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PROCEDURE FOR THE FABRICATION OF PRINTED CIRCUIT BOARDS

by

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ABSTRACT

The use of printed circuits in electronic equipment designed for research applications is described. Details of the procedure used and materials employed are given. These techniques are illustrated by specific examples of equipment in use in the Mineral Sciences Division.

RÉSUMÉ

L'utilisation de circuits imprimés pour la fabrication d'appareils électroniques en usage dans les laboratoires de recherches de la Division des sciences minérales est décrite.

Les détails sur les procédés en usage et le matériel employé dans la fabrication de modules et d'instruments y sont donnés. Cette méthode est illustrée d'exemples spécifiques d'appareils construits utilisant cette technique.

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INTRODUCTION

During the past few years, an attempt has been made to standardize electronic components and sub-assemblies, in order to facilitate the construction of complex electronic instruments used in various research programs.

A large number of electronic units were designed and built for the former Radioactivity Division and the Mineral Sciences Division, according to the classical methods, using vacuum tubes, transformers, relays, etc. These instruments gave excellent performance, but they had several drawbacks. Their construction was time-consuming; they were bulky; and most of the input power was dissipated as heat, thus shortening the life-time of the components and requiring costly maintenance. Each unit was constructed separately as an individual device. The need for complicated networks of insulated wires, mounting brackets and binding posts often resulted in shorts, or open-circuits, or inductive couplings, the sources of which were difficult to trace.

The advent of solid state electronic components brought about a revolution in the design and construction of electronic circuits. Now, compact, dependable units can be built, using miniaturized components. These units operate at low currents and voltages, and they are readily available on the market at competitive prices. This has led to the adoption in this laboratory of a form of construction known as a printed circuit. These are already used by the electronic industry for mass production.

The printed circuit affords rigid mounting of parts in a relatively small space, each component being soldered to the supporting plate. Wiring errors are thus reduced to a minimum, because of the absence of inter-connecting leads.

Plug-in units serving a variety of functions can be readily attached to the circuit board, thus facilitating modifications of a master unit for various special purposes. The use of variable and semi-variable components permits an accurate adjustment of the circuit for optimum operation.

Duplication of a printed circuit board can be easily achieved by photoengraving methods from a standard matrix.

CIRCUIT DESIGNING

In a conventional layout, where parts and leads can be stacked at will, the circuit designer enjoys a large degree of freedom in the positioning of the components. Since with a printed circuit the conducting network is limited to a plane, the topology becomes more complicated. The network must be designed so that the components bridge the conductors with a minimum of points requiring interconnection by jumpers. All components should be oriented so that they are parallel to one side of the plate.

One of the chief advantages of the printed circuit technique is the flexibility with which electronic assemblies may be modified. The use of one standard circuit per board allows a true "black box" type of assembly to be built. In order that this may be possible, a standard-size board must be used; also, a standard polarity of input and output pulse should be adopted and only a limited number of power supply voltages should be required per board. While these requirements may involve an extra invertor or a Zener diode on a board, the disadvantage of the added complexity is overcome by the ease of interchange of functions. To facilitate the sandwiching of different boards in a standard chassis, or for adding boards to existing equipment, a standard geometrical size of 4 1/2 in. x 7 1/2 in. has been adopted. Power and signal connections to a circuit are arranged on one end only, so that interconnection may be made by means of a common cable.

Standard power supply voltages of $\pm$ 30V, $\pm$ 12V and $\pm$ 6V are used, and negative pulses only are available. While these criteria are generally followed, exceptions can be made if there is sufficient reason, but no such situation has yet been encountered. The use of a template for standard components helps in the positioning of the parts terminals on the drawing. Layout problems can be anticipated, but fewer modifications will be needed as experience is gained in design procedure. The designing of such a circuit is an art that can be mastered only by experience.

PREPARATION OF MATRIX

There are various methods for preparing the master drawing which is to be used in the fabrication of the matrix. An india ink drawing of the negative of a circuit on tracing paper proved to be unreliable, because of the non-uniformity of the outlines and the uneven blackening which result in pin holes and breaks in the final product. Cutting-out the circuit on a mylar base covered with a peelable red film ("cut-n-strip"), to produce a positive matrix, gave good results, but this could not be used for crowded circuits because of the difficulty of removing narrow strips of the film placed close together.

The technique adopted in this laboratory closely follows the one used in industrial procedures, with some simplifications. The relatively large size of our circuit boards has meant that a full-size drawing can be used for the original layout. This master is traced on drafting paper and photographed. The resultant negative is used as the matrix for the circuit.

