Thin Foil Printing in Today's Miniaturized World: Do Printing Rules Change?

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ABSTRACT
As components get smaller, assembling them gets harder. To conquer the never-ending challenges of SMT processing, engineers rely on design rules to help nip problems in the bud. One of the most popular rules is the Area Ratio of stencil apertures, which helps predict the amount of solder paste released onto the PCB pad, as well the print process' repeatability.

A series of experiments were devised and executed to test the well-known Area Ratio rule at stencils with foil thicknesses of less than 4 mil (100 µm). Different solder paste powder types and nanocoatings were also variables in the tests. The results will be discussed in terms of the currently accepted Area Ratio Rule, the Five Ball Rule and the Three Ball Rule.

Key words: Area Ratio, Stencil Printing, Thin foils, SMT Miniaturization, Nanocoating, SMD Pads

INTRODUCTION

A stencil aperture's **Area Ratio (AR)** is a simple calculation that divides the area of the aperture opening by the area of its wall. It was derived in the 1990's and compares the adhesive forces of the solder paste deposit on the PCB pad with the adhesive forces of the solder paste on the stencil walls. For the material to transfer efficiently, the forces holding it to the pad must overcome the forces holding it to the aperture walls. Therefore, calculating the relative areas represents the relative adhesive forces affecting solder paste release.

The amount of solder paste released from an aperture is referred to as **Transfer Efficiency (TE)** and expressed as a percent of total aperture volume. Stencil or solder paste release characteristics are often illustrated by plotting TE against AR.

AR guidelines were originally set at 0.66 as a minimum to ensure good (>80%) TE. Many of these original guidelines have been relaxed due to improvements in solder paste, stencil materials and nanocoatings. With good materials, equipment and tooling, and robust printing practices, apertures with ARs as low as 0.50 can often be printed in production on 4 mil thick stencil foils with excellent results.

Maintaining ARs of 0.50 or greater can be difficult for the stencil designer. Miniaturization is now driving finer and finer features, which, in turn, is driving thinner foils to meet classic AR design rules. This raises the question:

Do classic design rules apply in the case of thin foils?

EXPERIMENT

Design

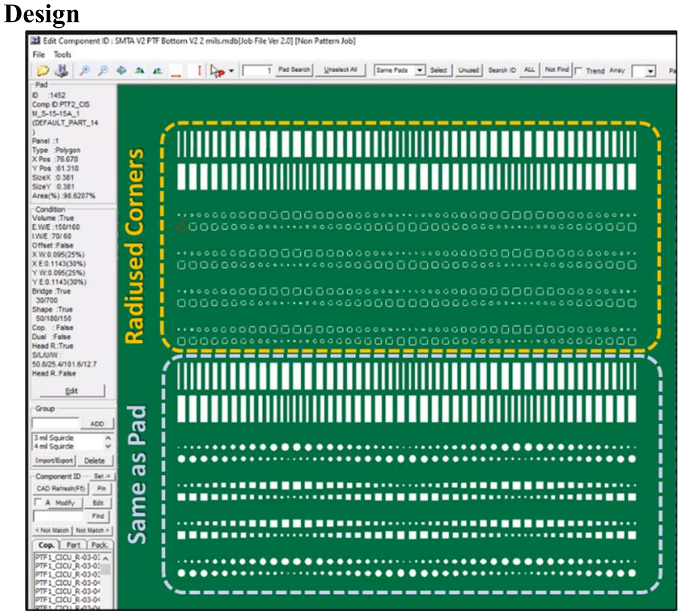


Figure 1. Print-To-Fail Patterns and Aperture Shapes

A simple 2x2 factorial experiment was devised using the Print-To-Fail (PTF) patterns of the SMTA Miniaturization Test Vehicle[1] shown in Figure 1.

The PTF patterns have pads that are square, circular or rectangular, solder mask- and non-solder mask-defined, in widths of 3 to 15 mils. Solder Mask Defined (SMD) pads are also referred to as simply "mask defined;" Non-Solder Mask Defined (NSMD) pads are also referred to as metal- defined or copper-defined. Each pad's corresponding apertures are either the same shape as the pad (S) or are square/rectangular with radiused corners (R). There are 32 datapoints on each print. Each dataset is made up of 20 prints, for a total of 640 datapoints for each combination of shape, definition, size and aperture geometry in the database.

Four stencils were tested: 2 and 3 mil thickness, with and without nanocoating.[3,4]

The solder paste used in this test was Indium 8.9 HF Type 5-MC. The powder particle size distribution was the standard 15-25 µm diameter. Type 4 was tried but showed too much variation on thin foils to be considered acceptable; therefore, the results for the Type 5 solder paste are analyzed and presented.

Execution
Print tests were performed in Koh Young America's demo room in Duluth, GA, using the following equipment set:

- Printer: MPM Momentum BTB
- Support tooling: Quick Tool; 3 modules
- Clamps: EdgeLoc with retracting top foils
- Squeegees: MPM FP100, 250 mm length
- Stencils: 2 and 3 mil BlueRing Nano-Slic Gold and Uncoated Fine Grain (Slic) stencils
- SPI: Koh Young 10 um aSPIer3
- SPI Height Threshold: 20 µm

The print parameters were:

- Speed: 30 mm/sec
- Pressure: 7.0 kg
- Separation Speed: 5.0 mm/sec
- Separation Distance: 3.0 mm

The under-stencil wipe parameters were:

- Speed: 30 mm/sec
- Sequence: wet/vac/vac or wet/vac/vac/dry
- Frequency: 1 (after each print)

Each test run began with 4–6 knead strokes to assure the solder paste reached its working viscosity and 2–7 setup prints to verify proper print performance and paste alignment before running the 20 data-producing prints. Execution time for the tests were approximately 30 minutes each, with continuous printing, under wiping and inspection.

Analysis
Data was exported to a *.csv file and imported to Excel for manipulation. A pivot table was created to review the solder paste volumes, TEs and CVs. Refer to Appendix A for details on the data manipulation methods.

Process Capability and the Coefficient of Variation
The Coefficient of Variation (CV, CoV or CofV) is calculated as the standard deviation of a population divided by its mean. Applied to solder paste deposits, CV represents the spread of the volume, height, area or offset data. Because the average volumes of solder paste deposits vary based on many input variables, basic standard deviations should not be used to evaluate different distributions of data. Expressing the variation as a percent of the average normalizes it for better comparison.

As solder paste deposits become smaller, minimizing their variation becomes more critical:

- As passive devices get smaller, they are more prone to positional, rotational or tombstone-type defects related to print quality.
- As integrated circuit packages get smaller and leadless, they are more prone to Head-in-Pillow, insufficient solder joints, voids and intermittent opens related to print quality.

Controlling the variation in print volumes limits the opportunities for defective solder joints and their associated rework or failure costs.

A widely accepted guideline for solder paste deposit CVs is:

- <10%: preferred
- 10-15%: acceptable
- >15%: unacceptable

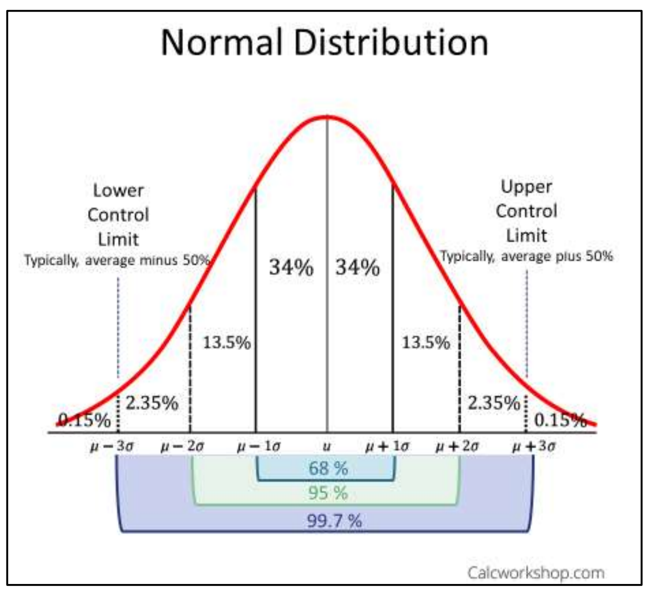


Figure 2. Normal Distribution as it relates to solder paste volume variation

These guidelines are based on principles of Statistical Process Control (SPC). Assuming a normal distribution of data as seen in Figure 2, 99.7% of the data should fall within +/- 3 standard deviations of the mean. If we apply a typical SPI control limit of +/- 50%:

- CVs of 10% will produce 99.7 % of deposits within +/- 30% of the target volume, leaving plenty of room for outliers or special causes of variation.
- CVs of 15% will produce 99.7% of deposits within +/- 45% of the target volume, leaving little room for variation.
- CVs of 16.7% or higher will produce deposits outside the control limits, indicating an out-of-control process.[2]

In this study, CVs were analyzed first to distinguish datasets worth investigating from those that were not. Datasets with CVs of 15% were reviewed prior to inclusion into the database.

Disqualification of the smallest deposits

Upon review of the data and PCBs, 3 and 4 mil deposits were removed from the results. Their CVs were all greater than 15%, and inspection of the PCBs revealed that many of the NSMD pads less than 5 mils were missing from the bare PCBs. This did not come as a surprise, as features that size present challenges to fabricators, who were granted waivers for features 5 mils or less.

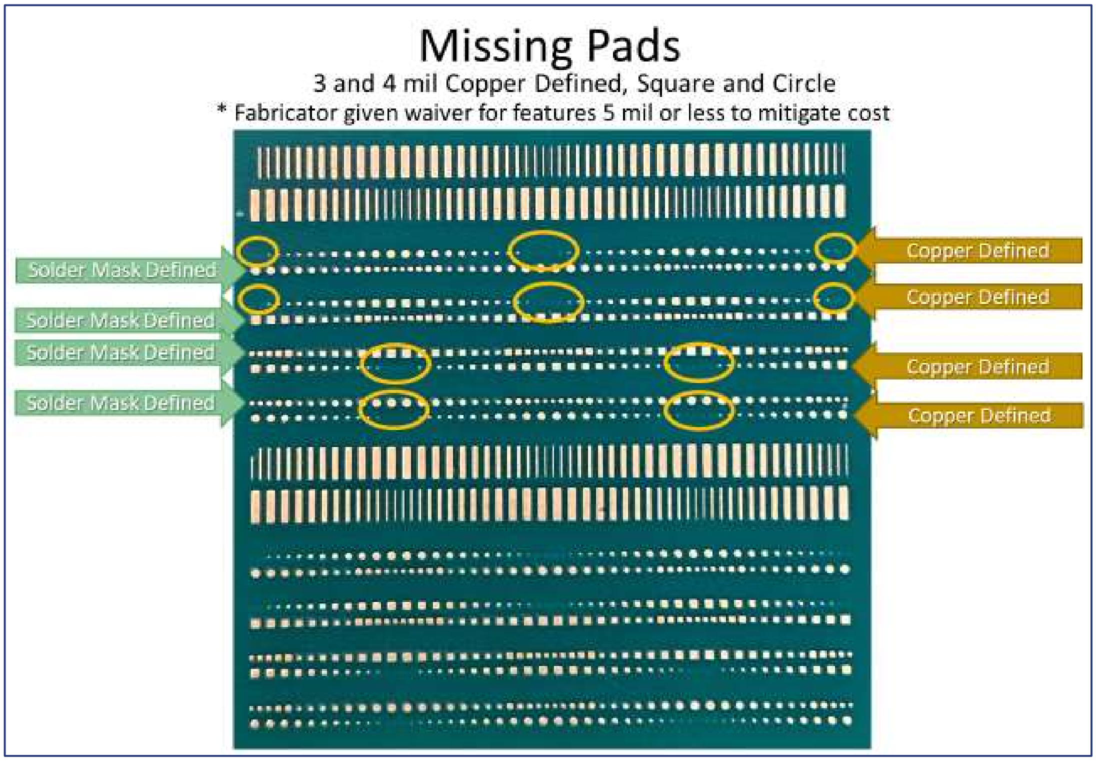


Figure 3. Missing pads in PTF test patterns

The pivot table results of the different combinations of foil thickness, coating, pad shape and pad definition and the calculated CVs can be seen in Appendix B.

