Dynamic Variation of Contact Resistance in Test Interfaces

Todd Sargent, MS

Southwest Test Workshop

June 10, 2002

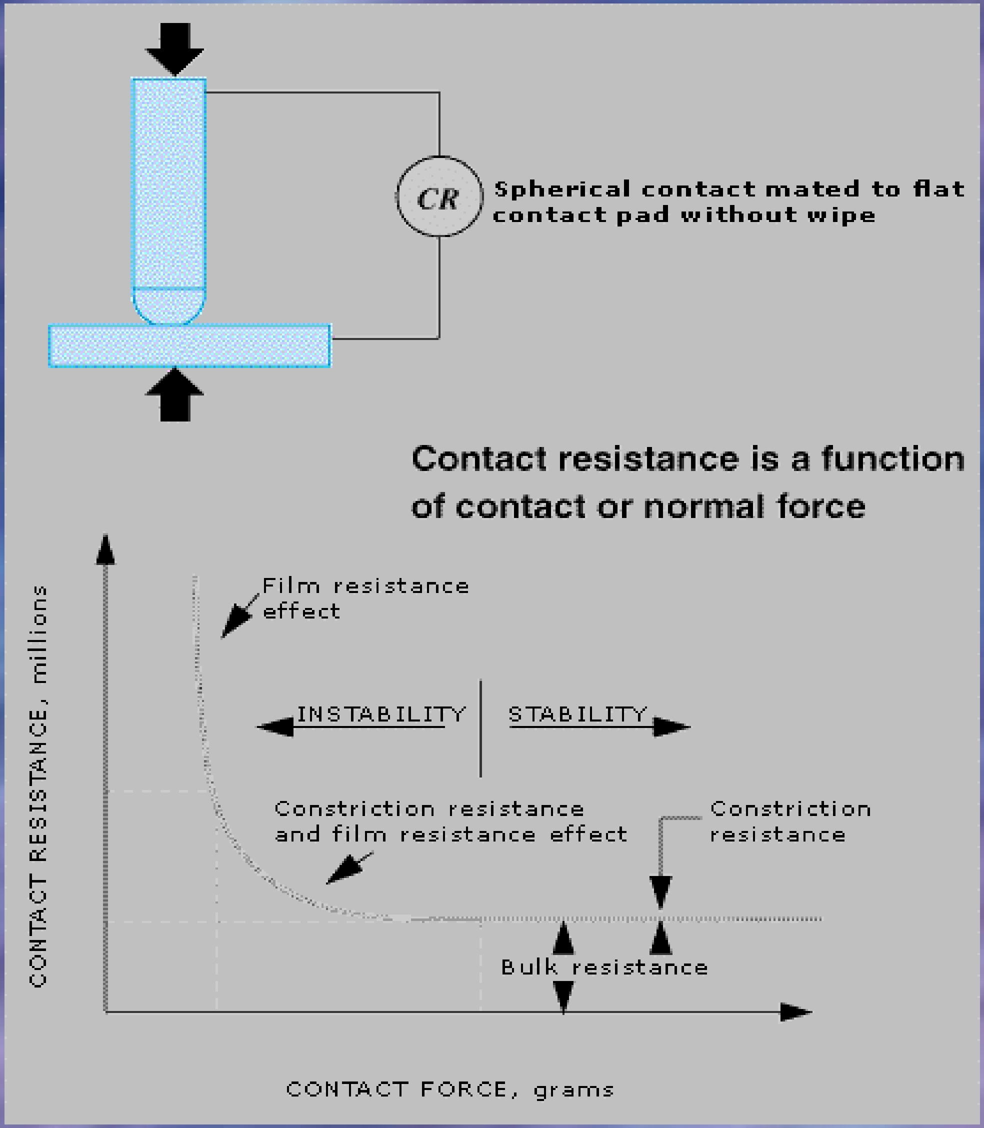
You Can Depend on inTEST

inTEST Corporation

Statistical Analysis doesn't have to be limited to standard control chart methods

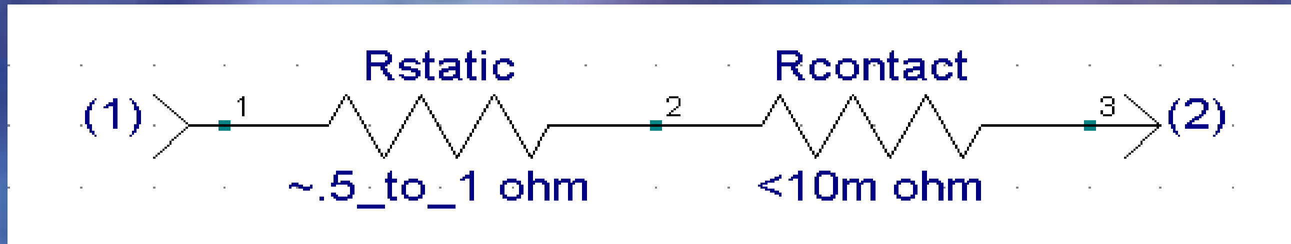
- Isolate the random variable (contact resistance)
- Look at the distribution function: is it recognizable? Repeatable?
- Gaussian control charts are ubiquitously useful, but not necessarily the best choice for all distributions.
- Gaussian control charts converge only in the limit of infinite number of samples (the Central Limit theorem)
- Some distributions are difficult to manage, even with invocation of the central limit theorem. Examine the distribution of the mean values of your samples as a function of the number of samples: how quickly does it converge to a Gaussian?
- If your variable fits a known distribution function, make use of that fact for immediate assessment of reliability
- Control limits can be set, and judgments made, early, from smaller sample sizes by considering the goodness of fit.

Force and Contact Resistance



Brush-Wellman, http://www.brushwellman.com/www/Technical/DesignGuide/Figure4

Isolation of Dynamic Resistance Variation



- Physical mechanism is spring probe tip into a via hole
- Total resistance is measured, and Rcontact is opened and closed N times. Resolution = 1 milliohm. Rstatic is different for every channel, and variance(Rstatic) >> Rcontact. Contact Resistance << Total resistance
- For each channel, the minimum value of N total resistance measurements is subtracted from all N values.
- Remaining N-1 values are taken to be the "contact resistance".
- If Rcon fails our test, we replace the spring probe responsible.
- Using this system, we are able to detect cable faults that vary by only a few milliohms. There isn't anything else that contributes.

