# SPC Process Revitalization in a High Mix Low Volume Fab

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**Abstract**

**Implementing and maintaining an effective Statistical Process Control program can be extremely challenging in a high mix, low volume semiconductor fab. The number of charts can be quite large and managing them can overwhelm already burdened engineering resources. Appling a few data stratification strategies, a statistically based normalization technique and accepting a few compromises, MACOM has been able to significantly reduce the number of charts required to detect out of control events and improve the resolution of such events.**

## BACKGROUND

MACOM's fab in Lowell, MA is a classic high mix, low volume fab that supports a diverse set of technologies including Silicon, Gallium Arsenide, Indium Phosphide and Gallium Nitride. The product portfolio it supports is quite broad. Individual product volumes vary considerably, with many produced only sporadically. With respect to Statistical Process Control, such environments are particularly challenging when compared to low mix, high volume environments in which processes can be monitored and controlled consistently and nearly continuously.

## SPC IMPLEMENTATION CHALLENGES

To kick this effort off, the team conducted a fairly detailed review of the SPC charts and methods implemented in the Lowell wafer fab. Below are summarized the general findings of the review:

1) Over 1500 charts were identified in the MES SPC module. It was difficult to determine which of the charts were truly being used for statistically based process control and which were simply trend charts used by engineers to collect data.

2) There were many cases in which data from multiple tools and multiple processes was plotted on the same SPC chart.

3) A detailed review of a few multi-tool charts revealed some tools exhibited less variation and trended closer to the target than other tools running the same process. This highlighted an issue of tool-to-tool variation that was not previously apparent, and that the practice of plotting data from more than one tool on one chart had been effectively hiding the tool-to-tool performance differences from the engineers.

4) Macom's MES SPC module was configured in the conventional mode that puts a tool into the down state when a data point is found to be out of control, but allows the affected lots to continue processing if the data point is within the specification limits. However, a review of several data collection operations revealed inconsistencies in the use of control limits and specification limits. In some cases, the true specification limits had been entered as control limits in the system and the specification limits had been left blank (Figure 1). The result of this practice would put a tool into the down state if an out of specification data point occurred, but there would be no systemic action or message to hold or scrap the out of specification product.

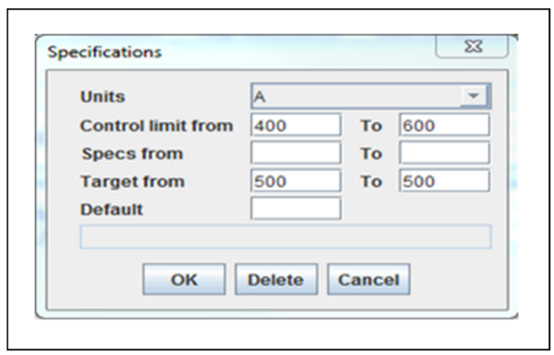


Figure 1.

5) Because of the inconsistent use of the fields for control limits and specification limits, it had become the norm to place all lots on hold for engineering disposition whenever a limit was exceeded. The intent of the policy was to prevent potentially non-compliant material from continuing through the process without anyone realizing it failed to meet the specification requirements. The practice of course adversely affected cycle time and other fab metrics.

6) A particular issue with the MES SPC module was identified in the system's batching functionality. "Batching"

refers to the combining of multiple lots into a single tool load for a process step (a fairly common practice in a high mix, low volume wafer fab). After the data was collected and entered into the system, the MES SPC module would include the data for the batch in the SPC chart as expected, but it would also duplicate the data for each of the lots in the batch in the same SPC chart. This issue inhibited the engineers' ability to calculate statistically valid control limits and detect true out of control events (Figure 2).

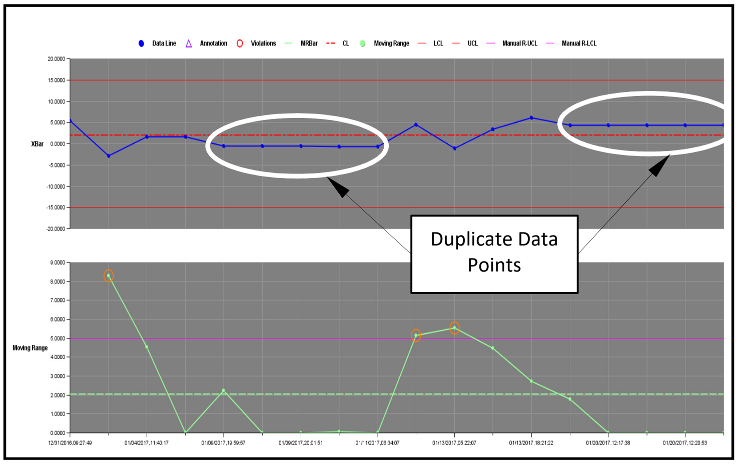


Figure 2.

