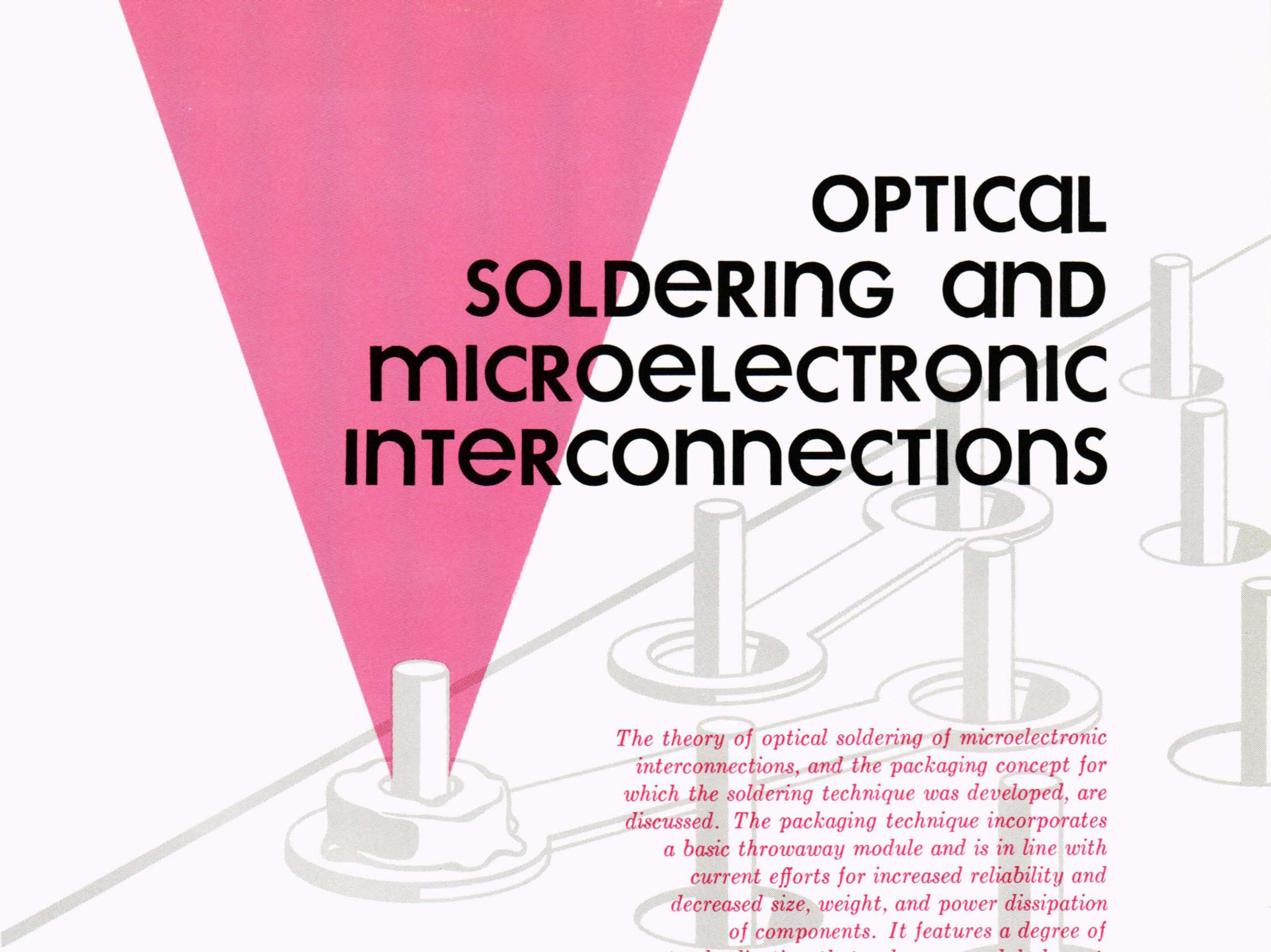

OPTICAL SOLDERING AND MICROELECTRONIC INTERCONNECTIONS

The theory of optical soldering of microelectronic interconnections, and the packaging concept for which the soldering technique was developed, are discussed. The packaging technique incorporates a basic throwaway module and is in line with current efforts for increased reliability and decreased size, weight, and power dissipation of components. It features a degree of standardization that enhances module layout, fabrication, and interconnection determination.

