





























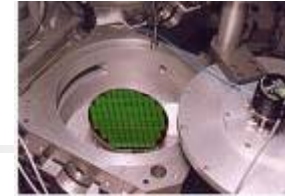








# Predictive Models for Resistivity (aka transfer functions)



- Mean =  $255.71 + 23.69 A - 49.06 B - 35.14 C - 25.54 AC - 16.57 B^2 + 27.75 C^2$   
( $p < 0.0001$ , Adj  $R^2$  0.84)
- Std dev =  $79.97 + 2.50 A - 14.81 B + 1.72 C - 12.43 BC - 9.41 A^2 - 9.80 B^2 + 44.56 C^2$   
( $p < 0.0001$ , Adj  $R^2$  0.88)

*All models are wrong, but some are useful.*

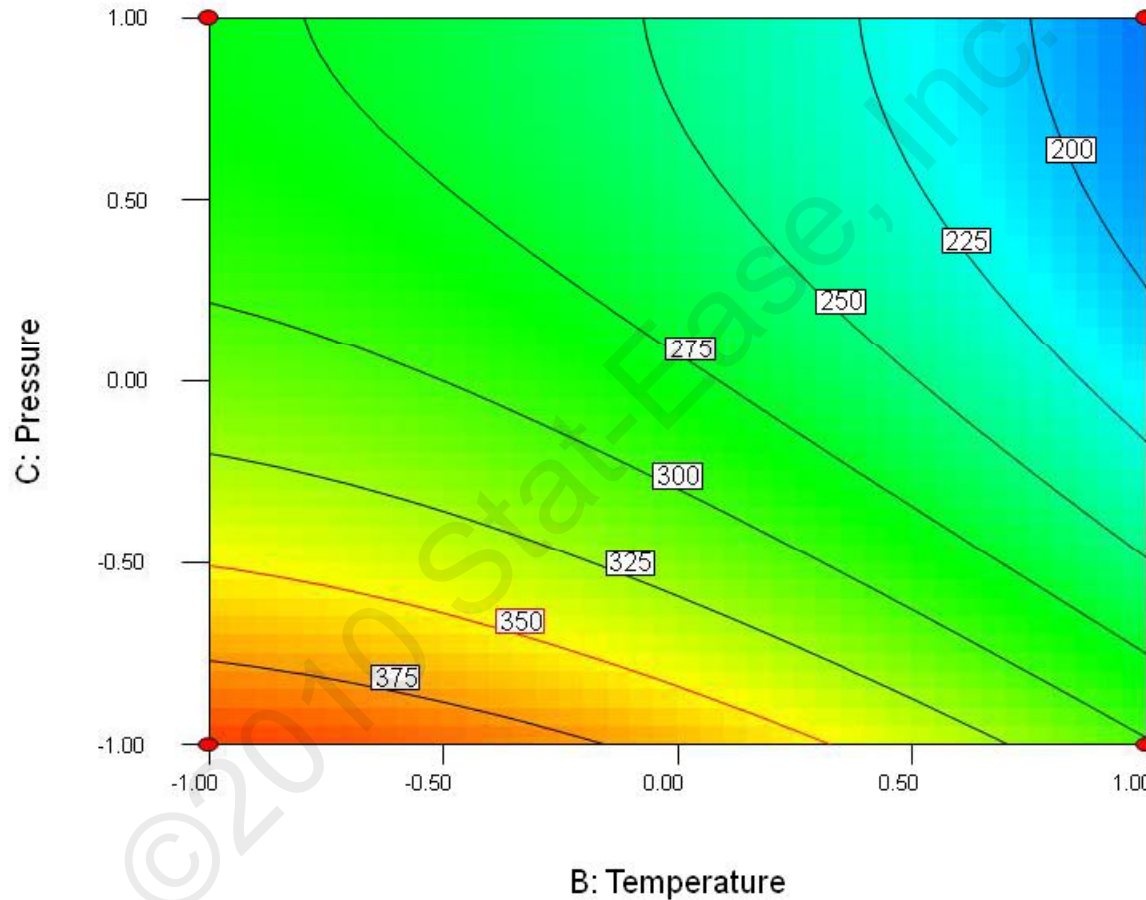
– G. Box

Caveats (the fine print!):

