cadence

CONFIDENTIAL

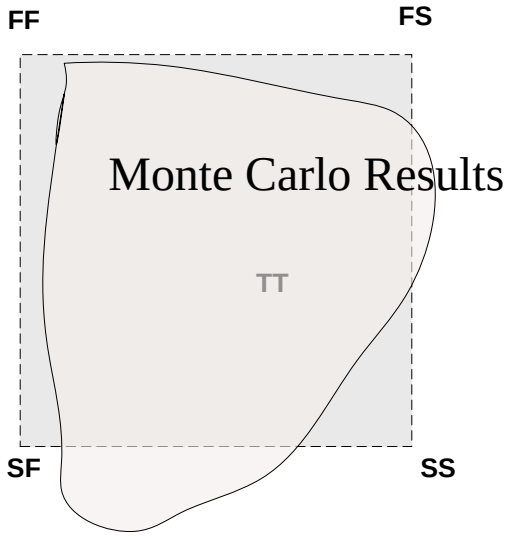
INVENTIVE

Monte Carlo Analysis

Leo Lv

02/08/2014

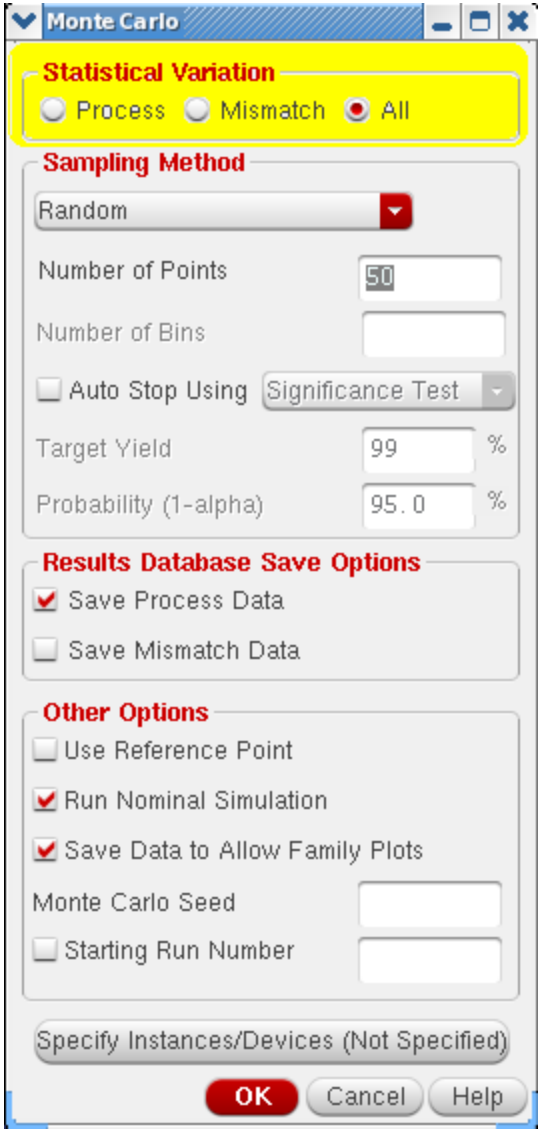
Monte Carlo VS Corner



MC gives an idea of yield

1. MC gives and idea of yield (or distribution). Corner is much more extreme and will give a too pessimistic result.
2. MC is more accurate and can get mismatch information.

Process & Mismatch: Definition




```
parameters rr=1000
statistics {
process {
vary rr dist=gauss std=20
}
}
```

```
parameters rr=1000
statistics
mismatch {
vary rr dist=gauss std=20
}
}
```

The distributions specified in the **process** block are sampled once per Monte Carlo iteration and are typically used to represent batch-tobatch or process variations.

The distributions specified in the **mismatch** block are sampled on a per subcircuit instance basis and are typically used to represent device-todevice mismatch for devices on the same chip.

In the case where the same parameter is subject to **both process** and **mismatch** variations, the sampled **process** value becomes the mean for the mismatch random number generator for that particular parameter.