G. J. Veth

Cordwood packaging of miniature components and semiconductor integrated circuits has generally favored welding rather than soldering of interconnections. This has come about principally because of the availability of controls in welding for the production of uniform joints. On the other hand, welding techniques lack the degree of automation that is available in soldering. The optical soldering techniques to be discussed retain this automation while incorporating the control necessary for solder joints of uniform quality. And in conjunction with the packaging concept for which it was developed, the efficient realization of high-density systems through soldering is discussed.*

Optical Soldering Technique

The main constituents of the optical soldering technique (Fig. 1) are:

1. A suitable radiant energy source.
2. A lens system for imaging the source energy

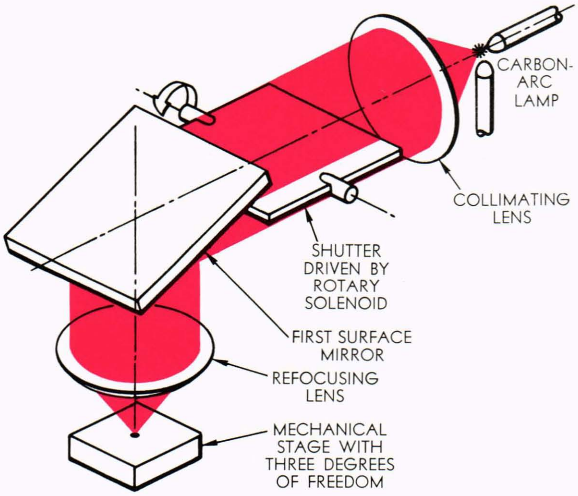

Fig. 1—Optical soldering system showing essential components.

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* The author wishes to acknowledge the assistance given him in the field of optics by Dr. William Liben, supervisor of the Microelectronics Group.

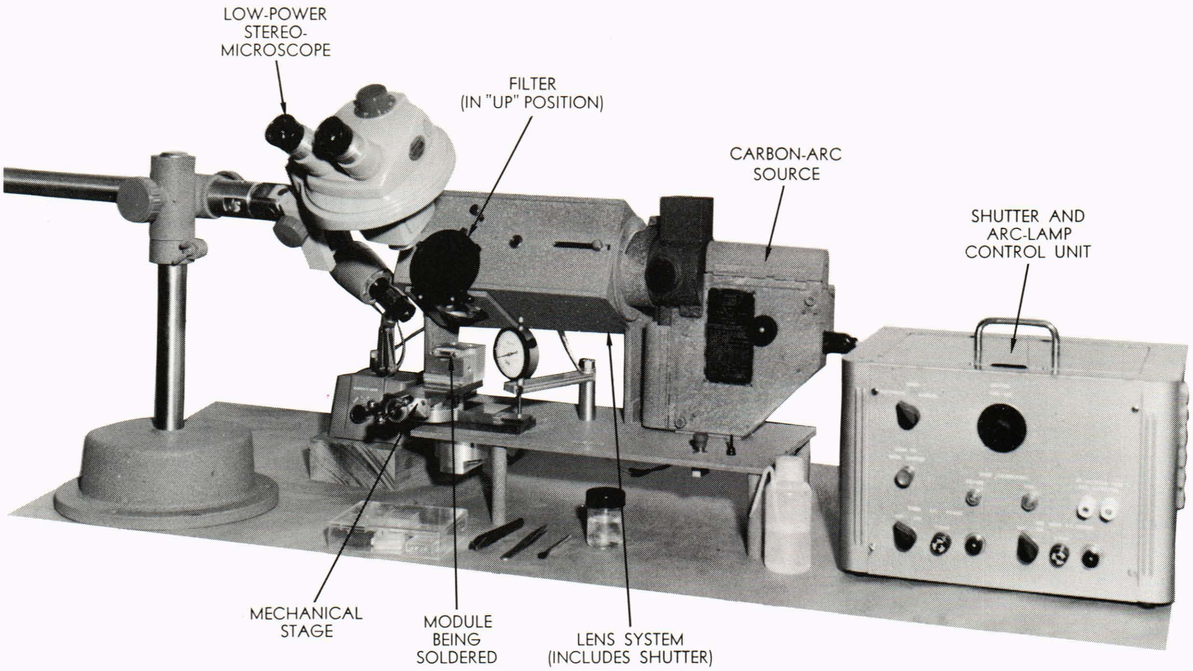

Fig. 2—Laboratory equipment used to implement the optical soldering concept.

with sufficient intensity and proper size.

