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Operations at the Donner Company

In October 1987, Edward Plummer, president of the Donner Company, was reviewing the company's position prior to planning 1988 operations.

The Donner Company manufactured printed circuit boards to the specifications of a variety of electronics manufacturers. Each board consisted of a thin sheet of insulating material with narrow metal strips (conductors) bonded to its surface. The insulating sheet acted as a structural member and supported electronic components connected by the conducting strips. In the customer's plant, assemblers (human and/or automated machinery) positioned electronic components in the pre-drilled holes in the board, soldered them into place, and then installed the board in the final electronic product.

At the end of 1987, there were 750 printed circuit board manufacturers in the United States. These manufacturers could be classified either as captive or contract manufacturers. Large electronics firms, such as IBM, AT&T, and Digital Equipment, produced much of their own requirements in captive board shops. When large quantities of simple technology boards, or small quantities of fast turnaround prototype boards were required, these customers would usually subcontract production to contract manufacturers. Smaller firms also purchased from contract manufacturers, particularly when small lots of special boards were needed. The more technologically complex a board, the more likely it was that customers would eventually produce it in-house.

Printed circuit boards, with their electronic components and circuitry, are the "guts" of virtually all electronic products. Due to the increasing use of electronics in all aspects of our lives, the printed circuit board industry has paralleled the growth rates of the computer, telecommunications and defense industries. This also has left the printed circuit board industry vulnerable to the frequent upturns and downturns of these industries.

Since the start of operations in 1985,[1] the Donner Company had specialized in making circuit boards for experimental devices and for pilot production runs. Most of the company's managers were engineers with substantial experience in the electronics industry. Plummer and the firm's design engineer, Bruce Altmeyer, had created several of the company's processing methods and had patented applications, processes, and modifications of some commercial machinery. Plummer and Altmeyer

[1] Income statements are shown in **Exhibit 1**.

Professor H. Kent Bowen prepared this case. This case derives partially from an earlier case, "Donner Co.," HBS No. 689-030 by Professor Roy D. Shapiro. This case was developed from published sources. Funding for the development of this case was provided by Harvard Business School and not by the company. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

both believed that the Donner Company was more adept than its competitors at anticipating and resolving the problems inherent in new designs and prototype production techniques.

Manufacturing Process

Donner's manufacturing process produced circuit boards known in the trade as "soldermask over bare copper" (SMOBC) boards. This SMOBC process became popular in the early 1980s as customers demanded denser circuit patterns and greater reliability.

The SMOBC manufacturing process consists of three stages: preparation, image transfer, and fabrication. In the first stage, artwork is produced while raw materials are prepared for processing. In the second stage, the conductor pattern is transferred to dielectric (insulating) base stock. In the third stage, the base stock is cut and shaped to create the individual printed circuit boards. The most common sequence of operations is listed in **Exhibit 2**.

Preparation Stage

The preparation stage begins once a customer order is received by the factory from Donner's shop supervisor. The customer provides artwork, which is used by Donner to generate an image replicating the exact circuit pattern, with actual dimensions. Depending on the final circuit board size, the individual image is often repeated to maximize the number of images per panel. Standard panel size is 12"x18". Because finished boards are often smaller than this, the typical number of images per panel is eight; the repeated image is therefore referred to as an "8 - up" image.

After an order is received from the shop supervisor, two steps are performed on the principal raw material—36"x48" laminate sheets of double-sided copper-clad glass epoxy, typically 0.059" thick—that will be used for the order. Each laminate sheet is inspected for visual defects just before it is sheared, typically into eight 12"x18" panels, and then location holes are punched to help align the panels for drilling, imaging, and routing later in the production process. Inspection, shearing, and the punching of location holes can all occur without referencing the artwork for the order.

Image Transfer[2]

Image transfer begins to configure the boards according to customer specifications and then to transfer the pattern of conducting and insulating strips to the laminate panel.

First, approximately 500 holes per circuit board are drilled, either manually on one of Donner's seven modified drill presses or automatically on the company's computer numerically controlled (CNC) Micronic-Jr. high-speed drill, recently purchased for $80,000 (**Exhibit 3**). In either case, the operator first pins a panel to the drill table using the location holes created in the previous production stage. In contrast to the operator-controlled manual drilling operation, the CNC drill automatically selects preprogrammed tools and then drills the holes in the correct positions. The drilling as well as the tool selection is driven by the (x,y)-coordinate locations specially programmed into the machine's computer. Before the production run, the operator uses the customer's detailed drawings to "digitize" the hole locations and hole sizes.