SELECTION OF LAMINATE MATERIAL

Of the many materials available, an epoxy-base laminate, coated at 1 oz. copper per ft^2, was found to be most satisfactory. The laminate initially purchased had to be scoured, degreased, and cleaned with appropriate solvents. The necessity for this cleansing procedure has been eliminated by the purchase of NVF plastic-coated copper laminate. The plastic protective coating can be peeled from the copper side and the laminate used without any preliminary treatment. The copper conductor is available in various weights, and the 1 oz./ft^2 material, which has a current carrying capacity of 2 amp in a 1/32 in. width, is sufficient for most transistor circuitry. The epoxy-based laminate is used because it is relatively heat-resistant and has a greater freedom from warping than the cheaper bakelite-based laminates used in consumer products.

SENSITIZING THE BOARD

In order to transfer the design from the matrix to the copper, the circuit boards must first be made sensitive to light. A commercial photo-resist (Kodak KPR) is used. The solution is brushed evenly on the clean copper surface with a camel's hair brush, and allowed to dry with the board in a horizontal position. This assures a thin, even coat of photosensitive material. This photo-resist is moderately sensitive to ambient light conditions, and precautions should be taken to reduce the average light in the room. The drying takes about 30 minutes at room temperature; however, this time may be reduced to 10 minutes if the board is placed in a well-ventilated oven at 100-150°F. The handling of the board during this procedure and in all subsequent operations must be done with great care. The photo-resist is an excellent fingerprint medium. It is obvious that dust, scratches, hairs and other foreign objects on the board will cause imperfections and produce an inferior final product.

PRINTING OF THE PLATE

When exposed to light, the photo-resist hardens and thus will prevent the etching of those parts of the board used in the procedure to be described later. Using the light box (described in the Appendix), the sensitized plate is exposed to light. Care should be taken to have the upper glass of the light box very clean. The matrix is placed, face down, on the glass, and the sensitized side of the laminate is then placed over the matrix. The plate is exposed for about 23 minutes. This exposure time can be reduced by using ultra-violet light. Over-exposure should be avoided because the photo-resist material on the copper to be removed will harden and interfere with the etching. Under-exposure will cause a pitting of the printed copper. The optimum exposure time was found by trial and error.

DEVELOPING THE CIRCUIT

The exposed plate is now developed, an operation which will remove the resist where it has not been exposed to light. A Kodak photo-resist developer solution in a Pyrex tray is used to develop the circuit. The plate is allowed to cool before immersion in the developer, to avoid deterioration of the sensitive coating.

The developing time is about 10 to 15 minutes, after which the plate is removed from the bath and a Kodak dye solution is sprayed on the printed side of the plate. This will only dye the remaining photo-resist on the printed circuit and reveal all the outlines, and thus any imperfection of the circuit will be seen at this stage. A careful application of photo-resist solution, with a small brush, can be used for correcting any faults which may appear. If the plate is too smeared to be corrected, it can be dipped in a bath of methyl ethyl ketone, which will remove the photo-resist from the copper.

After a washing in running water, the plate is dried and can be reprocessed.

ETCHING OF THE CIRCUIT

The final stage of the preparation of the plate is the chemical removal of the unwanted copper from which the unexposed photo-resist has been dissolved by the developing procedure.

A 5-gal Pyrex tank containing 4 gal of 2 lb/gal ferric chloride solution is used for this purpose. The solution is agitated with an electric stirrer.

The exposed plate is clamped in a plate holder and then immersed in the solution until the etching is completed. At room temperature this requires up to one hour, but if the solution is heated to approximately 150°F the etching time is reduced to 10-15 minutes. The plate is then washed with methyl ethyl ketone to remove the black dye remaining on the circuit. The plate should now be cleaned with a powdered cleanser so that all traces of photo-resist film are removed from the remaining copper. This will facilitate the soldering of components to the circuit.

Over-etching will damage the outline of the printed circuit, and under-etching can cause shorts and sometimes leakage.

MACHINING OF THE PLATE

The components used in the circuit are placed on the opposite side of the laminate from the copper. Holes are drilled through the plate to introduce the component leads that will be soldered to the copper conductors. An appropriate drill is used for this operation, suitable to the wire size involved.

It was found that sometimes the copper laminate had a tendency to separate from the epoxy plate at the rim of the hole, as a result of repeated soldering which might be required when changing components or in the servicing of the circuits. This problem was eliminated by the use of small copper eyelets riveted into the holes.

LAYOUT AND SOLDERING OF COMPONENTS

The coding or specifications on the components should be oriented the same way in order to facilitate reading of their values when mounted. Care should be taken to leave the terminal leads long and thus avoid excessive heat conduction when soldering them in the circuit.