3. Adequate arrangements for control of the heating period.
4. Image or module positioning arrangement for alignment of imaged energy and the joint to be soldered.

The components now in use at APL to implement this concept are shown in Fig. 2.

For the energy source, a carbon arc is used. Projection lamps had been investigated because their energy output is easily controlled, but the increased radiant energy per unit area obtained with the carbon arc has produced superior results. The use of lasers is an interesting possibility if their power output characteristics can be modified for such a purpose.

Though only a single lens is needed to image the radiant energy of the source, two lenses are used in order to get greater energy intensity on the imaged spot and to give more freedom in equipment design. The factors that determine the physical requirements of the lens system are: type and intensity of the radiant source; characteristics of the joint to be soldered and of the packaging concept to which this technique is applied; and the characteristics of the printed circuit boards.

By defining a time t_j (the time for solder joint formation) and a time t_b (the time until the printed circuit board is damaged by heat), the criterion for satisfactory soldering may be stated as $t_b > t_j$. The characteristics determining t_j are intensity of the incident radiation on the joint, absorption characteristics of the joint metals, joint size, and the size and number of heat paths leaving the joint. The characteristics determining t_b are the intensity of the incident radiation and the absorption and thermal characteristics of the printed circuit board material. The great number of variables hinders extensive theoretical evaluation, but some overall conclusions can be made readily. First, to reduce t_j, either the intensity of the incident radiation must be increased or the joint size and size of the heat paths leaving a joint must be reduced. And to increase t_b, either the intensity of the incident radiation or the absorption characteristics of the board should be decreased. The radiation intensity on the joint can be made to differ greatly from that on the board by adjusting the magnification of the lens system so that the imaged spot is the same size as the joint to be soldered. This magnification ratio may be considered the first lens-system requirement.

The second lens-system requirement is related to the radiant energy source. Assuming that a given intensity of radiation is required for satisfactory solder-joint formation, the lens system must be capable of capturing from the source this amount of energy plus the energy to supply the system losses.

The relationship between these requirements and the lens-system parameters is shown in the following equations.[1] The energy relationship between E_2, the illumination of the image at a point on the system axis, and B, the brightness of the source, is given as

$$E_2 = \pi B \sin^2\theta_2, \tag{1}$$

where E_2 is in candles/in.^{2} when B is in candles/in.^{2}, and θ_2 is the half angle of the exit pupil of the system. The assumptions made in deriving this result are: the source obeys Lambert's law of emission; the system is aplanatic; the refractive indices of the image space and object space are equal; and the system reflection and absorption losses are neglected. If it is assumed further that the largest dimension of the image is small compared to the focal length f_2, the (cosine)^4 variation of the illumination away from the axis may be neglected and the illumination assumed constant over the image and given by Eq. (1). The magnification relationship comes from the form of Lagrange's law stated below:

$$a_s \sin^2\theta_1 = a_I \sin^2\theta_2, \tag{2}$$

where a_s is the area of the light source, a_I is the area of the image, and θ_1 is the half angle of the entrance pupil of the system.

In the lens system shown in Fig. 1, with the source at f_1 of lens No. 1 (collimating lens) and with lenses of equal diameter, the image falls at the focal point (f_2) of lens No. 2 (refocusing lens). Consequently, the entrance pupil is lens No. 1 and the exit pupil is lens No. 2. For this case,

$$\sin^2\theta_1 = \frac{\rho_1^2}{\rho_1^2 + f_1^2}, \text{ and } \sin^2\theta_2 = \frac{\rho_2^2}{\rho_2^2 + f_2^2},$$

where ρ_1 and ρ_2 are the radii of lenses No. 1 and 2, respectively; and since $\rho_1 = \rho_2 = \rho$,

$$\sin^2\theta_1 = \frac{\rho^2}{\rho^2 + f_1^2}, \text{ and } \sin^2\theta_2 = \frac{\rho^2}{\rho^2 + f_2^2}.$$

Substituting these relationships into Eqs. (1) and (2) gives

$$E_2 = \frac{\pi B}{1 + 4\left(\frac{f_2}{D}\right)^2}, \tag{3}$$

and for the magnification,

$$m = \frac{a_I}{a_s} = \frac{1 + 4\left(\frac{f_2}{D}\right)^2}{1 + 4\left(\frac{f_1}{D}\right)^2}, \tag{4}$$

where $D = 2\rho$ is the diameter of the lenses.