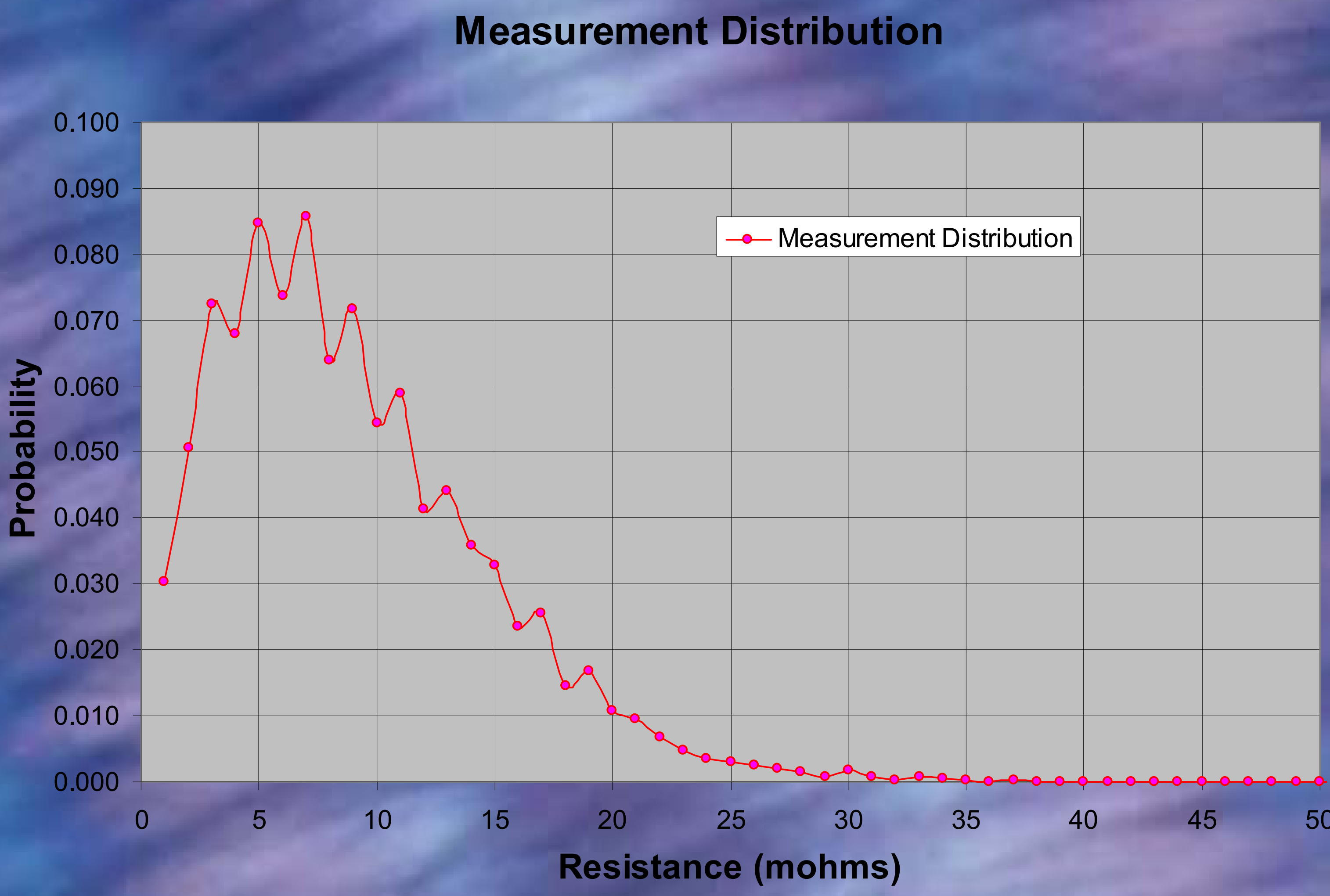
inTEST Corporation

Data Example

Channel	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
A0	0.012	0	0.021	0.005	0.009	0.007	0.001	0.008	0.012	0.012
A1	0.016	0.009	0.007	0.005	0.009	0.004	0.009	0.005	0	0.003
A2	0.007	0.03	0.005	0.012	0.016	0	0.008	0.013	0.015	0.012
A3	0.017	0	0.011	0.009	0.012	0.011	0.008	0.004	0.016	0.009
A4	0.004	0	0.011	0.004	0.004	0.011	0.013	0.009	0.006	0.008
A5	0.008	0.003	0.004	0.006	0.006	0	0.002	0.008	0.003	0.002
A6	0.001	0.006	0	0.009	0.004	0.007	0.006	0.01	0.008	0.003
A7	0.013	0	0.014	0.014	0.015	0.011	0.019	0.017	0.017	0.021
A8	0.007	0	0.013	0.009	0.002	0.005	0.005	0.016	0.015	0.008
A9	0	0.028	0.01	0.006	0.009	0.007	0.006	0.002	0.003	0.002
A10	0.017	0	0.015	0.009	0.015	0.01	0.013	0.012	0.007	0.006
A11	0.013	0.031	0.01	0.014	0.002	0.01	0.009	0	0.005	0.003

A sample of Rcon data. Columns are repetition number, Rows are channel. Typical # of channels > 900.