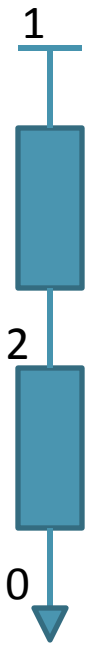
cadence

Process & Mismatch: Example

1. 如果一个参数，例如电阻值rr,只有process的变化，如下：

```
parameters rr=1000

statistics {
process {
vary rr dist=gauss std=20 percent=yes
}
}

r1 1 2 resistor r=rr
r2 2 0 resistor r=rr
v0 1 0 vsource dc=2 type=dc
```

MC分析结果，r1和r2均会变化，但变化同步，即V(2)始终为1V；



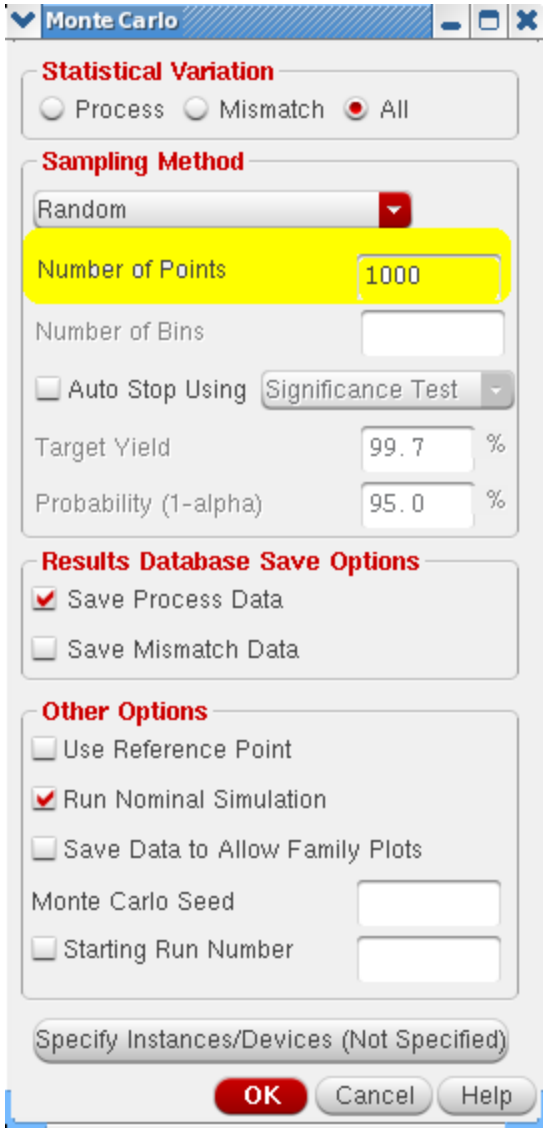
2. 如果rr只有mismatch的变化，如：

```
parameters rr=1000

statistics {
mismatch {
vary rr dist=gauss std=20 percent=yes
}
}

subckt res in out
r1 in out resistor r=rr
ends

x1 1 2 res
x2 2 0 res
```

MC结果，x1(r1)和x2(r2)变化不同步，即V(2)在1V上下分布取值；

mismatch: 参数rr处于subckt或inline subckt中，才会取值有变化；如果rr处于类似于1中本征器件中，则不会有mismatch的变化。而process的参数处于subckt(inline subckt)还是本征器件中，process的变化都会发生，且变化同步。