Assuming that it is desirable to obtain maximum illumination at the image, from a given source the f-number of the exit lens (f_2/D) should be as small as possible. Having established the (f_2/D) ratio, the f-number (f_1/D) of the entrance lens is fixed by the magnification desired.

In the actual equipment (Fig. 2) the optical parameters are listed below:

Lens No. 1 focal length = 1.5 in.
Lens No. 2 focal length = 2.5 in.
Diameter of lenses No. 1 and 2 = 2.5 in.

With 6.4-mm cored carbon rods, the source diameter is ≈ 0.180 in. Using this value, the diameter of the imaged spot is ≈ 0.125 in. This spot size is larger than desired, but the limited availability of the type of lenses used, together with the success of the present system, made further optimization unnecessary to meet the needs of this phase of our research. This system has registered a steady-state temperature of 800°F, using a thermocouple with 25-mil-diameter leads. This temperature is naturally dependent on the thermal conduction paths leaving the imaged spot, as mentioned previously. Excellent soldered joints have been formed using the solder-joint assembly of Fig. 3 with a 2-sec illumination.

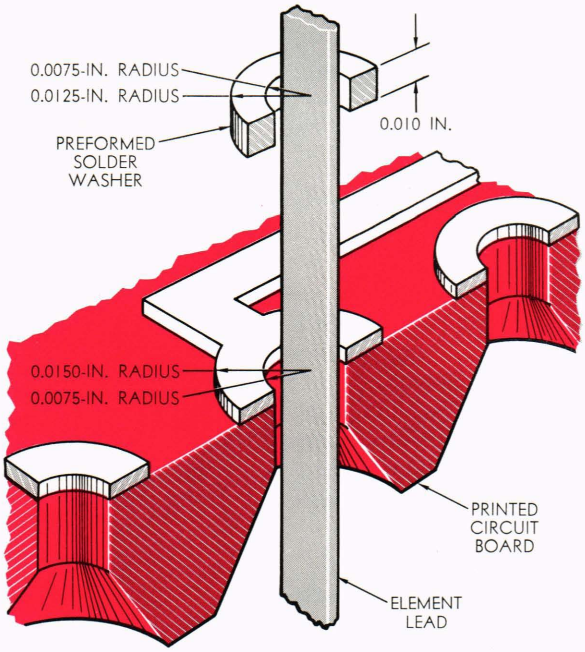

Fig. 3—Cutaway view of a typical solder-joint assembly, showing printed-circuit-board lands and preformed solder washers.

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[1] A. C. Hardy and F. H. Perrin, *The Principles of Optics,* McGraw-Hill Book Co., New York, 1932, chap. 19.