Unacceptable levels of variation were demonstrated by the 3 and 4 mil feature sizes; further statistical analysis was performed on the data from pads 5 mils and larger.

RESULTS

The SPC Run Charts shown in Table 1 illustrate the effects of pad definition.

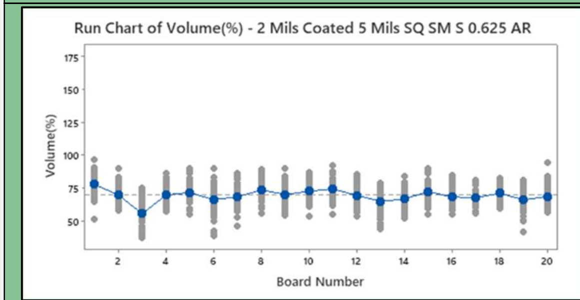
There is a sharp contrast in print variation between the solder mask defined and the copper-defined pads. In the best-case printing scenario of solder mask defined square pads, the CV of 12% indicates that 5 mil features can be printed repeatably using a 2 mil coated foil; the CV of 11% indicates the same for a capability with a coated 3 mil foil.

The CVs for copper defined pads were over 20% for both 5 and 6 mil features. The process of printing on copper defined pads did not show preferred capability (CV<10%) until feature sizes of 7 mils, even with square pads, which performed better than round ones.

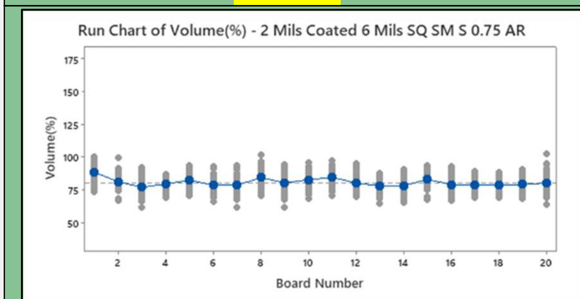
Table 1. Run charts of print data for square SMD and NSMD pads

INCREASED FEATURE SIZE = *better process control*

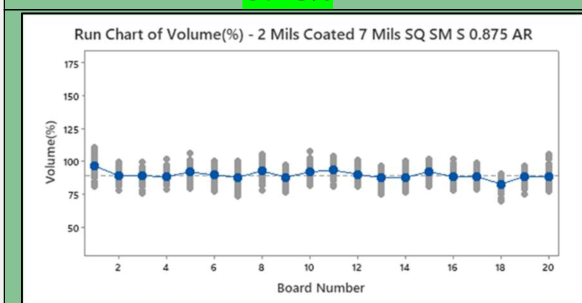
Solder Mask Defined (SMD) Pads



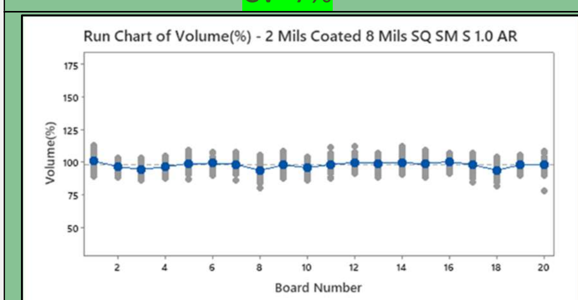
CV=12%



CV=8%

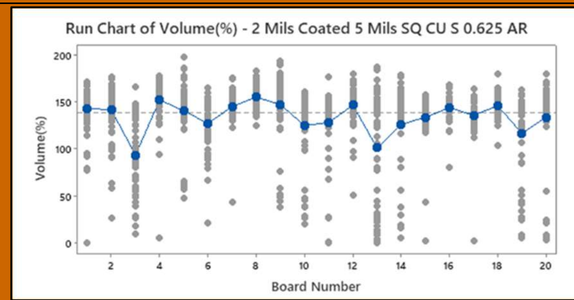


CV=7%

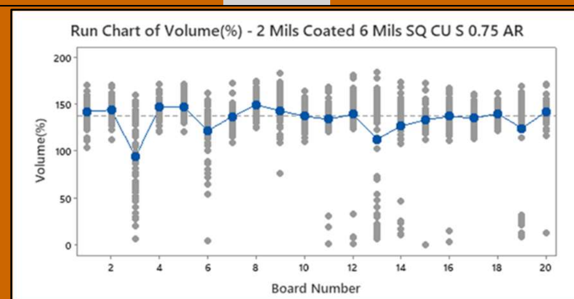


CV=5%

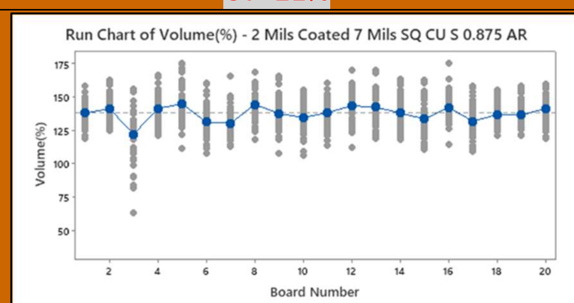
Copper-Defined (NSMD) Pads



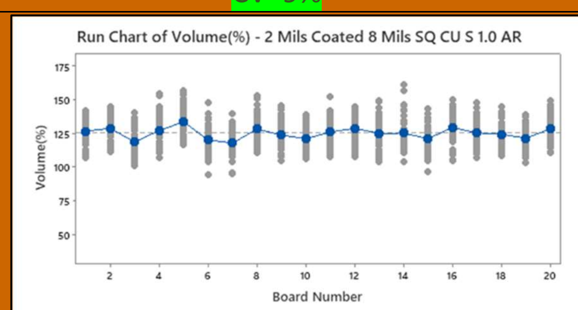
CV=27%



CV=21%



CV=9%



CV=9%

SOLDER MASK DEFINED PADS = *better process control*

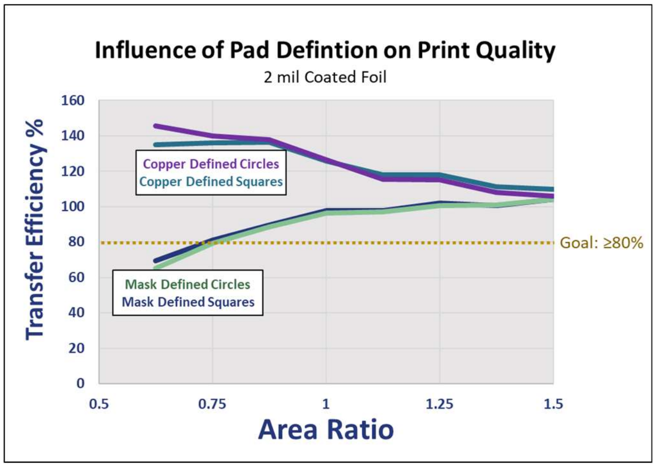


Figure 4. TE chart for 2 mil coated foil

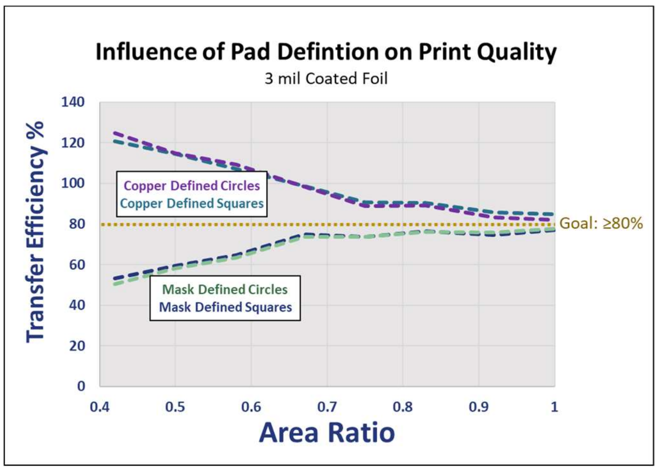


Figure 5. TE chart for 3 mil coated foil

The transfer efficiencies also vary greatly between solder mask and copper defined pads. Solder mask defined pads offer better gasketing than copper defined ones, and limit the amount of "squeeze out," or excess solder paste to transfer from the aperture to the PCB.

Figures 4 and 5 show the contrast in TE between the two pad designs for the 2 and 3 mil foils, respectively.

Regardless of foil thickness, the TE curves both show the same trends regardless of pad or aperture shape: for mask defined pads, TE's showed typical behavior, but on copper defined pads, excess paste was the rule rather than the exception.

On solder mask defined pads, TE is approximately:

- 70% at 5 mil
- 80% at 6 mil
- 90% at 7 mil
- 96% at 8 mil

These are all reasonable transfer rates with preferred or acceptable CVs.

On copper defined pads, TEs averaged:

- 140% at 5 mil
- 140% at 6 mil
- 130% at 7 mil
- 125% at 8 mil

These TE rates, coupled with highly unacceptable CVs on copper defined pads most likely indicate a lack of good gasketing between the pad and the stencil.

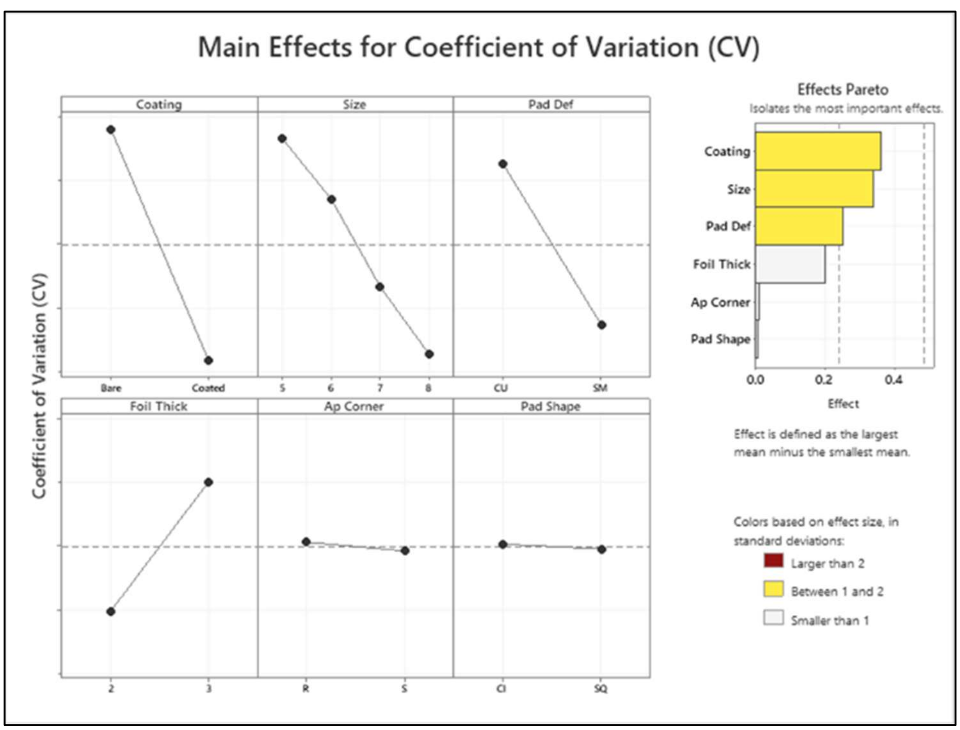


Figure 6. Main Effects Plot and Pareto Diagrams

The run charts also show unanticipated spread in the data for prints 3, 13 and 19. The effects are more pronounced on the smaller features. This will be discussed in detail in the discussion section addressing pad definition.

The Main Effects Plot shown in Figure 6 demonstrates the influence of the individual factors on print volume repeatability. The axis values have been omitted to focus on the relative impact of each and the inputs that minimize it.

The #1 factor influencing print repeatability was the stencil coating. Feature size was a close second, followed by pad definition. With lesser influence, the 2 mil foil produced more consistent print volumes than the 3 mil foil. Pad shape and aperture corner type had negligible influence on print variation.