Excessive heat can damage and alter the function of components, especially semiconductors. Cleaning the terminal leads with a pencil eraser at solder contact points will also shorten the heat contact time when solder is applied. The excess resin on the board can be removed by cleaning the soldered points with a solvent such as methyl ethyl ketone.

ILLUSTRATIVE MATERIAL

The Appendix contains eleven sketches and pictures describing both the equipment used for the fabrication of printed circuits and the different production stages of a printed plate.

An ultrasonic power amplifier using these printed circuit techniques is shown in Sketch 5; it was designed and built in the Mineral Sciences Division. All the components are mounted on printed circuit boards, including those on the front panel. This illustrates the versatility of the printed circuit method.

CONCLUSIONS

The use of printed circuits has simplified electronic design and made possible the production of elaborate equipment comparable to that produced by commercial firms. Duplication of equipment is facilitated and little trouble has been experienced in these operations.

ACKNOWLEDGEMENTS

The author thanks Dr. R.H. Goodman for his advice in establishing these methods for printed circuits and for his guidance in the construction of numerous instruments.

He is also indebted to Mr. C.A. Josling for preparing both the drawings included in this report and the masters used for the circuits.

REFERENCE

"Introduction to Printed Circuits", by Robert L. Swiggett (John F. Rider Publisher, Inc., New York, 1956), 101 pp.

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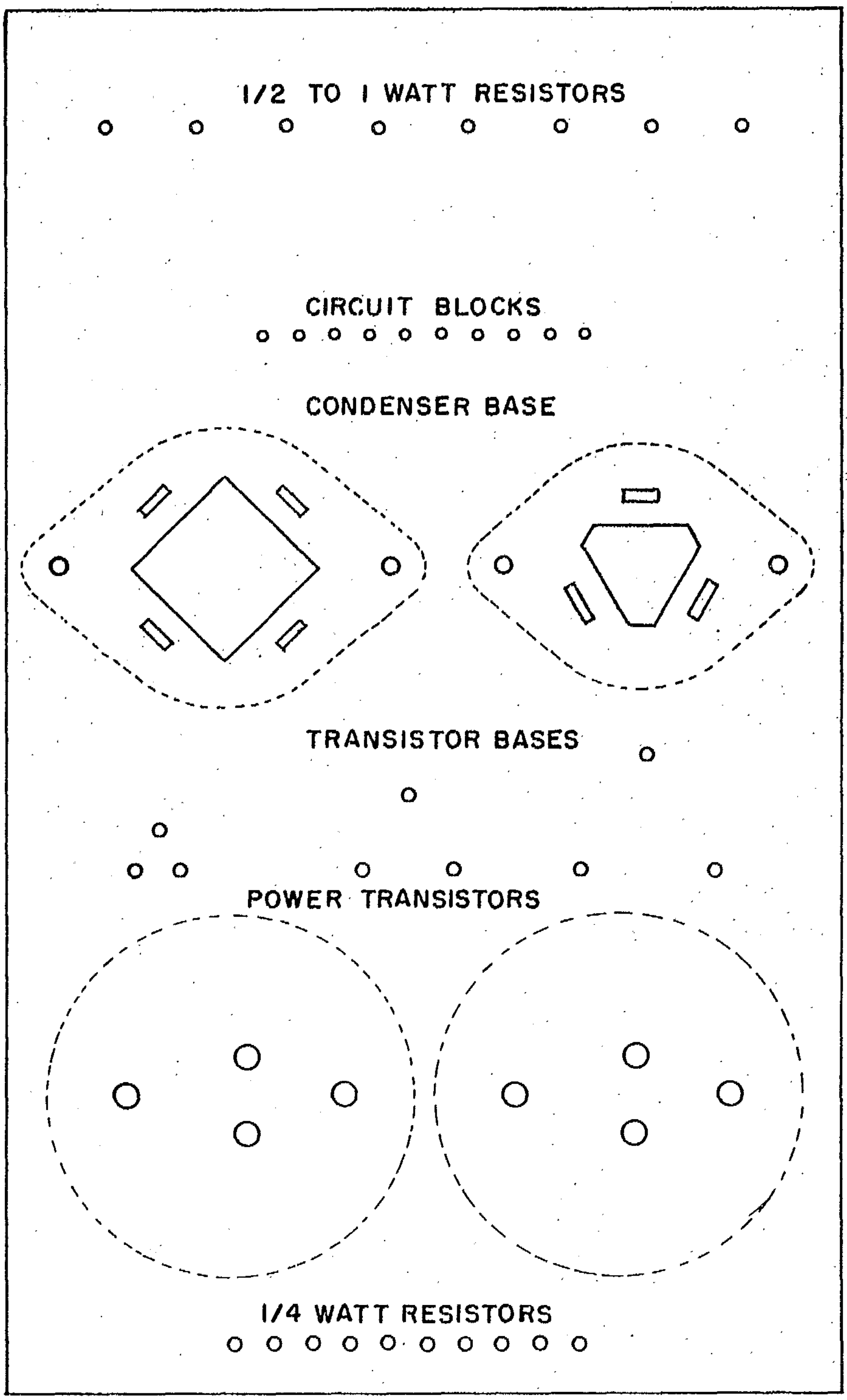
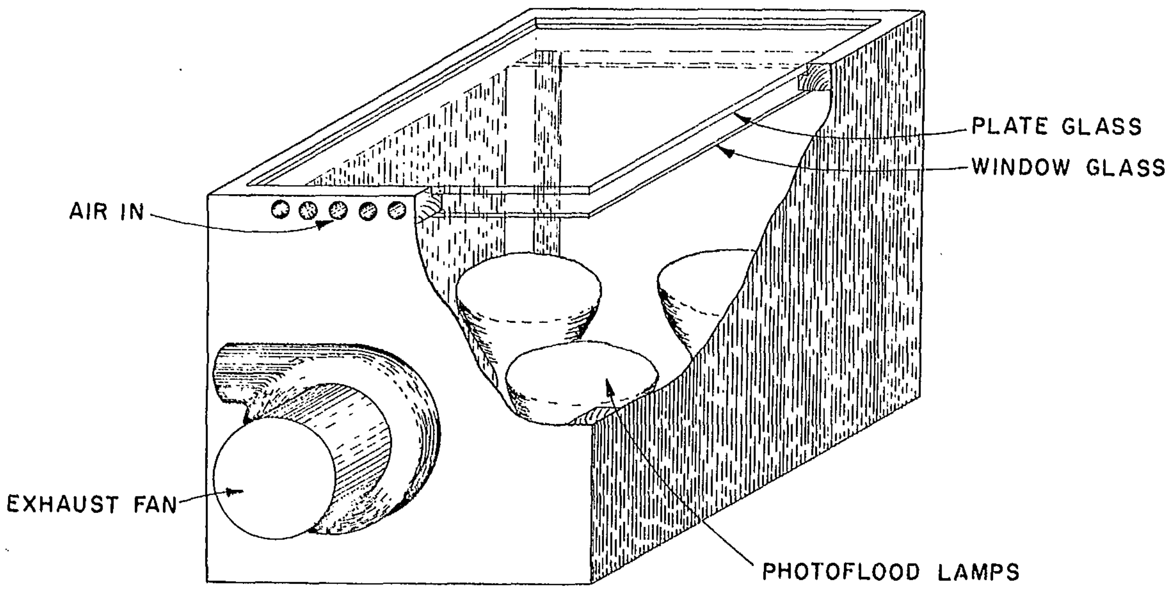
ILLUSTRATIVE APPENDIX

