II Prints

Typical changes from EM as marked on File II or III

This column to be initialed and dated when changes are transferred to other files.

#### FILE I EM

#### FILE I MG - TYPICAL

<table>
<thead>
<tr>
<th>Write up No. eng. change</th>
<th>Times shown</th>
<th>Changed by</th>
<th>Date completed</th>
<th>Conveyed by</th>
</tr>
</thead>
<tbody>
<tr>
<td>B6-47</td>
<td>2</td>
<td>6-8-60 C. J.</td>
<td>6-17-60</td>
<td>6-10-60 A.R.</td>
</tr>
<tr>
<td>90C-1</td>
<td>1</td>
<td>6-17-60 C. J.</td>
<td>6-21-60</td>
<td>6-18-60 A.R.</td>
</tr>
<tr>
<td>B7-62</td>
<td>3</td>
<td>6-19-60 C. O. P.</td>
<td>6-20-60</td>
<td></td>
</tr>
<tr>
<td>64C-1</td>
<td>1</td>
<td>6-23-60 C. O. P.</td>
<td>6-23-60</td>
<td>6-23-60 A.R.</td>
</tr>
<tr>
<td>EMC-1</td>
<td>1</td>
<td>6-24-60 D. J. M.</td>
<td>6-24-60</td>
<td>6-24-60 A.R.</td>
</tr>
<tr>
<td>MGC-1</td>
<td>2</td>
<td>6-25-60 M. W. V.</td>
<td>6-26-60</td>
<td>6-26-60 A.R.</td>
</tr>
</tbody>
</table>

This column is to be filled in by EM with the date on which the work was actually completed for long form write ups. For other changes it is to be left blank or dated the same as the last column.
APPENDIX F. ELECTRONICS ENGINEERING DRAWING NUMBERING SYSTEMS

In recent years various Electronics Engineering groups, such as Data Reduction and Nuclear Instrumentation, became involved in very complex systems that required a great many drawing numbers to be assigned to the various units comprising a system. It was determined that some method of simplification would be necessary for numbering in order to tie the units together as a system. The different needs of the various groups have led to the formation of three separate methods of numbering. As some confusion now exists regarding these systems, an outline of each follows.

1. The Original System (still being used by the majority of EE groups).

a. Drawing Number Breakdown Example

<table>
<thead>
<tr>
<th>GROUP CATEGORY</th>
<th>SERIALIZED NUMBER ASSIGNED TO DRAWINGS</th>
<th>CHANGE LETTER (INDICATING FIRST REVISION) I AND Q ARE OMITTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>9Y</td>
<td>243</td>
<td>A</td>
</tr>
</tbody>
</table>

This is the drawing number that is used to identify and tie together a unit. The system as originally set up used the schematic as the key drawing. This is the number that appears stenciled on the final unit when completed by the shops.

Anyone desiring to have built or to build a similar unit has only to know the schematic number. The schematic in turn refers to a parts list drawing number. This appears in the title block under "shown on." Upon investigating the parts list, it will be discovered that besides listing all the parts, such as resistors, capacitors, etc., it also includes a drawing list. This list includes assigned drawing numbers for all drawings necessary to build a complete unit. In the case of a unit that is purely a fabrication without a schematic (e.g., a bus panel), the assembly drawing becomes the key drawing for locating the individual fabrication drawings that make up a complete unit. No separate parts list is used. Parts and drawings are listed in a block in the upper right hand corner on the assembly drawing.
2. Data Reduction Numbering System

a. Drawing Number Breakdown Example

GROUP CATEGORY

SERIALIZED NUMBER (ONE ASSIGNED ALL DRAWINGS IN THE SYSTEM)

DRAWING SIZE

7V 389 1 - 00 - A

CHANGE LETTER (INDICATING FIRST REVISION) I AND O ARE OMITTED

NUMBER ASSIGNED INDIVIDUAL DRAWINGS IN THE SYSTEM ( KNOWN AS A "DASH NUMBER")

b. Key Drawing Number

This is the number used by Data Reduction to identify and tie together an entire system.

This system uses a print or drawing list as the key number, (e.g., 7V3891 Print List). This print or drawing list includes all the units comprising the system under the same number, but with dash numbers assigned to the various units comprising the system. (e.g., 7V3894-6 Relay & Register Unit). Note that the arrowed digit indicating the drawing size has been changed to "4." This is the size of the drawing for this particular unit, and the drawing will be found in the tracing file under this size. Dash numbers will continue to be added to this print list as the system is being developed. When the system is finally in operation, this print or drawing list will be the key for tying the system together for future servicing or possible duplication of the system.

3. Nuclear Instrumentation Numbering System

a. Drawing Number Breakdown Example

GROUP CATEGORY

SERIALIZED NUMBER (ONE ASSIGNED ALL DRAWINGS IN A PARTICULAR SYSTEM)

DRAWING SIZE

10X 101 2 - M - 1

THE FIRST DRAWING OF THE TYPE INDICATED BY CODE LETTER (KNOWN AS "DASH NUMBER")

TYPE OF DRAWING (SEE CODE BELOW)

Code for types of drawings:
A - Assembly (Mechanical)
B - Block Diagram
C - Component List (Formerly called Parts List)
D - Description & Instructions
E - Etched Wiring
b. **Key Drawing Number**

This system uses the print or drawing list number to identify and tie together all units comprising a system.

All units are listed on the print list using the same serialized number but with variations in drawing size, code letter and dash number. However, this group is mainly concerned with smaller "systems-type units", such as a bin and its associated plug-in printed circuit boards that perform a particular function. The bin with its power supply and associated wiring has its own schematic, parts list, and fabrications. The printed circuit boards, however, cannot be considered as actually being part of the bin because they plug in and are removable. Therefore, the printed circuit boards have their own individual schematic, parts list, and fabrication drawings. But in order to tie together the bin and its associated printed circuit boards that are performing a particular function, it is again necessary to resort to the print or drawing list as the key drawing. This is the number that should be stenciled on the bin.

**DEFINITIONS:**

Unit - A single, complete assembly (e.g., Ion Gage Power Supply Panel).

System - A group of units tied together to perform a particular function.

Systems-type Unit - A unit with a plug-in circuit or circuits used to perform a particular function (e.g., a bin and its associated printed circuit boards).

**PLEASE NOTE:**

In the future, all Electronics Engineering groups requesting a drawing number by telephone for an interim drawing are asked to substitute a zero in place of the drawing size number, as it is not always known what Drafting will assign as a final drawing size. (An interim drawing is a drawing or sketch of a temporary nature that has not yet been made into a formal production drawing by Electronics Drafting.) This will serve to indicate if the drawing is interim or a final production drawing now in Drafting's possession.

If there are any questions regarding the above, call Electronics Drafting at Extension 5558.
APPENDIX G. INSTRUCTIONS TO BEVATRON COORDINATORS AND ENGINEERS

The shortage of experienced electronics maintenance men has forced the Bevatron coordinators and engineers to devote much of their time to jobs that should be handled by the EM group. This unfortunate circumstance has existed for some time but it should not be considered the normal way of doing things at the Bevatron. It is up to the engineers and coordinators to find ways to expedite the learning period of EM men. Prints for new circuits should be very complete with detailed instructions.

It has been pointed out that the detailed wire-to-wire checking of write-ups by EM has been redundant because, thanks to the accuracy of the Installation shop, relatively few wiring errors are found. In the future the EM crew will be allowed to skip the detailed checking and proceed more directly to firing up the circuit and checking for operation.

This type of circuit checking puts the responsibility on the person firing up the circuit to acquaint himself thoroughly with its intended operation. During the course of checking out the system all interlocks, overloads, and signals should be checked for operation to be sure of proper circuit functioning.

Because not everyone will have the opportunity to fire up each circuit it is then the responsibility of the coordinator or engineer requesting the change to give the proper instructions. He should describe the reason for the change and give any special instructions for testing the circuit.

These instructions should be placed on the first page of the write-ups as a description and explanation of the change. If the instructions may be required at a later date when the installation has been completed, they should appear on the prints involved or as a separate design and engineering instruction sheet.

At times certain critical circuits will require more detailed checking by the EM. When this is the case, it will be up to the engineer or coordinator to designate clearly on the write-ups the special precautions to be taken. Don't take anything for granted.

The responsibilities of the EM extend beyond the checking out of new circuits. They are expected to take the initiative in looking for trouble in the circuits. This should help minimize the emergency repairs that are the normal occurrence at present.

For new (or old) EM to do effective preventative maintenance service they must be supplied with all of the information available about the various controls. At present the detailed information on the various electronic circuits is spread among several of the engineers and coordinators with different individuals specializing in certain main functional circuits. Only the highest quality of EM men can be expected to be an expert in all phases of the various controls, but we can at least help more than we have by issuing better instructions instead of letting ourselves be "built into the circuits." More and better written instructions should help eliminate those disturbing telephone calls in the middle of the night.
A certain amount of reasonable discretion is expected on the part of the EM crew leader, but if a particular trouble is not isolated within a half hour or so then he would be expected to call for help. A call under these conditions should indicate that there has not been sufficient training or written instructions to cover this special trouble. The person called should take steps to be sure that the required information is passed on to all crews in some written fashion.

**Sketches**

Sketches are generally for use within the group. However, occasionally they are handy for small jobs in the Electronic Installation Shop, Sheetmetal, or the Machine Shop; in this case they need a title, job number, the engineer's name and the date.

Sketches should be on tracing paper so that the engineer can keep the original tracing.

**Prints**

Prints are for use as construction as well as maintenance drawings.

