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ELECTRICAL CONDUCTIVITY STUDY OF
ETCHED-OUT PLATED-THROUGH HOLES IN
DOUBLE-SIDED PRINTED WIRING BOARDS

PDO 6984684, Topical Report

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ELECTRICAL CONDUCTIVITY STUDY OF ETCHED-OUT PLATED-THROUGH
HOLES IN DOUBLE-SIDED PRINTED WIRING BOARDS

BDX-613-1434 (Rev.), Published January 1976

Prepared by R. J. Setter, D/821, under PDO 6984684

A proposed method for producing nonplated-through holes in double-sided printed wiring boards has been proved not detrimental to the functioning of the boards. Electrical conductivity measurements of holes which had been drilled, plated through with copper, and subsequently etched out to produce nonplated-through holes indicated negligible conductance in the range from 1 to 6 picomhos (1 to 6 pS).

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SUMMARY

A proposed method for producing nonplated-through holes in double-sided printed wiring boards consists of drilling and plating them as normal plated-through holes and then etching out the copper. By eliminating a second drilling operation, this process would decrease the cost of printed-wiring-board fabrication. A study therefore was conducted to determine whether holes processed by the proposed method would provide the same (or an acceptable) degree of electrical isolation between the sides of the board as do holes which are drilled after the copper-plating operation.

Printed wiring boards containing one series of plated-through holes that were etched-out and a second series that were drilled after etching were prepared for study. The boards were 0.062 inch (1.57 mm) in thickness and the holes ranged in diameter from 0.025 to 0.310 inch (0.625 to 7.87 mm).

The first conductance measurements were made at various voltages up to 1500 Vdc. After a determination had been made that the current flowing through the holes varied linearly with the applied voltage, measurements were made at 1500 V only.

The holes that had been drilled after the copper-plating process proved to be so low in conductance (less than 0.05 nA) that no current measurement could be made. The etched-out holes exhibited negligible conductance ranging from 1 to 6 picomhos (1 to 6 pS). A statistical analysis of the data verified that there was a difference between the conductivity of the etched-out holes and that of the drilled holes.

Microscopic inspection of 48 etched-out holes at magnifications up to 200X revealed that seven of them had minute traces of copper extending back into the glass-epoxy matrix from the walls of the holes. All of the particles found were securely attached to the hole walls.

No relationship could be established between the occurrence of copper traces and the electrical conductance of the holes. This finding supports the conclusion that measurable conductance is the result of invisible residues having been left in the holes from the cleaning or etching solutions.

An evaluation of the findings of the electrical conductivity tests by all responsible Bendix product engineering groups indicated that the difference in conductivity between holes that have been etched-out and holes that have been drilled after etching is insignificant. The conclusion therefore was reached

that the proposed method for producing nonplated-through holes will cause no problems in the functioning of the printed wiring boards.

DISCUSSION

SCOPE AND PURPOSE

At the present time, plated-through holes in printed wiring boards are drilled prior to plating and etching. Nonplated-through holes, such as those for mounting or potting relief, then are added to the board through a second drilling operation.

A proposed process for fabricating the nonplated-through holes consists of drilling and plating them as conventional plated-through-holes, and then etching away the copper plating during the normal etching operation. Since all holes would be drilled during one operation, printed-wiring-board fabrication costs would be significantly reduced.

To evaluate the proposed process, printed wiring boards were fabricated according to the method described and were tested to determine the magnitude of electrical conductance through the etched-out holes. The boards then were microscopically examined under a magnification of 200X to determine the type of any conductive materials found in the holes, and the findings were evaluated with respect to the functional requirements for printed wiring boards.

PRIOR WORK

Prior to this study, various lots and designs of printed wiring boards were fabricated according to the proposed process. These boards were not used in WR product; they were used only on development projects and development hardware under the direction of the Design Laboratories. No history exists to link the cause of printed-wiring-board failure or malfunction with the etching of copper plating from holes.

ACTIVITY

Sample Preparation

Twenty-four 0.062-inch-thick (1.57 mm) printed-wiring-board panels were prepared according to the Bendix Kansas City standard panel-plating process (Figure 1). All holes except those labeled "control holes" were drilled prior to plating and then were plated through with copper. The copper plating in the holes then was etched away during the normal etching process to leave the holes unplated.

Figure 1. Test-Panel Design Showing Location of Test Holes

The control holes were drilled in the panels after plating to duplicate the present process for producing nonplated-through holes. The control holes were used in the electrical tests for reference purposes.

Conductivity-Measuring Equipment

A block diagram of the electrical system that was used to make the conductivity measurements is shown in Figure 2. Four interchangeable sets of probes were used--one for each hole diameter. The probes were of stainless steel with flat, polished surfaces for contacting the hole area. They were attached to an air-actuated positioning system which provided precise control of the probe position in relation to the hole that was being tested. The positioning system also controlled the pressure that was applied to each probe.