[2] See the **Appendix** for pictures of a typical circuit board, in cross-section, as it goes through this process.

After drilling, each panel is processed through a copper immersion bath. This process, called metallization, deposits a thin (.00005”) layer of copper in the drilled holes. This electrically connects the copper on both faces through the metallized drilled holes.

After metallization, the panels are washed, scrubbed and coated with dry film photoresist (DFPR). The film of the customer artwork is laid on top of the coated panels and the package is exposed to ultraviolet (UV) light. The panels are then passed through a DFPR developing machine which washes away the DFPR that has not been exposed to the UV light. After this developing step, the areas of the panel’s copper surface corresponding to the desired conductors remain bare; the remainder of the board is still coated with DFPR that has been “cured” by the UV light.

The copper conductors, now bare, are electroplated. First, an additional 0.0015” of copper is deposited on those areas of both surfaces not covered by DFPR and through the drilled and metallized holes. Tin is then flashplated 0.0005” thick over the copper plating. (The tin resists the chemical that etches away the DFPR during the next production step.)

In the next processing step, the DFPR that had been exposed to UV light is chemically stripped from the panel. This step exposes the copper that had not been previously electroplated. This copper layer, 0.0015” thick, is then chemically etched off the glass epoxy base. The plated tin protects the copper circuit pattern from chemical attack by this etchant. Following this etching process, the tin is chemically stripped from the circuits leaving only a copper image on the panel. At this point the desired circuit pattern has been created on both sides of the board.

Fabrication

The panels are now processed through soldermask silkscreening, leaving a protective epoxy coating over the circuit traces. The plated “through holes” are not covered with soldermask. Each panel is then dipped into a molten solder bath and the exposed copper of the plated holes are covered with solder.

Each individual circuit board is then separated from the panel and reduced to its desired finished “profile” (size and shape) either by CNC routing, or, for smaller lots, by stamping on a 20-ton punch press. The computer control necessary for the CNC router is prepared prior to the production run, from the customer’s artwork.

After profiling, the individual boards are visually inspected, electrically tested, packaged, and shipped. Because of its importance, one senior Donner employee was assigned to this final step.

Although work normally flows in this manner, the sequence of operations was modified for several customer orders each week because of specific requirements. In addition, special boards often required additional steps.

To reduce handling damage, panels were typically held in special racks, which could hold as many as 20 panels, between all process operations.

Supervision

Supervisory responsibility for various phases was shared by three people: Diane Schnabs, the expediter; Bruce Altmeyer, the design engineer; and David Flaherty, the shop supervisor. Schnabs and Altmeyer reported to the president; Flaherty reported to Altmeyer.

Schnabs had been hired in August 1987. She kept track of orders in process and initiated action if an order failed to progress through manufacturing satisfactorily. When the supervisor's daily progress report (showing the last operation performed on each order) indicated a delay, Schnabs investigated and usually secured the missing supplies or instructions, told the supervisor to start the job moving again, or called customers to advise them of possible late delivery. On average, Schnabs investigated from two to three slow orders each day. In addition, she conferred with the sales manager and president to determine how many small rush orders (usually having a four-day delivery date) should be sent into processing.

Altmeyer's primary duties were to inspect the customer's artwork and requirements in order to locate design errors, to determine the best means of processing and to identify unusual production problems. In addition, he commonly spent 10 hours a week talking with shop employees about these problems and others that cropped up in processing.

David Flaherty, the supervisor, was in charge of all other aspects of manufacturing from the time he received a shop order and blueprint until the order was shipped. In total, Flaherty supervised the activities of 22 production employees. Four of these were assistant supervisors who spent about 10% of their time instructing people in their areas or advising Flaherty on various problems.

Shop Employees

Employees (nonunion) worked a single shift, which consisted of 8 working hours per day. They used both manual and computer-controlled equipment to perform medium-duty, short-cycle repetitive tasks. Within each department, operators were cross- trained and capable of running most process steps. Many employees were qualified in more than one department.

The usual work flow required operators to interrupt their tasks from 6 to 12 times per day to secure more work from the upstream process, to seek advice on a problem, or to deliver completed work (to the supervisor, to a storage area, or to another operator).