Plot the Distribution Function



Equations of some common Probability Distributions

The Gaussian or "Normal" distribution:

$$G(z)=\frac{1}{\sqrt{2\cdot\pi}\cdot\sigma}\cdot e^{-\frac{(z-\mu)^2}{2\cdot\sigma^2}}$$

The Chi-squared distribution of degree ν:

$$\chi_\nu^2(z)=\chi_1^2(z)+\chi_2^2(z)+....+\chi_\nu^2(z)$$

$$P_{\chi 2}(z,\nu)=\frac{z^{\frac{(\nu-2)}{2}}\cdot e^{\frac{-z}{2}}}{2^{\frac{\nu}{2}}\cdot\Gamma\left(\frac{\nu}{2}\right)}$$

$$\mu=\nu$$

$$\sigma^2=2\cdot\nu$$

where z =random variable, μ =mean value, σ =std deviation, ν =degree

inTEST Corporation

Scaling and Normalizing

α is a scale factor that is to be determined such that αz corresponds to milliohms

$$f(\alpha, z, \nu) := \frac{(\alpha \cdot z)^{\frac{(\nu - 2)}{2}} \cdot e^{\frac{-\alpha \cdot z}{2}}}{2^{\frac{\nu}{2}} \cdot \Gamma\left(\frac{\nu}{2}\right)}$$

$$\mu = \alpha \cdot \nu$$

$$\sigma = \alpha \cdot \sqrt{2 \cdot \nu}$$

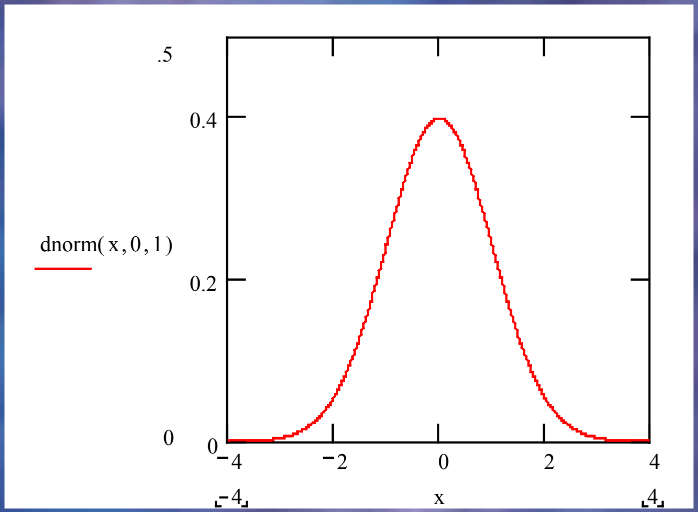
$$\chi(\alpha, x, \nu) := \mathrm{if}\left[x > 0, \frac{f(\alpha, x, \nu)}{\int_0^{\infty} f(\alpha, x, \nu)\, dx}, 0\right]$$

The function is renormalized to account for the scaling by α

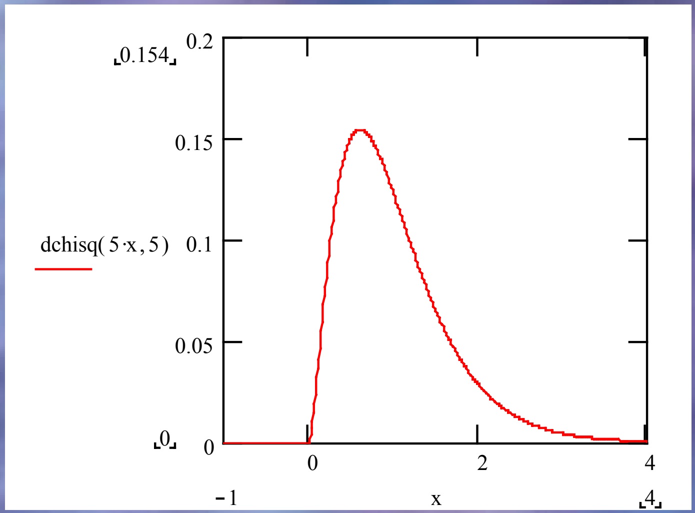
inTEST Corporation

Differences Between Gaussian and Chi-squared Distributions

- Gaussian (bell-shaped) curve deviates symmetrically about any mean value
- Mean and variance are independent