1. During run #17 the result for batch #5 of 572 significantly exceeded the other 10 outcomes, which ranged from 223 to 347. Given no special cause for this discrepant value, it was not ignored. In any case, this one value makes little difference.
2. To keep them simple, models reduced by backward regression at  $p$  of 0.10.
3. The log transformation\* should be applied per standard statistical practice to standard deviations (or variances) – the second of the dual responses. In this case it did not significantly improve the residuals by the Box-Cox assessment of power-law transformations, so for simplicity sake we left the results untransformed.
4. In the std dev model, the model term for C is not significant, but it is included to maintain hierarchy.

\* Calculation of POE for transformed responses requires some fancy footwork mathematically, involving application of the chain rule, for example. See p210-211 of *RSM Simplified* for details.

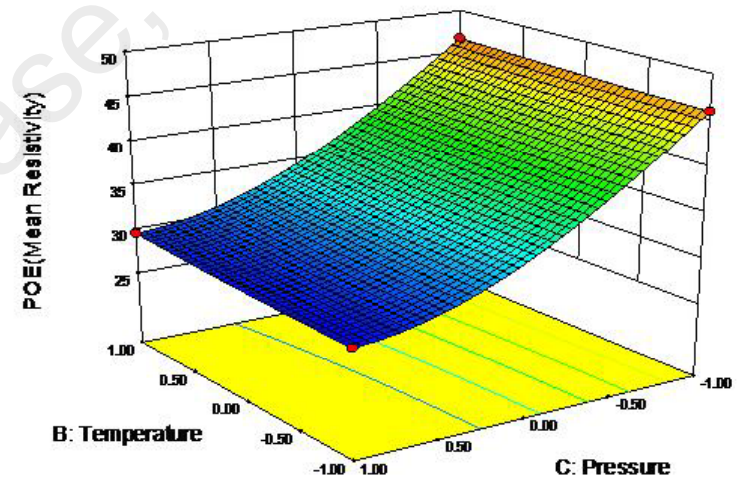
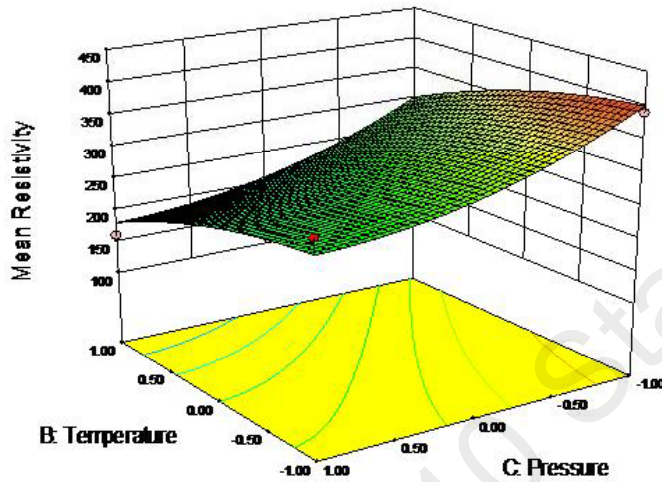
## Contour Plot of Resistivity Mean (Temp vs Pressure with Gas Flow at +1)\*



*\*(This factor, A, most linear – set high to achieve target of y = 350)  
PS. Best to stay within the ‘box’ of factorial settings in CCD – not axials.*

