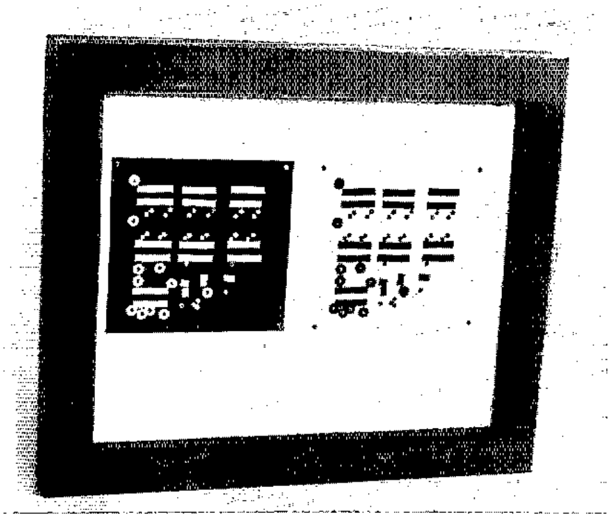

Fig. 1 — The art work (r.) and the resulting negative (l.) contact printed on Ortho A Litho film.

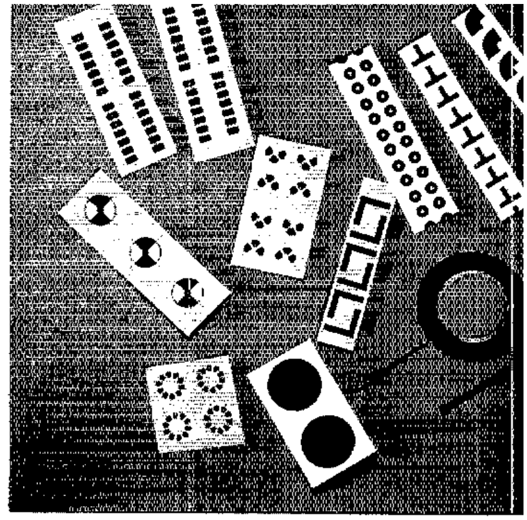

Fig. 2 — Some of the drafting aids which are available.

Fabrication of Printed-Circuit Boards

BY E. R. V. ANDERSON,* K6AWG

FOUR PRINCIPAL ways to fabricate printed circuit boards are available to the amateur. Each one requires a certain amount of skill acquired through practice; in addition, some knowledge of drafting, photography, and electronic circuit building is helpful in developing self-assurance in the work. But after the various techniques are mastered, numerous projects become possible using these same skills.

The first technique, and probably the most applicable to the needs of the amateur experimenter, is SCREEN PROCESS PRINTING. This process is also called SILK SCREENING, since the screens were originally made of silk stretched on a wood frame. We now have screens made of monofilament synthetic fibers, as well as of metal cloth, and these have characteristics which are superior in some respects for the screening process.

In this process, a stencil of the circuit interconnections is made and applied to a porous screen. Etch-resist lacquer is squeegeed through the stencil and screen onto a copper-clad board, a positive print in the etch-resist material being obtained. After drying, the board is immersed in etching solution which removes the unprotected copper, leaving the printed circuit.

A second and important technique is PHOTO-SENSITIVE RESIST printing. The copper-clad board is covered by a light-sensitive chemical coating and is then exposed through a photographic negative to ultraviolet light. After development by a special solution, a positive image of the circuit is left in the etch-resist material on the copper-clad board. Copper-clad boards may be obtained already coated by the manufacturer, or the coating material may be obtained in spray cans or in bulk, to be applied by the technician.

While this method is direct and simple, the details for obtaining good results require rigid control. In addition, the cost of materials is greater; only one board at a time can be made; and auxiliary equipment, such as an oven for controlled drying, is desirable.

A third method involves the application of a metallic-silver lacquer through a stencil directly onto plain unclad boards. The material may be sprayed on, or applied by screen-process printing, creating the circuit directly without etching.

The fourth method is to apply the etch-resist material by hand, as described in *QST*.[1,2] This works well, but is much more time consuming and is much less accurate in small detail.

In the paragraphs which follow, the steps for screen process printing are described in detail. They are:

1) Preparation of the artwork.
2) Preparation of the stencil.
3) The application of the etch-resist to the copper-clad board. (Boards clad with gold, silver, or other metals are also used.)
4) Etching the copper away.
5) Drilling the board to permit mounting of the circuit components.
6) Final assembly and testing.