Judgment and experience were important in all areas, especially where operators had to compensate for such factors as changes in the shop's temperature and the slow deterioration of the chemical action in various solutions. In other operations, skill and care were required to position both tools and work pieces accurately and to prevent scratching or marring of the circuit boards.

Order Processing

At the first step in the preparation of the factory order, Plummer and Altmeyer estimated labor and material costs. These estimates were then used in preparing a bid for the customer. If the customer subsequently accepted the bid, Donner Company would promise delivery in three weeks for orders of less than 1,000 boards and 5 weeks for larger orders. The estimate sheet and customer artwork were then pulled from the files and Altmeyer wrote out detailed material specifications (there were 30 base stock types used by the company) and a factory order showing the delivery date, the number of circuits, the material specifications, and the sequence of operations. The order was then sent to the purchasing agent, who required one or two days to locate the needed raw material at a low price and to order it. (The materials used in September are shown in **Exhibit 4.**) The order was then entered into a log, and a blueprint and factory order were sent to the supervisor. Most orders reached Flaherty about four days after the bid had been accepted.

Occasionally the president or sales manager promised delivery within four days in order to satisfy a customer's urgent need. These rush orders were expedited by Schnabs. As soon as the order was received, she wrote the material specifications, gave Flaherty a factory order and a blueprint, and instructed the purchasing agent to secure material for delivery on the same or following day.

When Flaherty received a factory order, he used his own judgment in scheduling preparatory work. Usually he delayed his scheduling decision for several days until the raw material arrived from the vendor. He then estimated the labor required in each step, examined the work in process at critical points, estimated the difficulties in meeting the new order's shipping dates, weighed the sales possibilities of these orders being held up, and then decided when to schedule the order. Flaherty spent much of his time determining when to move jobs ahead of others in the process and when to shift workers from one operation to another.

Until a job was shipped, the factory order and blueprint were kept by Flaherty, who gave them to any worker requiring information. A ticket denoting the factory order number was kept with the first rack of material as it moved through processing.

Facilities and Layout

When the company moved to its present location in January 1986, Plummer had chosen a production layout which he felt minimized installation costs, preserved the life of expensive machines, and isolated the operations' diverse environments. Cost had been an important consideration because the company had committed most of its funds for equipment and had not been able to attract outside capital.

The plating and etching processes, which released acid vapors, had been located far from the machining operations to prevent excessive corrosion of the machine tools. Similarly, the machining operations, which created dust, had been separated from the imaging, plating, and etching processes which were sensitive to dust and dirt. After a year and a half, neither the machine tools nor the graphics equipment exhibited signs of corrosion. Similarly, dust from the machining areas had not contaminated other processes. In October 1986, the company was fully utilizing the space in the existing plant. An 1,800-square-foot addition was due to be completed in November 1987.

Current Operating Problems

In assessing the company's operating position, Plummer was most concerned about the current difficulties which he described as productivity, quality, and delivery problems.

The production bottleneck was perplexing because it shifted almost daily from one operation to another, without pattern. Anticipating where work would pile up in the shop on a given day had proven difficult because individual orders imposed varying workloads on each operation. These variations stemmed from differences in order size, from orders bypassing some operations, and from differences in circuit designs. Also contributing to fluctuations were the four-day rush orders (usually three a week), orders requiring rework at one or two operations, and work delayed in process pending a customer's delivery of artwork modifications or a design change (one to nine a week). Approximately one-fourth of the jobs delayed in process were held as a result of telephone calls from the customer's engineers who had encountered a design problem. Then, any time from one day to two weeks later, the customer would relay permission to complete the order as originally specified or convey new specifications.

During the past several months, Flaherty had found compensating for these variations increasingly difficult because he had no accurate way of predicting where work would pile up or run out, or of assessing the future effects of any corrective action. A recent Wednesday's events were typical. Early in the morning, three workers engaged in manual drilling had run out of work. The supervisor, therefore, had shifted them to other tasks until other boards could be expedited to the drilling operation. In this case, Flaherty decided to meet the situation by expediting portions of two orders which were in process in the operations preceding drilling. By midmorning one of the workers transferred away from drilling had completed his new assignment and had to be given a different job. At noon, by which time the expedited orders had reached the drilling operation, all three workers were busy elsewhere.

Only the small orders (eight circuit boards or less) seemed to pose no scheduling problems. Such orders were always assigned to a senior employee, Arthur Dief, who carried each order from step to step, generally doing the work himself or occasionally having someone else perform it. Dief consistently met delivery deadlines, even on four-day rush orders, and his reject rate was usually zero.

