# PCB Etching Equipment- How Even Is It Etching?

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**Abstract**

*This paper describes a comparison of today's most popular etching equipment. The different Etching Lines are characterized by the precision measurement of the etched conductor widths across both production and test panels. The resulting differentials in etch are presented as three dimensional contour maps to easily show effects such as 'pooling' and any mitigation provided by the specific etcher designs. The majority of this data was collected as part of the purchase process for a new etching line.*

## Introduction

We present data collected from four different types of etchers during a purchase evaluation process. The etchers tested are ATOTECH, SCHMID, HOLLMULLER and FSL. Each vendor was provided with test panels previously pattern plated. These were then etched under optimal conditions, as specified by the etcher manufacturer.

The test panels were subsequently measured to establish a resist-width baseline and then stripped and remeasured to determine etch evenness and consistency.

## Test Panels

The tests were run on 18 in x 24 in .062 double sided test panels. The panels were electro-pattern plated with a 4 mil x 4 mil serpentine pattern over 1/2 ounce copper. The etching resist was tin.

## Etching Method

The etch settings are listed below. These were set by the etcher manufacturers with the exception of the FSL unit, which was run by a user with the user's normal settings.

## Etch Settings

| | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| Length | 51" | 40" | 39"(2ea.) | 49" |
| Speed(ft/min) | 13.3 | 9.5 | 14 | 5.2 |
| Temperature (degF) | 125 | 120 | 120 | 122 |
| PH | 8.4 | 8.3 | | 8.3 |
| Pressure (t/b,psi) | 35/35 | 26/20,23/22 | 35/35 | 15/15 |
| SpcGr | 1.203 | 1.16 | 1.169 | 1.22 |

## Measurements

The AIM 1000 system provides in-line measurement of etched conductor widths (and SMT pads). This system provides break-through capabilities in its ability to handle the production environment, and the wide range of product type variations. It also provides the necessary resolution and repeatability to control the etching process. It is currently in use by leading printed circuit manufacturers. Along with the repeatable measurements, the AIM has an etch evaluation feature which allows the manufacturer to view the evenness of etch across the entire panel area for any single panel or for a group of panels.

The panels were measured on AIM 1000 Serial No. 017 and AIM 1000 Plus Serial No. 027. The measurements are divided into two categories. Every panel was run to obtain a measurement sample. The measurement sample consists of several hundred measurements at random locations on the panel. In addition three panels from each etcher manufacturer were selected at random for etch map analysis. The etch map consists of tens of thousands of measurements covering 100% on the panel.

## Lot Results

Each of the four sets of panels were run through the AIM twice, once before strip and once after. Each panel yields an Xbar and S. As the number of measurements from each panel is always well over 20, Xbar and S are essentially equal to the estimated mean and standard deviation of the parent population. Using these values for the parent population with the specifications gives values of Cp, k and Cpk for each panel. The formulas used to calculate Cp, k and Cpk are contained in the text of Reference 10. The average values of Xbar, S, Cp, k and Cpk over each lot are given in the Cpk Analysis Table. As the panels in some lots may vary much more than the panels in other lots, but may have the same lot-average values, "process" values of Cp, k and Cpk are also calculated in the Cpk Analysis Table. These "process" values account for the interboard variance as well as the intraboard variance. The variances (standard deviations squared) are given in the Variance Table below. We assume the variances are independent which allows us to simply add them to each other. The square root of the total variance becomes the standard deviation for the "process" calculations.

**Pre-Strip and Post-Strip Measurements**

| | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| Pre-Strip: Ave Xbar | 4.80 | 4.95 | 4.81 | 4.75 |
| Average S | 0.22 | 0.25 | 0.18 | 0.21 |
| Post-Strip: Ave Xbar | 3.91 | 3.94 | 4.10 | 3.03 |
| Average S | 0.25 | 0.33 | 0.22 | 0.21 |
| Reduction in Ave Xbar | 0.89 | 1.01 | 0.71 | 1.72 |
| Increase in Ave S | 0.03 | 0.08 | 0.04 | 0.00 |

Notes: 1) Top/bottom not distinguished for lot data.
2) Pre-strip measurements generally are the width of the tin resist.

The Measurements Table above shows that the SCHMID etcher panels deviate by almost a mil from the target. FSL appears to have increased the average standard deviation more than the other etchers though this difference may not be statistically significant. FSL also has a pre-strip average standard deviation larger than the others which represents a handicap with respect to the others for comparing performance statistics. It is not known if the higher pre-strip standard deviation for FSL is a result of the etching process or if it is a precondition received by the FSL etcher.

Though we made every effort to ensure the panels sent out for etching all had the same quality of pattern plating, we have taken no measurements which would rule out our variations. In particular, pre-strip etch maps could have been helpful in this regard but none were made. Variations may have been present in the plating received by each etcher that were not insignificant. For example, it would appear that standard deviations of the pre-strip panels were higher for FSL than for the others. These higher standard deviations could have resulted from some etching of the tin, original variations in the pattern plate, measurement error, or normal measurement variation. Other pre-etch processes would probably be better suited to testing etchers, but since pattern plating was to be used by the purchaser, pattern plating was appropriate for these tests.

