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Foreword

Volume 4 of *Advances in Electronic Circuit Packaging* is more than just a report of what occurred at the Fourth International Electronic Circuit Packaging Symposium. It is also a history of a key industry in which definite trends are already evident.

The twenty-eight technical papers contained in this volume are the logical continuation of all the papers that have gone before them in previous sessions of the Symposium. This is so for a number of reasons – first, the nature of the Symposium's call for papers; second, the methods used in the selection of papers; and third, the techniques employed in sampling Symposium participants' opinions on the value of papers presented.

In its call for papers, the Symposium has made the most general possible appeal to all circuit packaging designers and engineers to submit paper outlines for consideration. In its selection of papers, the Symposium since its 1961 sessions has relied on the services of a Program Selection Committee elected by attendees from every segment of the circuit packaging field.

Finally, following each year's session, all participants are asked to evaluate the papers they have heard. The Program Selection Committee utilizes these evaluations in establishing ground rules for the selection of the following year's presentations. Thus the papers submitted in outline, and those selected for presentation, represent not only the "state of the packaging art" at that particular time, but also the "state of the mind" of circuit packaging design leaders.

Thus, with the completion of the Fourth Symposium, it has become possible to evaluate some of the "trends" in research and development which have established themselves in electronic circuit packaging in the years from 1960 through 1963. For this purpose, it is helpful to tabulate the papers presented in each of the four years. It is then a simple matter to indicate certain pertinent trends.

In the table below, the papers presented at all four Symposium sessions are classified and enumerated under twelve separate headings. There is bound to be some overlap of areas covered by even a single paper, but classification by the Program Selection Committee has been made as closely as possible within a category which reflects the major area of coverage in each case. Though four Symposia do not constitute a large body of historical data, some inferences regarding present trends can be made.

Category	1960	1961	1962	1963
Automation	–	2	1	–
Case Histories	7	3	3	5
Display/Control	–	1	3	–
Environment	1	2	1	3
Evaluation	3	1	–	–
Interconnections	–	1	2	3
Materials/Components	3	5	2	1
Methods	4	3	5	7
Microelectronics	3	2	6	5
Standards	1	–	–	2
Systems	–	2	1	–
Thermal Problems	2	2	3	2
Totals	24	24	27	28

Note first the numbers of categories represented at successive sessions. There were eight categories in 1960, eleven in 1961, ten in 1962, and eight again in 1963. Next, review the dominant categories at each session: In 1960, Case Histories with seven papers, followed by Methods with four; in 1961, Materials/Components with five papers, followed by Case Histories and Methods with three each; in 1962, Microelectronics with six papers,. followed by Methods with five; and in 1963, Methods with seven papers, followed by Case Histories and Microelectronics with five each.

Materials/Components has declined during the four-year period while Methods has increased. Mieroelectronics has grown in interest along with Microcircuits. Interconnections has had a slight but steady increase. Thermal Problems has remained essentially stable.

Balancing the declining interest in Materials/Components against the growing interest in Methods indicates that circuit packaging has found its "bricks and mortar" and is now concentrating on learning how to put them together for the best results. The growing interest in Interconnections seems to bear out this inference.

The revival of interest in Standards, which showed up with two papers in 1963, after a total absence for two years, may permit the inference that circuit packaging has reached a stage of development where fewer and fewer special or exotic materials and components are required. This is closely related to the declining interest in Materials/Components and the growing interest in Methods. If the Materials/Components area really has become stabilized for a time, surely the development of Standards goes hand in hand with the development of Methods.

The sustained interest in Case Histories emphasizes the generally felt need for the exchange of information in circuit packaging. Solutions to other problems may apply directly to our own. Certainly this thought has been expressed many times at each Symposium.

The comparisons made and inferences drawn here indicate a more organized progress in the still very exciting field of electronic circuit packaging. The Proceedings of the Symposium will continue to plot the magnitudes and directions of its advance.