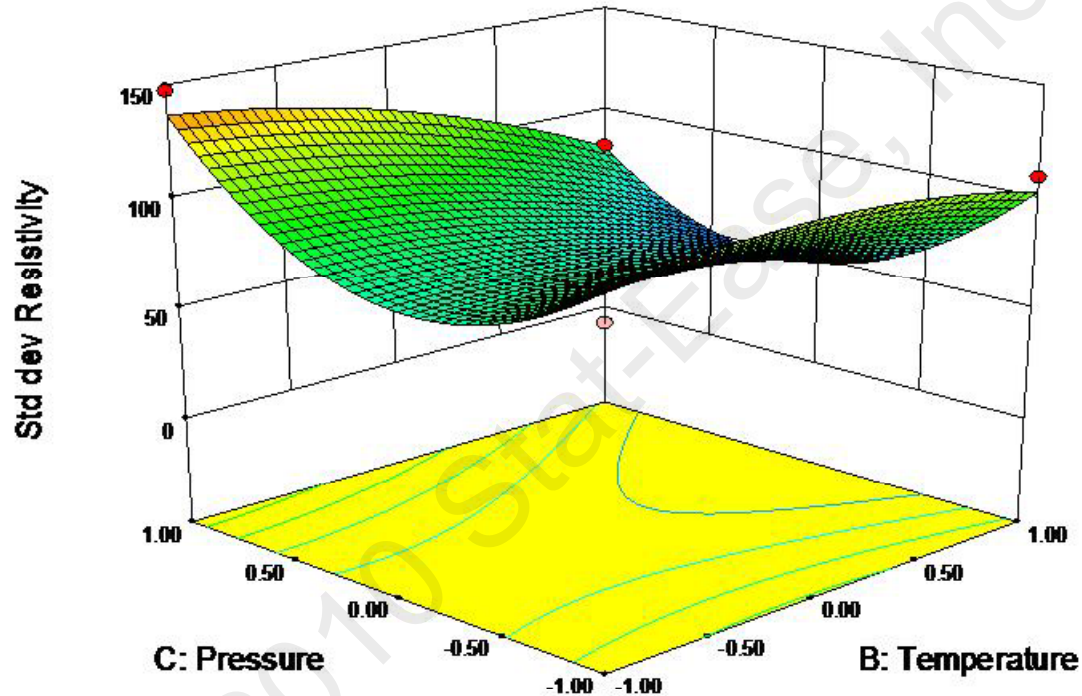
# Surfaces of Resistivity Mean (left) and POE\* (right) (Temp vs Pressure with Gas Flow at +1)

*Assumes these std devs of factors (in coded scale):  
Gas flow (A) 0.2, Temp (B) 0.1, Pressure (C) 0.3.*