Figure 2. Conductivity-Measuring System

Power for the conductivity measurements was obtained from an Alfred Electronics Model 265, variable, 0- to 1500-Vdc power supply which has, for safety, a 1-mA current-limiting switch. Measurements were made with a Keithley 414S picoammeter which was readable to ± 0.05 nA (as employed in the tests described).

The protection circuit was specially designed and constructed for this study to protect the ammeter in the event a high-voltage arc should occur between the probes.

Hole Selection

Figure 1 shows the panel location of each hole that was chosen for electrical testing. The holes were selected, by diameter, according to the plan shown in Table 1. The intent was to select a hole of each diameter from each major area of the board.

Test Procedure

The following procedure was used for each conductivity test made.

- The hole to be tested was positioned on the test fixture through the use of a microscope having a magnification of 10X.
- With the probes directly in line with the hole, the air system was activated to bring the probes in contact with the top and bottom surfaces of the board.
- The potential between the electrodes (probes) was increased from 0 to 100 V, the ammeter was observed, and the reading was recorded.
- The potential was increased in 200-V increments to a maximum of 1500 V. (Current readings were observed and recorded at each increment.)

Measurement Repeatability

To establish the variation that might be expected from repetitive measurements of any given hole, twenty consecutive measurements were made on one hole of each of the four diameters. The results obtained are shown in Table 2.

As indicated, the standard deviation was less than ± 0.2 nA in all cases, and any individual measurement can be expected to be within ± 0.4 nA of the average value for that specific hole.

Table 1. Hole-Location Plan, by Diameter

Hole Diameter (Inch) (mm)	Control Hole	Test Holes
0.310 (7.87)	A	1A, 2A, 3A
0.125 (3.17)	B	1B, 2B, 3B
0.060 (1.52)	C	1C, 2C, 3C
0.025 (0.635)	D	1D, 2D, 3D

Current Versus Voltage

Several holes were selected for measuring the current through the full voltage range from 100 to 1500 V. Figure 3 is a plot of the measurements obtained from two typical holes. As indicated, the current increased linearly with voltage throughout the range studied. Thus the resistance of a given hole did not change significantly with the voltage applied.

After the current-voltage relationship had been established, the remaining holes were tested at 1500 V only, and the conductance value for each hole was calculated from the following equation.

$$C = \frac{I}{V}, \quad (1)$$

where

C = conductance in mhos (or siemens),

E = current reading in amperes, and

V = 1500 volts.

Data Analysis

One method for comparing the relative conductance of the etched-out holes to that of the drilled holes is to average the values obtained from the twenty-four panels for each hole location. These values are shown graphically in Figure 4, and are listed together with their standard deviations in Table 3.

Table 2. Measurement-Repeatability Results, by Hole Diameter and Designation

Hole Diameter (Inch) (mm)							
0.025 (0.635) 2D (nA)*		0.060 (1.52) 2C (nA)		0.125 (3.17) 2B (nA)		0.310 (7.87) 3A (nA)	
2.6		9.2		9.5		4.1	
2.6		8.9		9.3		4.0	
2.7		8.8		9.4		4.2	
2.8		9.2		9.3		4.3	
2.6		9.1		9.2		4.1	
2.5		9.4		8.9		4.2	
2.7		8.9		9.1		4.3	
2.8		9.0		9.2		4.1	
2.6		9.1		9.3		4.3	
2.5		9.2		9.5		4.2	
2.8		9.2		9.2		4.2	
2.6		9.1		9.2		4.1	
2.7		9.2		9.3		4.2	
2.8		9.4		9.4		4.0	
2.6		9.3		9.6		3.9	
2.6		9.2		9.7		3.9	
2.9		9.3		9.3		4.2	
2.5		8.9		9.2		4.1	
2.6		9.1		9.1		4.3	
2.7		9.2		9.4		4.0	
$\bar{X}$	2.66	9.14		9.30		4.14	
σ	0.11	0.17		0.19		0.13	

*All current measurements were made at 1500 V.

The conductance of the drilled holes was so low that, in most cases, it could not be measured. A few of the holes did show slight conductance in the magnitude order of the system repeatability. In contrast, the etched-out holes showed a detectable current flow for all hole diameters.

Figure 3. Two Typical Current-Versus-Voltage Plots

To verify that the values from the two types of holes were indeed statistically different, a hypothesis test was made. If the case where $\bar{X}_1 \neq \bar{X}_2$ is considered, the critical value (Z) at 99.5-percent confidence level is 2.58. The values of Z for the data obtained from the experiment were calculated from the following equation.