DISCUSSION

Top Factors in Variability

As indicated in Figure 6, the stencil coating is the top factor in minimizing variation. It is also obvious in the side-by-side comparisons of TE and CV in appendix B, which show that the coating provides better print repeatability (lower CV) for every pad design configuration.

Although not quantified, cleanability was a considerable factor noticed during the testing. It was observed that the coated stencil released the paste to the automatic underwiping system far better than the uncoated one. The thin layer of smeared solder paste particles and flux that was left behind on the stencil after the auto wipe likely factored into its poorer print results.

The influence of pad size – the fact that the bigger the feature the easier it is to print – is related to AR, but does not necessarily follow general AR rules.

Pad Definition

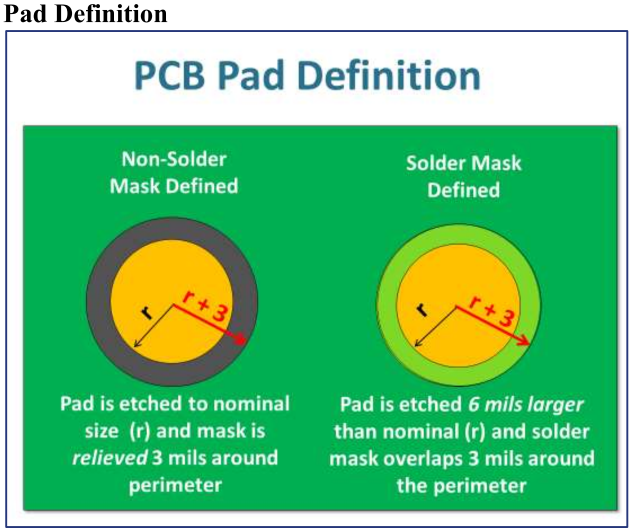


Figure 7. Comparison of PCB Pad definition

Figure 7 shows a basic diagram comparing the two methods of designing PCB solder pads. Non-Solder Mask Defined (NSMD) pads are etched onto the PCB at their nominal size. It is not uncommon however, to find pads over etched – *or undersized* – by up to 2 mils.

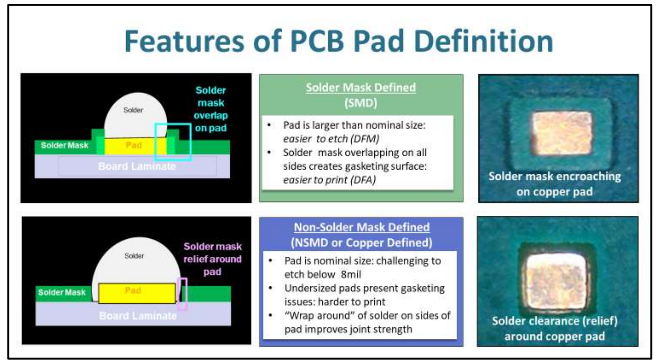


Figure 8. DFX impacts of pad definition

Figure 8 further describes features of the different types of pad definition. Given that smaller pad sizes are more susceptible to overetching, growing the copper size by 6 mils makes it much easier for the fabricator to etch – even it if gets overetched by (an acceptable) 2 mils, there is still enough room for the solder mask to encroach on all sides. When all edges of the pad are covered with solder mask, the mask provides an excellent gasketing surface for the stencil, resulting in less variation in print quality, and typically, slightly higher volumes.

When pads are metal defined they are naturally harder to gasket to than mask defined pads, but their propensity to be overetched exacerbates the gasketing problem. Poor gasketing of NSMD pads leads to excess solder paste deposition, as seen in Figures 4 and 5.

Another deleterious effect of overetched PCB pads is their impact on true AR. Recall that AR is calculated as the ratio of the area of the aperture opening to its walls. This calculation is based upon the assumption that the aperture opening fully contacts the PCB pad. When the pad is smaller than the stencil aperture, it does not offer as much area for the solder paste to stick to, thereby reducing the true AR and introducing additional variation to the process.

Traditional pad design, especially for BGAs, generally trends toward NSMD pads, because the solder mask relief enables molten solder to wrap around the edges of the pad, giving the solidified joint more shear strength than with SMD pads (Figure 8). For larger BGAs with feature sizes that are more easily printed and experience greater displacement during thermal expansion, NSMD pads are still generally preferred But in the case of very small features, mask defining them can actually add shear strength between the pad and the PCB due to the larger area of the pad and the reinforcement of the mask.

As previously mentioned, the fabrication notes for this test PCB allow a waiver for pads 5 mils and smaller. Inspection of the incoming PCBs showed many were missing their 3 and 4 mil NSMD pads (Figure 3) and some of the 5 mil NSMD pads were barely visible. The run charts in Table 1 show excessive noise for print numbers 3, 13 and 19, particularly on the NSMD pads. The issue appears to resolve as the feature sizes get larger, and only appears on the smallest SMD pads. The source of the noise in these three prints could likely be attributed to overetch of the pads on those specific PCBs.

Aperture Shape

Aperture shape had very little impact on print quality. This appears to contradict prior data generated on larger feature sizes and generally accepted design rules relating to radiusing aperture corners to improve paste release and repeatability.

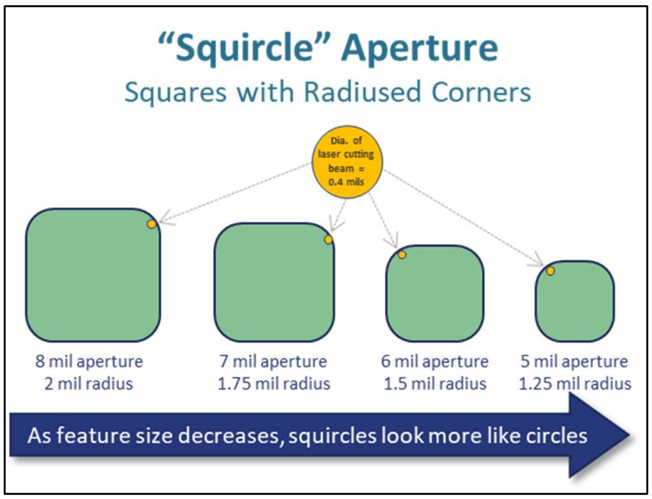


Figure 9. The effect of rounding aperture corners as aperture sizes shrink.

Typically, stencil manufacturers put a 2 mil radius on square apertures, and often apply the "squircle" aperture to round pads. At feature sizes under 8 mil, the radius is 25% of the side length of the square. As the squares get smaller and 50% of their side length is part of the corner radii, the squircle shapes become more circular than square, as seen in Figure 9, and the performance difference becomes relatively inconsequential.

Pad Shape

In a trend similar to the contradictory nature of the aperture shape results, pad shape had very little influence on print variability. The advantages of square pads (from a print perspective) also appear to dwindle as their size shrinks.

The Area Ratio Rule

Area ratios increase as foil thicknesses decrease. But with foils less than 4 mils thick, the difference is more dramatic.

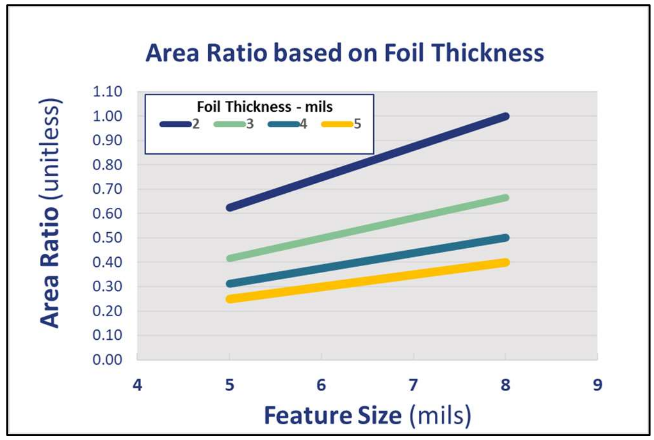


Figure 10. AR of small features increases dramatically as the foil gets thinner.

An 8 mil feature size has an AR of 0.50 on a 4 mil foil, 0.67 on a 3 mil foil, 1.0 on a 2 mil foil! Similarly, the AR for a 6 mil feature climbs from 0.5 on a 3 mil foil to 0.75 on a 2 mil foil!

With respect to print volume variation, size was a greater factor than AR. In many cases of mask defined pads, variation was acceptable or preferred for features 5 mils and larger.

With respect to TE, pad definition had a far greater effect on print capability than AR.

In the best cases of SMD pads and coated stencils, 5 and 6 mil features were the smallest to print successfully – on both 2 and 3 mil foils. The lowest AR of this combo was 0.42 and the highest was 0.75. However, in other scenarios, acceptable printing wasn't achieved until 8 or 9 mil feature sizes, with much higher ARs.

The Area Ratio Rule of 0.60 or higher cannot be applied to all situations when using thinner foils. Considering that foil thickness has 4 times the influence of aperture size on AR (the algebraically reduced AR calculation for circles is D/4t, where D is the diameter of the circle and t is the foil thickness and similar for squares as S/4t, where S is the side length of the square and t is the foil thickness), AR may no longer be the best overall indicator of solder paste release.

In this test, pad size and definition are the key design factors, and stencil coating is the key manufacturing factor. Size may be related to the three- and five-ball rules, yet to be discussed, but pad definition is related to design. Having the correct pad contact area to produce a true AR scenario and the benefit of good gasketing makes the biggest difference in printability of these fine features with thin foils.

When considering stepping a 4 mil stencil down to 2 or 3 mils to accommodate fine features, it should be noted that in these tests, both the 2 and 3 mil coated foils printed relatively comparably. Given similar results between the two thicknesses and faced with a choice, an assembler might consider stepping down to 3 mils as opposed to a 2 mils, as it would result in a more robust stencil with a longer production life.

Three Ball Rule

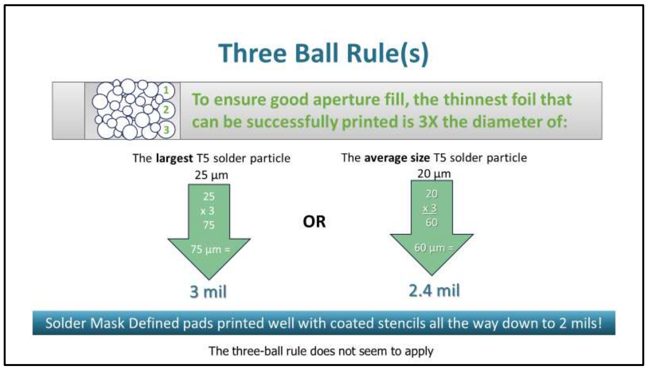


Figure 11. The "Three-Ball" Rule

The Three Ball Rule states that a stencil's thickness should be at least three times the diameter of the *largest* ball. A common corollary states that it should be at least three times larger than the *average* ball diameter. They are illustrated in Figure 11.

The Type 5 solder paste had the majority of its particles in the 15-25 micron range. Assuming the largest is 25 µm and the median is 20 µm, both scenarios can be theoretically tested:

- 3*25=75µ, or 3 mil
- 3*20=60µm. or 2.4 mil

The thinnest foil to produce good prints was 2 mils. Again, it appears that pad design and stencil coating enable this capability. For the uncoated stencils, the 2 mil printed better than the 3 mil for SMD pads; for the coated stencils, the 2 and 3 mil foils both printed comparably on the SMD pads.

The three ball rule does not appear to apply to SMD pads in this test, perhaps because the mask definition creates a "well" that effectively increases the depth of the aperture with respect to solder paste filling, but does not negatively influence release from the aperture.