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Contents

The B-Module

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This paper illustrates a new concept in welded circuit module construction. The B-Module has been specifically designed to provide for manual fabrication in small quantities at moderate cost, or for continuous, automated, mass production in large quantities at low cost. The concept is adaptable to all sizes and types of components, including integrated circuit subassemblies. Packing densities of the order of 80 components per cubic inch are practicable, depending on component sizes, using "off the shelf" components. The design results in a module which has high reliability, meets military specifications, provides high component density, and permits automated fabrication.

INTRODUCTION

MOST OF THE welded cordwood-type modules presently in use require several intricate hand-assembly operations. These designs are adequate when the production quantities involved are small, but the solution to large-quantity, continuous high-rate production requirements has long been a problem. The normal procedure has been to institute brute-force techniques requiring added manpower, welding equipment, facilities, and space, to say nothing of costly training programs. It is therefore desirable that a module design lend itself to continuous automated processes and still be practical to fabricate on a manual basis. This paper illustrates an approach, herein referred to as the B-Module, which meets these goals and also achieves a number of additional advantages. The design concept is adaptable to any circuit configuration and all sizes and types of components, including integrated circuit subassemblies. Packing densities in the order of 80 components per cubic inch are practical, dependent on component sizes, using standard "off the shelf" components.

B-MODULE DESCRIPTION

The B-Module utilizes stamped or etched parts to replace individual round or ribbon wires for circuit interconnections. Basically, it consists of a two-sided metal "basket" running longitudinally through the center of the module in which the components are inserted and the leads welded. The basket is designed to provide the required interconnections within the module. The following paragraphs contain a detailed description.

Horizontal Wiring Grid

The horizontal wiring grid is a thin, flat metal strip, which is stamped or etched into six equally spaced, parallel webs of material as indicated in Fig. 1. This grid is a detail part of the basket subassembly and forms a portion of the component interconnecting wiring. The fixture holes, located at each end, provide an accurate means of alignment during subsequent assembly operations.

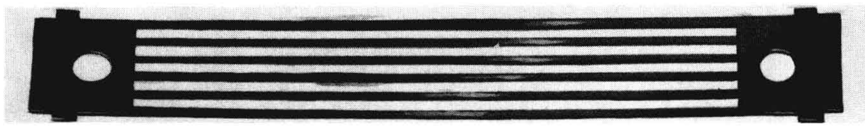


Fig. 1. Horizontal wiring grid.

Vertical Wiring Grid

The vertical wiring grid, like the horizontal grid, is a thin, flat metal strip, which is stamped or etched to form the grid pattern indicated by Fig. 2. The alternating length tabs projecting beyond the body of the grid are later formed to provide for component mounting. This grid is also a detail part of the basket subassembly and provides an additional portion of the component interconnecting wiring. Fixture holes are utilized as in the horizontal grid.

Insulator

A thin sheet of dielectric material is utilized as an insulator in the B-Module assembly. This insulator has small punched holes located to coincide with the intersection points of webs of the horizontal and vertical grids, where required by the circuit design. Fixture holes for locations are again used as illustrated in Fig. 3.

Basket Subassembly

The insulator is sandwiched between the vertical and horizontal grids, using the fixture holes for accurate alignment. The ribbons of the horizontal and vertical grids which intersect coincidental to the holes in the insulator are resistance welded at the intersection to form the subassembly. The welds, which pass through the holes in the insulator, are used to both mechanically and electrically interconnect the vertical and horizontal grids, where required by the circuit design.

After the welding has been completed, the next step is to program the subassembly into a circuit pattern. To accomplish this, the grids are punched to break the continuous metal webs and form the circuit design pattern required for that particular module.

The tabs, which project from the vertical grid, are formed to two levels to provide seats for the component leads. The formed basket subassembly provides approximately half the circuitry required for a given module. The other half of the circuitry is obtained by another basket subassembly identical to the first one, except for the programming of the weld and punch locations, which vary as dictated by the circuit design.