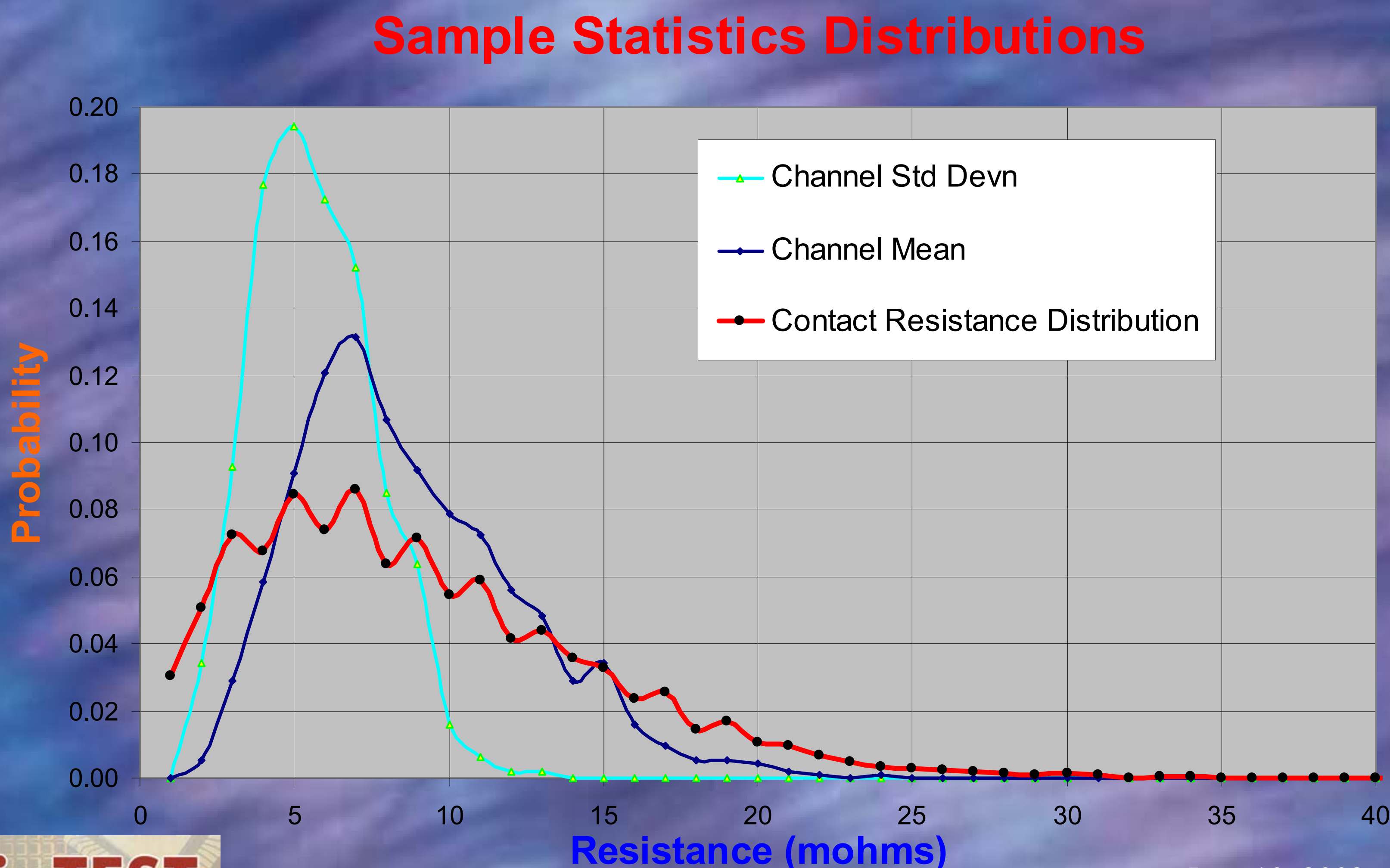


- Chi-squared distribution deviates asymmetrically and is always positive valued.
- Variance = 2 * Mean