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1 Schiebold, "Fast 'n' Easy Printed Circuit Boards," *QST*, August, 1969. Also see Fisk, "Sheet Frisket for Etched Circuit Boards," Technical Correspondence, *QST*, November, 1969, p. 45.
2 DeMaw, "Etched-Circuit Boards — Make 'em at Home," *QST*, January, 1970.

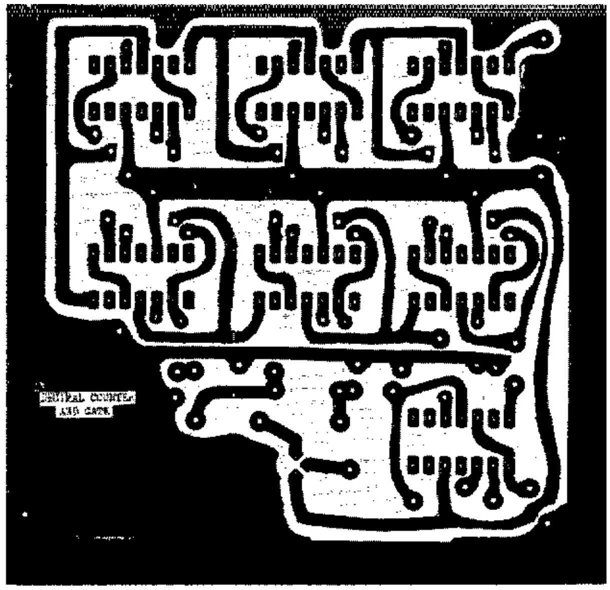


Fig. 3 — The finished art work for the front of the board using drafting aids.

Step 1 — Preparing the Art Work

While preparing the art work, a schematic of the circuit to be designed must be available for frequent reference. By "cut and try" methods, the components are arranged to determine what size board will be necessary to accommodate a given circuit. A modest amount of practice will be required to find the most economical layout without crossing connections. When crossed connections are unavoidable, they can be made by using wire jumpers on either side of the board.

Grid drafting paper, and grid Mylar (see Fig. 1), marked in 0.2- or 0.1-inch squares are available at the drafting supplies store. The author does the preliminary layout on paper because many starts will be made before the optimum design is arrived at. The grid permits accurate dimensioning of the various components. A 1/2-watt resistor, for example, requires 1/2 inch between connectors, when it is mounted flat. An IC dual-in-line package has seven or eight pins on a side, spaced 0.1 inch apart, each row separated by 0.3 inch. The size of the art work must remain accurate but large enough to be worked easily. The author therefore designs the layout at exactly twice the size of the final circuit board; afterwards by photographic reduction, a negative and positive transparency of the final circuit are obtained.

A statement concerning drafting aids should be made here. Tapes of various widths, as well as terminal rounds, corner pieces, and socket layouts for ICs, transistors, and tubes, are available. These are black and have adhesive material on the reverse side. If they are used instead of attempting to draw the design, neat, precise, and professional-appearing art work can be achieved with little drafting experience. Fig. 2 shows some of these aids.

After the final design is on paper (usually after many changes), the layout is reproduced on the grid drafting Mylar, with the grid serving to position the components. The interconnections are then made with drafting tape, after which the unused areas of the work are blacked out with india ink or poster paint (Fig. 3).

It is well to prepare the Mylar before drafting begins. The Mylar and a piece of white art board are cut to exact size and sandwiched together with double-sided adhesive tape (Fig. 1). The design on Mylar with a white backing is finally mounted on a sheet of black art paper, so that the reducing camera sees only a black and white positive rendition of what is to be the circuit board (Fig. 3). The next step is to obtain a positive transparency, produced photographically at exactly a two-to-one reduction in size. All blueprint firms have these facilities and will perform the work at modest cost.[3]

If both sides of the board are to be etched, the register for printing the reverse side must be accurate, and two pieces of art work, one for the front side, the other for the reverse side must be prepared. A negative transparency of the art work (Fig. 1) is used in preparation of the stencil for the reverse side, so that every point where components are to be mounted will be free of copper, thus preventing shorts to ground. Another scheme is to protect the copper on the reverse side with etch-resist material during the etching process, and after drilling, to mill or file away by hand the unwanted copper. Needless to say, this latter method is rather laborious.