The following is a suggested list of items which should be included on a normal schematic -

<table>
<thead>
<tr>
<th>Item Type</th>
<th>Required Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>item number, voltage, polarity</td>
</tr>
<tr>
<td>Capacitors</td>
<td>item number, capacitance, voltage, polarity, if any</td>
</tr>
<tr>
<td>Crystals</td>
<td>item number, type</td>
</tr>
<tr>
<td>Inductances</td>
<td>item number, inductance, current rating or resistance</td>
</tr>
<tr>
<td>Lamps</td>
<td>item number, voltage</td>
</tr>
<tr>
<td>Potentiometers</td>
<td>item number, resistance, power, rotation, taper if not standard, function, symbol if screwdriver adjust</td>
</tr>
<tr>
<td>Plugs</td>
<td>item number, where connected or function. Use PG1 for ac power</td>
</tr>
<tr>
<td>Resistors</td>
<td>item number, resistance, power, tolerance if better than 5%</td>
</tr>
<tr>
<td>Relays</td>
<td>item number, coil voltage, contacts to be wired to TS in sequence: open, closed swinger.</td>
</tr>
<tr>
<td>Transformers</td>
<td>item number, all winding voltages, and usually currents, mfr's type number and polarity if required</td>
</tr>
<tr>
<td>Pulse transformers</td>
<td>item number, polarity</td>
</tr>
<tr>
<td>Tubes</td>
<td>item number, tube type, function, pin numbers</td>
</tr>
<tr>
<td>Terminal strips</td>
<td>TS number, use point No. 1 as neutral or ground if possible.</td>
</tr>
</tbody>
</table>

The parts list should include the manufacturer if it is at all a special item.

(1) All controls are to be labelled as to function.
(2) On input and output: signal voltage, waveforms, reference to associated equipment, and power required dc and ac.
(3) Each stage labelled as to function, i.e., cathode follower, dc amplifier, etc.

(4) Description of operation of the circuit on schematic or if too long on separate size 1 sheet and reference on the schematic to that sheet.

(5) Functional block diagram on the schematic is helpful in explaining the circuit.

(6) If panel mounted - panel height on schematic, if cabinet or box - size on schematic.

(7) Keep plugs and TS output and inputs to the edge of the print and not buried in the middle of schematic.

Bevatron prints from the Electronic Drafting Room shall contain the following titles wherever applicable -

Line 1  Bevatron - General Area

(for example)
Bevatron - magnet power supply
Bevatron - injector
Bevatron - rf accelerator
Bevatron - master control room
Bevatron - counting area
Bevatron - vacuum system

Line 2  Unit and rack

(for example)
Ion gun - 430 kV PS regulator
Linac - pre-exciter

Line 3  Particular chassis and part of that chassis

(for example)
Bouncer - schematic
Bouncer PS - panel
APPENDIX H. TYPICAL WRITE-UP B6-73

WRITE-UP SHEET

<table>
<thead>
<tr>
<th>Installation</th>
<th>Maintenance</th>
<th>Write-up No. B6-73</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project</th>
<th>Job Title</th>
<th>Requested By</th>
<th>Coordinator</th>
<th>Remarks or Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV EXPERIMENTAL</td>
<td>PULL OUT OF H2 VENT IGNITOR CONTROLS</td>
<td>LOFGREN</td>
<td>MINTER / PIKE</td>
<td>ASAP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>4901-01</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Action</th>
<th>Drawing</th>
<th>Action</th>
<th>Drawing</th>
<th>Action</th>
<th>Drawing</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Y3284</td>
<td>F</td>
<td>7Y3504</td>
<td>F</td>
<td>5Y8063FIII</td>
<td>Be</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A - Reference ONLY  
B - MW File I Now  
C - MW File II Now  
D - MW File I After Job Comp.  
E - Correct Tracing & Distribute  
F - Obsolete  

Write-Up Registered  

- 1-26-61

SPECIFICATIONS -  
THIS WRITE-UP PROVIDES FOR REMOVAL OF  
the hydrogen vent ignitor controls  

1. Remove all the wiring in the two (2)  
conduits from the roof to the control  
boxes located at the following points  
Y0270 & J3001  

2. Remove wires & conduit from the two (2)  
control boxes to the water spillage  

MUB-1426
APPENDIX H. (PAGE 2 OF 2)

WRITE-UP SHEET

Page 2

Job Title: Pull out of H2 vent ignitor controls
Write-Up No.: B6-73

2. (Cont.) Interlocks located near the controls

3. Save the thermocouple wires for Chester Pike

4. Remove wires from:

   J3001-751-11"12  to  Y0181-26 ft 27
   Y0270-751-11"12  to  Y0181-05 ft 06
   HX181-26  to  HX204-41
   HX181-05  to  HX192-75
   HX181-06  to  HX257-17
   HX181-27  to  HX257-43

5. Remove control boxes and give same to Pike
APPENDIX I. BEVATRON WRITE-UP NUMBERS

New write-up (WU) numbers are to be assigned according to the following list of prime numbers.

WU B0 - Small items that do not involve control schematics, wire tables, or the cross connect book. These may be originated by coordinators, engineers, electronics maintenance or experimenters. The serial book and special sheets are located in EM shop Bldg 51 and in Rm 254 - 64.

WU B1 - Electrical work on or about the magnet, i.e., magnet yokes, pole base windings, pole face windings, flux loops, etc.

WU B2 - Main magnet power supply and 480 V distribution and magnet fans, magnet interlocks, fire alarms, etc.

WU B3 - Bevatron vacuum system.

WU B4 - Injector, including ion gun, L/A and inflector.

WU B5 - RF system, including the I pip, and beam-tracking and monitoring facilities.

WU B6 - General miscellaneous controls and equipment that do not fit in the other categories such as communication, radiation protection, etc.

WU B7 - Auxiliary magnets, spectrometers, $H_2$ targets and other services to experimenters.

WU B8 - Auxiliary-magnet power supplies, rectifiers, MG sets, and high-voltage rectifiers.

WU B9 - Test ion source.

WU B11 - Targets, probes, clippers and controls.

WU B12 - Jobs that are for counting equipment.

Following this schedule will allow us to keep an up-to-date list of outstanding jobs and also minimize the possibility of multiple listing.
APPENDIX K. COAX CABLE SYMBOLS ON PRINTS

See 4Y9335 B

"H" is special H-type connector (see Fig. 15)
"T" is standard coax T fitting
All feed-throughs are mounted on insulated panels

Chassis print number
R3513
Peaking strip
pre-amp
M.P. No. 1S
5Y5833

Control print number
4Y9335 A
PG3 OUT

PG2 IN

Coax feed-throughs

Dot stands for rear of panel

R3537-U-7

Dashed line used for coax patches in front of rack

R3538-U-7

Solid line used for cables in rear of racks

C3113-U-5

Do not connect the shield

C3112-U-5

This is used for special conditions where the shield is not connected to the connector in a normal way

MU-29060
APPENDIX L. TYPICAL WRITE-UP B06-100

WRITE-UP SHEET

<table>
<thead>
<tr>
<th>Project</th>
<th>BEVATRON</th>
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<tr>
<td>Job Title</td>
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<td>Coordinator</td>
<td>Whitlowe</td>
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<tr>
<td>Remarks or Programming</td>
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| Installation | Y |
| Maintenance | |

| Write-up No. | B6-03 |
| Account No. | |
| Written By | |
| W-U Checked By | |
| Term. No's. Posted | |
| E. I. Started | |
| E. I. Completed | |
| E. I. Checked | |
| E. I. Rec. Comp. | |
| E. N. Checked | |
| Coord. Rec. Checked | |

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<th>C - MU File I Now</th>
<th>D - MU File I After Job Comp.</th>
<th>E - Correct Tracing &amp; Distribute</th>
<th>F -</th>
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SPECIFICATIONS:

1. Pull in two 52c/10 cables between X-connects blocks HX 118 & 119 and rack H4136 & H4138
2. Mount these panels in the H41 rack and wire them as shown on sheets A & B
3. Do following X connects:
   - HX 118-61 → HX 120-78
   - HX 119-21 → HX 120-76

MUB-1428
### APPENDIX L. (PAGE 2 OF 3)

**WRITE UP:** B6-03  
**ITEM NO.:** 2  
**CABLE ROUTING:** Under false floor to X conn. rack.

**TERMINAL STRIP:** 14/16  

| TERMINAL STRIP 14/16 | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| TIE DOWN ON SIDE OF TERMINAL STRIP | H | 18-01  | 17-05 | 16-07 | 15-09 | 14-07 | 13-09 | 12-06 | 11-07 | 10-07 | 9-07 | 8-09 | 7-10 | 6-10 | 5-10 | 4-10 | 3-10 | 2-10 | 1-10 | 0-10 | 11-01  | 12-02 | 13-04 | 14-06 | 15-08 | 16-07 | 17-05 | 18-03 | 19-02 | 20-01 | 21-00 | 22-01 | 23-01 | 24-01 | 25-01 | 26-01 | 27-01 | 28-01 | 29-01 | 30-01 | 31-01 | 32-01 | 33-01 | 34-01 | 35-01 | 36-01 | 37-01 | 38-01 | 39-01 | 40-01 | 41-01 | 42-01 | 43-01 | 44-01 | 45-01 | 46-01 | 47-01 | 48-01 | 49-01 | 50-01 | 51-01 | 52-01 |

**H X-CONNECT BLOCK**

**TIE DOWN ON SIDE OF BLOCK**
APPENDIX L. (PAGE 3 OF 3)

WRITE UP: BG-03  ITEM NO. 2  CABLE TYPE: 5AC/16

CABLE ROUTING: Under false floor to X-conn. rack

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## APPENDIX M. WIRE TABLE SHEET FOR CONTROL RELAYS

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**Standard Wire Panel (22/23)**

- 43 - 44  22

**CONT. PAGE 2**

WU B06-100

MUB-1424
APPENDIX N. PART OF CROSS-CONNECT WIRING SHEET

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APPENDIX O. X4 TROUBLE LIGHT PANEL
APPENDIX P. BEVATRON VACUUM TANK RADIAL BAR SHORTS

Plan View of Vacuum Tank (not to scale)

Adjacent radial bars span two sectors except for the center sectors where the adjacent radial bars are one sector apart.