Five Ball Rule

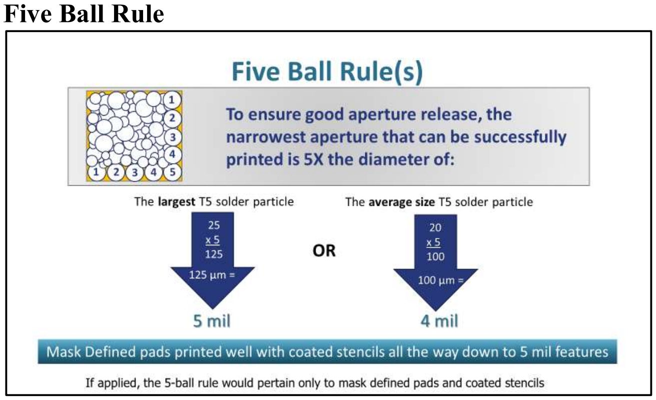


Figure 12. The "Five Ball" Rule

The Five Ball Rule states that a stencil's minimum aperture width should be at least five times the diameter of the largest ball. As with the Three Ball Rule, an existing corollary states that it should be at least five times larger than the average ball diameter, as seen in Figure 12.

So again, assuming the largest particle has a 25 µm diameter and the median has a 20 µm diameter, both scenarios can be theoretically tested:

- 5*25=125 µm, or 5 mil
- 5*20=100 µm, or 4 mil

The finest feature to print successfully on SMD pads, was 5 mils. Even in the best-case scenario, the 4 mil pads demonstrated too much variation to be considered valid data worth analyzing.

To interpret the Five Ball Rule with respect to thin foil printing, this data indicates that the largest ball diameter should be applied. However, it can only be applied to SMD pads, as NSMD pads produced unacceptable print volume variation.

CONCLUSIONS

In the context of solder paste stencil printing, reducing variation has always been as important as maintaining high transfer rates. However, in leading edge electronic miniaturization, where excess variation is the root cause of most soldering problems, it is arguably more important than average paste transfer rates. This analysis reviewed transfer rates, actual volumes and variation, with the focus on factors that minimize variation.

The factors that minimize variation can be grouped into two distinct categories: *Design* and *Manufacturing.*

With respect to product design, Solder Mask Defined pads and the sizes of those pads had the largest influence on repeatability. SMD pads are easier for PCB fabricators to make, and easier for SMT assemblers to print. It is highly recommended that any PCB features smaller than 8 mils should be mask defined (when using a Type 5 solder paste), and as pad sizes get smaller, the positive effects of mask defining the pads becomes more obvious.

With respect to manufacturing, coating the foil with the flux-repelling ceramic nanocoating has the largest influence on reducing variation. In fact, on Non-Solder Mask Defined (NSMD) pads, uncoated stencils were not capable of meeting the preferred CV metric of <10% for any features 8 mils or smaller, and in only one situation met the acceptable value of <15%. Uncoated stencils were also very difficult to clean using automatic underwipe.

Foil thickness appeared to have a considerable effect on print variation; however, a very profound effect was seen on the

uncoated stencils, and detailed review of the actual results between 2 and 3 mil coated foils are extremely close with respect to both actual volumes and CVs.
With respect to the traditional guidelines of The Area Ratio Rule, the Three Ball Rule and the Five Ball Rule, some principles may still apply, and some may not.

In the context of SMD pads and coated stencils, an AR of 0.6 or higher can be applied to the 2 and 3 mil stencils. Both fell a little shy of 80% TE goals, but met CV goals of <10%, indicating viable processes that could likely be optimized with further statistical analysis of the stencil design and processing parameters.

The Three Ball Rule was tested with both the largest and average sized solder particle and did not comply with the 3X guidance. It predicted minimum foil thicknesses of 3.0 and 2.4 mils, respectively, for the largest and average size particles. The thinnest foil to print successfully was actually 2 mils thick, thinner than the rule predicts. It should be noted again that the difference between SMD and NSMD pads was pronounced, and the successful printing occurred on the SMD pads. SMD pads may offer an advantage in aperture filling due to the extra depth they provide, but do not offer a disadvantage in paste release, which is based on stencil wall contact.

The Five Ball Rule may still partially apply. The finest feature to print repeatably was 5 mils, or 125 µm, exactly 5X the diameter of the largest ball, and only with coated stencils. None of the 4 mil features printed repeatability, even when mask defined and with a coated stencil.

DFX Takeaways:

- The best thing that designers can do to improve the producibility and reduce the cost of miniaturized electronics, is to *solder mask define the PCB pads.*
- The best thing that a PCB assembler can do to limit variation and improve yields is to *nanocoat the foils, no matter how thin they are.*

POTENTIAL FUTURE WORK

Similar tests using the same solder paste formulation[5] have been performed with Type 4 solder paste and 4 mil foils. Those tests have indicated that the T4/4mil combination repeatably prints (CV<10%) NSMD pads down to 10 mil, and SMD down to 9 mil and in some cases, 8 mil. Because the data were generated on different equipment sets at different locations and times, the data cannot be directly compared. Ideally, however, a consistent data set that compares performance of T4 with 4 mil foil and T5 with the 4 mil foil can help determine the best print scenarios for features in the 6-10 mil size range.

Smaller particle sizes present greater reflow challenges. If possible, on future print tests, a few extra boards should be printed at the end of the test and reflowed to help determine fusion (non-graping) characteristics of the solder paste, and the possible effects of inerting the reflow environment.

Ultimately feature sizes will continue to shrink, and technology will continue to develop. Type 5.5 and 6 solder pastes will probably be tested in the near term, as will newer foil materials that can retain specific print properties with lower profiles.

Type 5 solder paste presented underside cleaning issues with uncoated stencils in this test. In other tests, it has also presented similar issues in off-line stencil cleaning and misprinted board cleaning. Studies comparing the cleanability of wet T4 and T5 solder pastes would be beneficial in preparing for the inevitable transition to finer powders as electronic assemblies continue to shrink.

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APPENDIX A

Export and Analysis of SPI data

Step 1: Select Data

Note: The directions given here are for the SPI system used in this test. Users should consult with their manufacturer for specific export directions.
In the SPC setup menu, choose the data and format to export:

Export Item (in this order):

- ✓ Panel
- ✓ Component ID
- ✓ PAD ID
- ✓ Volume (%)
- ✓ Height (mil)
- ✓ Area (%)
- ✓ Offset X (mil)
- ✓ Offset Y (mil)
- ✓ Volume (mil^3)
- ✓ Time
- ✓ Barcode
- ✓ Result
- ✓ PCB ID
- ✓ Size X
- ✓ Size Y
- ✓ Job

Export As:

- Minitab CSV

Export Type:

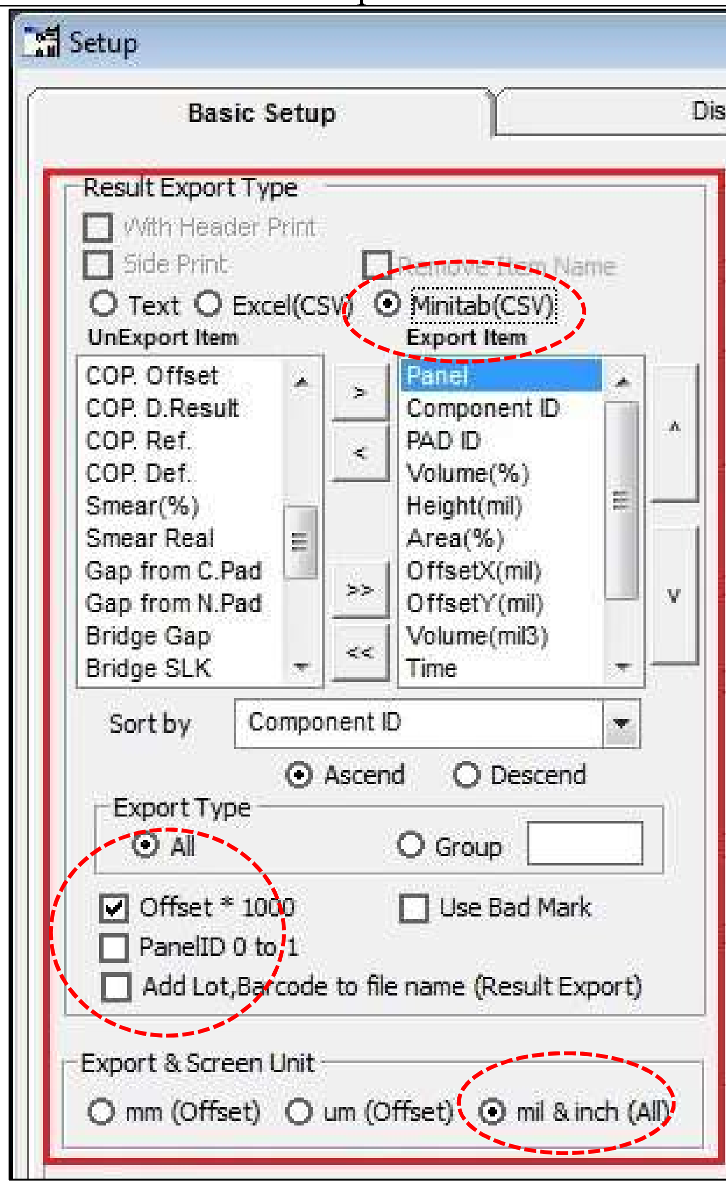
- All

Check

- Offset * 1000 (will export in mils)

Export Units :

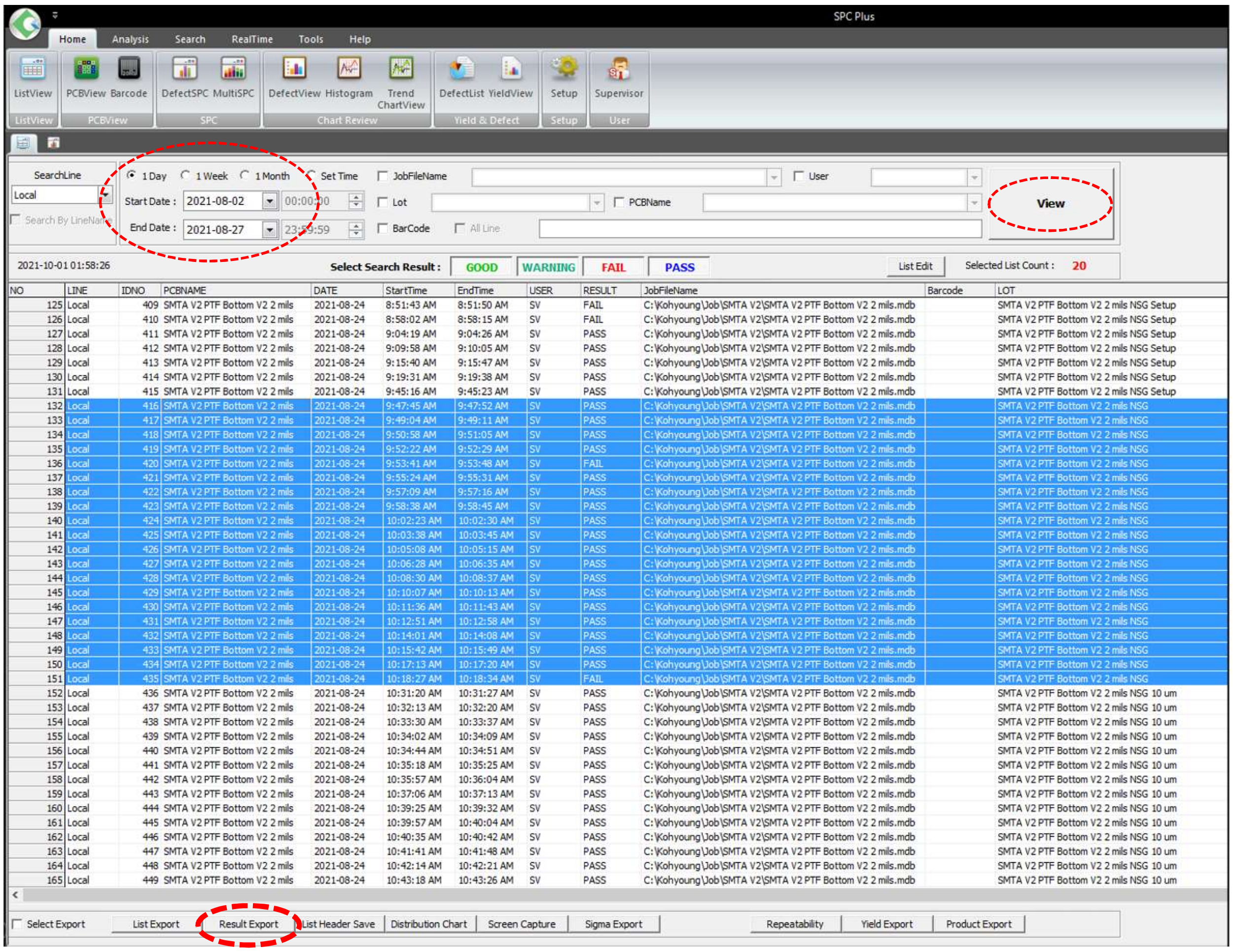
- mil & inch



Exporting just the data needed limits the size of the database, and reduces the cleanup work during analysis. Furthermore, exporting in mils precludes the need to convert it once in Excel or Minitab, and presents more user-manageable values versus inches or µms.