Productivity

Plummer realized that it was impossible to evaluate shop productivity precisely. However, during his daily trips through the shop he had noticed that several of the machines were idle more often than he would have expected. In commenting on the summary of productive labor shown in **Exhibit 2**, he noted that total standard labor hours did not include time which was spent reworking parts which failed inspection or were returned by customers. In addition, Plummer believed that the time required to move boards from one operation to another was not adequately reflected in the standards. The time standards used in **Exhibit 2** were based, in part, on a synthesis of what they knew to be the standards applied in competing firms (from whom they had hired various workers and assistant supervisors) and, in part, based on judgments made by Plummer and Altmeyer after experience gained in performing and observing those jobs. In preparing time estimates for a bid preparation, Plummer actually used figures which were substantially above those standards.

The president felt, however, that the job methods in use were far from ideal and that the standards did not reflect improvements which could probably be made in almost any job in the shop. As a specific example, he cited the plating operation. The plater worked at a desk inspecting panels and then carried the panels to the plating tanks 18 feet away, inserted them, and returned to inspect more panels. She interrupted her work at the desk every three or four minutes to inspect the panels in one of the tanks. Altmeyer thought 15% of the plater's time was spent simply walking between the desk and the tanks.

Plummer suspected that methods improvements were not being introduced because of the current pressure for output, the constant shifting of workers from job to job, and other immediate problems that inhibited experimentation with new ideas. Furthermore, job improvements often seemed, in retrospect, to have created more problems than they solved. For example, those infrequent cases in which improvements had substantially increased production at one station often resulted in work piling up at the following operations. The supervisor was then forced to reschedule orders and reassign workers, thus adding to the general confusion and occasionally creating personal friction.

Quality and Delivery Problems

Lloyd Searby, who joined the company as the sales manager in April 1987, was concerned about recent failures in maintaining quality standards and in meeting promised delivery dates. Since August, customer returns had increased from under 1% to about 3%, and shipments had averaged nine days late. Searby felt that a continuation of these conditions would impede his hope of increasing the present sales volume and achieving the company's sales goals. After having conducted an in-depth study of the potential market, the sales manager predicted that volume would fail to exceed $2 million in 1988 if he had to begin promising four-week deliveries on small orders, as four of Donner's competitors were doing. If, on the other hand, the company was able to regain its pre-August delivery performance, and continue to (reliably) promise three-week delivery, Searby felt sales should reach nearly $3 million in 1988. Both Searby and Plummer believed that the company should continue to bid only for low-volume, special circuit board business. Their sales estimates, therefore, were based on an order size profile similar to that actually produced in September 1987, as shown in **Exhibit 4**.

Quality

Plummer was also concerned about the present inspection system in which formal inspections of raw material (at the beginning of the process) and finished boards (at the end of the process) were supplemented by each worker's informal examination of the units as they moved through processing. The president felt that any effort to specify quality standards more exactly and to enforce them more rigorously might not be feasible because the standards varied from customer to customer and even from order to order. For example, in one recent episode a customer's engineers had praised the quality of Donner's work on one order even though the boards were scratched and marred and had one or two holes located out of tolerance. A week later, engineers at the same company rejected 25 apparently perfect boards because one conductor on each had a single nick, 0.005" by 0.001".

During the past several months, however, only one-tenth of the boards that had been returned were damaged or out of tolerance. The remainder were returned because Donner had missed or failed to complete one or two of the required operations. These boards were reprocessed and shipped within one or two days. The company's preshipment reject rate in September amounted to 7%, of which 1% were total losses and 6% were due to incomplete operations, and subsequently reworked.

Deliveries

Plummer had always emphasized a shipping policy aimed at clearing all the work possible out of the shop prior to the end of each month. As a result, substantially fewer shipments were made in the first half of each month than in the second half, as shown in **Exhibit 5**. Actual deliveries in August, September, and the first part of October had averaged 10, 8, and 9 days late, respectively. During that period, the company had continued its historical practice of quoting three weeks delivery on orders of less than 1,000 circuit boards and 5 weeks on larger orders. In August, when deliveries climbed to a volume of $32,000 per week, 8 new people had been added to the production force. Plummer observed that these eight workers had developed some skill by the second week in August but he believed that they would require three more months to become as skilled as the company's more senior employees.