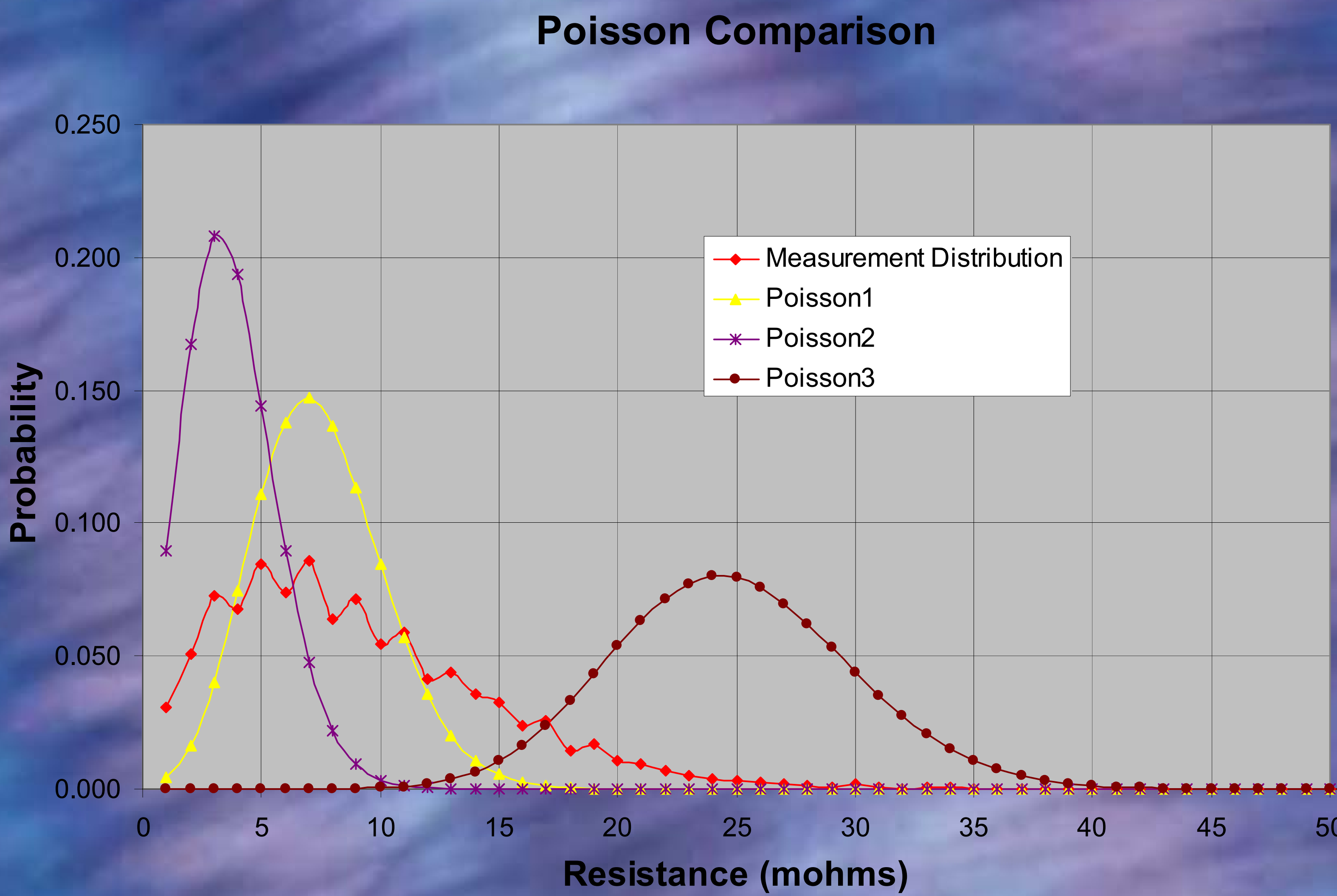


inTEST Corporation

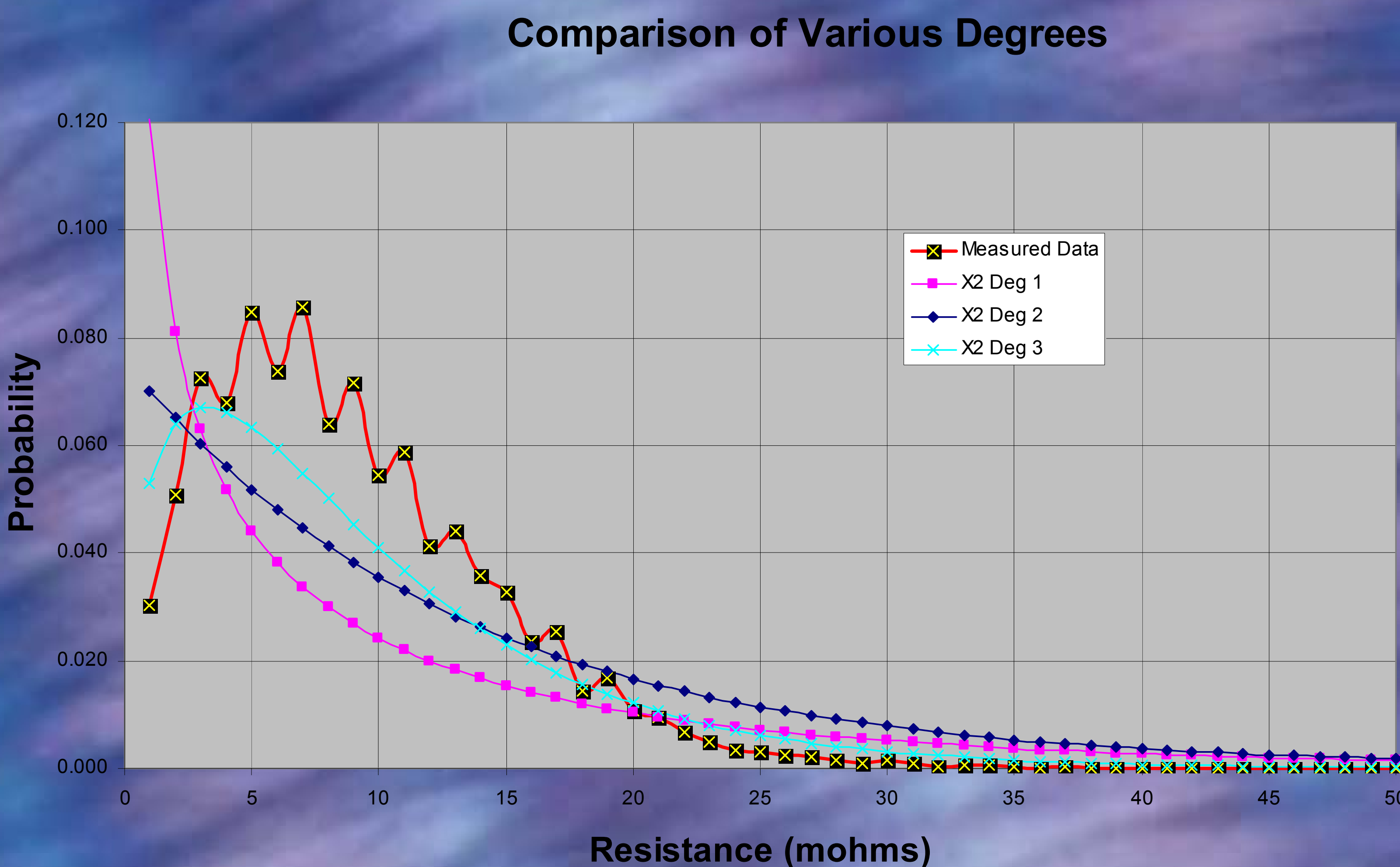
Distribution of Sample means & std deviations



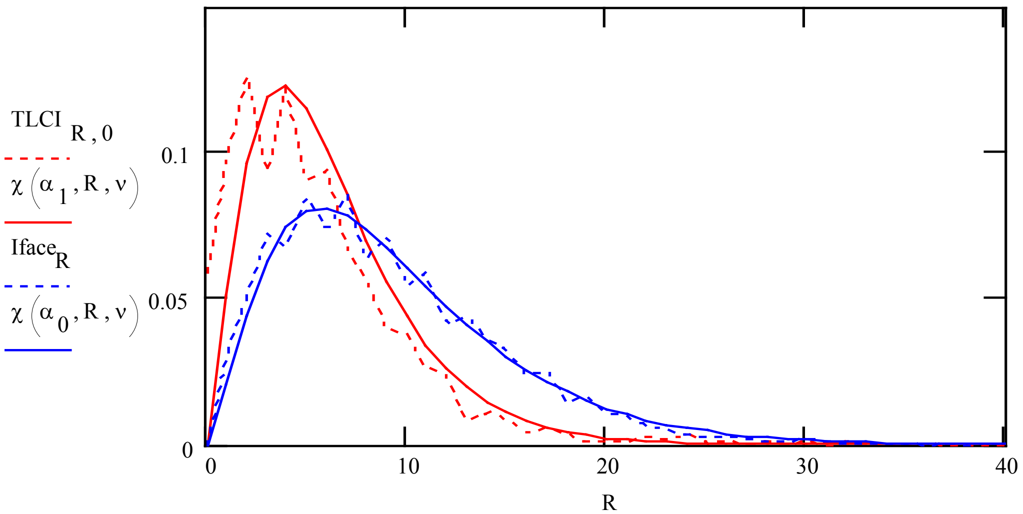
Poisson (doesn't) Fit



Data compared to Chi-Squared Degrees 1,2,3



Goodness of Fit to Degree 5
Scale (α) varies with force



$\alpha = \begin{bmatrix} 0.525 \\ 0.8 \end{bmatrix}$

$\nu \equiv 5$

χ^2 degree 5 fits best to the first 40 milliohms. Sporadic points out at >40 mohms tend to skew the fit; it is decided to unweigh those points for the purpose of fitting.

$$\text{Goodfit2}(x, y) := \sum_{n=0}^{M} \left(\overrightarrow{\frac{(x-y)^2}{x}} \right)_n$$

$M := 40$

$\text{Goodfit2}(\chi v, \text{Iface}) = 0.022$

$\text{pchisq}\left(\text{Goodfit2}\left(\chi v2, \text{TLCI}^{\langle 0 \rangle}\right), 100\right) = 1.475 \cdot 10^{51} \circ 10^{-163}$

=probability that these 2 functions would occur at random over M data points.