1) The Template for Components is made from a plastic sheet in which holes are drilled for different standard-sized components.

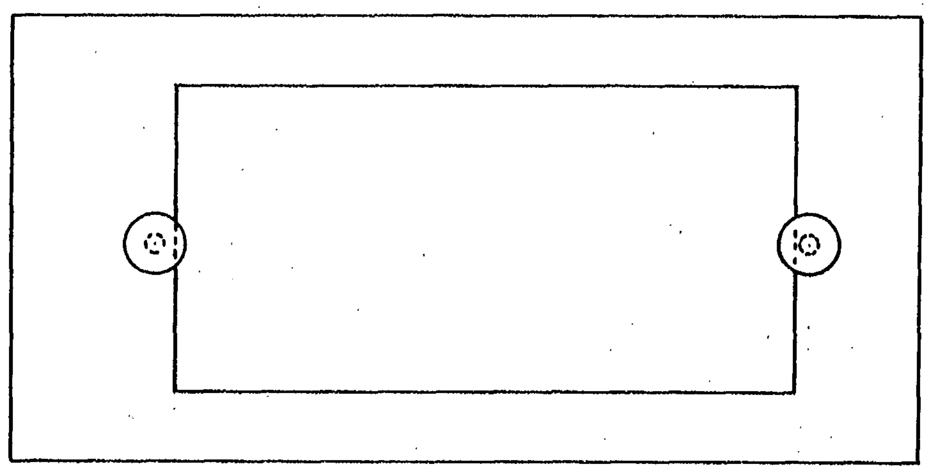


2) The Light Box



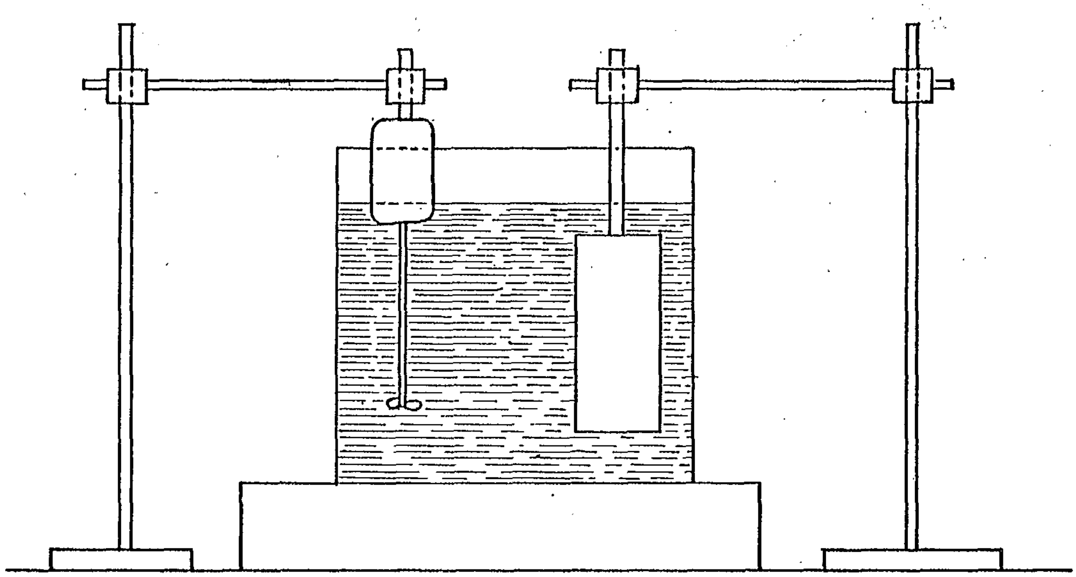
A 13 in. cubic wooden box, having a plate glass top and fitted with four 75-watt photoflood lamps, is used as a light source. A cooling fan draws the heat from the box through a channel composed of a second glass plate 1 in. below the top plate. The wooden side of the box is perforated between the two plates by a series of 3/4 in. holes through which cool air is drawn in and channelled to the opposite side, where there is a slot of 1/2 in. between the bottom glass plate and the side of the box. This permits the air to be drawn into the box and pulled out by a fan. The top plate is thus kept cool and the chance of having the matrix damaged by heat is reduced. The exposure time is controlled by an Instrument Development Laboratories Model 42 timer system.

3) Plate Holder

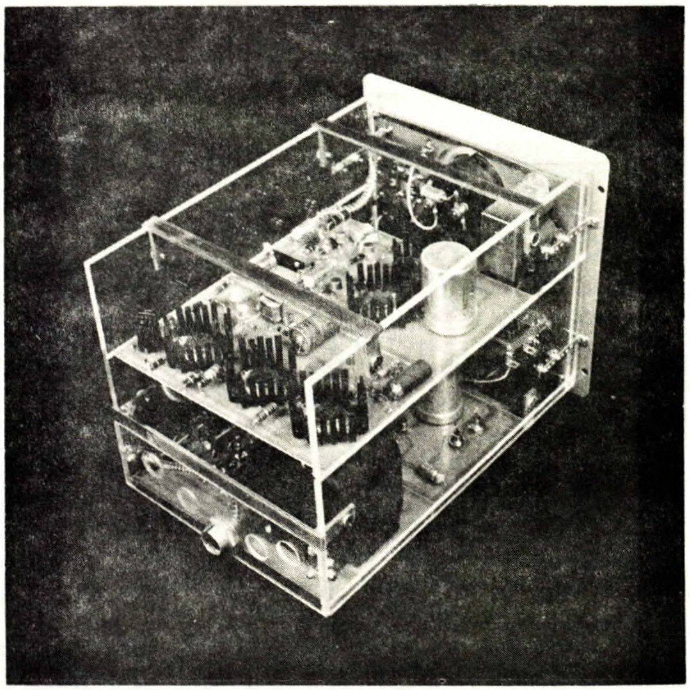


The plate holder used to immerse the plate in the etching solution is made of a plastic sheet 15 in. x 5 in. x 1/4 in. on which two Teflon retaining screws are mounted to hold the plates in position. This holder plate is clamped vertically in the etching tank.