Exhibit 1 Donner Company Summary of Profit and Loss ($000s)

	September 1987		August 1987		July 1987		Jan-June 1987		1986		1985	
Net sales	$124.8	100.0%	$144.4	100.0%	$85.7	100.0%	$327.9	100.0%	$404.5	100.0%	$246.0	100.0%
Cost of Goods Sold:												
Materials	42.6	34.1	49.9	34.6	29.1	34.0	110.3	33.6	138.0	34.1	77.2	31.4
Direct labor	32.3	25.9	32.7	22.6	19.7	23.0	91.9	28.0	109.0	26.9	67.2	27.3
Indirect wages, salaries	8.2	6.6	8.8	6.1	4.8	5.6	23.3	7.1	36.7	9.1	26.0	10.6
Manufacturing overhead	25.9	20.8	25.8	17.9	13.8	16.1	48.4	14.8	58.8	14.5	38.0	15.4
Total Cost of Sales	109.0	87.3	117.2	81.2	67.4	78.6	273.9	83.5	342.5	84.7	208.4	84.7
Gross profit	15.8	12.7	27.2	18.8	18.3	21.4	54.0	16.5	62.0	15.3	37.6	15.3
Selling expense	4.5	3.6	4.3	3.0	4.1	4.8	14.5	4.4	25.4	6.3	26.2	10.7
Administrative expense	8.2	6.6	8.1	5.6	7.8	9.1	30.3	9.2	34.5	8.5	18.3	7.4
Total Selling and Administrative	12.7	10.2	12.4	8.6	11.9	13.9	44.8	13.7	59.9	14.8	44.5	18.1
Net profit before tax	$3.1	2.5%	$14.8	10.25%	$6.4	7.5%	$9.2	2.8%	$2.1	0.5%	$(6.9)	-2.8%

Exhibit 2 September's Standard Production[f]

	Standard Production Times (min.)		September's Production		September's Total Standard Production			
Operation	*Setup*	*Run*	*Orders*	*Boards*	Setup *(in min)*	Run *(in min)*	Total *(in min)*	Total *(in hrs.)*
PREPARATION:								
Artwork generation	29	0.000	50	799	1,450	0	1,450	24.2
Inspect and shear	20	0.500[a]	60	5,761	1,200	360	1,560	26.0
Punch tooling holes	10	0.500[a]	60	5,761	600	360	960	16.0
IMAGE TRANSFER:								
Drill								
Manual	15	0.080[b]	51	936	765	37,440	38,205	636.8
CNC drill[e]	240[c]	0.004[b]	9	4,825	2,160	9,650	11,810	196.8
Metallization	10	0.750[a]	60	5,761	600	540	1,140	19.0
Dry film photoresist								
1. Panel prep	5	0.200[a]	60	5,761	300	144	444	7.4
2. Laminate & expose	20	2.000[a]	60	5,761	1,200	1,440	2,640	44.0
3. Develop	20	0.200[a]	60	5,761	1,200	144	1,344	22.4
Electroplate	25	8.500[a]	60	5,761	1,500	6,121	7,621	127.0
Strip DFPR	5	0.200[a]	60	5,761	300	144	444	7.4
Etch & tin strip	10	0.200[a]	60	5,761	600	144	744	12.4
FABRICATION:								
Soldermask	45	1.500[a]	55	5,744	2,475	1,077	3,552	59.2
Solder dip	30	0.500[a]	55	5,744	1,650	359	2,009	33.5
Profile								
Punch press	50	1.000[d]	47	1,223	2,350	1,223	3,573	59.6
CNC router	150[c]	0.500[d]	7	4,531	1,050	2,266	3,316	55.3
Inspect, test, pack	45	1.500[d]	60	5,761	2,700	8,642	11,342	189.0
Total					22,100	70,054	92,154	1,535.9

[a] Per panel; typical panel consists of eight circuit boards.

[b] Per hole; typical circuit board has 500 drilled holes.