Step 2: Export Data

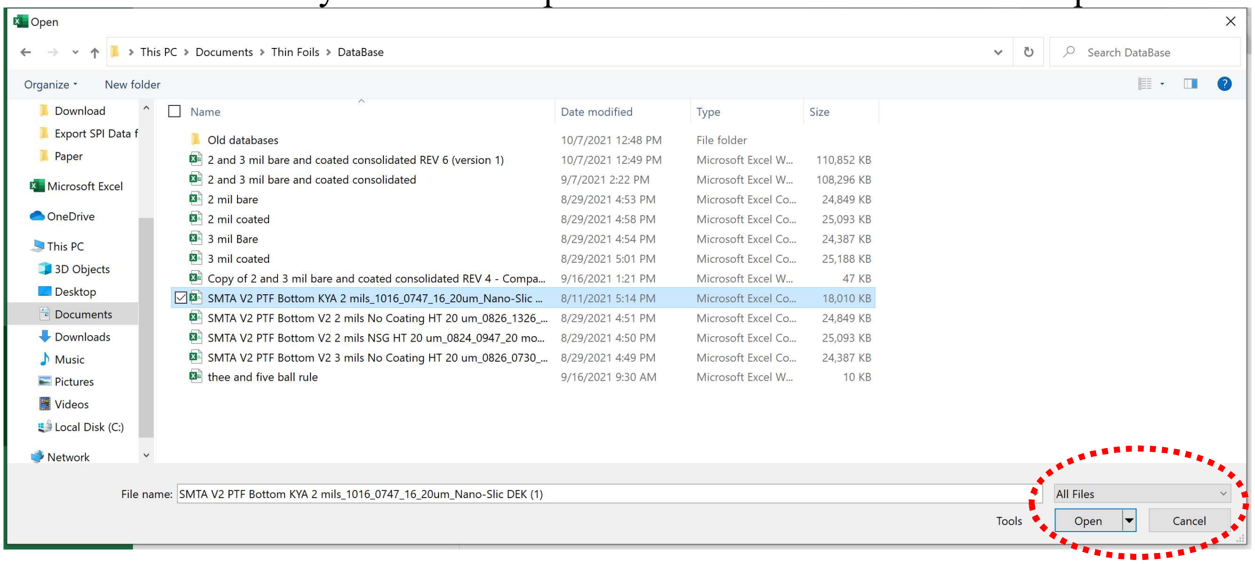
- Go to “ListView” in the SPC program
- Select the Start and End Dates and click “View”
- Locate and select the desired records
- Click “Result Export”
- Repeat for each of the individual runs (stencil thickness, coating)



Step 3: Import Data to Excel

The files are in a *.CSV format. In Excel, click on Open, and choose “All Files” from the dropdown in the lower right corner. This will allow you to see the CSV files.

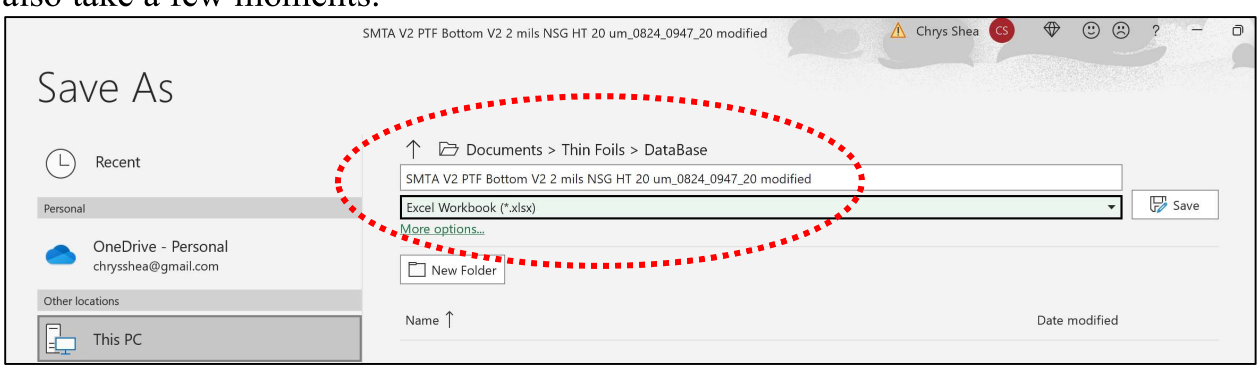
Double click the file you want to import or click on it and then click “Open.”



Importing and opening may take a few moments, as the file sizes are generally large.

As soon as the file is imported, save it as an Excel Workbook with the term “_modified” added after the filename. This is in case the file gets corrupted; the original data will still be safe.

Depending on the size of the database and the speed of the computer, saving may also take a few moments.



Step 4: Manipulate and Consolidate

Add columns for stencil (foil) thickness and coating to each individual database.

Foil Thickn	Coating	Panel	Component	PadID	Volume(%)	Height(mil)	Area(%)	OffsetX(mil	OffsetY(mil	Volume(mi
2	Coated	1	PTF1_CICU_	1	50.985	1.268	80.447	0.669	-1.285	8
2	Coated	1	PTF1_CICU_	2	34.268	1.182	57.993	0.664	-1.273	5
2	Coated	1	PTF1_CICU_	3	35.653	1.116	63.89	0.618	-1.532	5
2	Coated	1	PTF1_CICU_	4	74.278	1.383	107.424	0.339	-0.401	11
2	Coated	1	PTF1_CICU_	5	132.681	1.862	142.551	0.517	-0.307	34
2	Coated	1	PTF1_CICU_	6	121.139	1.91	126.86	0.27	-0.736	31
2	Coated	1	PTF1_CICU_	7	126.52	1.925	131.482	0.095	-0.897	33
2	Coated	1	PTF1_CICU_	8	108.457	1.838	117.99	0.399	-0.534	28
2	Coated	1	PTF1_CICU_	9	160.234	2.269	141.208	0.448	-0.353	65
2	Coated	1	PTF1_CICU_	10	163.412	2.404	135.936	0.221	-0.555	66
2	Coated	1	PTF1_CICU_	11	133.387	2.112	126.302	0.546	-0.517	54
2	Coated	1	PTF1_CICU_	12	118.754	1.981	119.917	0.196	-0.546	48

Rename each individual database according to its contents (stencil thickness, coating), then combine them into a new workbook. Excel can handle up to 1,048,576 rows of data.

This PC > Documents > Thin Foils > DataBase

Search DataBase

Name	Date modified	Type	Size
Old databases	10/7/2021 12:48 PM	File folder	
2 and 3 mil bare and coated consolidated	9/7/2021 2:22 PM	Microsoft Excel Work...	108,296 KB
2 mil bare	8/29/2021 4:53 PM	Microsoft Excel Com...	24,849 KB
2 mil coated	8/29/2021 4:58 PM	Microsoft Excel Com...	25,093 KB
3 mil Bare	8/29/2021 4:54 PM	Microsoft Excel Com...	24,387 KB
3 mil coated	8/29/2021 5:01 PM	Microsoft Excel Com...	25,188 KB
Copy of 2 and 3 mil bare and coated consolidated REV 4 - Co...	9/16/2021 1:21 PM	Microsoft Excel Work...	47 KB
SMTA V2 PTF Bottom KYA 2 mils_1016_0747_16_20um_Nano-...	8/11/2021 5:14 PM	Microsoft Excel Com...	18,010 KB
SMTA V2 PTF Bottom V2 2 mils No Coating HT 20 um_0826_1...	8/29/2021 4:51 PM	Microsoft Excel Com...	24,849 KB
SMTA V2 PTF Bottom V2 2 mils NSG HT 20 um_0824_0947_20...	8/29/2021 4:50 PM	Microsoft Excel Com...	25,093 KB
SMTA V2 PTF Bottom V2 3 mils No Coating HT 20 um_0826_0...	8/29/2021 4:49 PM	Microsoft Excel Com...	24,387 KB

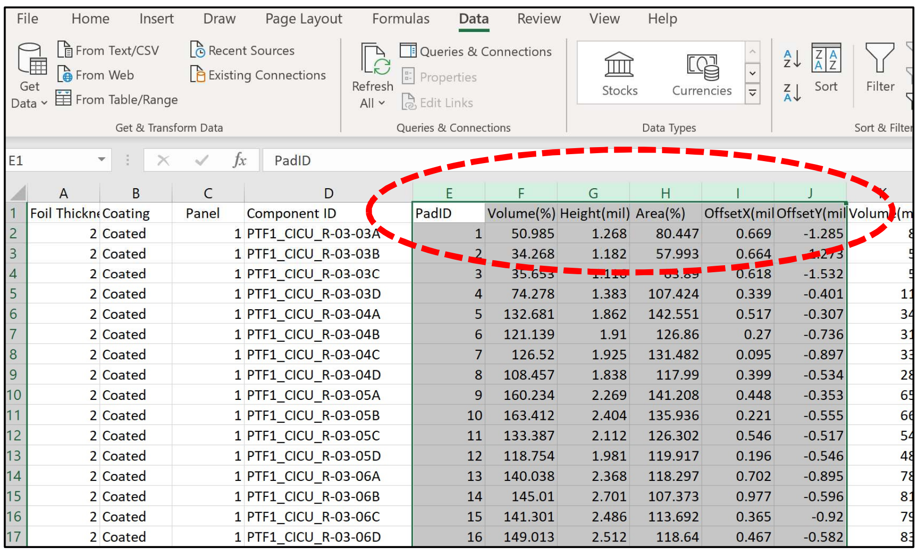
Step 5: Parse

Look at Column D in the spreadsheet. The Component ID is a code for the location, pad shape, pad definition, aperture corners, CAD identifier, aperture size and replicate. It should be parsed into separate columns, using the “Text to Columns” function in Excel.

Note: Any rows of data with blank Component IDs, such as the large QFP used to verify print quality, should be deleted.

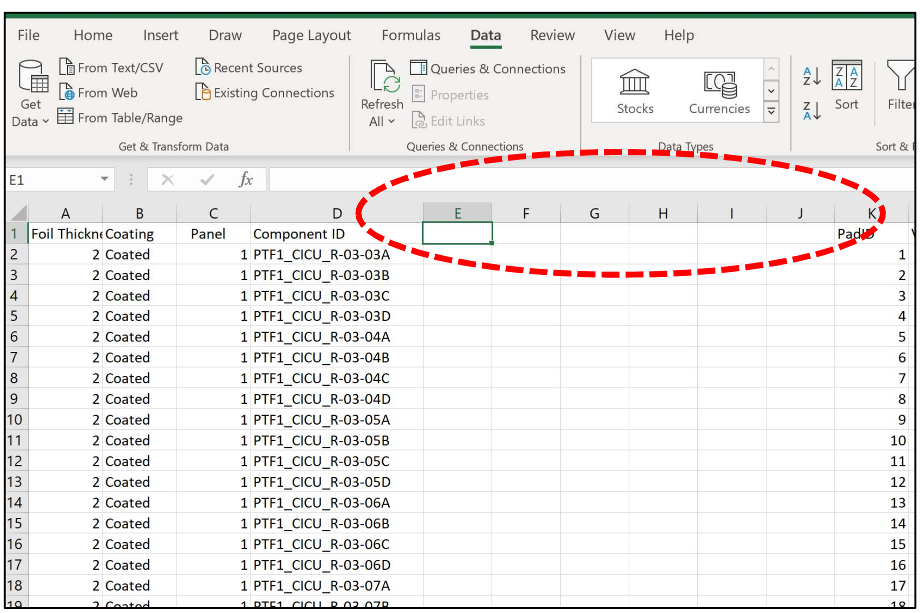
First, make room for the parsed data by inserting six columns to the right of Column D.