The voltage induced in the path as shown above can be

\[
\frac{4,000 \text{ (volts per quadrant)}}{88 \text{ turns}} \times \frac{2 \text{ (sectors inclosed)}}{36 \text{ (total sectors)}} = 2.52 \text{ V.}
\]

Resistance of Radial Bars (steel)

\[
R_B = \frac{L \rho}{A}
\]

\[
L = 101.2 \text{ in.}^2
\]

\[
A = 1.27 \text{ in.} \times 12 \times 10^{-6} \Omega \text{ cm}
\]

\[
= 376 \times 10^{-6} \Omega \text{ per radial bar,}
\]

\[
= 752 \times 10^{-6} \Omega \text{ for two radial bars.}
\]
Resistance of a Two Sector Length of Corner Bars.

\[ R_C = \frac{L}{A} \rho \]

\[ L_T = 101.5 \text{ in.} \]

\[ A = 2.11 \]

\[ \rho = 2.83 \times 10^{-6} \Omega \text{cm} \]

\[ R_C = \frac{101.5 \times 2.54}{2.11 \times 2.54^2} \times 2.83 \times 10^{-6} \]

\[ = 53.5 \times 10^{-6} \Omega \]

Total Resistance for Two Sectors.

\[ R_B + R_C = 805 \times 10^{-6} \Omega \text{ for two sectors.} \]

\[ I_{\text{max}} = \frac{2.52 \times 10^3}{805} \text{ A} \]

\[ = 3.130 \text{ A for a complete short circuit, on two sectors.} \]

Because of the way in which the corner bars are broken, the maximum loop that can be established with four shorts would include 12 sectors.

\[ R_{\text{Total}} = (752 + 6 \times 53.5) \times 10^{-6} \Omega \]

\[ = 1.07 \times 10^{-3} \Omega \]

\[ I_{\text{max}} = \frac{2.52 \times 6}{1.07} \times 10^3 \text{ A} \]

\[ = 14,100 \text{ A.} \]

The maximum currents shown here do not consider the reactance of the circuit, but do indicate that a serious problem exists. Even when one assumes a few m\(\Omega\) for a shorted joint. At present there are several shorts
between radial bars and corner bars that measure less than 0.5 $\Omega$ with a Simpson meter.

In several places, at least two of the required four joints shorted.

The upper and lower tank skins present a similar type of short-circuit problem. The skin is made of 18 gage (0.050 in.) stainless No. 302 with a resistivity of $\approx 72 \times 10^{-6} \, \Omega \cdot \text{cm}$. The skin spans the two sector area as shown in Fig. 1. The resistance from inner to outer radius of one skin is

$$ R = \frac{L}{A} \rho $$

$L = \approx 103$ in.

$A = 2.5$ in.$^2$

$\rho = 72 \times 10^{-6} \, \Omega \cdot \text{cm}$

$$ = \frac{103(2.54)}{2.5(2.54)^2} \times 72 \times 10^{-6} $$

$$ = 1.2 \times 10^{-3} \, \Omega \text{ for one skin.}$$

Assume $3 \times 10^{-3} \, \Omega$ for two skins and one point shorts.

Maximum $I$ for 12 sector short.

$$ I_{\text{max}} = \frac{(2.5) \times 6}{(3 + .320) \times 10^{-3}} $$

$$ = 4,500 \, \text{A.}$$
APPENDIX Q. RULES FOR WORK INSIDE THE BEVATRON
VACUUM TANK

(1) Only Authorized Work is to be done inside of the vacuum tank. This work should have been planned ahead of time and if possible be on the shutdown list for work to be accomplished. It is most important that the crew know what work is going on inside the tank at all times.

(2) Only Authorized Personnel are to be allowed inside the tank. The operating crew chief always has the last word as to who is permitted in the tank. Only those with a definite job are to go in (no sight-seeing allowed). Normally this would include:

(a) Operating crew,
(b) Electronics maintenance,
(c) Electronics installation,
(d) Engineers and coordinators as required, and
(e) At times other personnel may be permitted inside if the crew chief approves.

(3) Cleanliness at All Times. No matter who goes inside they must at all times keep the inside of the tank clean.

(a) Always wear the protecting suits and shoes.
(b) Be sure to remove all small objects from your pockets; keys, screws, bolts, coins, unnecessary pencils etc., that may accidentally drop out.
(c) Keep the work areas clean as you work, any waste scraps, wire insulation or other debris should be picked up as you work.
(d) Keep track of tools.
(e) If anything is dropped and cannot be found please notify the crew chief at once.
(f) Workman should keep an eye out for any condition inside of the tank that may look suspicious, even in areas not covered by his immediate job. Such unusual conditions should be reported to the crew chief.

(4) Radiation Hazard. When the tank is first opened at the beginning of the shutdown the operating crew chief will have the complete tank surveyed.

No one else is permitted inside the tank until the crew chief has given the OK.

If any particular spots are excessively hot they will be so labeled. These areas should be shunned if possible.

It should always be assumed that the gap has background activity. A new assessment of the radiation level in the gap will be made each day. This will determine the length of time allowed to work there. Those who work in the gap must log in and out in the main-control-room log book.
APPENDIX R. POWER SUPPLY SPECIFICATIONS

SPECIFICATION FOR

1.0 General This specification is not to be confused with any other LRL Berkeley or any LRL Livermore specification.

1.1 In addition to this specification, Schematic diagram No.__________, Layout drawing No.__________, and the following Fabrication Standards and Specifications are of equal significance:

- LRL 98-1 Fabrication Standard for Large Power Supply Equipment, dated__________.
- LRL 01-1 Fabrication Standard for Electronics Equipment, dated__________.
  (Applies to electronic chassis.)
- LRL 04-10 Approved Sources for Electronics Components.
- LRL 01-2 Standard for Assembly of Printed Wiring Boards.
- LRL 01-3 Fabrication Specifications for Printed Wiring Boards.

1.2 No exceptions, deviations or alternates to the above shall be taken with materials, dimensions, or techniques without written authorization of the LRL Electronics Engineering Department, transmitted via the LRL Purchasing Department. Deviations or alternates known at time of quotation shall be listed with the bid proposal.

1.3 An effort has been made to make the schematic, drawings and standard free of errors. If any errors or discrepancies are noted, they shall be brought to the attention of the LRL Purchasing Department who will transmit them to the LRL Electronics Engineering Department.

1.4 LRL may request a factory engineer to come to Berkeley to discuss technical matters pertaining to this specification, before any contract is awarded.

1.5 LRL may wish to witness the factory test of equipment, in which case the factory is to give LRL one week's notice of such tests.

1.6 All factory test data shall be submitted to LRL with or before delivery of equipment.
APPENDIX S.

1.0 GENERAL.

1.1 Purpose

1.1.1 The intent of this standard is to present the minimum requirements which must be met to insure high quality fabrication of electronics equipment for the University of California Lawrence Radiation Laboratory (LRL).

1.1.2 Suggestions for obtaining high quality fabrication as economically as possible without sacrificing reliability and safety are welcome, and will be given immediate consideration.

1.2 Standards

1.2.1 Equipment shall be designed, fabricated and tested in accordance with currently applicable portions of the industry accepted standards of the NEMA, IEEE, and ASA.

1.2.2 The California Electrical Safety Orders, Title 8, and the National Electric Codes shall be observed. Equipment shall comply in every respect with the applicable portions of these codes and standards.

1.2.3 In case of differences in any of these codes and standards, the more stringent shall apply.

1.3 Acceptance Levels

1.3.1 Design The design shall include arrangement of components for best circuit function and ease of maintenance. Controls shall be arranged for good appearance and operator convenience.

1.3.2 Materials and Workmanship Only the best quality materials shall be used throughout. Workmanship shall be neat, clean, and thoroughly presentable.

1.3.3 Components Components supplied shall be new, first quality components of current manufacture and ready availability.

* California Electrical Safety Orders, Title 8, available from: Printing Division, Documents Section, California State Printing Office, Sacramento 14, California. ($1.50)
2.0 MECHANICAL CONSTRUCTION

2.1 Cabinet Construction

2.1.1 Unless otherwise specified, the power supply shall be enclosed in a metal cabinet designed for floor mounting and free standing. Mechanical construction shall consist of an angle iron basic frame which shall sit upon I beam skids. The cabinet shall be equipped for both crane and fork lift handling of the complete unit, including the weight of the coolant. Lifting lugs or ears bolted to the frame and oriented for low stresses are to be used; no eye bolts shall be used for lifting.

2.1.2 The cabinet shall be "drip-tight", "ventilated", as defined in NEMA standards, Section IC1-2.68 and IC1-2.69.

2.1.3 Hinged panels or doors shall be provided for those areas requiring service access. Panels which are fastened with bolts or screws shall have separate alignment studs. To improve overall accessibility, a minimum number of fasteners shall be used. Quick operating fasteners are preferred. Light weight metals are preferred for large panels. See also Sections 3.2.1 and 3.2.2.

2.2 Dimensions and Tolerances

2.2.1 All dimensions and dimension tolerances shall be as given on the drawings, if furnished.

2.2.2 If tolerances are not given on the drawings, these tolerances shall apply:

  - Sheet metal work, plus or minus 1/32 inch.
  - Machined parts, plus or minus 0.005 inch.

2.2.3 Measurements of repeating tolerances, such as a series of equally spaced holes in a straight line, shall not show additive error tolerances.

2.3 Fabrication and Assembly

2.3.1 Holes may be either punched or drilled. All burrs and sharp points must be removed. Tool marks and fabrication blemishes must be kept to a minimum. Smooth finishes shall have no tool marks or fabrication blemishes. There shall be no sharp exposed edges or corners.

2.3.2 Formed edges are to be free of stress lines and cracks.

  2.3.2.1 Sheet metal forming machines shall be used, unless design dictates otherwise.

2.3.3 Unless otherwise specified, metal assembly hardware, such as screws, washers, small brackets, etc., shall be cadmium or nickel plated to a minimum thickness of 0.00015 inch. This does not include hardware that is an integral part of a component such as transformer core screws and mounting feet.
2.3.4 Machine screws that are not an integral part of a component shall be binder head type. Self-tapping screws shall not be used.

2.3.4.1 Screws that are not an integral part of a component shall extend zero (flush) to 1/8 inch past any nut used in the assembly for screw diameters up to ¼ inch. For ¼ inch diameter and larger, the extension shall be 1/8 inch maximum only for screws on the outside of the cabinet.

2.3.4.2 Lock washers shall be used under all nuts. A combination lock washer and nut assembly such as "Keps" (Shake Proof Division of Illinois Tool Works or equal) is preferred.

2.3.5 All components shall be securely mounted so as not to cause damage to any portion of the equipment nor affect its performance.

2.3.6 Components shall be mounted so that values and ratings can be easily read. Components subject to adjustment shall be mounted accessibly.