For one wishing to do his own photographic reproduction, camera equipment and darkroom facilities must be available. The author uses the following equipment:

1) A 4 × 5-inch Speed Graphic camera with an f/32 127-mm lens.
2) Darkroom facilities including a 4 × 5-inch contact printer.
3) An easel constructed in a home workshop (Fig. 4).

[3] $6.50 in Los Angeles during 1970.

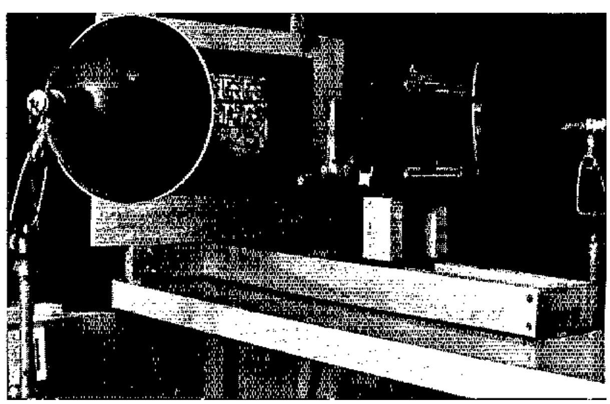


Fig. 4 — The easel and camera arrangement for photographic reduction of the art work.

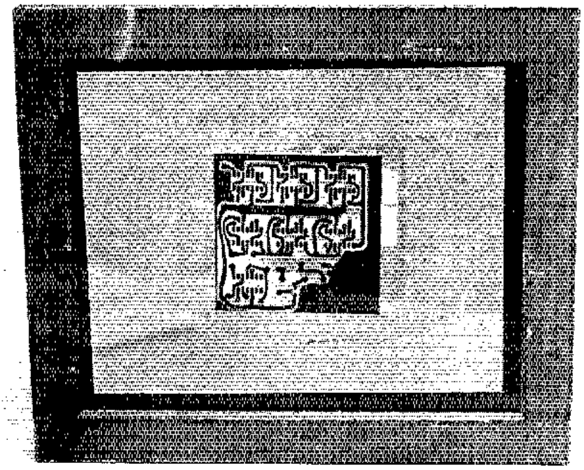


Fig. 5 — The positive transparency and stencil material mounted in the frame, prepared for exposure to ultraviolet light.

The easel can accommodate a drawing board upon which the art work is attached. The camera is mounted on a slide, so that the exact point for the desired reduction and focus can be ascertained. Preliminary trial with rulers mounted on the drafting board, and on the ground glass of the camera, was helpful in this determination.

The photographs, both positive and negative, are prepared on lithographic copy film[4] which renders blacks and whites only with no half tones. The grid of the Mylar art work does not photograph on this film. Most ordinary films are panchromatic, recording shades of all colors, and are not suitable for this purpose.

The exposure is made at f/32 to obtain the sharpest focus, with two photoflood lamps as a light source, each placed at 45 degrees and approximately three feet from the art work (Fig. 4). The exposure time is three seconds with this arrangement. Special developer, producing high-contrast negative or positive transparencies with completely opaque blacks, is used. Thereafter, processing is the same as in ordinary photography. A contact print on the same film provides the positive transparency necessary to make the stencil.

Step 2 – Preparing the Stencil

McGraw light-sensitive stencil material No. 4571[5] on stable-base vinyl is available in large sheets or in smaller packages designed for school graphic art courses. A chemical developer which is dissolved in water, and afterwards stored in the refrigerator, is provided with each kit. Hydrogen peroxide, 3 percent, as purchased in the pharmacy, serves just as well, if diluted to 1/2 percent and discarded after each run (one part of 3-percent H_2O_2 to five parts of water).

The stencil material is exposed to an ultraviolet light source in an ordinary photographic proofing frame provided with a Plexiglas front (Fig. 5), since ordinary glass is opaque to ultraviolet light. The orientation of the positive transparency and of the stencil material is important. The frame is opened and placed with the Plexiglas side down on a flat surface. The positive transparency is positioned on the Plexiglas so that when viewed from above, it appears in the right orientation (i.e., not as the mirror image of the art work). An ample piece of the unexposed stencil material is placed on top of the transparency with the vinyl backing *next* to the film, and with the emulsion side of the material uppermost. The back of the frame is then closed and all is ready for the exposure.