7) A previous effort to reduce the number of charts in the MACOM wafer fab applied a normalization method in order to combine multiple processes on the same chart for a single tool [1]. In that method, the relative deviation from target was the control variable (calculated as (Measurement - Target) / Target * 100%). Typical fixed limits for such charts were ±5% or ±10%. The method proved somewhat successful, reducing the number of charts to one per tool. However, different processes often have different natural variation, which the normalization method described did not accommodate in a statistically valid manner. In some cases the fixed limits were too narrow, but more often they were too wide, which increased the risk of a Type-II error (i.e. an out of control event could occur, but it would not be detected because the limits were too wide).

### IMPROVED NORMALIZATION METHOD

An improved normalization method is based on z-scoring, a standard method for normalizing data so it may be represented by the standard normal distribution. The normalization equation is shown below.

$$Z = \frac{(\text{Measured Value} - \text{Mean})}{\text{Standard Deviation}}$$

An alternative to the conventional z-scoring method replaces the distribution mean with the process target in the normalization equation as shown below.

$$Z = \frac{(\text{Measured Value} - \text{Target})}{\text{Standard Deviation}}$$

This alternative z-score is preferred over the conventional z-score because it highlights processes that are not well centered on their targets.

The improved method was first demonstrated for data collection operations in the Diffusion work area, which grows a wide range of thicknesses of various oxide and nitride films using multiple furnaces. Table 1 lists all of the thicknesses of a film for just one furnace.

| Funrace FNB2 | | | | |
|---|---|---|---|---|
| Data Collect | Target | | Data Collect | Target |
| DC_1 | 50 | | DC_9 | 1500 |
| DC_2 | 150 | | DC_10 | 1600 |
| DC_3 | 200 | | DC_11 | 2000 |
| DC_4 | 250 | | DC_12 | 3000 |
| DC_5 | 392 | | DC_15 | 4500 |
| DC_6 | 675 | | DC_16 | 5000 |
| DC_7 | 1000 | | DC_19 | 8000 |
| DC_8 | 1450 | | | |

Table 1.

This one furnace would require 15 separate SPC charts if conventional X-Bar charts were used (i.e. one chart per film thickness). Using the z-score normalization method, only one Z-Chart is required for this furnace.

The first step in setting up the Z-Chart is to calculate the standard deviation for each process to be plotted on the chart. This is done by plotting historical data for each process on an I-MR chart and removing any outlier (i.e. values associated with special causes) data points. Each standard deviation is then calculated as 2.66 * MR-Bar / 3 and stored as a variable in the MES data collection operation for the process. Figure 3 contains an example of the MES variable settings section for a particular data collection operation. It contains all of the information necessary for the MES to perform the z-score normalization automatically.

| UD407 (Target = 200) | |
|---|---|
| | |
| Id | Specs |
| Component | Lot |
| Mean Thickess | USL=235, LSL=180 |
| Target | Target=200 |
| STD_DEV_FOR Z_SCORE | $ UD407_STD_DEV |
| Z_SCORE | (Mean Thickness-Target)<br>STD_DEV_FOR_Z_SCORE |
| TOOL_ID | $Tool |

Figure 3.

Figure 4 contains an example of the original I-MR chart for this data collection using Furnace_1

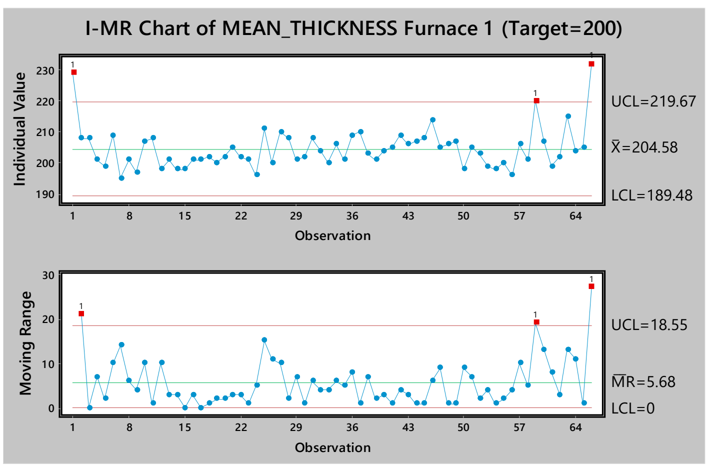


Figure 4.

Figure 5 contains the normalized Z-Chart for the same data set as in Figure 6.

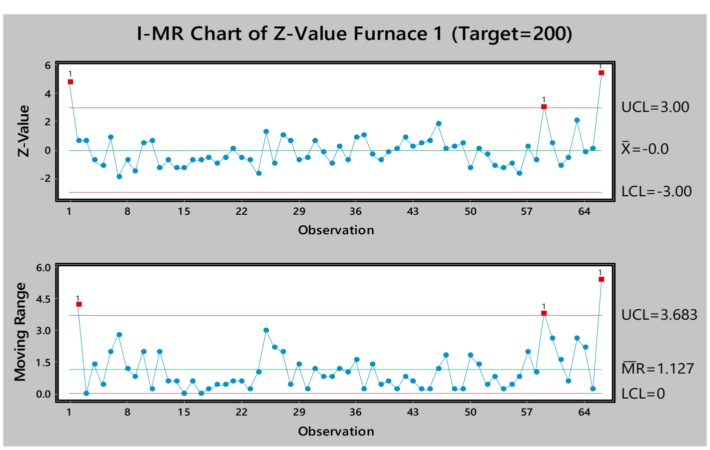


Figure 5.