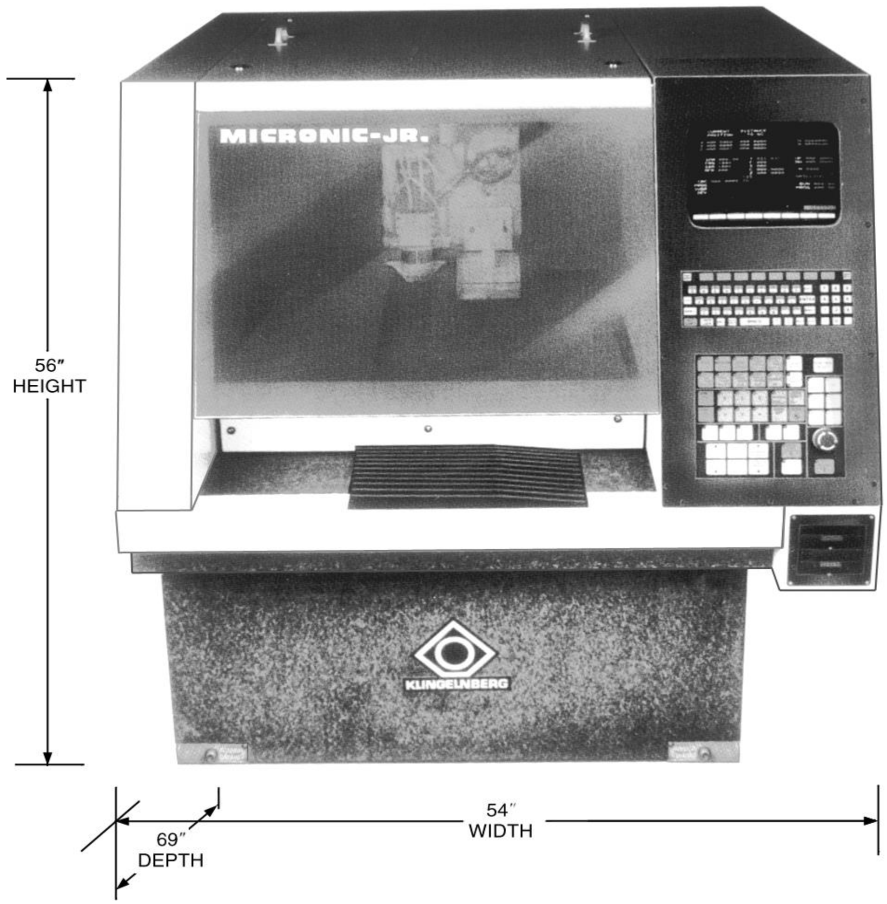
[c] This setup time is almost entirely the preparation of the required computer control.

[d] Per circuit board.

[e] Shop floor policy dictates that only orders for more than 100 boards be drilled on this equipment.

[f] This represents the "typical" flow. The design of the circuit board often requires some deviation from this path, and special boards often require operations not shown here.

Exhibit 3 The Micronic-Jr. Drill



Source: Company promotional literature.

MICRONIC JR.

Micronic Jr. offers many of the features, advantages and benefits normally associated with high production PCB generation machinery.

This includes:

- ► Prototype and low volume production capacity
- ► First Article
- ► High Accuracy
- ► Small hole drilling capability
- ► Stand-Alone Programmer Capability (optional)
- ► Single Spindle Operation
- ► Mass Tool Changer
- ► DNC interface (optional)

Exhibit 4 Actual Order Size: September 1987

Order Size (number of circuit boards in each order)	Base Stock Code Letters	Number of Orders	Total Number of Circuit Boards
1	A, B, D, E	7	7
2	A, B, F, H	7	14
3	B, D	2	6
4	A, B, C, F, H	7	28
5	A, D	2	10
6	B, C	2	12
10	B, D, E	3	30
11	D, F	2	22
12	A, J, K	6	72
14	A, E, G	3	42
20	D	1	20
40	B, K	2	80
50	C, E	2	100
60	C	1	60
84	J	1	84
100	C	1	100
113	E	1	113
136	C	1	136
140	F	1	140
154	A	1	154
200	D	1	200
229	E	1	229
252	A	1	252
800	G	1	800
1,000	D, M	2	2,000
1,050	A	1	1,050
		60	5,761

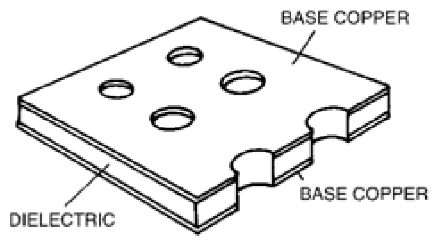
Exhibit 5 Value of Actual Shipments in September 1987 (in dollars)