Basket Assembly

The horizontal wiring grid is a thin, flat metal strip, which is stamped or etched into six horizontal grids, and two additional insulators are used. The horizontal grid is sandwiched between the two insulators and next the two basket subassemblies. The middle horizontal grid is offset by one ribbon space from the horizontal grids in the basket subassemblies. In other words, the middle grid ribbons fall in line with the spaces between the ribbons of the

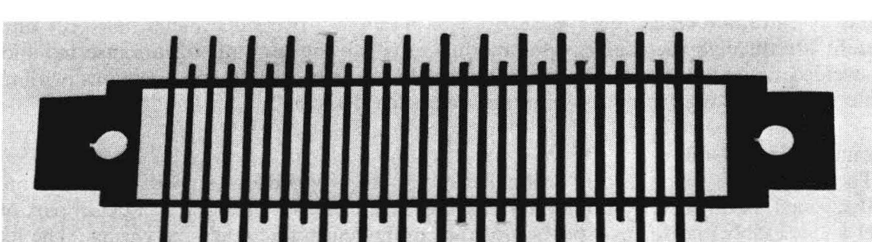


Fig. 2. Vertical wiring grid.

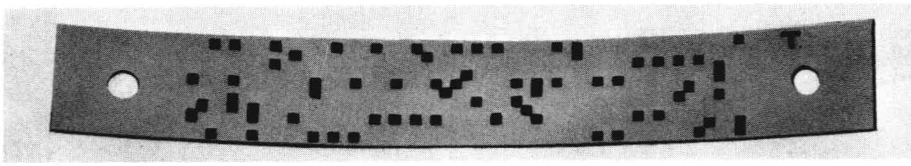


Fig. 3. Dielectric insulator.

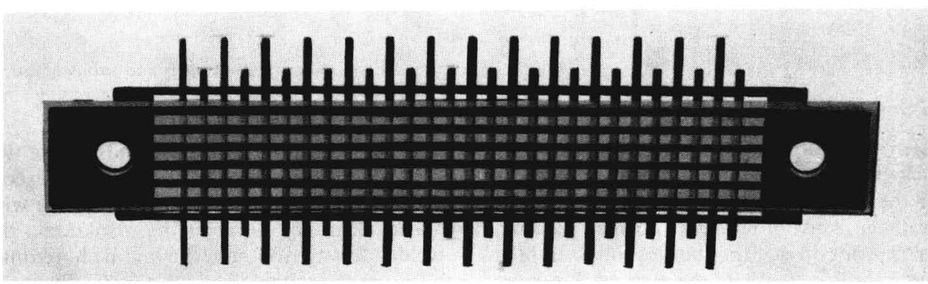


Fig. 4. Welded basket subassembly.

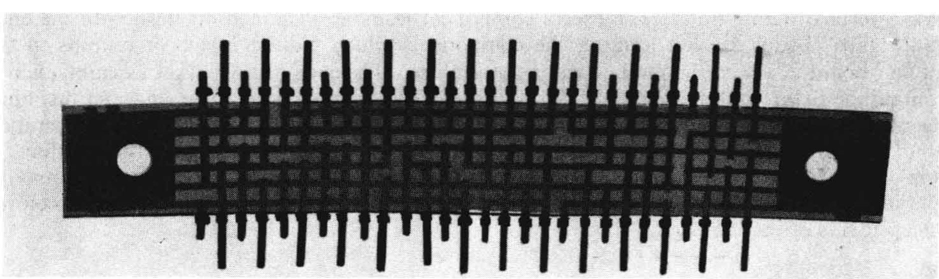


Fig. 5. Punched basket subassembly.

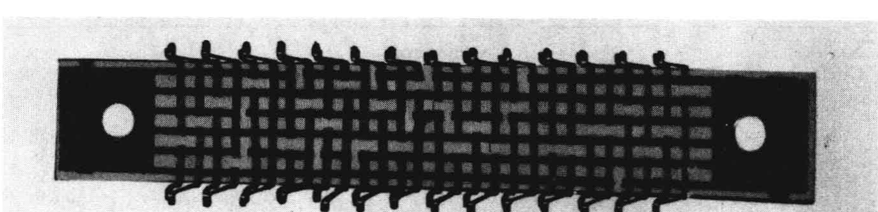
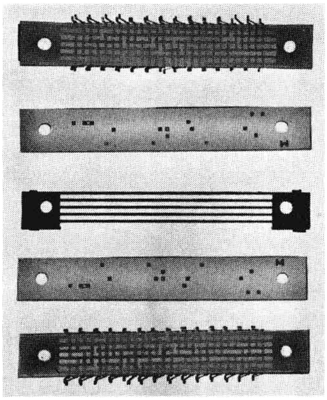


Fig. 6. Formed basket subassembly.