$\text{pchisq}(\text{Goodfit2}(\chi v, \text{Iface}), 100) = 3.147 \circ 10^{-163}$

BLCI FIT

Limits and Simultaneous Events

- Gaussian control charts use 3 sigma limit
- Compare the number of χ^2 deg 5 std devns that correspond to the same probability:

$$\mathrm{pnorm}(3,0,1) = 0.999 \qquad \frac{\mathrm{qchisq}(\mathrm{pnorm}(3,0,1),5)}{\sqrt{2\cdot 5}} = 6.268$$

- Consider the probability that multiple events occur during one test: Let NC=number of channels, NR=number of repetitions
- Probability of NC events occurring simultaneously, for NR repetitions, where P(1) is probability of 1 contact:
  - P(NC*NR) = P(1)^(1/(NC*NR)

Sample Deviation and Chart Limits

- Compute moving average deviation from data (ex: TLCI)
- Compute NSD, the number of χ^2 deg 5 std devns that correspond to P(NC*NR) simultaneous events, and scale to milliohms using α fit to product.
- Compute control chart limits in usual manner: limit = mean + NSD deviations (moving average)

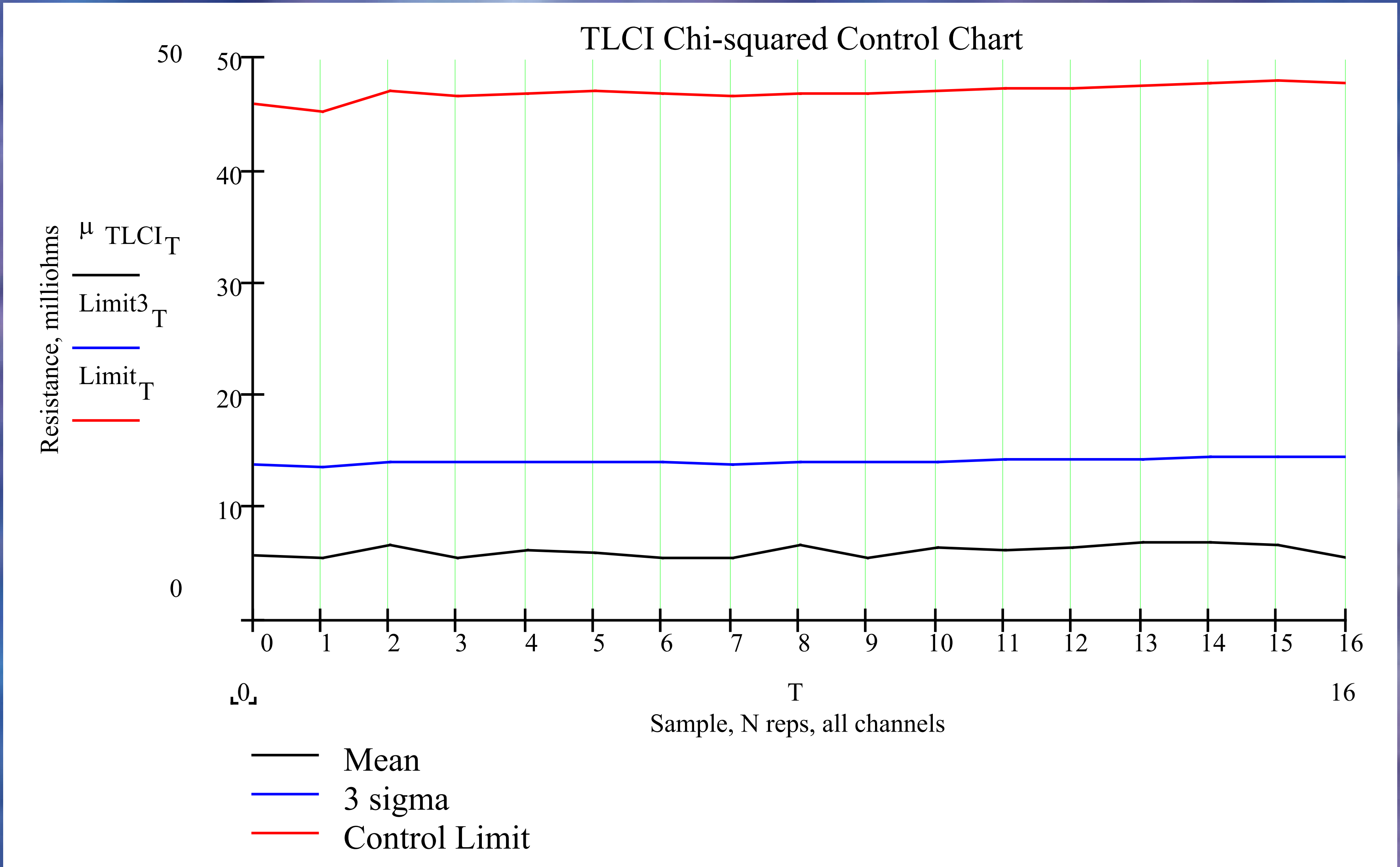
$$\sigma_{TLCI_T} := \alpha_1 \cdot \sqrt{2 \cdot \mathrm{mean}\left(\mathrm{submatrix}\left(\mu_{TLCI}, 0, T, 0, 0\right)\right)} \qquad \sigma_{TLCI_{16}} = 2.78 \qquad \alpha \cdot \sqrt{10} = \begin{bmatrix} 1.66 \\ 2.53 \end{bmatrix}$$

$$NSD := \frac{1}{\alpha_1 \cdot \sqrt{2 \cdot \nu}} \cdot \mathrm{qchisq}\left(\mathrm{pnorm}(3, 0, 1)^{\frac{1}{NR \cdot NC}}, \nu\right) \qquad NSD = 15.051$$