A comparison of the charts in Figure 4 and Figure 5 reveals the positions of the 3 out of control points relative to the control limits has not changed as one would expect. For the Chart in Figure 5, the conventional z-score normalization was used (i.e. Z = (Measured Value - Mean) / Standard Deviation). It's not apparent from the figure that the process is tracking above its target.

Figure 6 is based on the same data as Figure 4 and Figure 5, but the alternative z-score normalization method was used (i.e. Z = (Measured Value - Target) / Standard Deviation). Applying this method, the control limits are centered about the process target rather than the distribution mean. Although this did not affect the number of out of control points in this case, it did reveal the process has been running approximately one standard deviation above its target (with X-Bar = 0.91).

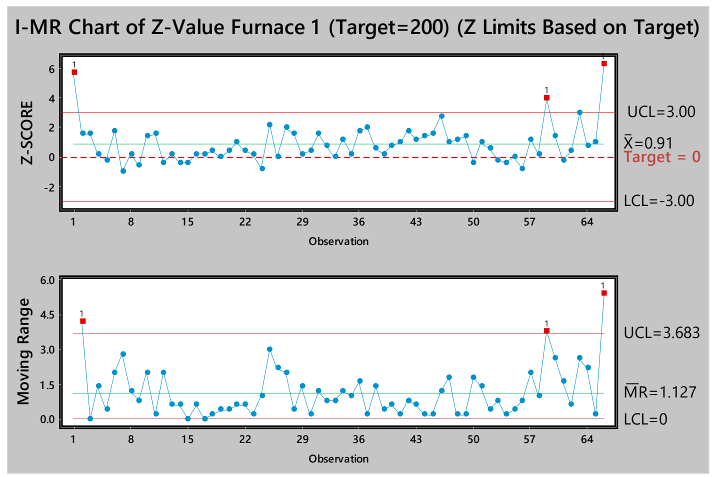


Figure 6.

## Z-Score Implementation Challenges

Although the MES system supports z-score normalization by process, it does not index the normalization tool-by-tool for tools running the same process. This can be a serious problem if different tools running the same process have significantly different standard deviations.

Because of this MES limitation, one must choose a standard deviation that is a compromise across the tools. Doing so effectively causes the control limits to be too narrow for some tools and too wide for other tools which results in increased Type I and Type II errors, respectively.

The goal of the process engineer of course is to match the performance of the tools as closely as possible. If a reasonable level of matching cannot be achieved, some tools may have to be disqualified from running the particular process.

## Addressing the Other Challenges Identified

**1) Data from multiple tools is plotted on one SPC chart.**

Understanding that when a process goes out of control, it generally does so on one tool at a time. Plotting more than one tool on the same chart can "cloak" the offending tool. Therefore, the scope of each Z-Chart was limited to a single tool.

**2) Control and specification limits are applied inconsistently.**

A detailed data extract from our MES system was performed showing all of the data collection operations for the Macom fab with the values populated in the control limit and specification limit fields. The list is being reviewed by the engineering team to identify and correct invalid use of limits. Once the values have been corrected, the MES SPC module may be used in the conventional mode (i.e. tool down when lots out of control, lots on hold when out of specification) without requiring lot holds and engineering disposition for every event.

**3) When lots are batched, duplicate data points are plotted.**

Working with the MES supplier, the source code was updated to plot one data point per batch, but maintain the lot-to-batch relationship internally in the MES database.

**4) The MES system does not index normalization variables tool-by-tool for tools running the same process.**

Working with the MES supplier to enable this capability.

## Summary

A comprehensive review of SPC charts and practices was conducted in Macom's fab in Lowell, MA. Several opportunities for improvement were identified, some of which were system based while others were operational. Best practices were evaluated and implemented as appropriate. One best practice was the implementation of the Z-Chart in this high mix low volume fab as a good compromise for statistical process control charting. It greatly reduced the number of charts required to control processes by allowing multiple processes to be plotted on the same chart while providing statistically valid control limits for each of the processes. Applying the Z-Chart in the Diffusion work area, the number of control charts was reduced from 70 to 14.

As the method presented is rolled out to the other work areas in the Macom fab, similar impacts on chart count and improved SPC management are anticipated.

## Acknowledgements

The authors would like to thank the unit process engineers Vinny Wang, Dan Bouchard, IT Lead Stephen Sheehan and fab management for their hard work and collaboration in developing the solutions implemented.

## References

[1] Carter and Collins, Consolidation Method for SPC Data Review in a High Product Mix Semiconductor Fab, 2016 CS ManTech Technical Digest, pp.131-134, May 2016.

## Acronyms

SPC: Statistical Process Control
MES: Manufacturing Execution System
X-Bar: Process Mean
MR-Bar: Moving Range Average