(a)

(b)

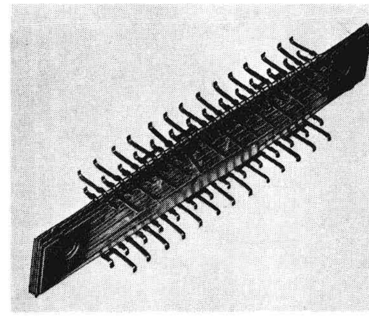


Fig. 7. Basket assembly: (a) component parts and subassemblies; (b) finished basket assembly.

horizontal grids in the basket subassemblies. By the same token, the vertical grids in the two basket subassemblies are offset from each other by one ribbon space. The result is that except for the two extreme outer horizontal grids, no ribbon in the five-layer matrix falls in line with another. This allows, with proper placement of weld clearance holes in the insulators, any vertical ribbon in either basket subassembly to be welded to any ribbon in the middle horizontal grid. In this manner, the two basket subassemblies are mechanically and electrically interconnected to form the final "basket" assembly. The finished basket assembly contains all wiring and interconnections to complete a given circuit.

Component Assembly

The components are now nested on and resistance welded to the projecting formed tabs of the vertical wiring grids. The excess component leads are trimmed off flush with the ends of the tabs. Leads are left long on the components which require inputs or outputs to the mother board to which the module will be assembled. The ends of the basket assembly, which contain the fixture holes, are cut off flush with the last component at either end. At this time, the module is checked electrically and may be repaired or reworked if needed. The last operation is to transfer mold or encapsulate the component assembly for environmental protection. A final electrical test of the completed module is made at this time. Note that modules may be marked or coded in any desired manner during the molding process by the use of colored encapsulants or mold inserts.

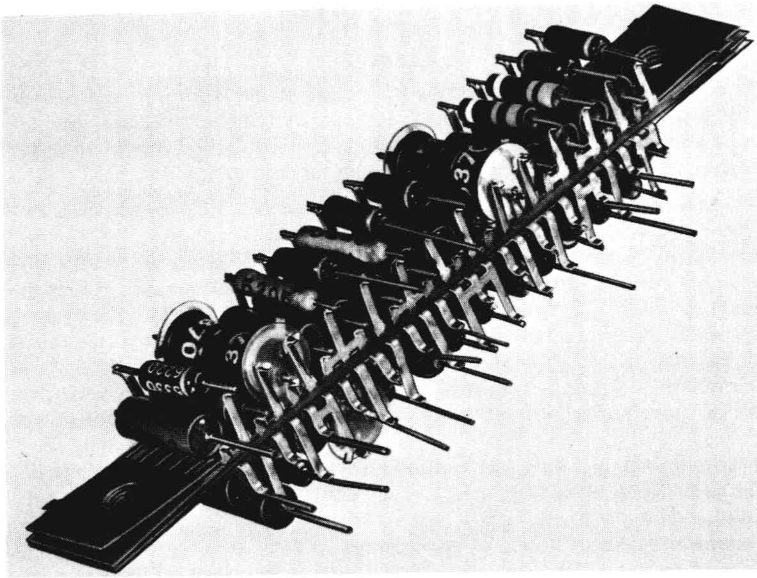
Physical Dimensions

All B-Modules, regardless of circuit configuration, are 0.63 in. wide and 0.58 in. high. Table I lists the length and volume of six typical modules that meet a specific design requirement.