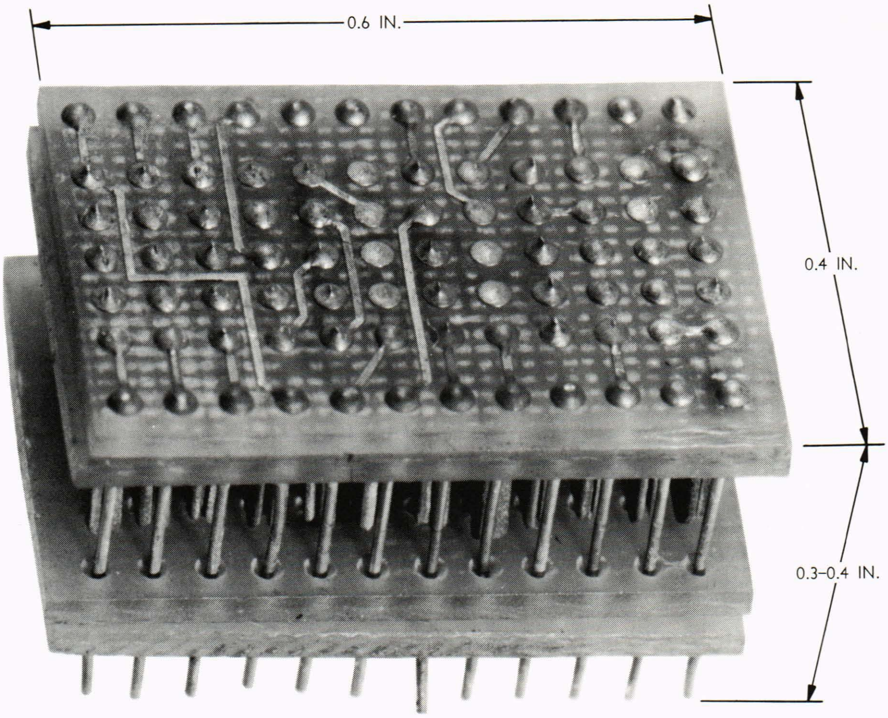

Fig. 4—The basic throwaway module containing microelectronic circuits for which the optical soldering technique was developed.

The shutter mechanism for controlling illumination is a flat plate driven by a rotary relay that is timed electrically. The timer, which is in the control unit, has built-in time increments of 1 through 10 sec, with provision for external extension of the time period by the addition of suitable capacitors. This type of shutter mechanism is designed for fabricating modules in which holes are nonstandard.

To fabricate the modules in the packaging concept discussed below, however, the shutter timer is not required because the standard-hole matrix is used. A full row of solder joints can be prepared in advance and then soldered by passing it through the imaged hot spot at a constant rate by means of a mechanical stage. Since this stage has three degrees of freedom to permit proper alignment of the joint and the imaged hot spot, automatic module positioning and soldering by means of servo control mechanisms is a strong possibility for future development.

The Packaging Concept

The packaging concept around which the optical soldering technique was developed is based on use of a basic throwaway module as is shown in Fig. 4. This is considered to be the minimum or near-minimum replaceable unit that will entail the least replacement cost for a given system over its intended lifetime. Thus, the size of such a unit can vary from an individual component to an entire system, according to system use, expected unit reliability, and initial construction and expected maintenance costs of the system. The 12-element module may not be ideal for all systems, but its constituent parts and the construction principles it illustrates are easily extended to other sizes.

The basic module consists of three components: bulk, semiconductor, integrated circuit elements; printed circuit boards for element interconnections; and riser wires to transport signals in and out of the module and between the upper and lower planes of element interconnections. Figure 5 is an exploded view of the first three elements of a basic module such as the one shown in Fig. 4. The volume of the 12-element module in Fig. 4 is 0.64 to 0.96 in.^{3}, depending on its height.

The module thus defined was developed with the following objectives in mind:

1. Maximum packaging density consistent with reasonable unit-volume power dissipation.
2. Adherence to Navy specifications for microelectronic packaging as set forth in the pro-

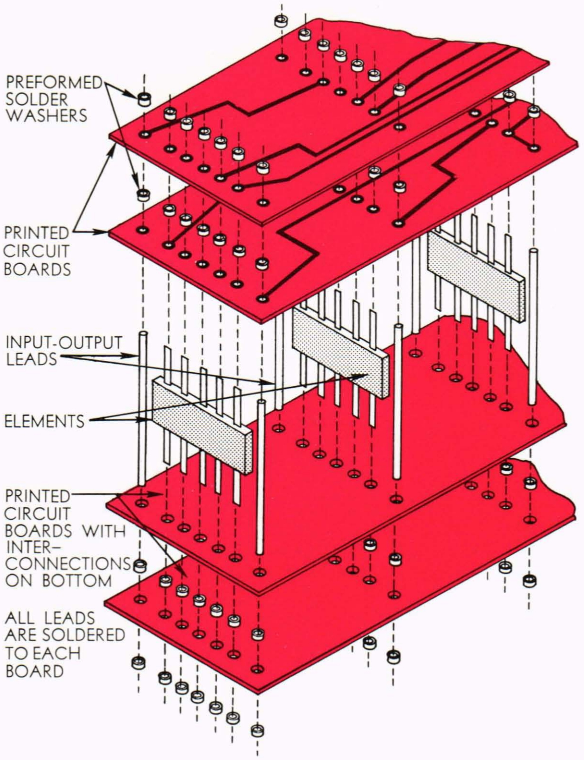

Fig. 5—Exploded view of the first three elements of a basic module, showing constituent parts.

posed guide for microelectronic standards.[2]

3. Ease of determining, laying out, and making interconnections.
4. No bending or twisting of semiconductor element leads, and minimum stress on element leads during and after packaging.
5. Ease of fabrication consistent with mechanical strength.