The midday sun on a clear day at middle latitudes will expose the stencil material properly in 30 to 60 seconds. Longer times will, of course, be required for less intense sunlight. Since the author works mostly at night, he uses a 15-watt black-light fluorescent lamp mounted in an ordinary fixture (Fig. 6). A stencil exposed for 30 minutes, with eight inches between the printing frame and the light source, develops in 2 to 3 minutes. After development, the stencil is washed in hot water (110 to 120 degrees Farenheit) until the unexposed material softens and washes away, leaving the negative image on the vinyl backing. The stencil must then be washed for several minutes in cold water to harden the gelatin material which constitutes the image.

Our attention must next be directed to the silk screen (Fig. 7). The screen may indeed be of silk, graded as to fineness of the mesh as "10XX" or "12XX." Screens made of nylon or metal cloth have excellent characteristics, but are more expensive. The screen frame generally is not obtainable in assembled form, so, if possible, one should buy the screen at a screen printing supply store where the customer may watch the stretching of the cloth. After observing the procedure once, the amateur should be able to master the technique easily.

A back board made of 3/4-inch plywood, to which the screen is attached, must be obtained. Since one must remove the screen from its back board at various stages of the process, hinged clamps, called Jiffy clamps (Fig. 8), are desirable.

[4] Kodak Kodalith Ortho Type 2, or DuPont Cronar Ortho A Litho film.

[5] McGraw Colorgraph Co., 175 W. Verdugo Ave., Burbank, CA 91502.

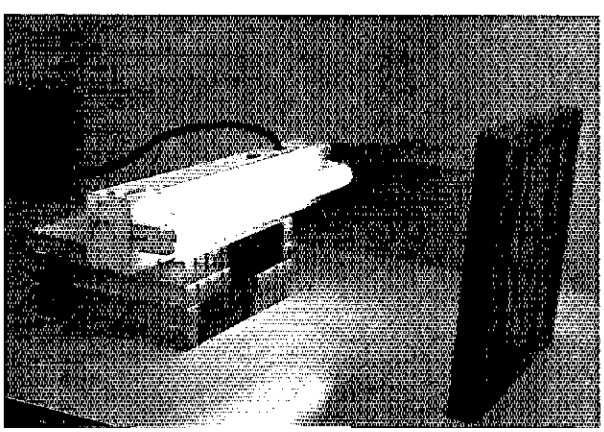


Fig. 6 — The ultraviolet light source and printing frame set up for exposure of the stencil material.

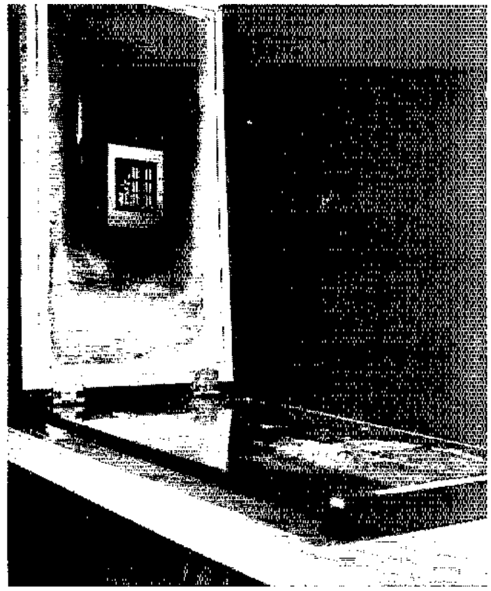


Fig. 7 — The printing screen with stencil mounted on the back board by "Jiffy" clamps.

Ordinary hinges with removable pins will also serve. A screen of something like 15 × 28 inches is preferable to a smaller one, as it allows more space for manipulation of the squeegee. A new screen must be scrubbed well with trisodium phosphate, followed by an abrasive washing powder such as Ajax, and flushed well afterwards to remove all remnants of the washing compound. This procedure removes any oily residue and sizing, as well as foreign matter which might obstruct the mesh. Furthermore, the stencil will not adhere properly to a poorly prepared screen.

The screen as well as the vinyl-backed stencil, which by now has been prepared, should be wet. The stencil is placed on a hard surface, the stencil side up and the vinyl backing down. The screen, which has been detached from the back board, is lowered carefully into contact with the stencil. The area over the stencil is blotted with absorbent paper toweling to insure intimate contact as well as complete removal of all air bubbles. The screen is then allowed to dry. After the first 15 minutes, under average conditions of heat and humidity, the drying can be forced with the heated air from a hair drier. When the screen and stencil are completely dry, the vinyl will come away, leaving the stencil attached to the screen. If the vinyl does not separate easily, the screen is not dry enough.