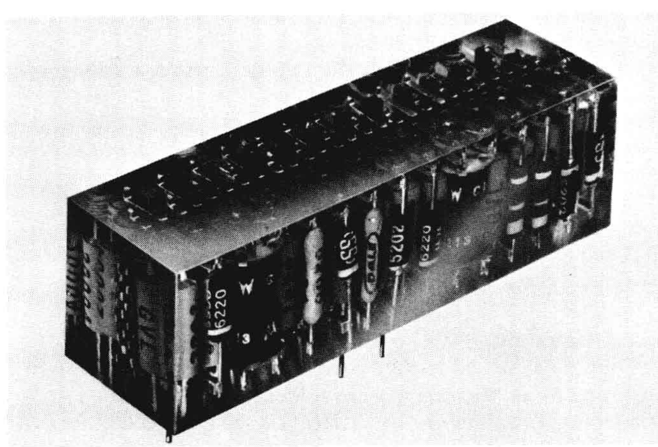
TABLE I

Typical Module Sizes

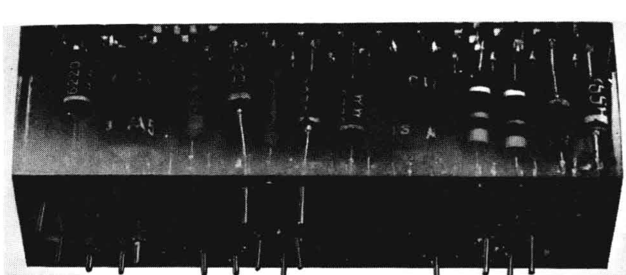
No. of Circuits	Type of circuit	Number of components	Length, in.	Volume, in.^{3}
5	Two-input diode "AND" diode "OR" gate	21	0.98	0.358
2	High current driver	18	0.98	0.358
4	Emitter follower amplifier	20	0.98	0.358
1	Trailing edge flip-flop	43	1.87	0.650
2	Inverter amplifier	17	0.98	0.358
1	Single-shot multivibrator	30	1.87	0.650



(a)



(b)



(c)

Fig. 8. Component assembly: (a) prior to encapsulation; (b) after encapsulation; (c) completed assembly.

RELIABILITY

Although the actual numerical reliability advantage of the B-Module design is not known at this time, its features are such that overall decrease of built-in defects or human errors in assembly can be anticipated as compared to most existing cordwood module designs.

The following features are advantageous to high module reliability:

1. The large surface area of the ribbonlike interconnecting material provides large contact area for the weld and for electrode contact resulting in consistent welds.
2. Automated machines will provide excellent control of electrode positioning prior to the weld pulse and prevent element slippage during the weld. The result is a high degree of weld uniformity.
3. The parallel electrode position for welding the component leads to the tabs eliminates many difficult electrode positioning and maintenance problems.
4. The elimination of plaques and the reduction in length of the path which the encapsulating material must travel between components decreases the possibility of voids in the encapsulant.
5. A low component operating temperature results from the short heat path to the module's surface, the large dissipating surface, and the heat transfer through the component leads to a mounting board.
6. Few operator assembly decisions are required, thus human error is held to a minimum.
7. The use of only one weld schedule for all interconnections and the parallel electrode position simplifies electrode dressing.
8. Since a header is not required in the B-Module design, the problem of adhesion between the encapsulant and the header is removed as a potential defect.
9. The module is easily repairable prior to encapsulation.
10. All circuit interconnections are made prior to mounting the components, thus decreasing the chance of component damage during fabrication.

The B-Module requires more welded joints than most other cordwood modules. For comparison purposes, a flip-flop circuit was analyzed using an in-house cordwood technique (see Fig. 9) and the B-Module.

The effect of the additional welds on module reliability is shown below.

Known:

1. Cordwood module has 139 welds.
2. B-Module has 207 welds (68 additional welds).

Assume:

1. Cordwood failure rate = 16.7×10^{-6} failures/hr (predicted).
2. Weld failure rate for both cordwood and B-Module = 0.1×10^{-8} failures/hr. (Equivalent to Atlas Missile Program solder joint failure rate.)

Computation shows that the additional welds decrease the total MTBF by 0.41 %.