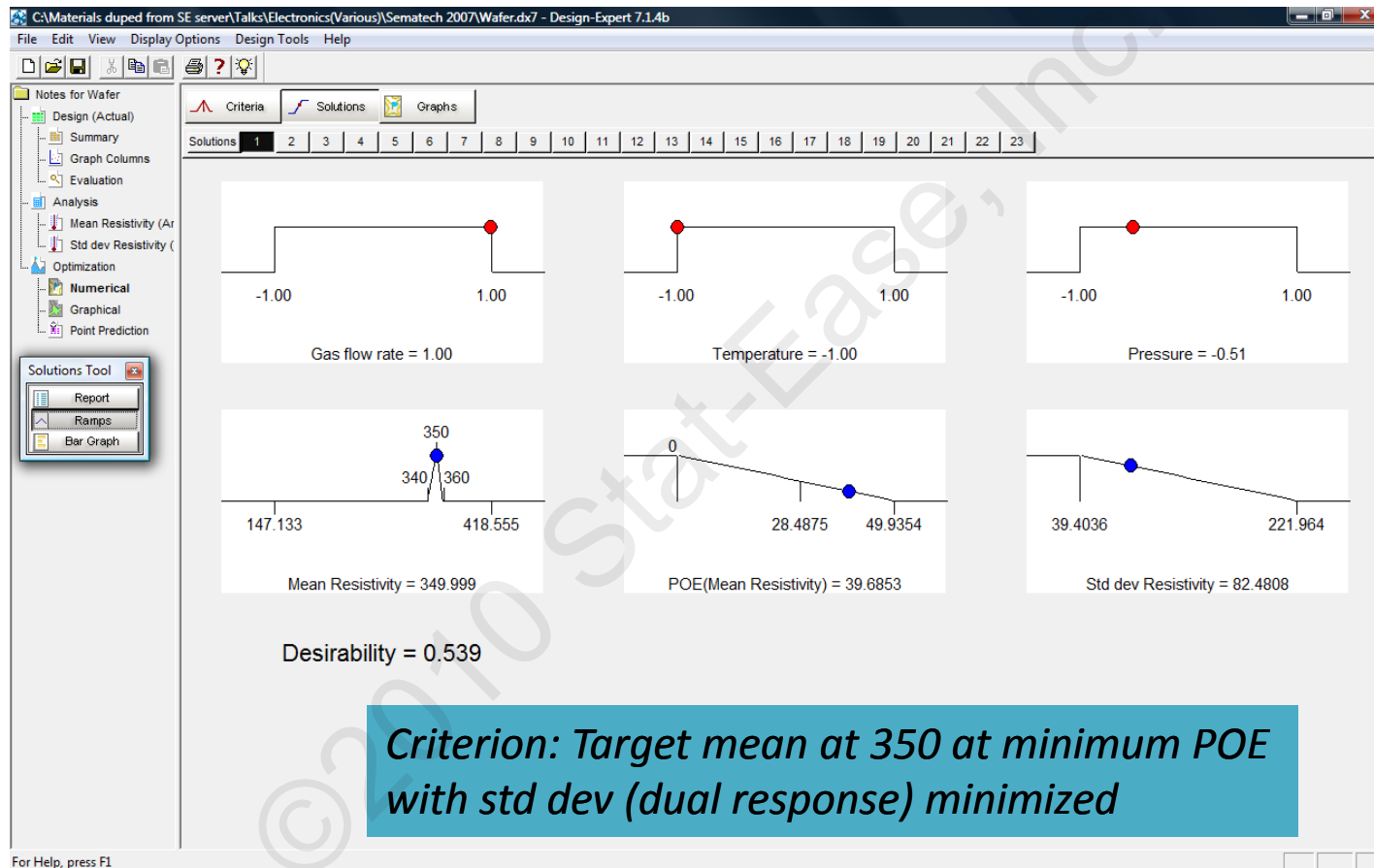
*Wafer*

## Response Surface of Resistivity Standard Deviation (Temp vs Pressure with Gas Flow at +1)



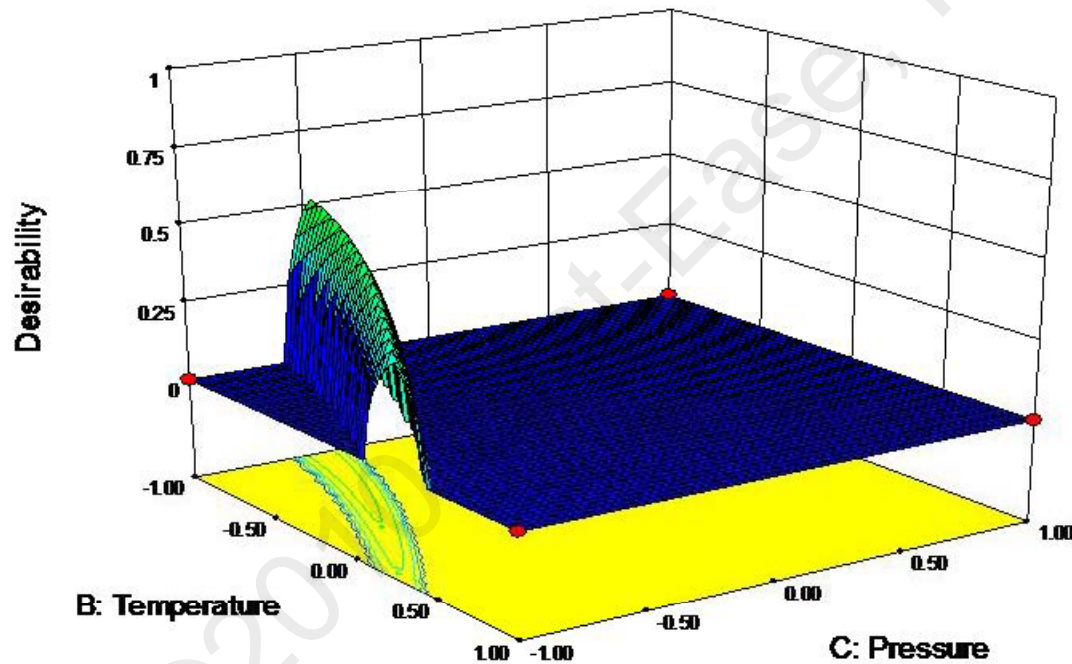
*Note: Generally standard deviation will be log linear, so then POE is moot. However, even when it does exhibit second-order behavior like this, it adds little or nothing to make use of the POE if it is minimized at minimal standard deviation, and nonsensical to trade it off for consistently greater variation.*