The first objective is a necessary compromise. For any given system, as components are placed closer together the unit-volume power dissipation increases to a point where satisfactory system operation ceases because of excessive temperatures.[3] This trade-off between packaging density and power dissipation is one of the important considerations of microelectronics. It exemplifies an often-ignored engineering objective of minimizing the power necessary to perform a given system function. In the basic module of Fig. 4, allowing one watt/in.^{3} as a reasonable, maximum, unit-volume power dissipation, the maximum average circuit dissipation would be about 10 to 15 milliwatts. The packaging density of our concept is over 100 circuits/in.^{3}, or over 1000 components/in.^{3} if we assume at least 10 components in each circuit.

The second objective is essential in order to standardize module sizes for efficient module integration in ever-changing military systems. This constraint defines module size and input-output lead sizes and locations. For the module dimensions now used, module lengths that are multiples of four elements meet these Navy recommendations.

The other objectives were met by standardizing the printed-circuit-board hole matrix and by simplifying construction. The standard-hole matrix permits construction and use of the interconnection diagram shown in Fig. 6. The element positions are chosen by giving consideration to desired input-output locations, as defined by signal flow requirements between basic modules. Since the element packages used are symmetrical, they may be inverted or reversed to achieve optimum interconnections. If more riser wires are required, elements may be removed. For each element sacrificed, five riser wires are gained. Each plane of interconnections is then properly transferred to a diagram of the standard-hole matrix. Again, from standardizing the hole matrix and because all holes in every printed circuit board have a conductive land, the layout of the printed circuit artwork is simplified. This is done by preparing a master layout having a permanent matrix of all circular lands. Interconnections are then easily laid out with black tape. Once a glass photographic slide is prepared for the printing process, the tape conductors may be removed and another circuit quickly prepared.

Printed circuit boards are now being prepared by conventional techniques, with the boards printed, etched, and drilled, and holes then countersunk. These countersinks act as guides for the element leads and riser wires during assembly, and allow a tight fit of two-layer assemblies, which the raised solder joints would prohibit if the boards were not countersunk. Drilling is done with a No. 80 drill. The standard-hole matrix allows efficient manual drilling and possible automation of the drilling and countersinking procedure. After countersinking, boards are trimmed to size and indexed.

A more desirable method of preparing the printed circuit boards would be to mold the boards, including the countersinks, and then plate them; the holes would thus be plated through. This would eliminate drilling and countersinking and permit printed wiring to be placed on both

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[2] *General Specification for Microelectronic Modular Assemblies*, U. S. Naval Air Development Center Report No. NAVAIRDEVCEN EL5-13A, May 1, 1962, and Amendment No. 1, July 10, 1962, Johnsville, Pa.

[3] J. J. Suran, "Circuit Considerations Relating to Microelectronics," *Proc. I.R.E.*, **49**, Feb. 1961, 420–426.