4) Schematic of the Etching Tank

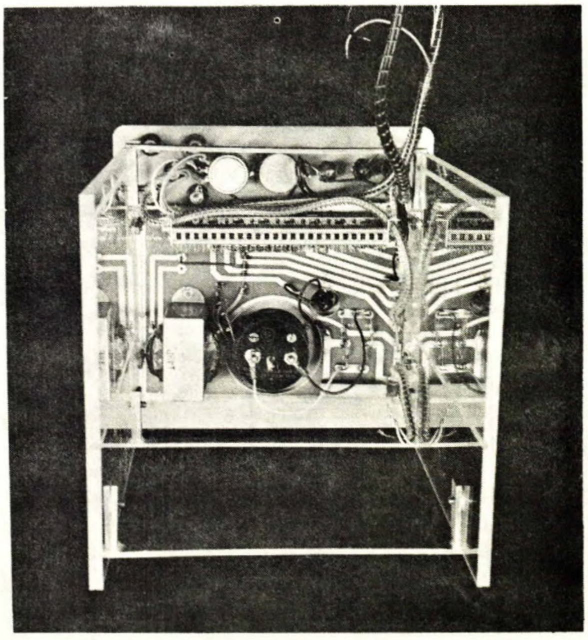


5) Standard Chassis



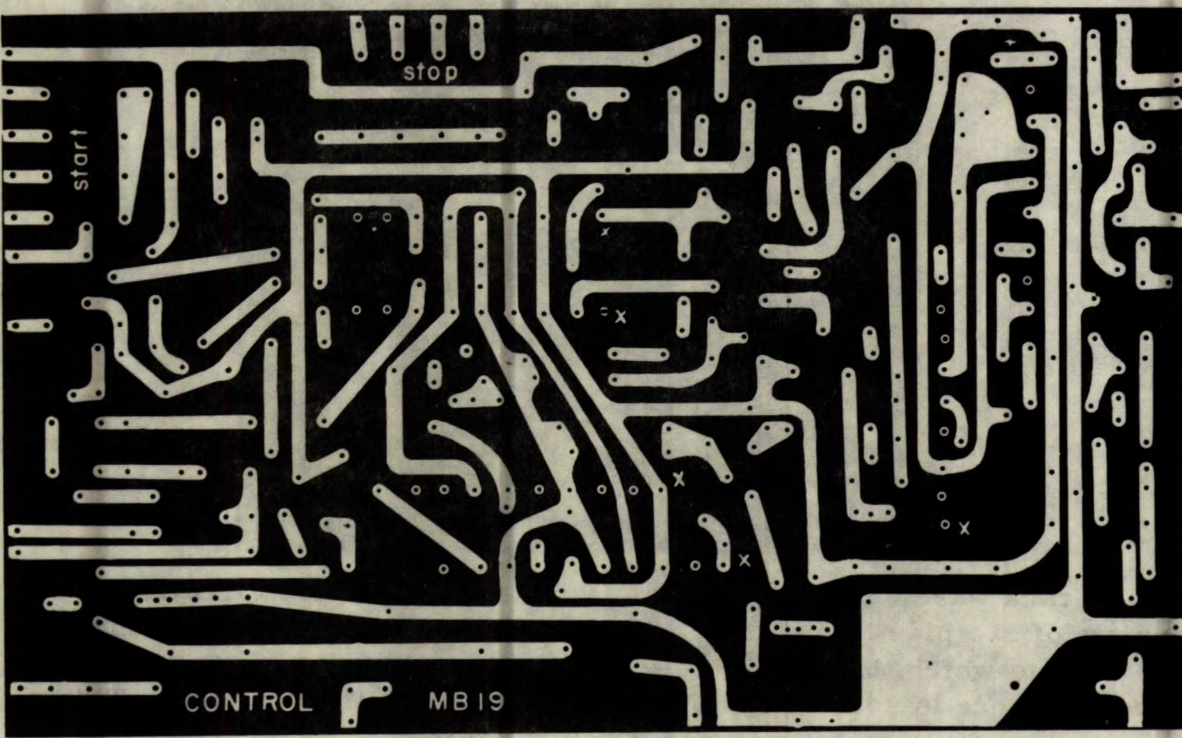
A rack was constructed to hold the standard printed circuit. It consists of two plastic plates, 7 3/4 in. x 11 3/4 in. x 1/4 in., with 1/8 in. grooves into which the modules slide. The two plates are retained at the proper distance by four strips of brass fixed in position by bolts. This rack can be housed in a Hammond # 1401F cabinet.