- Highlight columns E through J



	A	B	C	D	E	F	G	H	I	J
1	Foil Thickn	Coating	Panel	Component ID	PadID	Volume(%)	Height(mil)	Area(%)	OffsetX(mil	OffsetY(mil
2	2	Coated	1	PTF1_CICU_R-03-03A	1	50.985	1.268	80.447	0.669	-1.285
3	2	Coated	1	PTF1_CICU_R-03-03B	2	34.268	1.182	57.993	0.664	-1.273
4	2	Coated	1	PTF1_CICU_R-03-03C	3	35.653	[illegible]	[illegible]	0.618	-1.532
5	2	Coated	1	PTF1_CICU_R-03-03D	4	74.278	1.383	107.424	0.339	-0.401
6	2	Coated	1	PTF1_CICU_R-03-04A	5	132.681	1.862	142.551	0.517	-0.307
7	2	Coated	1	PTF1_CICU_R-03-04B	6	121.139	1.91	126.86	0.27	-0.736
8	2	Coated	1	PTF1_CICU_R-03-04C	7	126.52	1.925	131.482	0.095	-0.897
9	2	Coated	1	PTF1_CICU_R-03-04D	8	108.457	1.838	117.99	0.399	-0.534
10	2	Coated	1	PTF1_CICU_R-03-05A	9	160.234	2.269	141.208	0.448	-0.353
11	2	Coated	1	PTF1_CICU_R-03-05B	10	163.412	2.404	135.936	0.221	-0.555
12	2	Coated	1	PTF1_CICU_R-03-05C	11	133.387	2.112	126.302	0.546	-0.517
13	2	Coated	1	PTF1_CICU_R-03-05D	12	118.754	1.981	119.917	0.196	-0.546
14	2	Coated	1	PTF1_CICU_R-03-06A	13	140.038	2.368	118.297	0.702	-0.895
15	2	Coated	1	PTF1_CICU_R-03-06B	14	145.01	2.701	107.373	0.977	-0.596
16	2	Coated	1	PTF1_CICU_R-03-06C	15	141.301	2.486	113.692	0.365	-0.92
17	2	Coated	1	PTF1_CICU_R-03-06D	16	149.013	2.512	118.64	0.467	-0.582

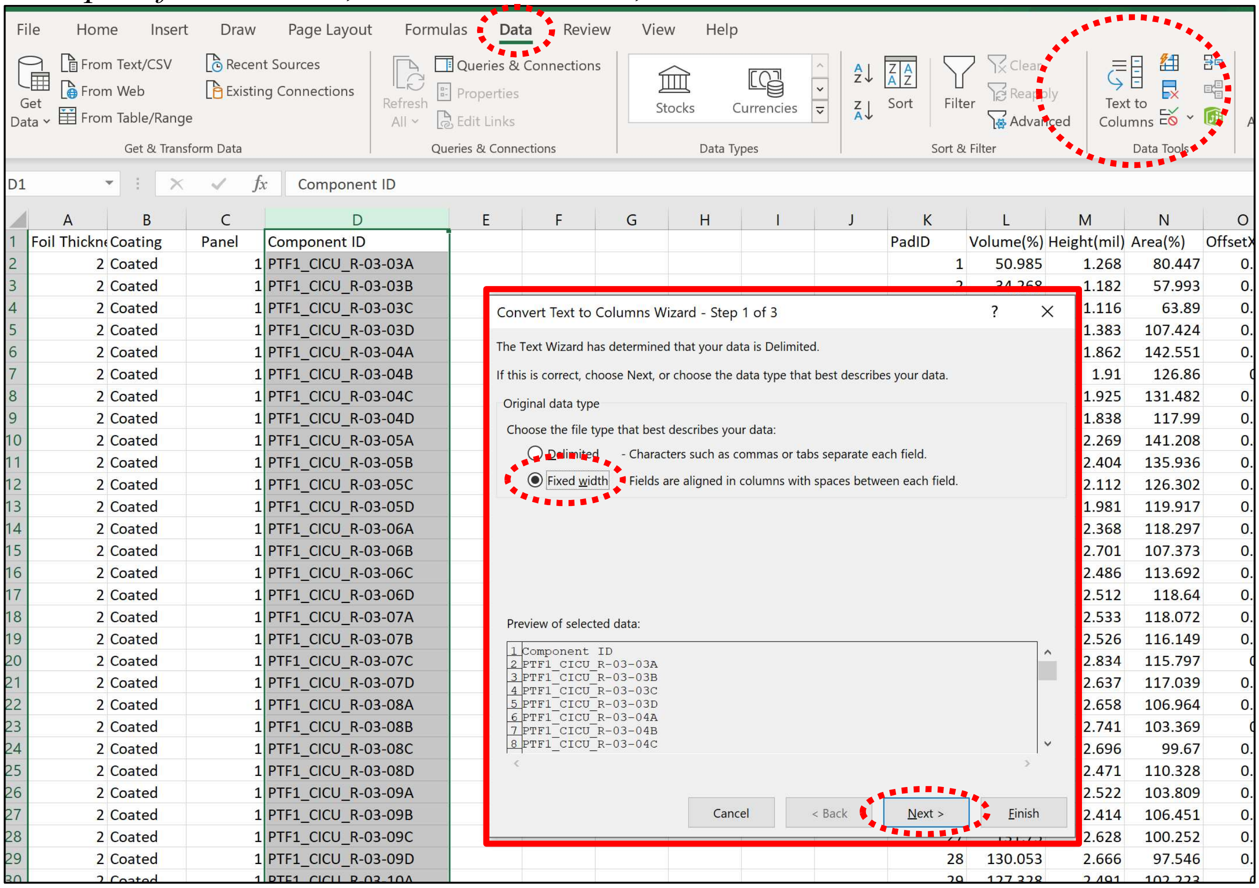
- Right click and insert



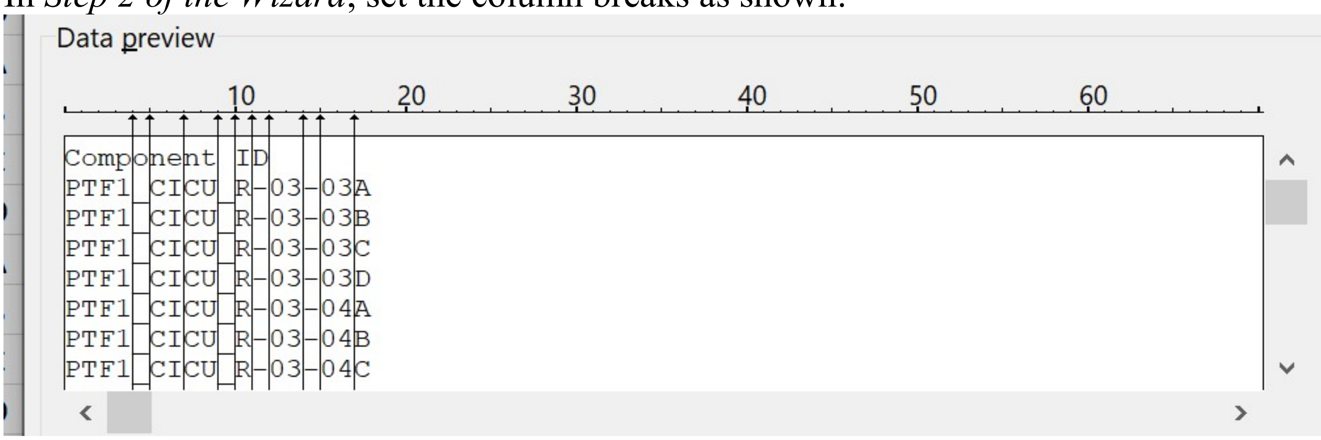
	A	B	C	D	E	F	G	H	I	J	K
1	Foil Thickn	Coating	Panel	Component ID							PadID
2	2	Coated	1	PTF1_CICU_R-03-03A							1
3	2	Coated	1	PTF1_CICU_R-03-03B							2
4	2	Coated	1	PTF1_CICU_R-03-03C							3
5	2	Coated	1	PTF1_CICU_R-03-03D							4
6	2	Coated	1	PTF1_CICU_R-03-04A							5
7	2	Coated	1	PTF1_CICU_R-03-04B							6
8	2	Coated	1	PTF1_CICU_R-03-04C							7
9	2	Coated	1	PTF1_CICU_R-03-04D							8
10	2	Coated	1	PTF1_CICU_R-03-05A							9
11	2	Coated	1	PTF1_CICU_R-03-05B							10
12	2	Coated	1	PTF1_CICU_R-03-05C							11
13	2	Coated	1	PTF1_CICU_R-03-05D							12
14	2	Coated	1	PTF1_CICU_R-03-06A							13
15	2	Coated	1	PTF1_CICU_R-03-06B							14
16	2	Coated	1	PTF1_CICU_R-03-06C							15
17	2	Coated	1	PTF1_CICU_R-03-06D							16
18	2	Coated	1	PTF1_CICU_R-03-07A							17

Highlight Column D, click on Data, then on Text to Columns to open up a wizard.

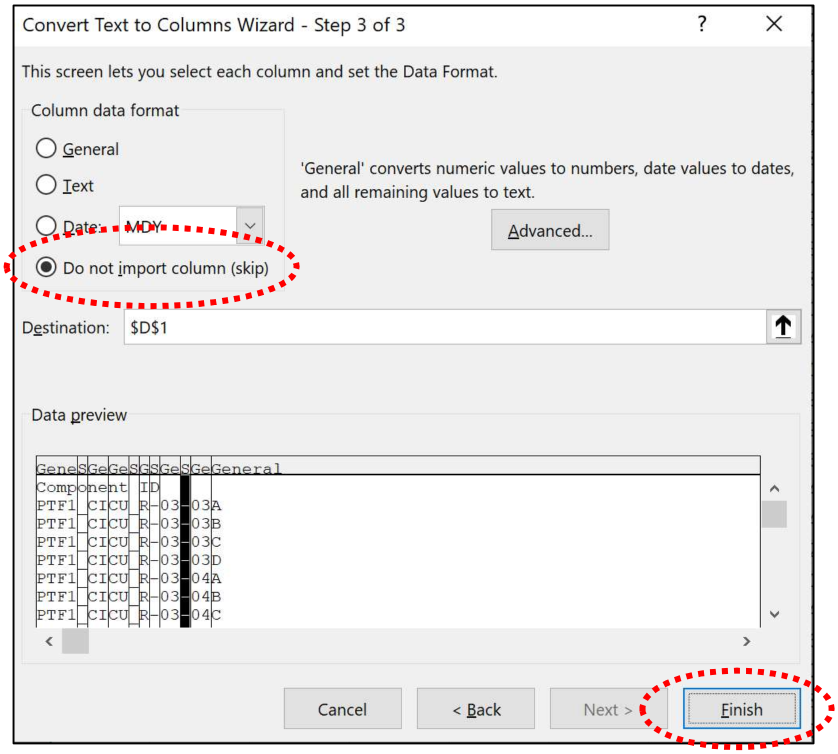
In *Step 1 of the Wizard*, click Fixed Width; click next



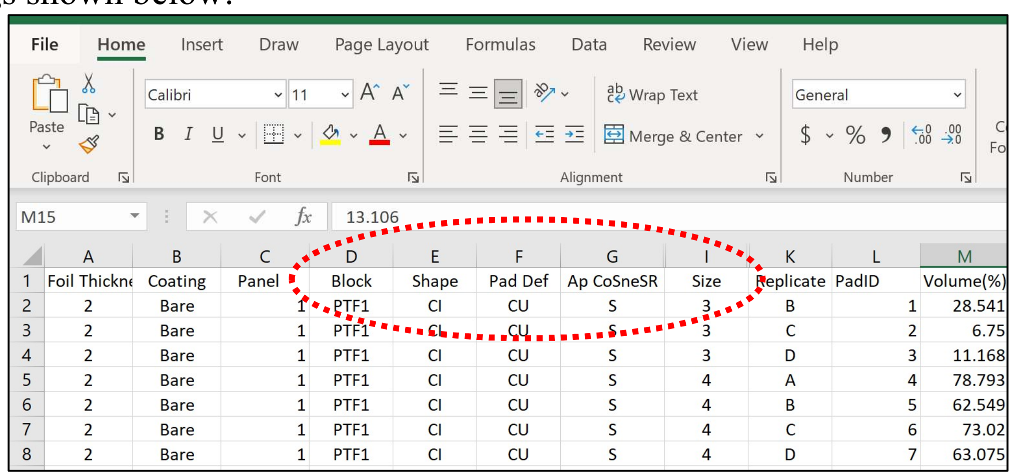
In *Step 2 of the Wizard*, set the column breaks as shown:



In *Step 3 of the Wizard*, individually highlight the unwanted columns - the underscores and dashes - and click on “Do not import column (skip)” for each one. Click Finish.