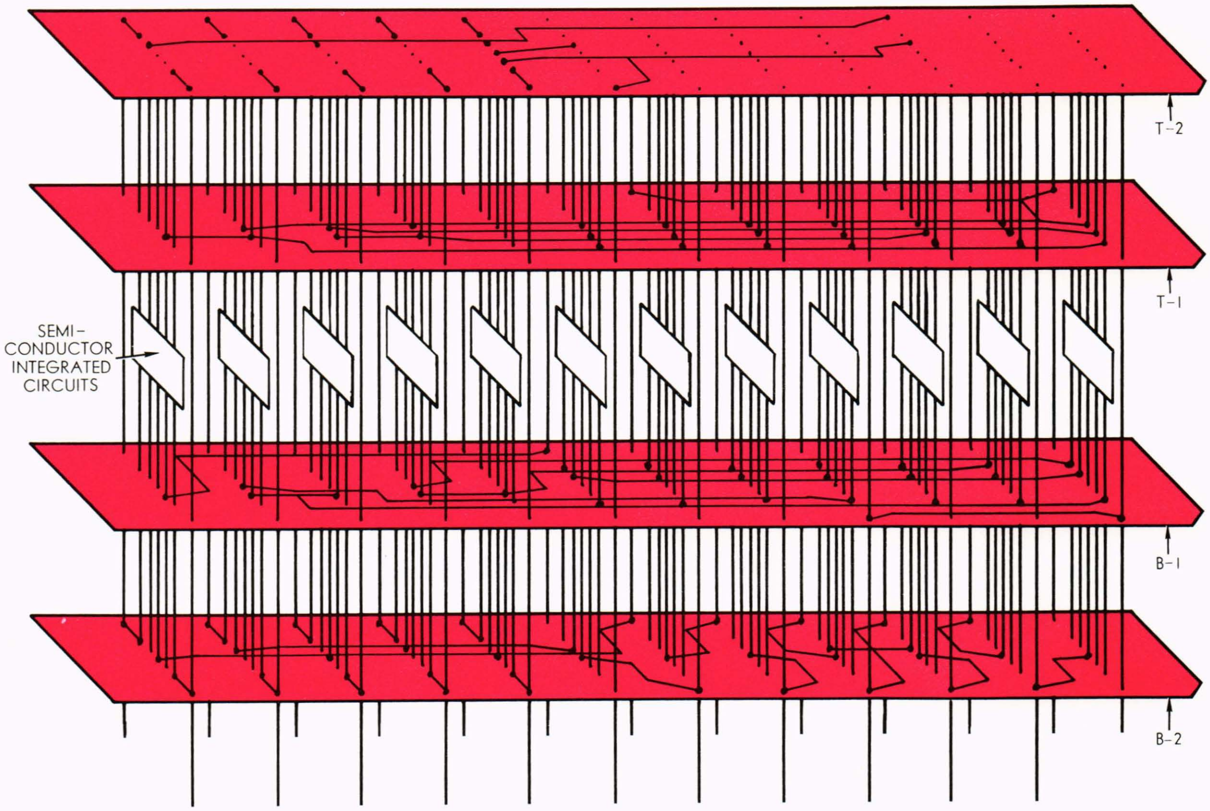

Fig. 6—Diagram used to determine module interconnections, demonstrating an advantage of a standard-hole matrix in the printed circuit boards.

sides of the boards. Most modules would then need only a single upper board and a single lower board to permit the necessary element interconnections. This, in turn, would simplify the soldering process.

The basic module is fabricated by the following method:

1. Elements are placed into board B-1 (Fig. 6), and board T-1 is located above it. This assembly is first placed in a single-board holder, then in a jig.
2. Riser wires are dropped into position.
3. Solder washers are placed over the wires in one longitudinal row, the row is fluxed, and it is then soldered by passing it through the hot spot. Succeeding rows are soldered in a like manner.
4. The module is inverted and step (3) is repeated.
5. If double rather than single boards are necessary, boards B-2 and T-2 are inserted, the module is placed in a double-board holder and then in a jig; steps (3) and (4) are then repeated.

The holders and jig are so designed that the level of the board to be soldered can be adjusted to the proper height to permit the solder-joint assembly to pass through the desired portion of the hot spot. The solder washers are positioned, and the joints are fluxed with a hypodermic needle with the aid of the low-power stereomicroscope shown in Fig. 2. During soldering, the filter shown in Fig. 2 is lowered into position, and the forming of each joint is monitored as it is passed through the hot spot. The riser wires are 10-mil tinned copper cut to 0.4-in. lengths, the solder washers are of standard 60-40 tin-lead composition, and the flux is a low-viscosity, high-temperature flux suitable for use on copper. Both solder washers and flux are commercially available.

This packaging and soldering technique has been applied to a module the same size as that shown in Fig. 4 but containing miniature conventional components. In this case, however, a standard-hole matrix cannot yet be used because of the lack of standardization of the sizes of the components. When such standardization has been achieved, the standard-hole matrix with its interconnection and packaging advantages will be used.