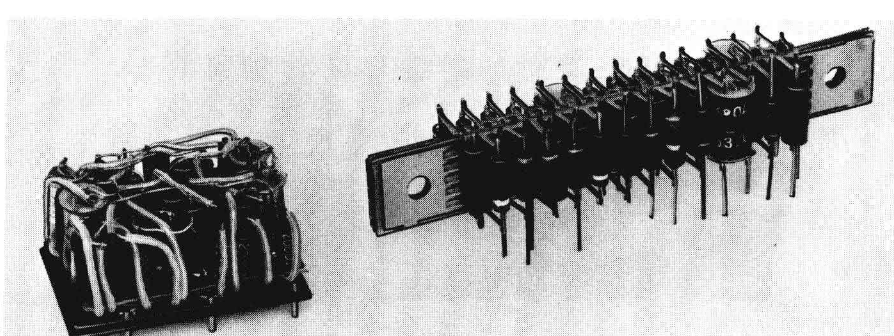


Fig. 9. Module used for weld comparison.

AUTOMATED PRODUCTION

A definite need for the automation of modules has become apparent. A flow diagram (Fig. 10) shows a planned automated production line for B-Modules. This diagram shows, by area, the direction of part flow, transfer machines required, punch presses, welding stations, component insertion stations, transistor stations, and encapsulation area.

Transfer Machine No. 1 and No. 2. Raw strip stock is fed from three spools into separate punch presses, where they are stamped into the horizontal grid, vertical grid, and insulator hole patterns. As the strips emerge from their respective presses, they are automatically merged and fixturized in proper alignment. As the fixturized subassembly indexes through the weld station, programmed welders make the necessary interconnections. The welded subassembly then progresses through a blanking station where programmed punches operate to perforate the grids. Upon completion of the punching, the vertical grid tabs are formed and the subassembly is trimmed to length. The completed upper and lower basket subassemblies are then advanced to bench station No. 1.

Transfer Machine No. 3. Transfer Machine No. 3 is simply a double station, progressive die setup. The center horizontal grid and its two insulators are perforated and blanked, and then conveyors advance the parts to bench station No. 1.

Bench Station No. 1. This area is used to fixturize the upper and lower basket subassemblies with the middle horizontal grid and insulators. The fixturized parts are then sent on their way to transfer machine No. 4.

Transfer Machine No. 4. The fixturized basket assembly is resistance welded by programmed welders. The part then indexes through the component insertion stations. The components are automatically dropped onto the upper basket tabs and held in place by the nest-type fixture. Welding of the components is done automatically by programmed welders. The part is advanced to bench station No. 2.

Bench Station No. 2. This station is used to simply invert the module in the fixture to allow component insertion and welding to the lower half of the module. The fixturized module is fed into transfer machine No. 5.

Transfer Machine No. 5. This transfer machine is identical to transfer machine No. 4, with the elimination of the basket assembly matrix weld station. The components are inserted and welded and passed on to area No. 6.

Area No. 6. The excess component leads are trimmed flush with the basket tabs, except for the mother card interconnection leads. Transistors may be automatically or manually inserted. If manual insertion is used, they are inserted and welded at bench stations. Welding the transistors in place completes the assembly and the module is given a "go–no-go" type of electrical test. Any faulty modules are sent to a repair station while the rest are routed to the encapsulation area. The modules can be either cast or transfer molded into their final form factor. The last operation is a final electrical test to ensure a finished working module.

CAPACITANCE STUDY

In the B-Module, the capacity formed by the "basket" assembly will depend primarily on the cross-sectional area between planes, distance between planes, the dielectric, and the number and location of welds. In the cordwood-type construction, it will depend on the wire routing, the interconnection configuration, and wire length to the input and output pins.

From a preliminary analysis, it appeared that under worst-case conditions the output capacities could add appreciably to the total input and output pin capacities. However, further investigation showed clearly that the input and output pin capacities of the B-Module and the cordwood-type are comparable. Table II shows the measured results of a trailing edge flip-flop circuit utilizing the two packaging techniques.