**Post-Strip Cpk Analysis**

| | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| Ave Xbar | 3.91 | 3.94 | 4.10 | 3.03 |
| Delta from Target | 0.09 | 0.06 | 0.10 | 0.97 |
| Ave S | 0.25 | 0.33 | 0.22 | 0.21 |
| Ave Cp | 1.35 | 1.07 | 1.60 | 1.80 |
| Ave k | 0.26 | 0.17 | 0.16 | 0.97 |
| Ave Cpk | 1.02 | 0.89 | 1.34 | 0.03 |
| Process Cp | 0.87 | 0.82 | 1.17 | 1.33 |
| Process k | 0.09 | 0.06 | 0.10 | 0.97 |
| Process Cpk | 0.79 | 0.78 | 1.06 | 0.04 |

Note: target = 4.00 mils, specifications = ± 25%

The Cpk performance statistics take into account both capability or tightness of distribution (Cp), and centering or closeness to target (k). Of the four etchers only HOLLMULLER had a process Cpk greater than 1. SCHMID's Cpk's are very low because the etched panels deviated so far from the target (k>>0). SCHMID has the best Cp capability values followed in order by HOLLMULLER, ATOTECH and FSL. A Cp greater than one means the ± 3 sigma distribution would fit within specifications assuming the process is centered. A Cpk greater than one means the ± 3 sigma distribution is within specifications. FSL has the highest average standard deviation in the lot results indicating relatively greater variations in the conductor width within each panel. However, this greater variation is not seen on the three panels randomly chosen for the FSL etch maps.

**Pre-Strip and Post-Strip Variance Table**

| | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| PRE-STRIP | | | | |
| Interboard | 0.009 | 0.013 | 0.008 | 0.005 |
| Intraboard | 0.052 | 0.067 | 0.035 | 0.053 |
| total | 0.062 | 0.080 | 0.044 | 0.058 |
| POST-STRIP | | | | |
| Interboard | 0.081 | 0.046 | 0.032 | 0.015 |
| Intraboard | 0.065 | 0.119 | 0.049 | 0.048 |
| total | 0.146 | 0.165 | 0.081 | 0.063 |

Note: The interboard variance is equal to the square of the standard deviation of the means in the lot. The intraboard variance is equal to the square of the average value of the single-panel standard deviation (Ave S above). The square root of the total variance is the standard deviation used with the Average Xbar and Specifications to calculate the process values in the Cpk Analysis Table.

In the Variance Table we see more directly which etcher is most affected by high standard deviations within each panel (intraboard) and which has the highest variations in mean from panel to panel (interboard). All four etchers have small pre-strip interboard variances yet ATOTECH ended up with the highest post-strip interboard variance. This signifies poor process control as a function of time (temporal). SCHMID has the best temporal process control. FSL, as seen in the prior tables, has higher standard deviations within each panel (intraboard variance). This is evident somewhat before strip but especially after strip.

**Single Panel Etch Map Results**

The etch map is a perspective view of the circuit panel showing the distribution of line width averages across the board. On average the etch map data consists of over 30,000 measurements for each panel. This data is reduced into the average values over a two inch grid. The averages are then plotted to create an etch map. Etch maps are described in further detail in Appendix B. To evaluate a map first the panel must be rotated to the same perspective as the etch map. In the instance where the bottom of the panel is measured, the panel is flipped over being careful to note which side was the leading edge and which side was toward the front of the conveyer. On the etch map the leading edge of the panel is labeled and the word "console" indicates the front of the AIM 1000 conveyer. The words "air ducts" indicate the rear of the AIM 1000.

The apparent height on the etch map corresponds with the deviation from the panel average. The height that appears as the middle color represents the average line width, for the predominant width class, over the board. In the rainbow sequence, which was used for these tests, green will indicate the average conductor width, red will indicate 0.5 mils larger than the average and magenta is 0.5 mils smaller than the average. Hills represent areas on the panel where the conductors are wider than average; likewise, valleys represent areas of narrower conductors. The height of the framework is one mil. The etch map topography is centered around the average on the panel, not the specification target value. Thus, a perfectly even etch map may still represent a bad panel since the average may be outside the specification limits.

Etch maps were run on three panels selected at random for each etcher manufacturer. Both sides of each of the three panels were run. To confirm measurements, etch maps were repeated on random panels. The means were compared and the etch map contours were compared. The etch map data themselves are presented in the Data Appendix C. The results are summarized below.