2.3.7 Mounting hardware shall be assembled to facilitate replacement of parts and assemblies.

2.3.8 All semiconductors shall be mounted for ease of replacement and use of a torque wrench.

2.3.9 In the interest of safety and reliability, all materials shall be as fire resistant as possible. Approved materials are: Track-resistant "Glastic", Grade FR canvas "bakelite" (Spaulding C-832, or equal) NEMA grades FR-1 and FR-2 paper phenolic, NEMA grade FR-3 paper epoxy, NEMA grades FR-4 and FR-5 glass epoxy, and Plexiglass (Lucite) 5009B.

2.3.10 Resilient washers shall be used whenever brittle materials are bolted in assembly.

2.3.11 Control knobs of set screw type must have a metal insert, and be secured with two set screws, preferably Allen head type.

2.3.12 Terminal strips which are mounted on a metal surface shall be insulated by a Bakelite sheet a minimum of 1/32 inch thick unless such continuous insulation is provided by the terminal strip.

2.4 Finish

2.4.1 Finish and Paint of Cabinet

2.4.1.1 All metal work shall be cleaned free of all scale, grease, or foreign matter and followed immediately by a primer coat of rust resistant paint. The interior and exterior of the cabinet shall be finished with two coats of paint as specified by LRL.

2.5 Marking - Front of Front Panel

2.5.1 All components mounted on the front panel or door of the cabinet shall have laminated phenolic identification plates mounted below the component, and secured with screws.
2.5.2 A nameplate on the front shall include the following data:

- Input line voltage and current at rated output
- Rated output voltage and current for all connections
- LRL Specification number (LRL-98 series)
- LRL schematic diagram number
- Manufacturer's type and serial number
- Total weight of unit
- Month and year of manufacture

2.6 Marking - Internal

2.6.1 All major components shall be marked at the most readable point with neat legible letters by means of stencils or rubber stamps. Component marking shall be as given on the schematic or wiring diagram.

2.6.2 Black ink or paint shall be used on light background and white ink or paint on dark background.

2.6.3 Components mounted on front panels shall have letter or number designations on rear of panel.

2.6.4 Stencil the first and last terminal of each terminal strip, and every fifth terminal in between.

3.0 ELECTRICAL

3.1 Components

3.1.1 No component shall be operated at or subjected to temperatures greater than recommended by the component manufacturer. See also Section 4.3.

3.1.2 No insulation shall be subjected to temperatures greater than recommended in the National Electric Code.

3.1.3 All transformers shall be marked with the voltage and volt-ampere ratings and all leads shall be identified. See also 3.2.8.

3.1.4 Small 115 volt single phase circuit breakers rated 10 amps or less shall be Heinemann AM-12-curve 4 series. Three phase breakers, up to 100 amps and single phase breakers from 10 to 100 amps shall be Westinghouse molded case, or equal. Over 100 amps, circuit breakers shall be General Electric AK-2, or equal, with adjustable over-voltage trip, under-voltage trip and key lock handle preferred accessories.

3.1.5 Current/volt meters shall have an accuracy of at least 2% and a nominal 4 inch case made of bakelite and glass. Other plastic cases are not acceptable. Meters shall have a core magnet movement or be provided with equivalent magnetic shielding.

3.1.6 Current metering shunts shall be Westinghouse or Weston 50 milli-volt shunts unless otherwise specified.

3.1.7 A running time meter, when used, shall read to 99,999 hours.
3.1.8 Allied type BO6A115, BOHR06A115, BODR06A115, or Ohmite type DOSX-7T, 115 volt ac coil relays shall be used for control circuits at 240V, 10A or less. For control circuits over 240V or 10A, Arrow-Hart & Hegeman type IMP or CRA shall be used.

3.1.9 Resistors shall not be operated at more than 60% of their rated wattage.

3.2 Wiring Methods and Practices

3.2.1 A local line circuit-breaker with covered line terminals shall be provided. Protective covers and interlocks shall be provided in accordance with the following table:

<table>
<thead>
<tr>
<th>Breaker</th>
<th>Doors</th>
<th>Outside</th>
<th>No voltages shall be exposed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td>Open</td>
<td>Panels Off</td>
<td></td>
</tr>
</tbody>
</table>

II

| Breaker On | Doors Open | Outside Panels On | No voltages greater than 300V dc or RMS shall be exposed. Circuits having greater than 1.0 KVA rating shall not be exposed. |

3.2.2 Fuses shall be behind doors and mounted in accordance with 3.2.1. Protective covers shall be easily removable. See also 3.2.3.

3.2.3 Wires and busses operating at greater than 300V dc or RMS shall be kept separated from lower voltage circuits. In no case shall they appear on the same terminal strip or terminal board with lower voltage terminals. 460V RMS (nominal) line components (such as fuses, contactors, control relays and transformers) are preferred in a separate enclosure within the confines of the cabinet.

3.2.4 Wires and busses carrying greater than 20A shall be kept separated from lower current circuits. In no case shall they appear on the same terminal strip or terminal board with lower current terminals.

3.2.5 Circuits shall be wired with minimum air clearance to ground and to adjacent components of approximately 0.3 inch per 1000 volts as specified in NEMA Standard Publication No. IC1-1959 for Industrial Control, Section IC1-2.73.

For circuits operating at over 5000 volts, the minimum clearances will be specified by LRL for each particular design.

3.2.6 Capacitors shall be provided with a means of draining the stored charge.

The residual voltage of a capacitor shall be reduced to 50 volts or less within one minute after the capacitor is disconnected from the source of supply in the case of capacitors rated 600 volts or less, and in five minutes in the case of capacitors rated more than 600 volts.
3.2.6 (continued)

The discharge circuit shall be either permanently connected to the terminals of the capacitor or capacitor bank, or provided with automatic means of connecting it to terminals of the capacitor on removal of line voltage. Manual means of connecting the discharge circuit shall not be used. The windings of transformers, or other equipment directly connected to capacitors without a switch or overcurrent device interposed, constitutes a suitable discharge means.

3.2.7 A tie point or component terminal shall be used for junction of wires. Splicing of wires must be approved by LRL. Taped connections are not permitted. The junction points shall be identified on the schematic. Semiconductor terminals shall not be used as tie points.

3.2.8 All transformer leads including unused leads, such as transformer center taps or primary taps, shall be terminated on terminal strips. Unused component leads shall be terminated on terminal strips or tie points.

3.2.9 The designer shall be responsible for using wire of sufficient size, voltage rating, and insulation to meet applicable codes and provide protection for equipment and personnel. Wire No. 18 AWG and smaller shall be stranded-tinned copper or bunch-tinned copper. Do not use wire with a nylon sheath over the thermoplastic insulation because the addition of the sheath allows the insulation to burn.

3.2.10 When mounting small components such as capacitors and resistors, the component pigtails shall not be stretched tight. The lead shall be bent slightly between the component body and the tie point, in order to avoid damage due to thermal expansion and contraction. There shall be at least 3/16 inch, but no more lead length than is necessary, between the component body and the soldered connection. Leave no more than 1/16 inch of pigtail beyond terminal.

3.2.11 The schematic shall show accurately all wiring connections in the power supply with all terminal points and tie points identified by number. The wiring of each power supply shall conform electrically to the schematic. In the case of identical power supplies, the wiring shall be the same for all power supplies.

3.2.12 Different colored wires shall be used wherever possible to facilitate wire tracing. Wire numbers may be used in lieu of colored wires if completely identified on schematic. White wire shall be used for neutral connections only.

3.2.13 Wire insulation shall not be more than 1/8 inch from the terminal to which the wire is connected.

3.2.14 All wiring shall be harnessed or laced. Long runs are to be firmly secured to the framework with insulating clamps. Wiring shall not be pulled tight over sharp metal edges or around metal corners.
3.2.15 Cabling to components on hinged panels or doors shall be done by making long loops in the cable along the hinge so that repeated opening of the door shall not damage the wire or its insulation. Stranded wire shall be used in such cabling.

3.2.16 All control relays shall be wired with one side of the coil tied directly to neutral.

3.2.17 All bolted or screwed electrical connections shall not be dependent on any insulating material, ceramic, plastic, or otherwise, to maintain contact pressure.

3.2.18 Step start resistors, when required, to reduce starting inrush currents, shall be connected to the load side of the contactors.

3.2.19 Wafer switch contacts shall be clear of flux and lubricated with Lubriplate 105 (Fiske Bros. Refining Co.), or equal. This lubricant is recommended for any electronics part requiring lubrication.

3.2.20 Electrolytic capacitors shall be spaced away from heat radiating surfaces whenever possible if mounting details are not furnished.

3.2.21 Plug-in interconnections within the equipment shall use the same terminal numbering sequence at both ends of the cable. All wires within the cable shall be connected to separate terminals. All plug terminals shall have wires connected to them. When parallel plug connections are used for increased current rating the connections shall be made in the chassis connector and not in the cable plug.

3.3 Soldering

3.3.1 Unless otherwise specified, the solder shall be at least 60% tin bearing, and meet the requirements of Federal Specification QQ-S-571 for metallic composition and rosin flux.

3.3.2 Only rosin, rosin-alcohol or equivalent plastic mixtures shall be used as flux. The flux shall promote the appropriate spreading of the solder over the plated or pre-tinned parts to form integrally thereon a coat of solder which feathers out to a thin edge.

3.3.3 In soldered joints, the lead does not have to be completely wrapped around the terminal for mechanical strength. The lead should have a half wrap in contact with the terminal and the soldering must be done so as to provide both a good mechanical and a good electrical connection.

3.3.4 There shall be no voids in the solder on or near component leads.

3.3.5 Insulation shall not be damaged by soldering.

3.3.6 Excess flux shall be removed. Ultra-sonic cleaning methods shall not be used where semiconductor components are involved.
3.3.7 Soldering techniques shall not exceed the temperature-time rating of any component. One recommended technique for connection of semiconductor components, precision resistors, and similar temperature sensitive elements is as follows:

1. Pre-tin the terminal to which the connection is to be made.
2. Firmly grasp the circuit element lead between the element and the terminal with a pair of cool long-nose pliers.
3. Complete the soldering operation using minimum heat and time to provide a satisfactory joint.

3.3.8 Leads consisting of gold-plated Dumet, gold-plated Kovar, or gold-plated nickel must be carefully soldered initially, because further soldering may destroy the electrical connection.