6) Printed Front Panel

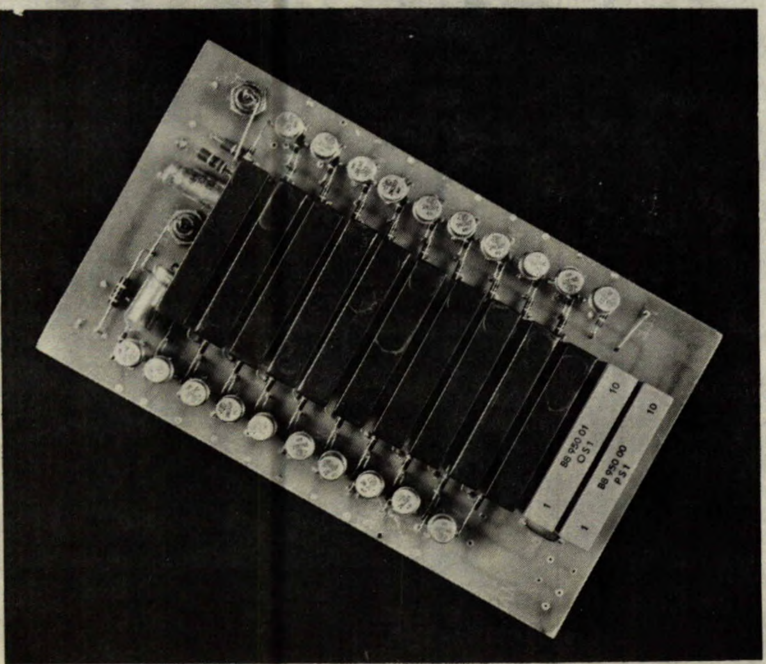


Provision can be made to have a printed front panel on which all controls are directly interconnected by printed connectors.