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}}, \quad (2)$$

Figure 4. Average Conductance From 24 Test Panels

Table 3. Summary of Test Data From 24 Panels

Hole Identification	Average Conductance (Mhos $\times 10^{-14}$) or (S $\times 10^{-14}$)	Standard Deviation
A	4.2	7.8
1A	179.0	230.0
2A	214.0	152.0
3A	52.0	70.0
B	1.7	4.0
1B	266.0	212.0
2B	248.0	243.0
3B	305.0	234.0
C	1.0	2.3
1C	403.0	472.0
2C	484.0	312.0
3C	538.0	368.0
D	1.7	3.5
1D	34.2	31.2
2D	21.8	23.9
3D	17.5	21.0

where

Z = critical value at 99.5-percent confidence level,

$\bar{X}_1$ = average value of drilled holes,

$\bar{X}_2$ = average value of etched-out holes,

σ_1 = standard deviation of drilled holes,

σ_2 = standard deviation of etched-out holes, and

N_1 and N_2 = number of holes tested.

The calculated values of Z for each test case are shown in Table 4. In every case, the value of Z was greater than 2.58, thus indicating that the conductance values for the etched-out holes were from different populations than the conductance values for the drilled holes.

Table 4. Calculated Z Values
From Hypothesis Test

$\bar{X}_1 \neq \bar{X}_2$ Values	Calculated Z Values
A $\neq$ A ₁	3.721
A $\neq$ A ₂	6.753
A $\neq$ A ₃	3.325
B $\neq$ B ₁	6.106
B $\neq$ B ₂	4.965
B $\neq$ B ₃	6.349
C $\neq$ C ₁	4.172
C $\neq$ C ₂	7.584
C $\neq$ C ₃	7.149
D $\neq$ D ₁	5.071
D $\neq$ D ₂	4.077
D $\neq$ D ₃	3.636

Other methods for analyzing the data to account for the different hole diameters did not appear relevant to the decision concerning adoption of the etching-out process for producing nonplated-through holes.

Inspection of Etched-Out Holes

Twelve etched-out samples of each of the four different-sized holes, 0.310, 0.125, 0.060, and 0.025 inch (7.87, 3.17, 1.52, and 0.635 mm), were selected for visual inspection. Of these, six samples of each size were selected from the holes that showed the higher conductance readings, and six were selected from the holes that showed the lower conductance readings. This method of selection was used to determine whether the incidence of higher conductance was related to the presence of copper in the holes.

Equal numbers of holes from the higher- and lower-conductance groups were sectioned and mounted--twenty-four in the transverse position and twenty-four in the axial position. The transverse mounts were ground and polished so that the metallographic sections that were inspected varied from 10 to 90 percent of the panel thickness. The axial mounts were ground and polished so that the metallographic sections varied from 10 to 90 percent of the hole diameter. Each polished section was then inspected under magnifications of 40, 80, and 200X.

Of the 48 holes inspected, seven exhibited minute traces of copper. Four of these were from the high-conductance group and three were from the low-conductance group. Five of the seven traces of copper found measured less than 0.0005 by 0.0005 inch (12.7 by 12.7 μm). The other two traces measured approximately 0.001 by 0.002 inch (25.4 by 50.8 μm). The traces of copper extended from the hole surface back into the substrate material a distance of approximately 0.0004 to 0.004 inch (10.0 to 100 μm), with the majority of the traces extending back less than 0.001 inch (25.4 μm). All of the copper particles found were securely attached to the hole walls.

The following conclusions were drawn from the results of this inspection.

- Minute traces of copper were present on the hole surfaces.
- There was no evidence that the presence of copper was related to the measured conductance.
- The copper found in the holes was the result of copper having been deposited in substrate cavities and subsequently shielded from the etchant during the etching operation.
- The measured conductance was the result of small amounts of residue having been left from the etching or cleaning solutions (but invisible at 200X magnification).
- The residues can be removed or greatly reduced by additional rinsing with water; this however is unnecessary, since the electrical conductance is in the negligible range from 1 to 6 picomhos (1 to 6 pS) and therefore does not affect the functioning of the printed wiring boards.

ACCOMPLISHMENTS

A proposed method for producing nonplated-through holes in double-sided printed wiring boards has been proved not detrimental to the functioning of the boards.

Electrical conductivity measurements of holes which had been drilled, plated through with copper, and subsequently etched-out to produce nonplated-through holes indicated conductance in the range from 1 to 6 picomhos (1 to 6 pS). An evaluation of the findings by all responsible Bendix product engineering groups indicates that this magnitude of conductance is insignificant.

Adoption of the production method described will eliminate a drilling operation from the printed-wiring-board fabrication process.

FUTURE WORK

Upon agreement with appropriate Design Laboratory personnel, Bendix Kansas City will incorporate the proposed method for producing nonplated-through holes into the standard process for fabricating printed wiring boards.

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