**Summary of Etch Map Results**

| | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| Ave Xbars Side 1 | 3.55 | 4.23 | 4.15 | 2.69 |
| Delta from Target | -0.45 | 0.23 | 0.15 | -1.31 |
| Ave Xbars Side 2 | 3.60 | 4.31 | 3.94 | 3.14 |
| Delta from Target | -0.42 | 0.31 | -0.06 | -0.86 |
| Ave Side 2 - Side 1 | 0.05 | 0.08 | -0.21 | 0.45 |
| Ave Single Side Range | 1.01 | 0.78 | 1.13 | 0.94 |
| Ave Sigmas | 0.39 | 0.32 | 0.39 | 0.34 |

Note: 1) 3 panels, target = 4.00 mils

**Panel by Panel Table of Etch Map Results**

| 3 Random Panels | ATOTECH | FSL | HOLLMULLER | SCHMID |
|---|---|---|---|---|
| Xbar and sigma #1 Side 1 | 3.48 ± 0.38 | 4.04 ± 0.36 | 4.24 ± 0.32 | 2.66 ± 0.26 |
| Xbar and sigma #1 Side 2 | 3.62 ± 0.32 | 4.14 ± 0.26 | 3.86 ± 0.40 | 3.02 ± 0.26 |
| side 2 - side 1 | 0.14 | 0.10 | -0.38 | 0.36 |
| Range Side 1 | 1.27 | 1.10 | 0.94 | 0.63 |
| Range Side 2 | 0.66 | 0.53 | 1.34 | 0.52 |
| Xbar and sigma #2 Side 1 | 3.56 ± 0.42 | 3.96 ± 0.32 | 3.98 ± 0.46 | 2.56 ± 0.32 |
| Xbar and sigma #2 Side 2 | 3.64 ± 0.32 | 4.28 ± 0.26 | 3.88 ± 0.32 | 2.94 ± 0.32 |
| side 2 - side 1 | 0.08 | 0.32 | -0.10 | 0.38 |
| Range Side 1 | 1.46 | 0.83 | 1.60 | 0.92 |
| Range Side 2 | 0.64 | 0.50 | 0.85 | 0.77 |
| Xbar and sigma #3 Side 1 | 3.62 ± 0.40 | 4.70 ± 0.32 | 4.24 ± 0.44 | 2.86 ± 0.46 |
| Xbar and sigma #3 Side 2 | 3.56 ± 0.40 | 4.52 ± 0.38 | 4.08 ± 0.30 | 3.46 ± 0.42 |
| side 2 - side 1 | -0.06 | -0.18 | -0.16 | 0.60 |
| Range Side 1 | 1.02 | 0.97 | 1.37 | 1.52 |
| Range Side 2 | 1.00 | 0.73 | 0.66 | 1.27 |

Notes: 1) Extra panels run for confirmation of measurements are not included in this table, but are available in Appendix C.

2) Range refers to the difference between the highest and lowest 2" box averages in the map. Within the data in each 2" box there will be narrower and wider conductors. Panels with larger ranges also generally have large standard deviations.

3) Top/bottom information has been lost, but for each etch manufacturer, all tops will be the same side and all bottoms will be the other side.

The most even etch maps came from the FSL and SCHMID panels. They demonstrated the best spatial control capabilities. Further, both sides of the best panels were evenly etched. The mapped HOLLMULLER and ATOTECH panels had the highest ranges over individual panel sides. They also had higher average standard deviations than the FSL and SCHMID panels. The lower standard deviation for FSL contrasts with the FSL lot results, which showed a higher standard deviation within each panel. The high standard deviations in the FSL lot data may result from very local variations along each conductor, not just variations in etch over the whole panel.

In the etch maps in Data Appendix C we find several consistencies. Some panels from each of the four etchers have wider-than-average conductors at the leading edge, especially at the corners. Both sides of the panel may be affected, though not every panel showed this. The ATOTECH panels vary quite a bit from even to uneven etching. Side 1 of the FSL panels tended to have wider conductors along the conveyer edge away from the AIM 1000 console, especially toward the middle of the panels. Side 1 of the HOLLMULLER panels tended to have wider conductors along one side than along the other. Side 2 of the SCHMID panels tended to have wider conductors along one side than along the other. The SCHMID panels show poor top/bottom process control. For these panels side 1 is etched almost a half mil more than side 2, which is itself over-etched by almost a mil.

## Conclusion

Each of the tested etchers appears capable of evenly etching a printed circuit board, both top and bottom sides. Top-side pooling, and industry wide concern, was not immediately obvious and may have been obscured by other variations in these data. However, even with ± 25% specifications, at least some of the panels from each etcher contained some conductors that were too narrow or too wide. Achieving an even etch, and maintaining it for panel after panel requires process control, not just capability. The individual performances in our tests are primarily a matter of how well the etching process was controlled. Some of the panels were etched very unevenly (poor spatial process control), some of the panels varied a great deal from top to bottom, and some varied quite a bit from other panels etched by the same etcher (poor temporal process control). To perform well, not only must the etching process be capable and controlled, but there must be adherence to specifications. One etcher failed in this last respect, without regard to its capability or control. Was this the etching operator's fault? Real time in-line measurement would have undoubtedly helped. Indeed, we can probably attribute most of the observed shortcomings to the lack of adequate measurement during the etching process.

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