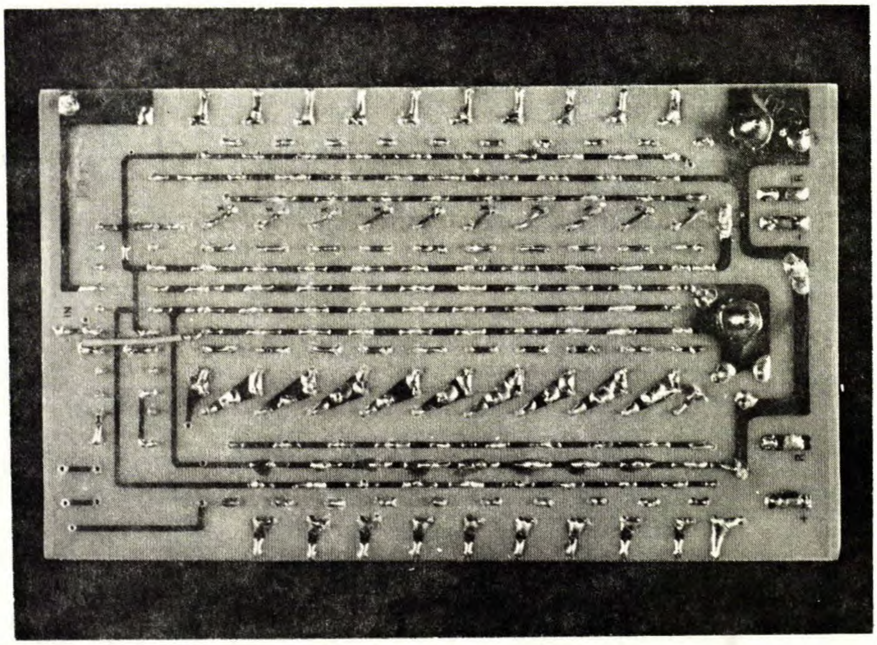
7) Picture of a Matrix



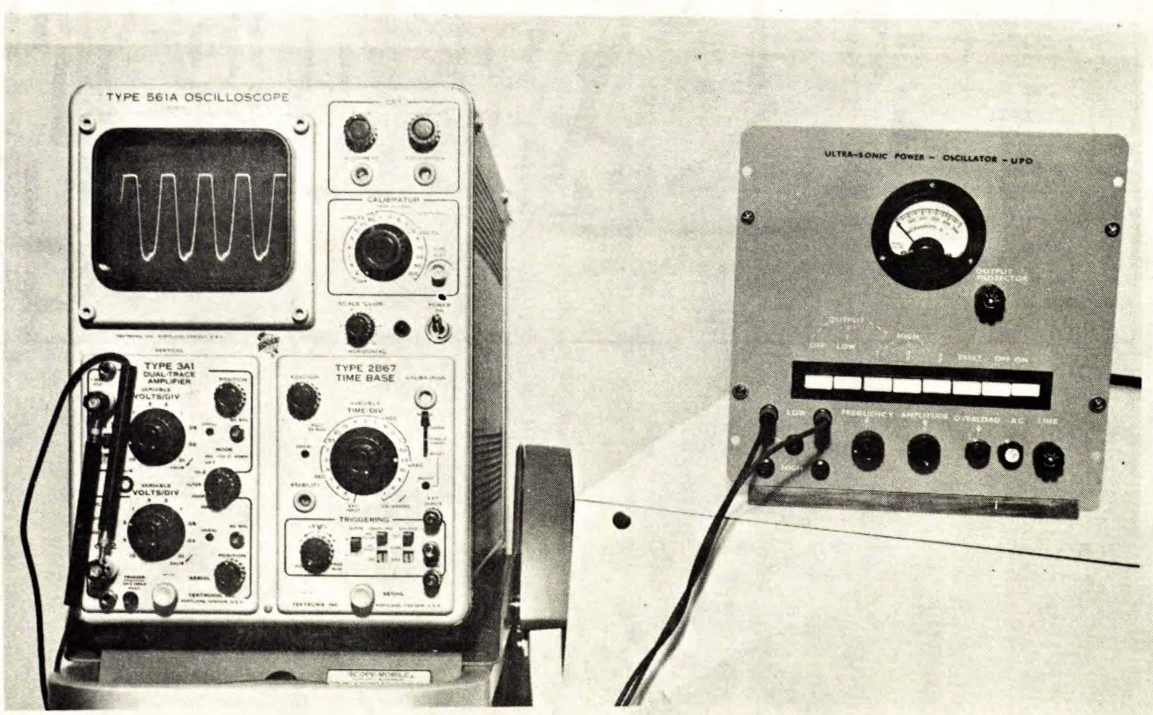
8) Picture of a Completed Board



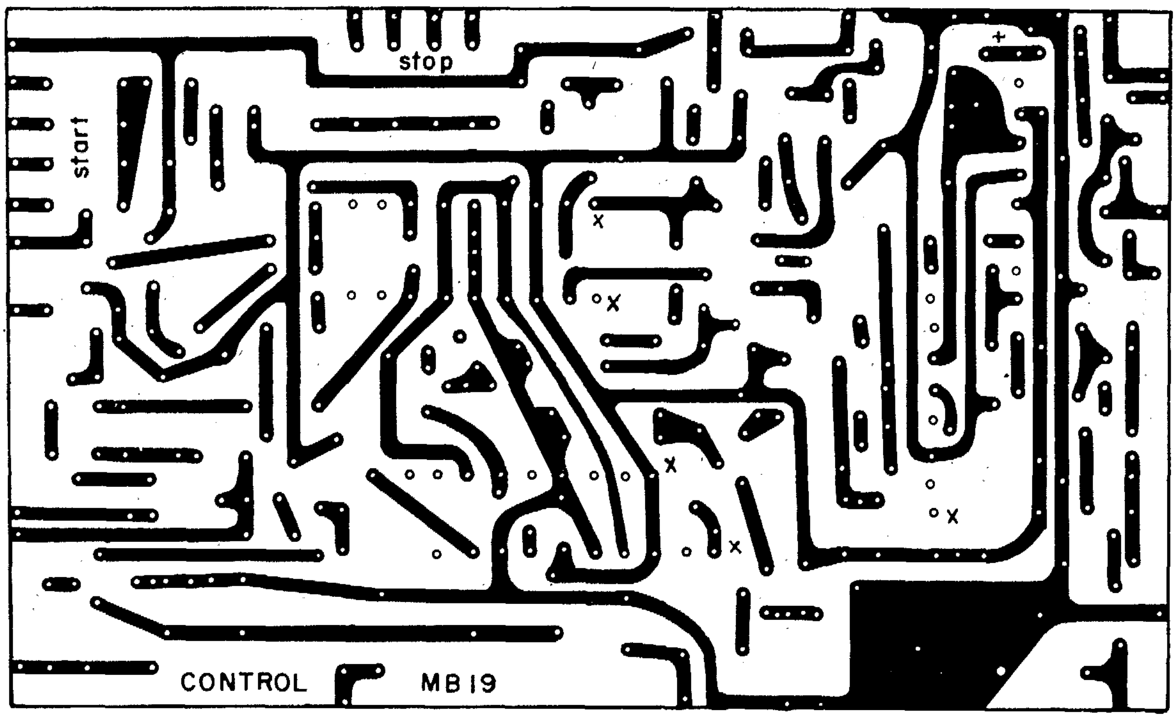
9) Bottom View of a Completed Board



10) Front Panel of a Transistorized Instrument



11) Picture of a Printed Plate



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