3.3.9 Compression-type lugs and taper-pin connections may be used. For conductors No. 8 AWG and larger, the compression-type lug and crimping tool must be approved by LRL. Except for plug-in-components and bolted and screwed connections, all other connections shall be soldered. No wire-wrap terminals shall be used unless all coils are soldered.

4.0 VENTILATION AND COOLING

4.1 Air-Cooling System

4.1.1 Ventilation and cooling shall be designed for indoor units with an ambient air temperature of 50°C.

4.1.2 Forced-air cooling of components is acceptable provided filtering is used on the intake air. The filters shall be located such that they may easily be removed for cleaning. Filters shall be dry-type and free of oil.

4.1.3 Air-flow interlocks shall be provided whenever forced-air cooling is used.

4.2 Water-Cooling System (if used)

4.2.1 Demineralized water with a conductivity of about 10 micro-ohms per centimeter will be supplied from LRL water system for cooling. Maximum supply line water temperature will be 90°F. Normal supply pressure may vary from 80 psi to 125 psi gauge. The minimum differential pressure drop between the supply and return lines will be 40 psi. Return line pressure may be as high as 40 psi. Design for 200 psi gauge test. See also 4.2.6

4.2.2 The entire water system shall be constructed of copper, brass, bronze, or 18-8 stainless #316 or #304, except that insulating connections shall be made with Weatherhead H9 rubber hose. No plastic tubing allowed. All targets or piping subject to electrolysis shall be made of stainless 304 ELC. Hose barbs or fittings subject to corrosion or electrolysis shall be readily replaceable without soldering.
4.2.3 An all-bronze Y strainer with 10 mesh brass or monel strainer, Bailey No. 100 with 3/64 inch perforations or equal, shall be used in the supply line. This is to be located and adequately supported at the rear of the cabinet such that it can be readily cleaned without dripping water on components. Strainer shall be located so it can be serviced with the dc power cables attached to the supply.

4.2.4 A Hayes Shureflow water-flow interlock with integral indicator light shall be connected with unions in the return line of each parallel water path. They shall be located within the outline of the cabinet such that they are readily available for servicing or checking through a door or without removing any panels, or dripping water on components.

4.2.5 Water connections shall be located at the rear of the cabinet near the bottom. Female pipe thread fittings shall be provided for external connections.

4.2.6 Layout of the water system, particularly insulating hose connections, should be designed so as to avoid spraying electrical components in the case of a water leak. There shall be complete absence of visual water leaks after circulating 80 psi water at 85°C for 30 minutes, then immediately pressurizing the system at 200 psi with cold water for 30 minutes. The above cycle shall be repeated five times. All leaks shall be repaired and all tests repeated until system is water tight.

4.2.7 When short hoses are used to make insulated water jumpers, no hose shall be less than 10 inches long or be subjected to a voltage gradient greater than 100 volts per inch unless otherwise specified. The hose, when dry, shall measure greater than 100 megohms per inch when checked at a voltage gradient of 500 volts per inch.

4.2.8 Water system shall be shipped dry to prevent damage due to freezing.

4.3 Semiconductor Cooling

4.3.1 Air-cooling and/or water-cooling of semiconductor devices shall be such that a maximum junction temperature of 125°C for silicon devices and 65°C for germanium and selenium devices is not exceeded. LRL approval of the design of the heat sink and cooling system may be required.

4.4 Noise Level

4.4.1 The sound intensity level due to blowers, fans, pumps, water rushing, and magnetic components shall not exceed 72 db above 0.0002 dynes per sq. centimeter (10^-16 watts per sq. centimeter) measured 6 feet from the cabinet. The ambient sound level at the time of measurement shall not exceed 62 db above 0.0002 dynes per sq. centimeter. Any vertical or overhead reflecting surfaces shall be at least 10 feet from the point of measurement. The 40 db weighting switch position of a standard sound level meter shall be used regardless of sound level being measured.
1.0 GENERAL

1.1 Purpose

The intent of this standard is to present the minimum requirements which must be met by sellers to insure high quality fabrication of electronics equipment for the University of California Lawrence Radiation Laboratory (LRL). It applies to all electronics equipment produced for LRL.

1.1.1 Precedence Before contractual awards are made, the seller will be supplied with all applicable items of design information. When discrepancies occur between one or more items, precedence for use is established in the order in which they are listed below. This order of precedence may be altered only by a special specification which is part of the Purchase Order.

1. The Purchase Order and special specifications which are part of the Purchase Order.

2. This standard

3. The schematic circuit diagram

4. The parts list

5. Other drawings

6. Photographs or a prototype

1.1.2 Waivers When the seller is responsible for the design and/or development and fabrication of equipment, the requirements of this standard may be waived in favor of techniques suggested by the seller. However, any such waiver must be approved in writing by LRL.

1.2 Acceptance Levels

1.2.1 Materials and Workmanship Only the best quality materials shall be used throughout. Workmanship shall be neat, clean, and thoroughly presentable.

1.2.2 Components Components supplied by the seller shall be new, first quality components of current manufacture and ready availability; and he shall advise LRL of the discontinuance (by the component manufacturer) of any component listed in an order.
1.2.3 **Substitutions** Substitutions may be used for items designated "or equal" when approved by LRL Electronics Department. All substitutions must be authorized in writing by the LRL Purchasing Department.

2.0 **MECHANICAL CONSTRUCTION**

2.1 **Dimensions and Tolerances**

2.1.1 All dimensions and dimension tolerances shall be as given on the drawings.

2.1.2 If tolerances are not given on the drawings, these tolerances shall apply:

Sheet metal work, \( \pm \frac{1}{32} \) inch
Machined parts, \( \pm 0.005 \) inch

2.1.3 Measurements of repeating tolerances, such as a series of equally spaced holes in a straight line, shall not show additive error tolerances.

2.2 **Fabrication and Assembly**

2.2.1 Holes may be either punched or drilled. All burrs and sharp points must be removed. Tool marks and fabrication blemishes must be kept to a minimum. Smooth finishes shall have no tool marks or fabrication blemishes. There shall be no sharp exposed edges or corners.

2.2.2 Formed edges are to be free of stress lines and cracks.

2.2.2.1 Sheet metal forming machines shall be used, unless design dictates otherwise.

2.2.3 Unless otherwise specified, metal assembly hardware, such as screws, washers, small brackets, etc., and any perforated steel covers shall be cadmium or nickel plated to a minimum thickness of 0.00015 inch. This does not include hardware that is an integral part of a component such as transformer core screws and mounting feet. For aluminum parts see Section 2.4.1.

2.2.4 Machine screws that are not an integral part of a component shall be binder head type. Self-tapping screws shall not be used except to attach outside covers.

2.2.4.1 Screws that are not an integral part of a component shall extend zero (flush) to 1/8 inch past any nut used in the assembly.

2.2.4.2 Lock washers shall be used under all nuts. A combination lock washer and nut assembly such as "Keps" (Shake Proof Division of Illinois Tool Works or equal) is preferred.
2.2.5 Lucite or Plexiglass shall be flame-retardant grade such as Plexiglass 5009B. All exposed surfaces shall be smooth. Cementing shall be according to the manufacturer's specification for the materials involved.

2.2.6 In the interest of safety and reliability, all materials shall be as fire resistant as possible. Examples of such materials are: Grade FR canvas "bakelite" (Spaulding C-832, or equal), NEMA grades FR-1 and FR-2 paper phenolic, NEMA grade FR-3 paper epoxy, and NEMA grades FR-4 and FR-5 glass epoxy.

2.2.7 Ceramic and ceramic coated parts (insulators, power resistors, sockets, etc.), shall be mounted with nylon or fiber washers in contact with the ceramic. As a general rule, resilient washers shall be used whenever brittle materials are bolted in assembly.

2.2.8 Control knobs of set screw type must have a metal insert, and be secured with two set screws, preferably Allen head type.

2.2.9 Terminal strips which are mounted on a metal surface shall be insulated by a Bakelite sheet a minimum of 1/32 inch thick, unless such continuous insulation is provided by the terminal strip.

2.2.10 Top and bottom covers shall be fastened to the top or bottom by means of S-clips, and to the rear by number 6 X ¾ self-tapping screws (hex head with slot) unless otherwise specified.

2.2.11 Chassis plugs shall be mounted from the wiring side of the panel unless there is interference with making a fully-mated connection. The key-way shall be on the upper side and numbering and lettering shall be upright in the normal chassis position, unless otherwise specified.

2.2.12 Prints shall not be used as templates for mechanical location.

2.2.13 Resistors with adjustable terminals shall be mounted with the terminals accessible for adjustment.

2.2.14 Front panels shall not be secured to chassis by circuit components.

2.3 Mounting and Clamping

2.3.1 All components shall be securely mounted in a manner so as not to cause damage to any portion of the equipment, nor affect its performance.

2.3.2 Components shall be mounted so that values and ratings can be easily read.

2.3.3 Mounting hardware shall be assembled to facilitate replacement of parts and assemblies.
2.3.4 All stud-mounted semiconductors require good thermal connection to a heat sink. When stud-mounted semiconductors are used, the thermal filler and tightening torque shall comply with Specification LRL-60-1, "Mounting Specifications for Stud-Mounted Semiconductors", which then becomes part of this standard. If the semiconductor to be mounted is not shown in LRL-60-1, the manufacturer’s recommendations for thermal connection shall be used.

2.3.5 When transistors are mounted on a heat sink or other special mounting, wires shall be connected to terminal points to facilitate replacement. See also 3.3.1.

2.4 Finish

2.4.1 Preparation and Finishing of Bare Aluminum Parts To insure long-term shielding properties and to be sure that all machining can be done before finishing, an Iridite finish shall be used. For front panels see 2.4.2.

2.4.1.1 Degrease with Perchlor Vapor for 5 minutes.

2.4.1.2 Caustic etch with Allied Research NE-6, or equal, ¼ fluid oz. per gallon of water, 70-90°F, 2 to 3 minutes.

2.4.1.3 Rinse immediately in cold running water.

2.4.1.4 Immerse in Iridite No. 14, 3 oz. per gallon of water, 75-95°F, 3 to 5 minutes.

2.4.1.5 Rinse immediately in cold running water.

2.4.1.6 Dip into hot water (below 160°F) to facilitate drying. Prolonged hot rinsing destroys protective properties.

2.4.1.7 Air dry. There shall be no streaks or stains on the parts.

2.4.2 Finish and Paint of Front Panels The panel shall be painted a Hammertone gray (unless otherwise specified) by the steps listed below. Only the front face and all edges shall be painted. The rear surface shall be kept clean to permit grounding to the caustic etch surface. In the case of aluminum panels the rear surface and edges may be either the satin finish provided by the caustic etch, or Iridite finish per 2.4.1.