Step 3 — Application of the Etch-Resist to the Copper-Clad Board

This step in the process is perhaps the most difficult, and requires considerable skill. An extremely important consideration for success is to have a scrupulously clean copper-clad board. Even a finger print on the otherwise cleaned copper can interfere with the etching process. The author scrubs the board with a suspension of pumice in household ammonia, after which the board is washed thoroughly and permitted to dry. Care should be taken not to touch the cleaned surface.

The area of the screen around the stencil is now covered with masking tape, so that the screen is protected from the etch-resist lacquer everywhere except through the stencil (Fig. 9). The register of the print is determined by placing the circuit board under the stencil in the best position, then sticking it to the base board with double-sided adhesive tape. Register guides made of thick art paper, and fixed with the same tape, are helpful, especially if more than one board is to be printed (Fig. 10).

The etch-resist lacquer is obtained at the screen printing supplies store. Its consistency, when the can is opened, may not be right for the purpose. The material can be treated with lacquer thinner,[6] but only slightly. If it is too thick, it cannot be forced through the screen properly; if it is too thin, it will bleed out from the desired markings, contaminating those portions of the board which should remain clear. To obtain the proper consistency, place a portion of the lacquer in another container. Thin this portion so that when it is lifted from the main mass with the mixing stick and allowed to drip back, the bead will stand above the surface for three or four seconds before it gradually disappears.

[6] Some lacquers require solvents other than common lacquer thinner. Be sure to consult the manufacturer's specification sheet for the particular brand of etch resist being used.

Fig. 8 — A close-up view of the "Jiffy" clamps for holding the printing screen on the back board.

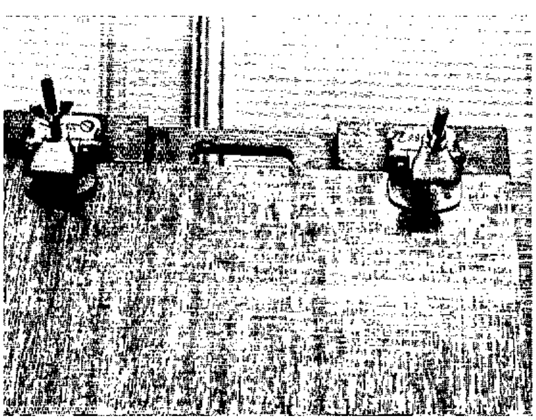
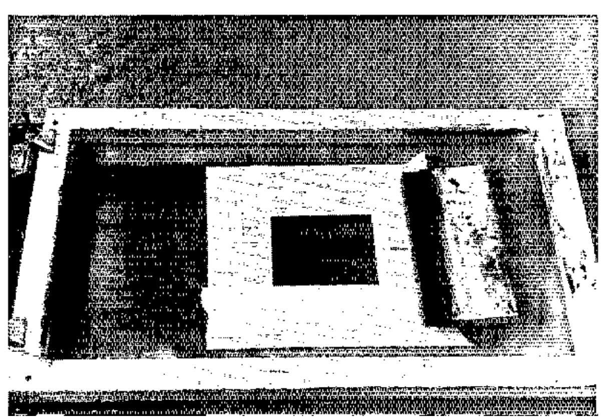


Fig. 9 — The printing screen, the stencil masked with masking tape, and squeegee, ready for printing.



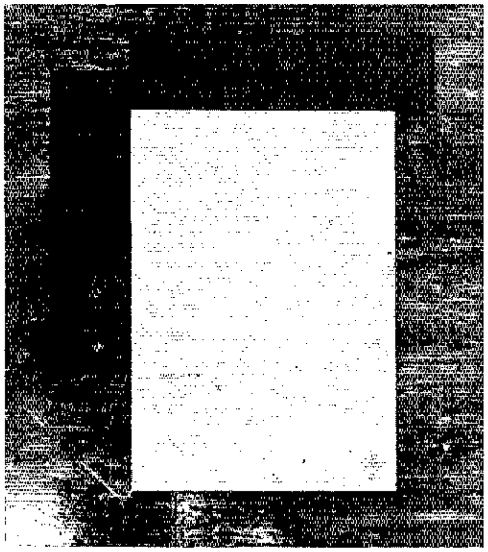


Fig. 10 — The register margins prepared from heavy art paper fastened to the back board with double-sided adhesive tape. A copper-clad board is shown in place, ready for printing.