After the columns populate, hide column H (CAD ID), and add the column headings shown below:



Save the database! It is now ready for pivoting in excel or exporting into statistical software package.

The codes for the different pad stacks are as follows:

PTF Pattern Codes

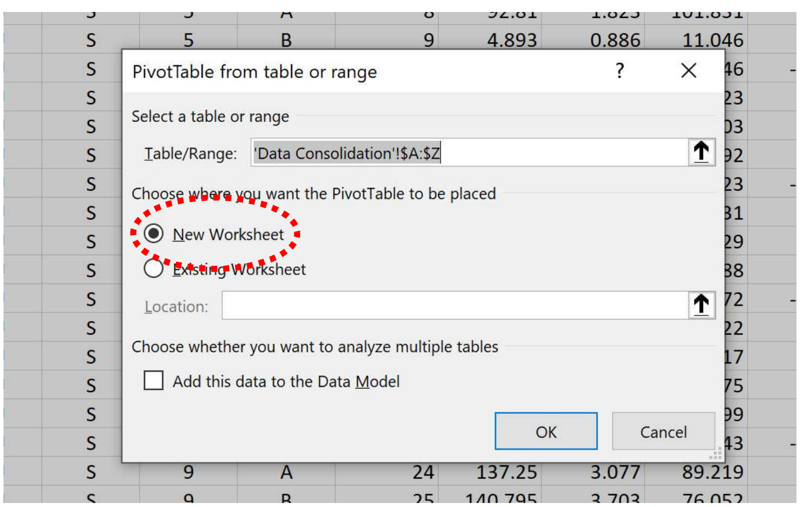
PTF(block #)_(shape)(pad definition)_(aperture corners)_(CAD identifier).(size)(replicate)

Block #:	1 to 8 (there are 8 individual blocks in the test area)
Shape:	CI = Circle SQ = Square HR = Horizontal Rectangle VR = Vertical Rectangle
Pad Definition:	Cu = Copper (metal, or NSMD) defined SM = Solder Mask Defined
Aperture Corners:	R = Radiused or Squircles S = Square or Circular
CAD Identifier:	03 or 15; the size of the first feature on the line for CAD reference only
Size:	03 to 15 mils
Replicate	A, B, C or D (there are 4 replicates per paired row of features)

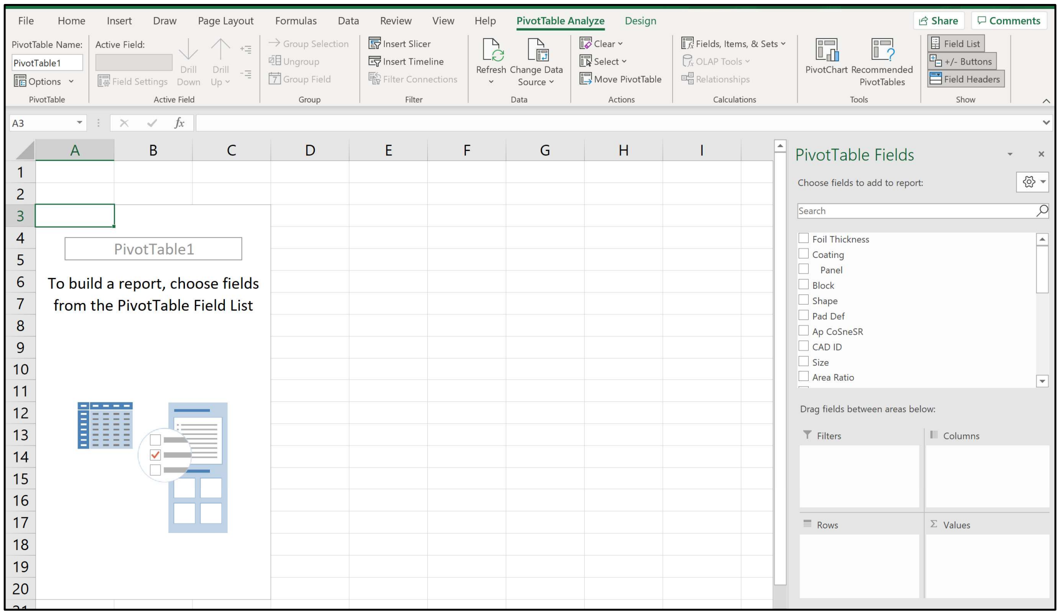
Step 6: Pivot Table

The pivot tables are easy to build:

- Click on the upper left corner of the sheet to highlight all contents
- Go to Insert, click on Pivot Table
- In the dialogue box, click New Worksheet and OK



- A new worksheet will appear:



There are many different ways to view data in pivot tables. This method was used to analyze the data from the Thin Foils experiment.

In the PivotTable Fields, drag the following fields to the Filters area:

- Foil Thickness
- Coating
- Shape
- Pad Def
- Ap CoSneSR

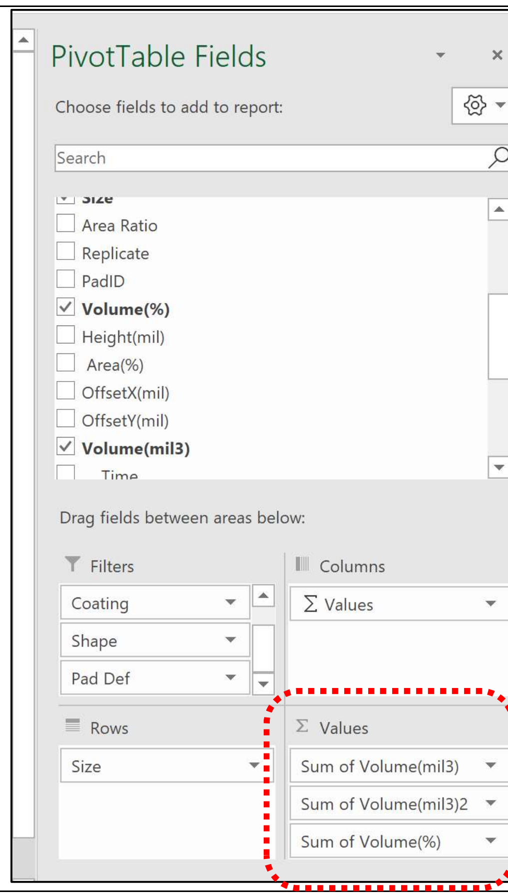
Into the Rows area, drag:

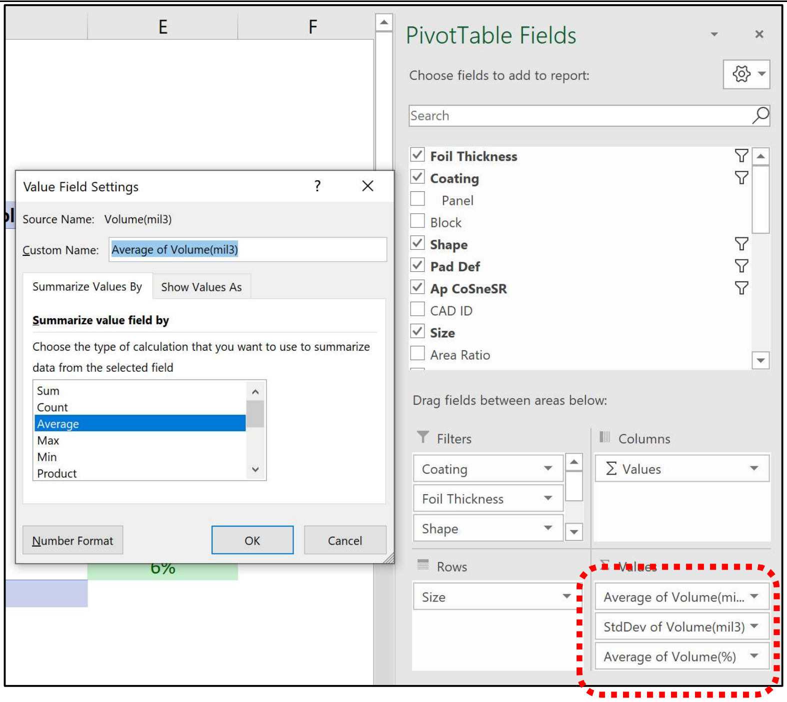
- Size

Into the Σ Values fields, drag:

- Volume (mils3)
- Volume (mils3)
- Volume (%)

The Volumes will show as Sum of Volume. The need to be changed to Average and Standard Deviation.