# Most Desirable\* Process Settings



\* For details, see Derringer's "A Balancing Act: Optimizing a Product's Properties," *Quality Progress*, posted at [www.statease.com/pubs/derringer.pdf](http://www.statease.com/pubs/derringer.pdf) © 2002 American Society for Quality (ASQ).

## 3D View of Desirable Combinations of Temperature vs Pressure (gas flow at +1 level )



PS. Authors of this case study recommend coordinate (1.18, -0.80, -0.57) vs our optimal point at (1,-1,-0.5), but we do not extrapolate outside the CCD's box.

## Summary and Conclusions

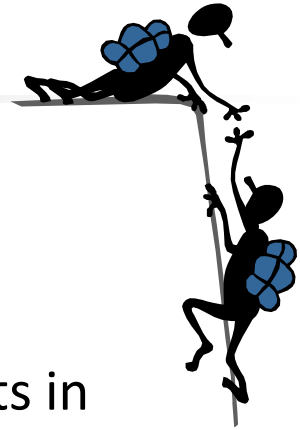



- Response surface methods (RSM) provide statistically-validated predictive models, sometimes referred to as “transfer functions,” that can then be manipulated for finding optimal process configurations.
- Variation transmitted to responses from poorly-controlled process factors can be accounted for by the mathematical technique of propagation of error (POE), which facilitates ‘finding the flats’ on the surfaces generated by RSM.
- The dual response approach to RSM captures the standard deviation of the output(s) as well as the average. It accounts for UNKNOWN sources of variation.
- Dual response plus POE provides a more useful model of overall response variation.
- The end-result of applying these statistical tools for design and analysis of experiments will be in-specification products that exhibit minimal variability – the ultimate objective of robust design.

## Further Reading for More Detail on Methodology

1. Mark J. Anderson and Patrick J. Whitcomb, *RSM Simplified – Optimizing Process Using Response Surface Methods for Design of Experiments*, Productivity Press, NY, NY, 2005.
2. Mark J. Anderson and Patrick J. Whitcomb, “Robust Design – Reducing Transmitted Variation,” *Proceedings from the 50th Annual Quality Congress*, 1996, pages 642-651. Milwaukee: American Society of Quality. (Write-up of talk presented by MJA at the 13th SEMATECH Statistical Methods Symposium in San Antonio, TX, on April 24, 1996.)
3. Wayne A. Taylor, “Comparing Three Approaches To Robust Design: Taguchi Versus Dual Response Versus Tolerance Analysis,” presented at 1996 Fall Technical Conference (FTC) of the American Society of Quality (ASQ) and American Statistical Association (ASA).
4. Geoff G. Vining and Raymond H. Myers, “Combining Taguchi and Response Surface Philosophies: A Dual Response Surface Approach,” *Journal of Quality Technology*, Vol. 22, No. 1, January 1990, pp. 38-45.

# How to get help



- Search publications posted at [www.stateease.com](http://www.stateease.com).
- Use Screen Tips  in Stat-Ease software, view reports in annotated mode, check for context-sensitive Help (right-click) or search the main Help system.
- E-mail [stathelp@stateease.com](mailto:stathelp@stateease.com) for answers from Stat-Ease's staff of statistical consultants.
- Call 612.378.9449 and ask for "statistical help."

*Thanks for attending!*