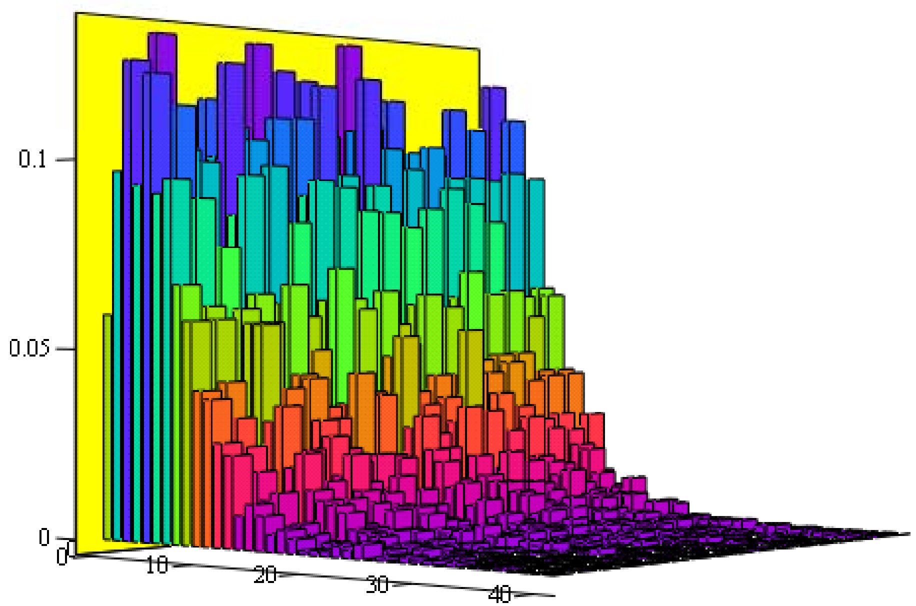
$$\mathrm{Limit}_T := \mathrm{mean}\left(\mathrm{submatrix}\left(\mu_{TLCI}, 0, T, 0, 0\right)\right) + NSD \cdot \sigma_{TLCI_T}$$

$$\mathrm{Limit3}_T := \mathrm{mean}\left(\mathrm{submatrix}\left(\mu_{TLCI}, 0, T, 0, 0\right)\right) + 3 \cdot \sigma_{TLCI_T}$$