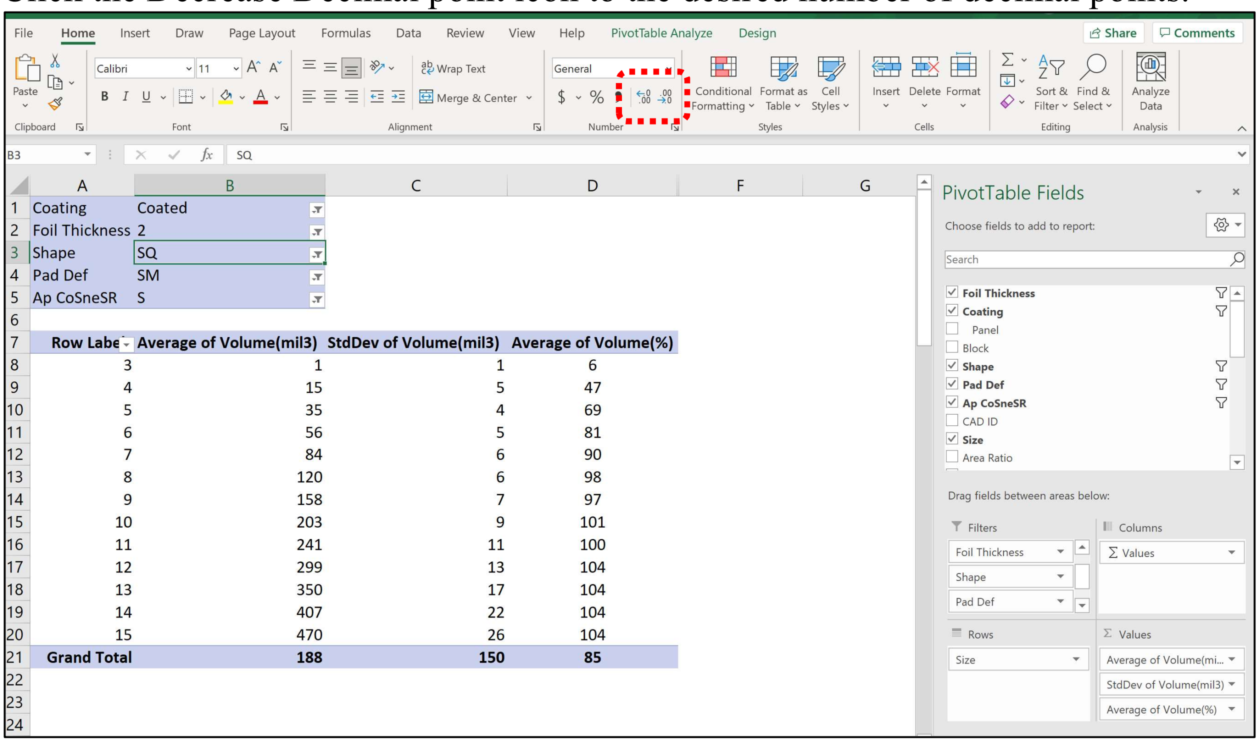




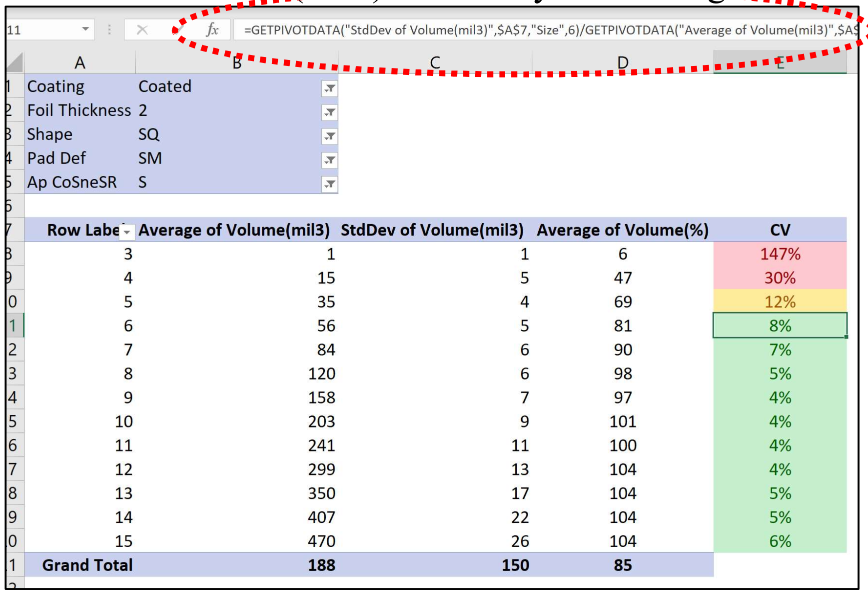
In the Σ Values field, click on the arrow next to Volume (mils3) and click on "Value Field Settings."

Choose the Average and Standard Deviation for the Volume (mils3) and the Average for Volume %.

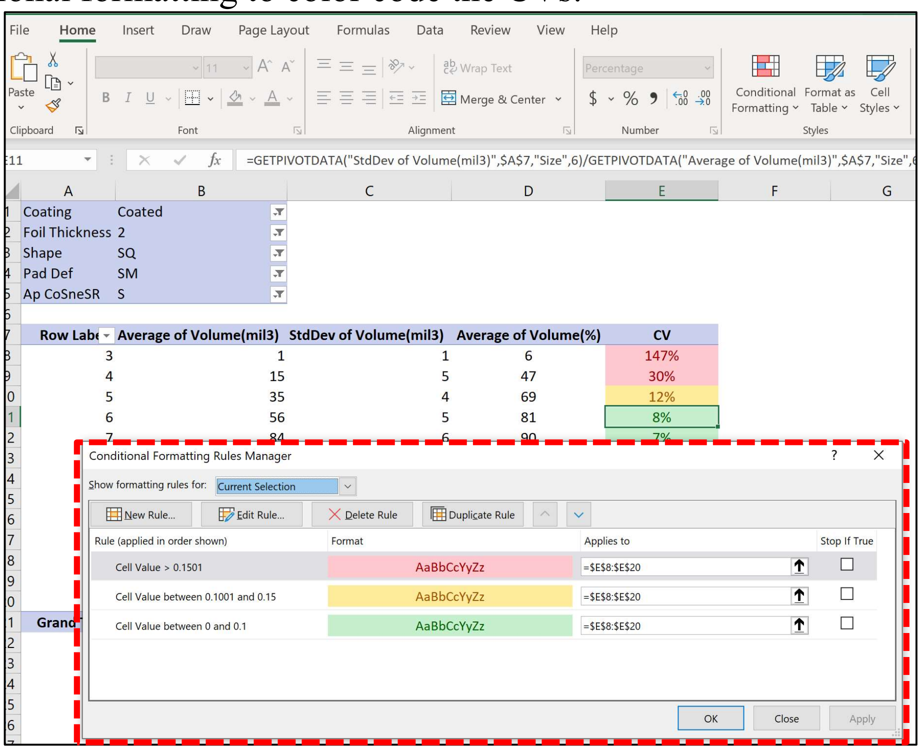
The basic pivot table is now constructed.
Click the Decrease Decimal point icon to the desired number of decimal points.



It is very helpful to add a column that calculates the Coefficient of Variation, or CV. It is the StdDev of Volume(mil3) divided by the Average of Volume(mil3).



Use conditional formatting to color code the CVs:



The Pivot Table is ready to go. The results of the filtering by coating, foil thickness, shape and pad definition can be viewed in Appendix B.

APPENDIX B

Volume, TE and CV Data from Thin Foil Test

BEST CASE

Coating	Coated
Foil Thickne	2
Shape	SQ
Pad Def	SM

SIZE	VOL	TE %	CV
3	1	8	124%
4	16	49	30%
5	35	69	12%
6	57	81	8%
7	85	89	7%
8	122	98	5%
9	159	98	5%
10	204	102	4%
11	243	101	5%
12	300	104	4%
13	351	104	5%
14	408	104	5%
15	472	105	6%

Coating	Bare
Foil Thickne	2
Shape	SQ
Pad Def	SM

SIZE	VOL	TE %	CV
3	2	9	111%
4	12	37	47%
5	31	63	20%
6	58	83	9%
7	87	92	6%
8	124	99	5%
9	162	102	4%
10	209	107	4%
11	253	106	4%
12	311	109	4%
13	367	110	4%
14	426	110	5%
15	496	111	5%

Coating	Coated
Foil Thickne	3
Shape	SQ
Pad Def	SM

SIZE	VOL	TE %	CV
3	3	13	75%
4	21	43	19%
5	40	53	11%
6	63	59	8%
7	92	65	6%
8	140	75	5%
9	179	74	4%
10	230	77	4%
11	270	75	5%
12	334	77	5%
13	390	77	5%
14	445	76	6%
15	514	76	7%

Coating	Bare
Foil Thickne	3
Shape	SQ
Pad Def	SM

SIZE	VOL	TE %	CV
3	1	5	177%
4	3	7	90%
5	18	25	67%
6	52	49	39%
7	104	73	12%
8	162	87	8%
9	224	94	5%
10	293	100	4%
11	358	100	4%
12	451	105	3%
13	538	107	3%
14	631	108	3%
15	737	110	3%

WORST CASE

Coating	Coated
Foil Thickne	2
Shape	CI
Pad Def	CU

SIZE	VOL	TE %	CV
3	11	72	34%
4	40	138	19%
5	66	146	16%
6	87	140	16%
7	116	138	12%
8	139	126	12%
9	167	115	11%
10	204	115	11%
11	230	108	11%
12	271	106	12%
13	294	98	11%
14	329	94	11%
15	372	93	12%

Coating	Bare
Foil Thickne	2
Shape	CI
Pad Def	CU

SIZE	VOL	TE %	CV
3	3	21	86%
4	19	65	44%
5	42	91	45%
6	61	97	47%
7	97	114	30%
8	132	120	19%
9	168	118	15%
10	212	122	14%
11	251	119	14%
12	295	116	15%
13	328	110	14%
14	372	107	14%
15	426	107	15%

Coating	Coated
Foil Thickne	3
Shape	CI
Pad Def	CU

SIZE	VOL	TE %	CV
3	17	76	34%
4	54	124	16%
5	84	125	13%
6	107	115	12%
7	138	109	11%
8	163	98	12%
9	193	89	12%
10	237	89	12%
11	266	83	12%
12	315	82	13%
13	345	76	12%
14	386	74	12%
15	439	73	12%

Coating	Bare
Foil Thickne	3
Shape	CI
Pad Def	CU

SIZE	VOL	TE %	CV
3	0	1	575%
4	5	12	158%
5	18	26	122%
6	21	22	145%
7	69	53	93%
8	150	90	44%
9	233	109	18%
10	304	117	13%
11	366	115	11%
12	441	116	12%
13	506	113	11%
14	577	111	12%
15	661	111	12%

2nd BEST

Coating	Coated
Foil Thickne	2
Shape	SQ
Pad Def	CU

SIZE	VOL	TE %	CV
3	15	90	37%
4	52	161	20%
5	67	135	27%
6	95	136	21%
7	130	137	9%
8	157	126	9%
9	192	118	9%
10	236	118	8%
11	268	111	8%
12	317	110	8%
13	349	103	7%
14	390	99	8%
15	443	99	8%

Coating	Bare
Foil Thickne	2
Shape	SQ
Pad Def	CU

SIZE	VOL	TE %	CV
3	6	34	79%
4	26	80	47%
5	32	63	81%
6	62	88	59%
7	110	115	29%
8	158	126	13%
9	202	127	10%
10	253	130	9%
11	306	129	9%
12	359	126	8%
13	404	121	7%
14	464	120	7%
15	530	119	7%

Coating	Coated
Foil Thickne	3
Shape	SQ
Pad Def	CU

SIZE	VOL	TE %	CV
3	19	80	33%
4	66	137	15%
5	90	121	14%
6	120	115	12%
7	153	107	9%
8	184	99	9%
9	221	91	9%
10	271	90	9%
11	311	86	9%
12	367	85	9%
13	403	80	7%
14	454	77	8%
15	514	76	8%

Coating	Bare
Foil Thickne	3
Shape	SQ
Pad Def	CU

SIZE	VOL	TE %	CV
3	2	6	289%
4	5	11	168%
5	7	9	170%
6	18	17	134%
7	67	47	95%
8	183	98	30%
9	273	114	9%
10	352	120	7%
11	429	120	6%
12	513	120	5%
13	588	117	5%
14	678	116	5%
15	780	116	5%

2nd WORST

Coating	Coated
Foil Thickne	2
Shape	CI
Pad Def	SM

SIZE	VOL	TE %	CV
3	1	5	158%
4	12	39	45%
5	30	65	23%
6	49	79	15%
7	75	88	13%
8	106	96	9%
9	140	97	10%
10	179	101	10%
11	216	101	9%
12	267	104	10%
13	314	104	10%
14	367	105	10%
15	421	105	10%

Coating	Bare
Foil Thickne	2
Shape	CI
Pad Def	SM

SIZE	VOL	TE %	CV
3	1	5	159%
4	9	30	57%
5	26	58	29%
6	50	80	16%
7	77	91	12%
8	113	102	10%
9	148	104	10%
10	190	109	11%
11	232	110	10%
12	283	112	11%
13	336	113	11%
14	393	114	11%
15	456	115	11%

Coating	Coated
Foil Thickne	3
Shape	CI
Pad Def	SM

SIZE	VOL	TE %	CV
3	3	15	74%
4	17	40	31%
5	34	50	20%
6	54	58	15%
7	80	63	13%
8	122	74	10%
9	160	74	10%
10	203	76	10%
11	243	76	10%
12	299	78	11%
13	352	78	10%
14	407	78	10%
15	466	78	11%

Coating	Bare
Foil Thickne	3
Shape	CI
Pad Def	SM

SIZE	VOL	TE %	CV
3	0	0	585%
4	2	5	117%
5	15	21	82%
6	44	47	46%
7	91	71	23%
8	147	89	12%
9	204	96	11%
10	265	102	11%
11	327	103	10%
12	410	108	11%
13	490	110	11%
14	579	112	11%
15	676	113	11%