Squeegeeing is the next step in the process. Plenty of paper towels should be at hand, as well as a large disposable paper bag to receive the soiled materials at the end of the procedure.

To begin the printing, a line of lacquer is laid neatly with the mixing stick at one end of the stencil, on top of the masking tape. After charging the squeegee with lacquer, it is drawn with firm pressure across the stencil. Prior to the pass, a 1/4-inch-thick strip of wood is placed under the end of the screen frame, so that the screen does not actually touch the work (Fig. 11). When the pass is made, the screen stretches down into contact with the work. If more than one board is to be printed, all boards should be clean and in readiness before the printing begins.

A number of soft, clean rags should be available for the clean-up operation. The soiled masking tape is stripped off the screen and thrown into the paper bag. The screen is then cleaned with a cloth saturated with lacquer thinner. The stencil is durable and should remain in good condition for many printings.

When it is desired to remove the stencil from the screen, the screen is scrubbed briskly with a detergent containing an enzyme, but not a bleaching agent. A soft brush is used. A final scrubbing is given with Ajax followed by a thorough rinsing of both sides with water. The screen is now ready for the application of another stencil.

Step 4 – Etching the Copper

In the etching process, one of two solutions may be used. Either works well when means are provided for agitation and warming during the process. These solutions are:

1) Ferric chloride, ($FeCl_3$), 500 grams; water to make 1000 milliliters. (This quantity is approximately 33 ounces.)

Since the solution is acid, only earthen, glass, or plastic containers should be used. Metal utensils should not be permitted to contact the solutions. Needless to say, care must be exercised to protect clothing and eyes, and prolonged contact with the skin is not advisable.

2) Ammonium persulphate, $(NH_4)_2S_2O_8$, 250 grams; mercuric chloride, ($HgCl_2$), .060 grams (60 mg); concentrated sulfuric acid (96 percent), 15 milliliters; water to make 1000 milliliters.

The water must be hot to get the salts to dissolve. Mercuric chloride is a dangerous poison if swallowed, so one should carefully wash his hands after working with this solution. Kitchen utensils should *never* be used and then returned to the kitchen cabinet. These solutions are generally available (already prepared) from electronics supply houses where printed circuit materials are sold.

Steps 5 and 6 – Drilling the Board and Final Assembly

The etch-resist material is removed from the circuit board with lacquer thinner, and again cleaned with pumice in ammonia. For drilling, the author uses a Dremel tool with a No. 2 dental burr. Your dentist can order the burrs for you from his supply house at a cost of less than two dollars per dozen. Carbide burrs are also available at approximately two dollars each. They remain sharp, however – many times longer than steel ones, even after drilling glass-epoxy boards. Diamond burrs do not work well because they fail to bite in quickly enough to drill an accurately placed hole.

Final assembly, soldering, and testing follow. If the copper is cleaned well before the soldering begins, the results will be superior. If the required facilities are available, dipping the board in hot, molten solder, after liquid flux has been applied, greatly facilitates the soldering. Without the molten solder, just painting the board with liquid flux protects the exposed copper from oxidation while "stuffing" and soldering is going on. All traces of chlorides should be removed, since they are the chief cause of subsequent corrosion in a humid environment. QST

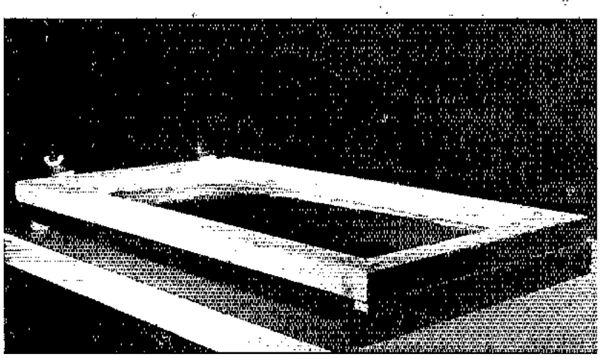


Fig. 11 — The printing screen in position on the back board, ready for printing. Note the wood strip under the end of the screen. It is used to prevent the screen from touching the work until the actual printing is done.