Control Chart for TLCI Data



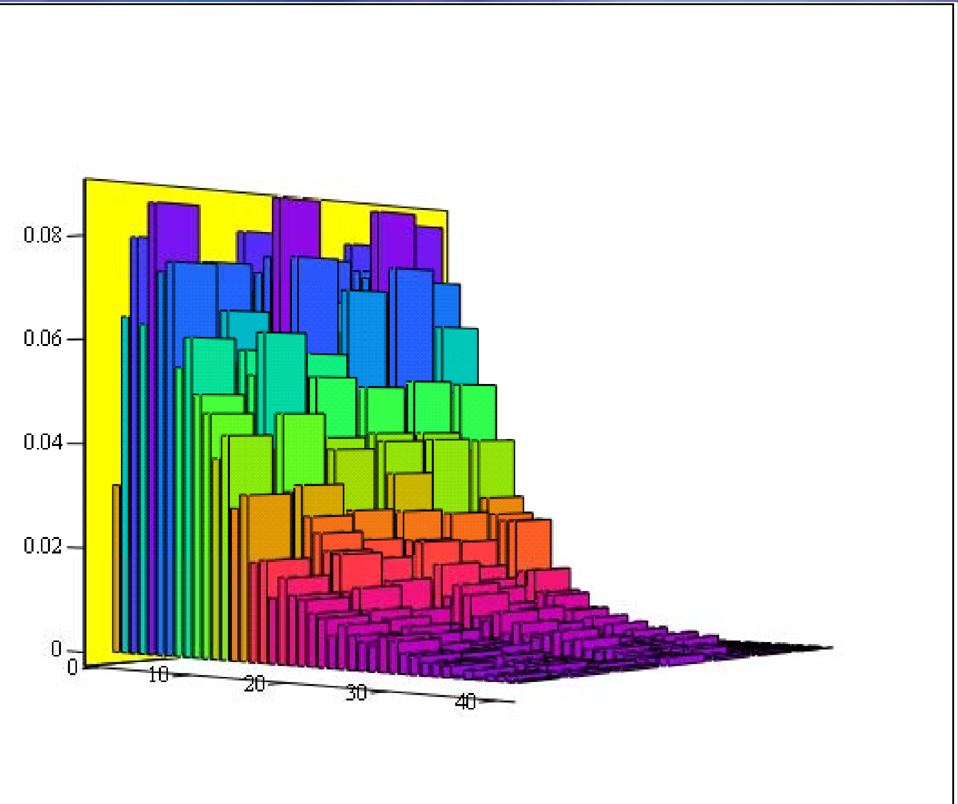
3D Chart of TLCI



TLCI Contact Resistance Distributions, 17 units

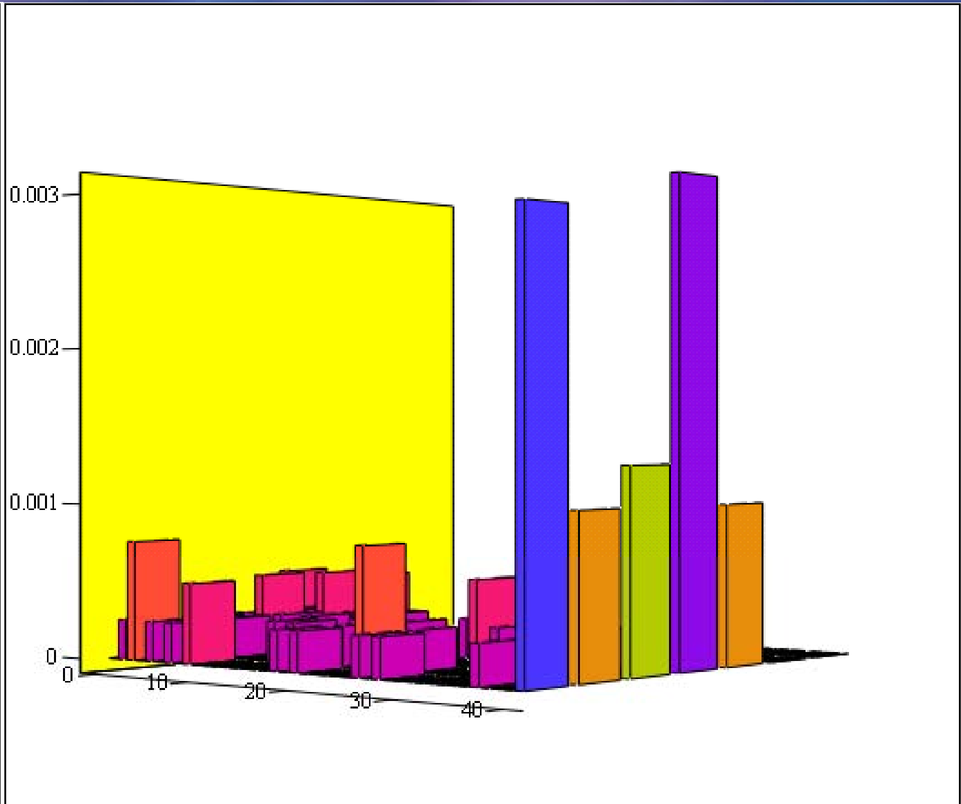
TLCI2

3D Charts of One BLCI Being Worked In



BLCI Contact Resistance Distributions, 6 units

BLCI2



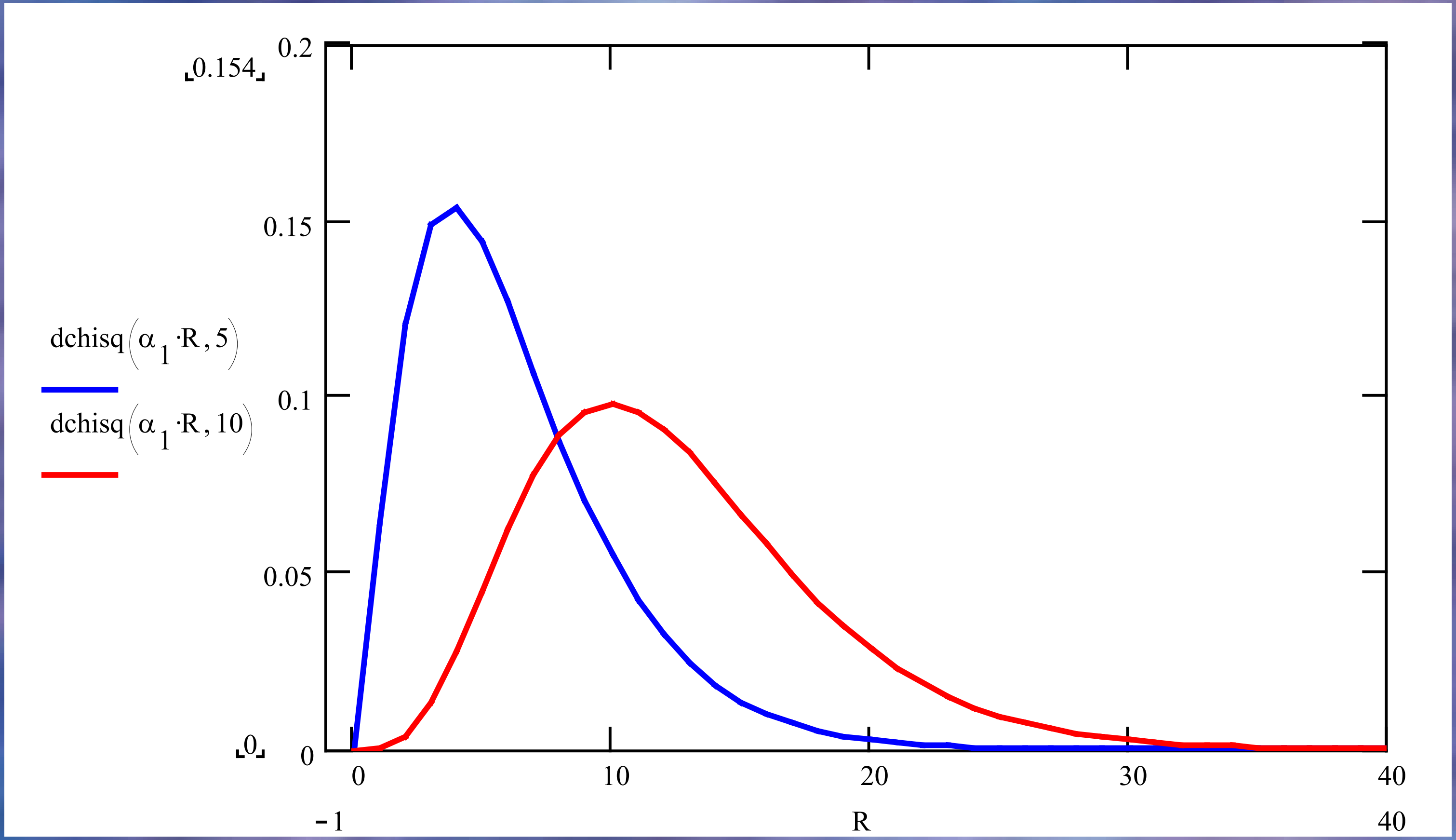
BLCI Contact Resistance Distributions, 6 units

BLCI3

Magnified view of 60 to 100 milliohm range. Last point = sum of all values greater than 100 mohms

Series Connection of multiple contact resistances

Placing two contacts in series gives a χ^2 distribution of degree 10:



Hypothetical Inferred Mechanism

- Radial tolerance, $r^2 = x^2 + y^2$ of x- & y- position random variables (tolerances) is χ^2 degree 2
- Distance between spring probe and via centers is described by the mating of two (χ^2 degree 2) distributions:
  1. The Spring probe position
  2. The via hole position in the PCB
- The sum or difference of two χ^2 degree 2 distributions is χ^2 degree 4
- Variation of the z- coordinate by depth of spring probe may be contributor of the fifth degree.

Summary

- Assumption that contact resistance distribution is described by a Gaussian function is incorrect and seriously underestimates the variance
- Control limits are very different when a non-Gaussian function is used as a basis for the control chart
- Contact force affects the contact resistance distribution by scaling the resistance variable
- Contact force does not affect the form or degree of the contact resistance distribution.
- Two spring-probe interface contact resistances in series are described by a χ^2 distribution of degree ten.
- The mechanism of variation may be related to the pattern tolerances in the connection planes