THERMAL ANALYSIS

The use of the thermal electrical analogy method of solution for heat transfer problems was chosen because of the information of this type available on the cordwood module. This

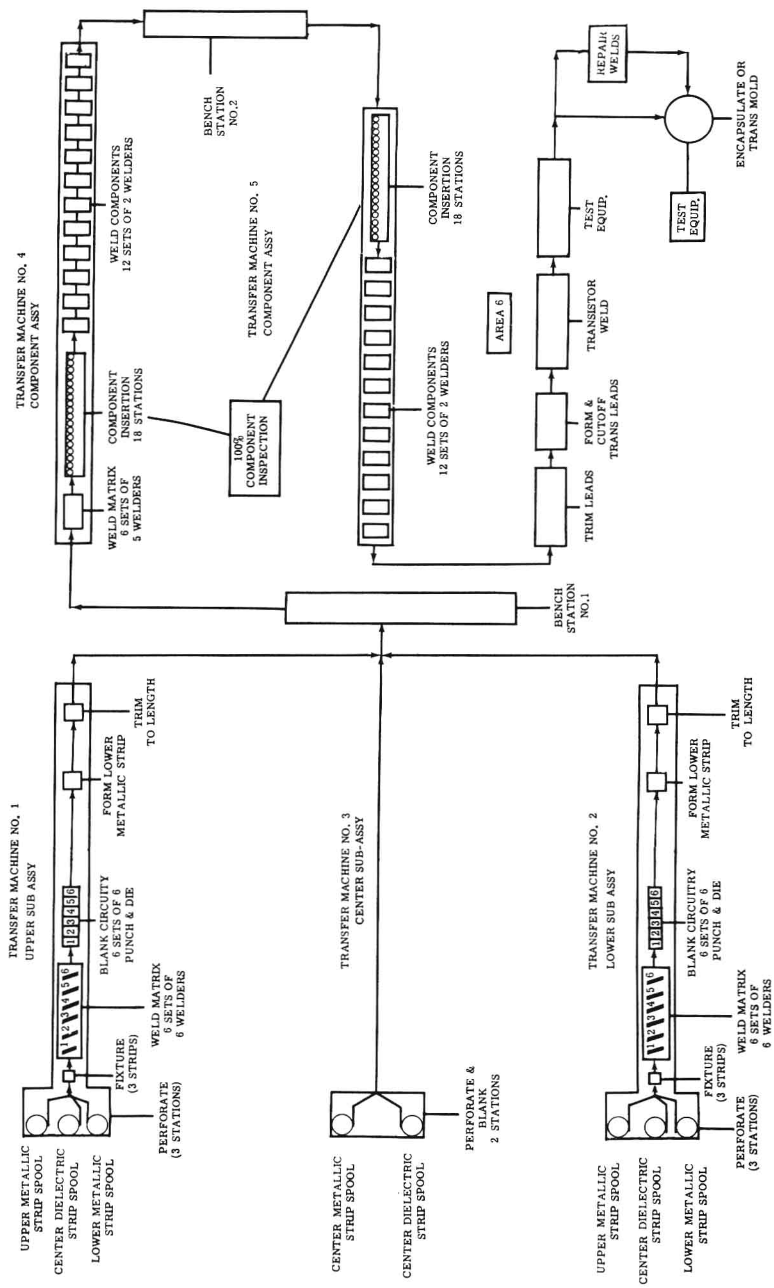


Fig. 10. Automation flow diagram.

TABLE II

Input/Output Capacitance

Circuit	Capacity, pF	
	B-Module	Cordwood-type
Clock input	29	32
"I" input	15	17
"O" input	16	18
"I" output	36	24
"O" output	27	23.5

method of analysis is based on the similarity of the equations describing heat transfer and electrical circuits. The analogous parameters are shown in Table III.

In general, a given package configuration may be presented by a network of resistors, each of which presents an element of thermal resistance to heat flow. The network may then be solved for the primary paths of heat transfer from the source to the surface cooling area. This method of solution offers increased facility to compare alternate designs of component and/or circuit packaging.

Figures 11 and 12 depict the cross section of the modules on which this study is based, and the following heat paths may be established:

Side of Module R_A: This path is through the epoxy coating, R1.

End of Module R_B: This path is through the epoxy encapsulant, R2.

Top of Module R_C: Two paths are used here—one directly from the component assembly through the epoxy, R3; the other is via the component tabs of the basket, R4, and the remaining epoxy, R5.