Date	Daily	Cumulative
1	$11,118	$11,118
2	(1,188)	9,930
3	4,057	13,987
4	1,696	15,683
8	2,226	17,909
9	8,430	26,339
10	2,395	28,734
11	(684)	28,050
14	2,560	30,610
15	5,926	36,536
16	(147)	36,389
17	3,952	40,341
18	13,216	53,557
21	10,070	63,627
22	5,561	69,188
23	2,275	71,463
24	176	71,639
25	(1,327)	70,312
28	(7,975)	62,337
29	17,939	80,276
30	44,560	124,836

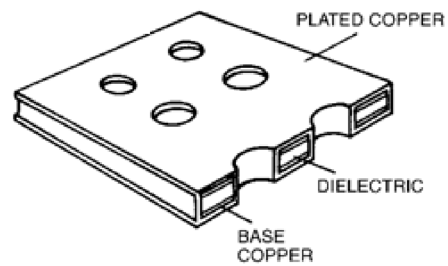
Appendix

Close-up of a Circuit Board, in Cross-Section, Moving Through Image Transfer

1. Metallization

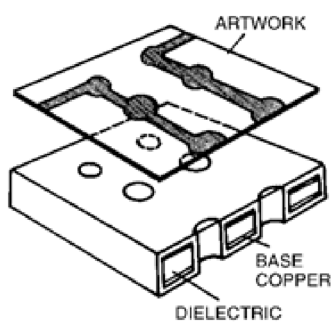


Copper laminate has been drilled.



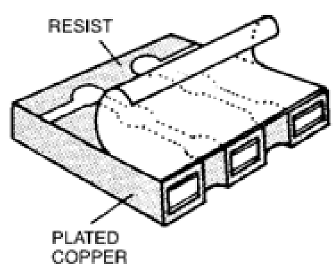
Metallization, or through-hole plating, is accomplished using heavy-deposition electroless copper or light electroless copper followed by an electroplated "flash" copper.

2. Prep and laminate



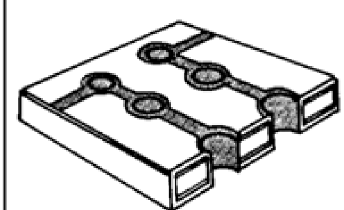
The panel is coated with DFPR. Then, artwork is registered to the panel, which is exposed to UV light.

3. Expose



The resist has been exposed and the cover sheet is removed.

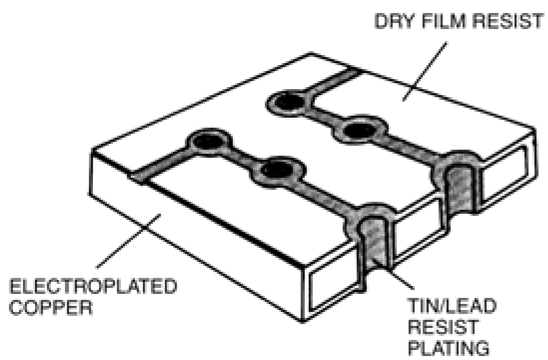
4. Develop



Unexposed resist is developed off in a mildly alkaline solution, and the desired image can now be electroplated or etched.

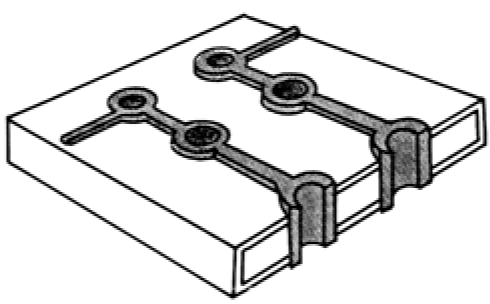
Appendix (continued)

5. Electroplate



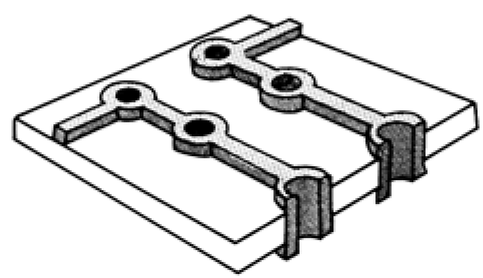
Panel is electroplated with desired thickness of copper and tin/lead.

6. Strip



Dry film resist is stripped away using an alkaline solution such as 3% potassium hydroxide.

7. Etch & Tin Strip



Panel is etched using spray etching, either acid or alkaline (pH below 8.5).