2.4.2.1 Clean the panel after performing all machining operations and before painting. Cleaning shall include degreasing followed by caustic etch with Oakite No. 60, or Oakite No. 160, or Pennsalt No. 2562, or equal.

2.4.2.2 A prime coat shall be applied following the caustic etch (primer to be NALCO #20-09 Gray or equal). After air-drying, bake by placing the panel in a cold oven and raising to 250°F, then remove.
2.4.2.3 The paint shall be applied following the primer. Paint with Hammertone gray, using DUTCH BOY #42A96, no substitute. Bake at 250° F for 15 minutes.

2.4.3 Brass and copper sheet metal shall be bright-dipped.

2.5 Marking—Front of Front Panels

2.5.1 Front panels shall be silk screened, as shown on the drawings, as to letter size and placement with black color unless otherwise specified. All markings shall be permanent.

2.5.2 The name of the chassis unit, as given on the drawing, shall be placed on the front panel as shown on the drawings. When no drawings exist, the name shall consist of ¼ inch letters centered on the panel ¼ inch down from the top. If components interfere, place the name so that the information clears the components.

2.5.3 The basic schematic diagram number shall be placed directly below the title, and the serial number, when used, shall be in close proximity to the title and schematic number.

2.6 Marking—Chassis

2.6.1 All major components shall be marked at the most readable point on the chassis with neat legible letters by means of silk screen, stencils, or rubber stamps. The Western Electric #2315R stamp is acceptable. Examples of major components are tubes, transformers, chokes, large resistors, can type capacitors, and terminal strips. Components marking shall be as given on the schematic diagram.

2.6.1.1 Black ink shall be used on light background and white ink on dark background.

2.6.1.2 The complete schematic diagram number, name of seller, month and year of manufacture, and the serial number (when used) shall be placed on the back of the chassis in lower left corner (when viewed from the rear) if possible; otherwise located where convenient. If a nameplate is used, it must be metal and the above information may be included in the nameplate.

2.6.1.3 Plugs mounted on the rear panel shall be marked on the chassis exterior with name (if any) above the plug and the number below it.

2.6.1.4 Plugs, switches, pots, and fuses mounted on front panels shall have names silk screened on the front of the panel and letter or number designations (such as P1, S1) on rear of panel. Rear chassis shall have designations on both sides of chassis. Stencilling on inside of chassis shall be located for maximum readability.
2.6.1.5 Stencilling on the back of front panels which shows above the chassis shall read right side up when the chassis is in normal position. Stencilling on the panels which shows below the chassis plates shall read right side up when the chassis is upside down.

2.6.1.6 Electron tubes shall be marked with "V" number on top and bottom of chassis. The tube type is shown on the top only. Mark keyway location, unless otherwise indicated.

2.6.1.7 Multi-channel circuits within the same chassis shall be stencilled to read left-to-right from the operating face. This includes component designations, so that the lowest designated components (such as PG2, S3, ME1 etc.) are components of the lowest numbered channel. In the case of no operational controls, and only one side of the chassis is exposed, the chassis shall be stencilled to read left-to-right from the exposed face.

2.6.1.8 Stencil the first and last connection point of each terminal strip and taper-pin block, and every fifth connection point in between (Western Electric strips, at least every tenth between). Marking to read left-to-right from the external connection face.

3.0 ELECTRICAL ASSEMBLY

3.1 Electronics Components

3.1.1 Unless otherwise specified, electronics components supplied by the seller shall be as described in Specification LRL-04-10, "Approved Sources for Electronics Components". See also 1.2.3 "Substitutions".

3.2 Wire and Cable - Type and Sizes

3.2.1 General purpose hook-up wire shall consist of stranded-tinned copper or bunch-tinned copper with 600V, 105° C thermoplastic insulation per MIL-W-16878C, Type B, for No. 22 AWG and No. 24 AWG. For No. 20 AWG and larger, the insulation shall be per MIL-W-16878C, Type C, 1000V, 105° C. Do not use wire jacketed with a nylon sheath because the addition of the sheath allows the insulation to burn.

3.2.2 Hook-up wire shall be selected so that the following ratings are not exceeded.

<table>
<thead>
<tr>
<th>Wire Size AWG</th>
<th>Current Amps</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
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<td>16</td>
<td>8</td>
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<td>18</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>3.5</td>
</tr>
<tr>
<td>22</td>
<td>2.5</td>
</tr>
<tr>
<td>24</td>
<td>1.5</td>
</tr>
</tbody>
</table>

NOTE: This table has been derated from EIA Standard to satisfy close spacing and temperature problems of electronics chassis.
3.2.3 The seller shall be responsible for using wire of sufficient size and voltage rating to protect equipment and personnel.

3.2.3.1 Filament circuits: The wire size shall be determined by the filament transformer. Example: 6.3 @ 3 amps use #20. Do not use a wire size of smaller than #20 on any filament string.

3.2.3.2 0-1000V dc circuits: #20 general purpose hook-up wire preferred. Do not use Type B over 500V.

3.2.3.3 1000V to 2500V dc circuits: Adequately sized wire with thermoplastic insulation per MIL-W-16878C, Type D.

3.2.3.4 2500V to 10KV dc circuits: Cathode ray tube wire, Belden 8869, or equal.

3.2.3.5 10KV to 20KV dc circuits: Cathode ray tube wire, Belden 8868, or equal.

3.2.3.6 Shielded cable, unless specified as co-axial transmission line, shall consist of stranded-tinned copper not less than No. 25 AWG for single conductor wire used in sub-assemblies and not less than No. 22 AWG for all other uses. The wire or wires shall have thermoplastic insulation, metallic shield, and a moisture resistant covering, such as vinyl plastic.

3.2.4 Color code of hook-up wire to be used in all chassis wiring is as follows:

- Black - grounds (grounded elements and returns)
- Brown - heaters and filaments off ground
- Red - power supply B+
- Orange - Screen grids
- Yellow - cathodes, emitters
- Green - control grids, bases
- Blue - plates, collectors (that are not tied directly to power supply)
- Violet - special circuits
- Gray - ac power and interlock wiring
- White - above or below ground returns, and neutrals

NOTE: The above is EIA standard, except for additions of interlock wiring, neutrals, and transistor nomenclature.

3.3 Interconnections

3.3.1 A tie point of the type specified on the parts list, shall be used for junction of two or more wires. Insulation of individual wires shall be continuous. Splicing of wires is not permitted. Unused component leads, such as transformer center taps, shall be terminated at tie points or taped and secured. All connections to terminals shall be accessible. Semiconductor terminals shall not be used as tie points.
3.3.2 Wire insulation shall not be more than 1/8 inch from the
terminal to which the wire is connected.

3.3.3 Wires shall be arranged to prevent abrasion of the insulation.

3.3.4 Attach no more than three terminal lugs with one bolt or
screw. Grounding to chassis shall be made with grounding or
screw-down lugs. All bolted or screwed electrical connections
shall not depend on any insulating material, ceramic, plastic,
or otherwise, to maintain contact pressure.

3.3.5 Grounding points and use of shielded wire shall be only as
shown on the drawings. Consult the schematic and other draw-
ings before referring to photographs or prototype.

3.3.6 AC and filament leads need not be twisted unless specified.
These leads may be run in as desired if neatly dressed, pro-
vided they are kept isolated from all signal and dc leads.
Long runs of wire shall be secured.

3.3.7 Interconnection leads shall be as short as possible. Avoid
excessive capacitance to ground and keep inductance to a mini-
mum in leads of high impedance circuits.

3.3.8 Voltage regulator tubes and reference tubes using 7 pin min-
iture sockets shall have two socket terminals wired in
parallel for connection to each of the tube's elements, unless
the tube is to be wired to interrupt the circuit. For example,
tube types OA2, OB2, 85A2 should have the anode connection
made to socket terminal numbers 1 and 5 parallel and the
cathode connection to any pair of terminal numbers 2, 4, and 7.

3.3.9 Potentiometers are wired so that "CW", or arrow, designates
the clockwise rotation of the pot, viewed from the shaft side.

3.3.10 Transformer secondaries shall be wired to their associated
locations in the circuit according to AIE Color Code. Example:
Brown filament leads. Use terminal strips for tie points,
then wire to appropriate circuit.

3.3.11 Wafer switch contacts shall be clear of flux and lubricated
with Lubriplate 105 (Fiske Bros. Refining Co.), or equal.
This lubricant is recommended for any electronics part re-
quiring lubrication.

3.3.12 When mounting small components such as capacitors and resis-
tors, the component pigtails shall not be stretched tight.
The lead shall be bent slightly between the component body
and the tie point in order to avoid damage due to thermal
expansion and contraction. There shall be at least 3/16 inch,
but no more lead length than is necessary, between the compon-
ent body and the soldered connection. Leave no more than 1/16
inch of pigtailing beyond terminal.

3.3.13 Circuits over 1000 volts shall be wired with a minimum clear-
ance to ground and to adjacent components of 0.3 inch per
1000 volts, except over 5000 volts, one inch per 10,000 volts
is adequate.
The seller shall be responsible for safe construction in the assembly of equipment involving high voltage.

3.3.14 Electrolytic capacitors shall be spaced away from heat radiating surfaces whenever possible if mounting details are not furnished.

3.4 Soldering

3.4.1 Unless otherwise specified, the solder shall be at least 60% tin bearing, and meet the requirements of Federal Specification QQ-S-571 for metallic composition and rosin flux. The self-contained flux shall promote the appropriate spreading of the solder over the plated or pre-tinned parts to form integrally thereon a coat of solder which feathers out to a thin edge. Examples of acceptable solder meeting Federal Specification QQ-S-571 are as follows:

1. Alpha centri-core energized rosin filled solder
2. Ersin multicore No. 364 flux core solder
3. Ersin multicore savbit flux core solder
4. Kester "44" rosin core solder

3.4.2 Only rosin, rosin-alcohol or equivalent plastic mixtures shall be used as an auxiliary flux, and then only when absolutely necessary.