Bottom of Module R_D: Here two paths are again established. One path, R_E, is directly via the component leads, R6. The other path, R_F, is similar to the top of the module with the addition of the projections and air gap between the encapsulation and the mother card to which it mounts.

Each section of material was treated as having a "lumped" resistance R_T. Based on a circuit dissipating 850 mW, the B-Module has a thermal differential between components and surface measurements of 1.22°F, in comparison to 3.07°F for a cordwood module. This lower differential is due to the greater heat transfer to the surface. The calculated improvement for the circuit is summarized in Table IV where the improved heat transfer is reflected in the reduced thermal resistance R_T of the B-Module. Due to the method of component placement in the B-Module, these figures will vary with component count.

TABLE III

Electrical and Thermal Analogous Parameters

Item	Electrical		Thermal	
	Description	Symbol	Description	Symbol
Source	Voltage	V	Temperature	°F
Flow	Current	I	Heat	Btu/hr
Resistance	Electrical R	R_E	Thermal R	R_T
Law	$V/I = R_E$		°F/Btu-hr $= R_T$	
Conductance	$A/\rho L$	$1/R_E$	$k(A/L)$	$1/R_T$

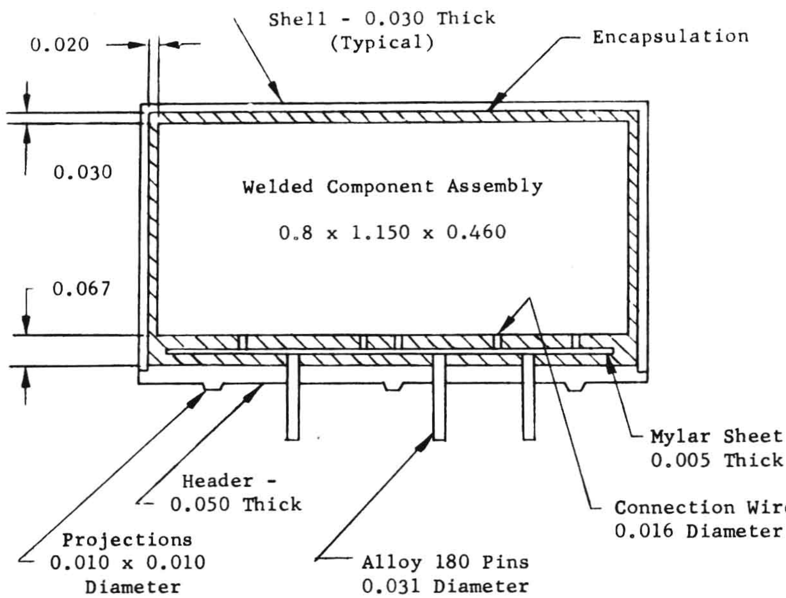


Fig. 11. Section of typical cordwood module.

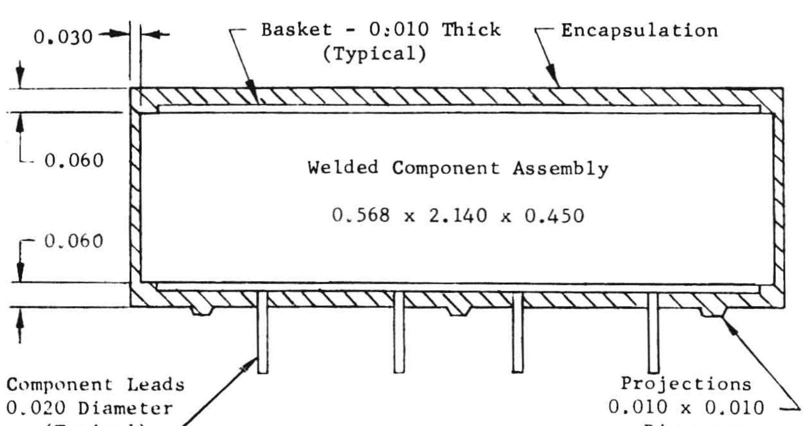


Fig. 12. Section of typical B-Module.