3.4.3 In soldered joints, the lead does not have to be completely wrapped around the terminal for mechanical strength. The lead should have a half wrap in contact with the terminal and the soldering must be done so as to provide both a good mechanical and a good electrical connection.

3.4.4 There shall be no voids in the solder on or near component leads.

3.4.5 Insulation shall not be damaged by soldering.

3.4.6 Excess flux shall be removed. Ultra-sonic cleaning methods shall not be used.

3.4.7 Soldering techniques shall not exceed the temperature-time rating of any component. One recommended technique for connection of semiconductor components, precision resistors, and similar temperature sensitive elements is as follows:

1. Pre-tin the terminal to which the connection is to be made.
2. Firmly grasp the circuit element lead between the element and the terminal with a pair of cool long-nose pliers.
3. Complete the soldering operation using minimum heat and time to provide a satisfactory solder joint.
4. Allow complete cooling before removing the pliers from the element lead.
3.4.8 Leads consisting of gold-plated Dumet, gold-plated Kovar, or
gold-plated nickel must be carefully soldered initially, be­
cause further soldering may destroy the electrical connection.

3.4.9 Compression-type lugs and taper-pin connections may be used.
The compression-type lug and crimping tool must be approved
by LRL. Except for plug-in components, all other connections
shall be soldered.

4.0 PRINTED WIRING

4.1 When specified, etched wiring boards may be used in place of con­
ventional wires within electronics equipment.

4.1.1 When the seller is required to assemble, using printed
wiring boards, Specification LRL-01-2, "Standard for
Assembly of Printed Wiring Boards", shall become part of
this standard.

4.1.2 When the seller is required to provide the printed wiring
boards, Specification LRL-01-3, "Fabrication Specifications,
Printed Wiring Boards", shall become part of this standard.

5.0 INSPECTION

5.1 It shall be the responsibility of the seller to inspect all units.
The completed equipment shall be neat and clean, which includes re­
moval of spattered solder, spattered flux, metal chips, etc. Screw
heads and nuts that are deformed shall be replaced. Burned wires
shall be replaced. Errors in wiring or assembly shall be corrected.
Unless otherwise specified, "hot" testing is not required.

6.0 SUGGESTIONS FOR IMPROVEMENTS

6.1 LRL desires to obtain high quality electronic equipment as econ­
omically as possible without sacrificing reliability. The best
possible relation with the seller is important. Constructive
suggestions for better ways and means of attaining this goal are
welcome, and will be given immediate consideration.
APPENDIX U

STANDARD FOR

ASSEMBLY OF PRINTED WIRING BOARDS

1.0 GENERAL

The intent of this standard is to set forth the practices which shall be followed by sellers assembling Printed Wiring Boards for use by the University of California Lawrence Radiation Laboratory.

2.0 APPLICABLE DOCUMENTS

The following documents, the issue in effect on date of request for quotation, form part of this standard. They are listed in order of their precedence in event of conflict between them.

2.1 The schematic, other drawings and specifications.

2.2 Photographs or the prototype.

3.0 SUPPLY OF PRINTED BOARDS

3.1 When the seller is required to supply the Printed Wiring Board, such board shall be produced in accordance with UCLRL Specification 01-3, Fabrication Specifications Printed Wiring Boards.

3.2 When UCLRL provides the Printed Wiring Board the seller shall, upon receipt of such boards, perform a visual inspection for damage in shipment. If any board is judged defective per Specification 01-3, foil pattern, hole schedule or outline drawing, the UCLRL Field inspector will either approve use of the questionable board or will arrange for replacement.

When boards are accepted by the seller, the seller then becomes responsible and liable for such boards.

4.0 CLEANLINESS AND MECHANICAL HANDLING

Great care and cleanliness are required to produce a printed wiring assembly of good quality. The following rules shall be followed:

Prepared by J. T. Lavrischeff Date 12/15/61 Approved by Date

Revised by Date
4.1 Handle boards only by their edges.

4.2 Never stack boards without some mechanical separator between them. If paper is used, it must have low sulphur content.

4.3 Store boards only in a clean dry atmosphere in plastic, mylar or cellophane bags.

4.4 Abrasive or acid dip cleaning methods shall not be used.

5.0 MOUNTING COMPONENTS

The drawings for the particular item of equipment will show the location of the various components. The schematic shall determine polarity of components. The following general rules shall be followed unless otherwise specified:

5.1 Components shall be mounted on the left side of the board when the board is vertically positioned and viewed from the edge opposite the connector. Connections to the board are numbered bottom to top. Boards having un-numbered connections can be vertically positioned by placing the reference edge on the bottom as shown on the applicable outline drawing.

5.2 No sharp edged metallic instruments shall be used in forming component leads. An acceptable tool is a pair of round nose pliers.

5.3 Whenever possible, a component shall be mounted so that the markings showing electrical value are visible.

5.4 Whenever possible, the leads shall extend straight out from the component. When a bend is required between the component and the solder joint, it shall be directly over the hole into which the lead is to be soldered.

5.5 All components shall be mounted without strain on the lead wires, but not greater than 1/16 inch away from the board. (See Figure 1).

5.6 Axial component leads shall not be bent less than 3/32 inch from where they emerge from the component and total lead length to the board shall not be less than 5/32 inch. (See Figure 1).

5.7 Component leads shall not be bent over more than 30° normal to the board on the solder side of the board, unless clenched leads are specified.

5.8 Strain-relief loops are not necessary unless so indicated.
6.0 THROUGH BOARD CONNECTIONS

6.1 Eyelets

6.1.1 Eyelets shall be used for through board connections.

6.1.2 Component lead wires shall not pass through eyelets, or be soldered to eyelets.

6.1.3 Eyelets shall be soldered as shown in Figure 2.

7.0 SOLDERING PRACTICES

7.1 Soldering with conventional soldering irons.

7.1.1 Idling temperature of the soldering iron tip shall not exceed $700^\circ$ F.

7.1.2 No silver bearing solder shall be used, the solder shall be at least 60% tin bearing, and meet the requirements of Federal Specification QQ-S-571, for metallic composition, and rosin flux. The soldering flux shall promote the appropriate spreading of the solder over the plated copper base to form integrally thereon a coat of solder which shall feather out to a thin edge.

Examples of acceptable solder meeting Federal Specification QQ-S-571 are as follows:

Item 1 - Alpha cen-tri-core energized rosin filled solder
Item 2 - Ersin multicore number 364 flux core solder
Item 3 - Kester "44" rosin core solder

7.1.3 The soldering time shall not exceed the temperature-time rating of any component.

7.1.4 Acceptable soldered terminations are shown on attached drawings (Figures 1 and 2). Excess flux shall be removed completely. To avoid damage to semi-conductors, ultrasonic cleaning processes shall not be used. Care must be taken not to destroy component markings.

7.1.5 Leads consisting of gold-plated Dumet, gold-plated Kovar, or gold-plated nickel must be carefully soldered initially, because further soldering may destroy the electrical connection.

7.1.6 There shall be no voids in the solder on or near component leads.
7.2 **Dip Soldering of Printed Wiring Boards, Unclenched Leads**

7.2.1 Dip or wave soldering may be used in the assembly of printed wiring boards unless otherwise indicated. The following rules shall be followed:

7.2.1.1 Solder temperature shall not exceed 510° F.

7.2.1.2 Any flux which has an acid content shall not be used.

7.2.2 See 7.1.2

7.2.3 See 7.1.3

7.2.4 See 7.1.4

7.2.5 See 7.1.5

7.2.6 See 7.1.6

7.3 **Dip Soldering of Printed Wiring Boards, Clenched leads** (Use only when specified)

7.3.1 See 7.2.1

7.3.2 See 7.1.2

7.3.3 See 7.1.3

7.3.4 Acceptable soldered terminations are shown on attached drawings (Figure 3). The contour of the lead wire shall be visible after soldering. Excess flux shall be removed completely. To avoid damage to semi-conductors, ultrasonic cleaning processes shall not be used. Care must be taken not to destroy component markings.

8.0 **LEAD TRIMMING**

8.1 Component lead wires shall be trimmed to the lengths shown in Figure 1.

8.2 Final trimming of any given wire shall be done after the completion of the soldering of that wire.

8.3 Mechanical shock can injure many components, particularly semi-conductors. Any pre-trimming of semi-conductor components must be done by shearing.

8.4 Final trimming methods must not injure the soldered connection.

9.0 **MARKING & IDENTIFICATION**

9.1 The completed board assembly shall bear the identifying mark of the manufacturer and the schematic number of the circuit. Transistor positions shall be marked "Q1","Q2" etc. Only one side of the board need be marked. If the markings touch any of the etched circuitry, a non-corrosive ink must be used.

10.0 **INCOMING INSPECTION AT UCIRL**

10.1 It shall be the responsibility of the seller to inspect all units. UCIRL may inspect some or all units of each shipment.
The inspection shall include at least the following:

10.1.1 A search for any deviation from normal good shop practice.

10.1.2 A search for any of the following listed defects:

10.1.2.1 Damaged or peeled conductor pattern.

10.1.2.2 Components improperly mounted on board.

10.1.2.3 Reversed leads on transistors, diodes, etc.

10.1.2.4 Improper lead terminations, including soldering and trimming.

10.1.2.5 Extraneous solder on board, components or conductor pattern.

10.1.2.6 Incomplete flux removal.

10.1.2.7 Delamination of the base material.

10.1.2.8 Any extraneous material on the portion of board to be inserted in connector.

10.2 Unit containing any of the defects listed above or any other defect indicating non-compliance with this specification will be rejected. If a simple repair cannot be made, the board shall be discarded, and must be replaced at the seller's expense. The Production Control Inspector shall be sole judge concerning the possibility of repair of defective boards, or the use of components salvaged from defective boards to produce another board.
Angle of bend not to exceed 30°.

Component to clear board by not more than 1/16". If component touches the board, there shall be no strain on the lead wires.

Not necessary to fill center of eyelet.

Spec. LRL-01-2C
APPENDIX V.
FABRICATION SPECIFICATIONS
PRINTED CIRCUIT BOARDS

1.0 GENERAL

1.1 These specifications are intended to describe printed circuit boards designed by the Lawrence Radiation Laboratory and to be constructed by the seller. Requirement is for etched and plated conductive pattern on flame retardant base material.

2.0 QUALITY

2.1 The quality of material and workmanship shall comply with the highest standards obtainable for printed circuit boards, all boards to be manufactured in a thoroughly neat and workmanlike manner.

3.0 DEFINITIONS

3.1 The definition of all terms used herein shall be in accordance with MIL-STD 429.

4.0 MATERIAL

4.1 Paper base epoxy boards are to be fabricated from NEMA Grade FR-3, cold punch, flame retardant, Spauldite EXXP-845 or Textolite (GE) 11577 or equal. The insulating base material shall be coated on both sides with electrolytic copper, two-ounce per square foot. All equivalents must be approved by the Laboratory and the seller must obtain authorization, in writing, before use.
4.2 Glass epoxy boards are to be fabricated from NEMA Grade FR-4, cold punch, flame retardant, Spauldite G-10-839 or Mica 818 or equal. The insulating base material shall be coated on both sides with electrolytic copper, two-ounce per square foot. All equivalents must be approved by the Laboratory and the seller must obtain authorization, in writing, before use.

5.0 FABRICATION AND TOLERANCES

5.1 Outline Drawing

5.1.1 Finished boards must conform to the drawing dimensions and tolerances specified on the attached drawing.

5.1.2 Foil circuit to be on one or both sides, as applicable, with connector tabs always on both sides, connector tabs shall be aligned, from one side to the other (registered) within the tolerances shown on the outline drawing. Registration of foil circuits shall be within the tolerances shown for the connector tabs.

5.2 Base Laminate

5.2.1 Board material shall be flat within 0.005 inch per inch.

5.2.2 Gouges will not be acceptable if gouge touches circuit pattern; acceptable in base laminate only if gouge does not exceed 0.050 inch in length and depth is not greater than 0.030 inch, or 1/3 or maximum board thickness, whichever is smaller.

5.2.3 Delamination of base laminate may be repaired with epoxy. Each board so repaired must be tagged so as to call it to the attention of UCRL Inspector. If such repair, however,
in the opinion of the Inspector is defective for the intended use the part will be rejected.

5.3 Conductor Pattern

5.3.1 Original conductor line widths and location dimensions are determined by the photographic transparency provided by the Laboratory. Whenever possible the transparency will be approximately twice the size of the required foil pattern. It shall be the responsibility of the seller to reduce the artwork to the required dimension which is determined by the center to center dimension of the two outside contact fingers as follows:
For 22 contact fingers this dimension shall be $3.281 \pm 0.010$ in.
For 15 contact fingers this dimension shall be $2.189 \pm 0.010$ in.

5.3.2 When foil circuit is on one side of board only, circuit pattern shall be printed on reverse side of board with white ink. Registration of printed pattern to foil pattern shall be within plus or minus 0.031 inch.

5.3.3 Poor definition of land and conductor edges shall not reduce the land diameter or conductor width by more than 10% of the original value. Feathered edges shall not exceed 5% of the total circuit area per board.

5.3.4 Individual irregularities in land diameter or conductor width due to pits, pin-holes, scratches, etc., shall not reduce the diameter or width to less than 2/3 of the original value. In no case shall the conductor width be less than 0.030 inch.
5.3.5 Irregularities in cross section of lands or conductors due to nicks, cuts, scratches, over-etching, etc., shall not reduce the original thickness by more than 20%.

5.3.6 Plating over surface defects in the circuit pattern shall not be construed as elimination of the fault, regardless of the material in such plating.

5.3.7 Portion of board to be inserted in connector shall be free from all defects visible to the unaided eye.

5.3.8 Electrical conductor breaks will not be accepted.

5.3.9 Peeling (delamination of copper) will not be accepted.

5.4 Holes

5.4.1 Holes are to be 0.038 inch in diameter, plus or minus 0.003 inch (#62 drill), except as shown in 5.7 or as designated on a hole schedule.

5.4.2 Holes may be either punched or drilled and shall not break open any lands. The center void in the circuit land shall be drilled out. In the absence of a center void, the center of hole to the center of land must be coincident within 0.015 inch.

5.4.3 Burrs will not be accepted.

5.5 Gold-Plated Circuit and Connector Tabs

5.5.1 Foil circuit and connector tabs shall be gold-plated. The minimum thickness of gold-plating shall be 0.000075 inch.

5.5.2 Plating shall pass a scotch tape pull test and a visual inspection by UCRL will determine acceptability.
5.6 Solder-Coated Circuit and Gold-Coated Connector Tabs

5.6.1 Solder-coating shall completely tin all exposed copper.

5.6.2 The coat shall have a uniformly smooth and bright appearance, and be reasonably free from nodules.

5.6.3 The coating shall be free of areas of pits or graininess.

5.6.4 All holes shall be open for component-lead insertion.

5.6.5 Connector tabs shall be plated with gold as in 5.5.

5.6.6 Both sides of the finished board are to have a protective coating of water-base lacquer, or Sealbrite #230-10 or equivalent. The connector tabs are not to be coated.

5.7 Eyelets

5.7.1 Thru-board connections shall be made with funnel-flange eyelets, or by reliable plated-thru techniques. Thru-board connections shall be made at all connector tabs where lands are provided. Other places will be designated on a hole schedule.

5.7.2 Eyelets shall be oxygen-free copper and shall be plated with a minimum of 0.00005 inch of gold.

5.7.3 Eyelets used with solder coatings shall be tin-plated, clean, and free of tarnish.

5.7.4 All eyelets shall be firmly attached to the circuit board so that they cannot be rotated before soldering. Splits shall not extend down into the barrel of the eyelet.

5.8 Cleanliness

5.8.1 The boards shall be clean and the circuitry, including eyelets, shall be in a solderable condition.
6.0 IDENTIFICATION

6.1 Each board must bear the identifying mark of the seller, indicating that the board has been inspected by the seller and has passed all UCIRL Specifications before shipment. This mark must not touch any of the etched circuitry.

7.0 PACKAGING

7.1 Boards shall be individually packaged in transparent plastic envelopes. Envelopes shall not be sealed unless specified on the purchase order.
APPENDIX W.

ARTWORK SPECIFICATION

PRINTED WIRING BOARDS

1.0 GENERAL

1.1 Artwork shall be made at least twice size (2x).
   Experimental and prototype artwork may be actual size if time
   requires.

1.2 The basic grid dimension when reduced shall be 0.10 inch.
   Where component lead placement does not allow the 0.1 in. grid
   dimension, the grid dimension may be reduced to .05 in.

2.0 CONDUCTIVE PATTERN (Dimensions are after reduction)

2.1 Use free flowing lines and rounded corners in conductor layout.
   The minimum radius of curvature shall equal the conductor width at
   the radius. Included angles up to 90° require fillets.

2.2 Conductor spacing shall be in accordance with Table I. The minimum
   line or land separation shall be 1/32 inch (0.031).

2.3 Conductor widths shall be such that currents do not exceed the values
   shown in Table II at 50° C. The minimum line width shall be 3/64 in.
   (0.047).

2.4 Lands shall be employed for each individual lead. Land placement
   shall be such that components can be mounted in accordance with Spec.
   01-2B, Specification for Assembly of Printed Wiring Boards.
   Components mount on one side of the board as shown on the outline
   drawing.

2.5 The land shall be of such size as to add an annular ring extending
   at least .040 inch beyond the edge of the hole for at least 50% of
   the circumferential distance around the hole. The minimum width of
   the annular ring at any point shall be .025 inch. The only exception
   are lands for transistor leads which may have a minimum .025 inch
   annular land all around the hole.

2.6 Conductive pattern to be on side opposite components or both sides
   as applicable, with connector tabs always on both sides.

Prepared by J. Lavrischeff Date 7/3/62 Approved by

Revised by Date 7/3/62
Dimensions applicable to the connector tabs shall be within the tolerances shown on the outline drawing. Registration of circuit patterns shall be within the tolerances used for the connector tabs. Fiducial marks shall be used to aid registration.

2.7 Lands shall be provided for thru-board connections and at every active connector position.

2.8 Conductor lengths shall be as short as practical.

2.9 Avoid crossing conductors with component leads.

2.10 The conductor lines shall provide a 1/32 inch margin from board edges. A 3/16 inch margin shall be provided when using metal slides.

2.11 When the board is to be dip soldered avoid large unrelieved expanses of copper which could blister.

3.0 HOLES

3.1 There shall be a minimum distance between edges of holes equal to the board thickness.

3.2 Holes shall not be located closer than \( \frac{1}{32} \) times the board thickness from the edge of the board.

4.0 BOARD SUPPORT

4.1 Provisions for mounting of the board shall provide support at intervals of not more than 6 inches.

5.0 IDENTIFICATION

5.1 The artwork number shall appear as part of the circuit pattern.
TABLE I
MINIMUM SPACING OF ADJACENT CONDUCTORS

<table>
<thead>
<tr>
<th>MAX. OPERATING PEAK VOLTAGE DIFFERENCE</th>
<th>MINIMUM SPACING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 150</td>
<td>0.031 inches</td>
</tr>
<tr>
<td>151 - 300</td>
<td>0.062 inches</td>
</tr>
<tr>
<td>301 - 500</td>
<td>0.125 inches</td>
</tr>
<tr>
<td>501 &amp; OVER</td>
<td>0.0003 in./per volt</td>
</tr>
</tbody>
</table>

TABLE II
CONDUCTOR WIDTH IN. (2 OZ./SQ.FT.) AMPERES AT 50°C OHMS/IN. AT 25°C

<table>
<thead>
<tr>
<th>CONDUCTOR WIDTH</th>
<th>AMPERES</th>
<th>OHMS/IN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 (0.250)</td>
<td>3.0</td>
<td>0.0003</td>
</tr>
<tr>
<td>1/8 (0.125)</td>
<td>1.5</td>
<td>0.0018</td>
</tr>
<tr>
<td>1/16 (0.062)</td>
<td>0.75</td>
<td>0.0035</td>
</tr>
<tr>
<td>3/34 (0.047)</td>
<td>0.57</td>
<td>0.0052</td>
</tr>
</tbody>
</table>
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