How Many Runs Needed: Basically…

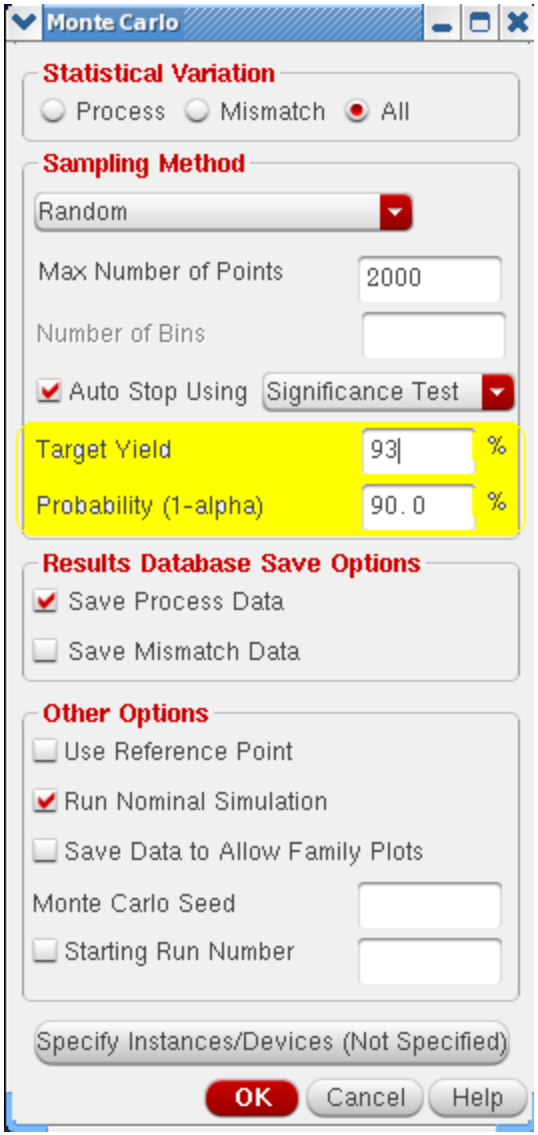


Basically, The number of runs depends on the accuracy you want to achieve on your yield estimates.

If you want to know whether the yield is over 99.7% (3 sigma), 1000 simulations needed…

cadence

How Many Runs Needed: Fortunately…



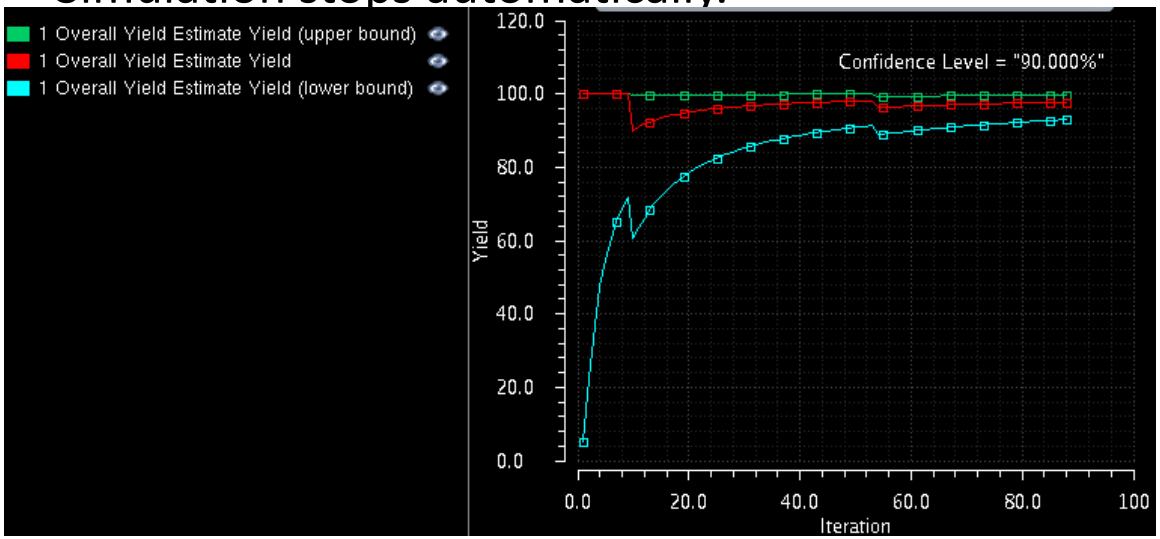
Fortunately, based on Confidence Level (Probability), number of runs can be reduced, when:

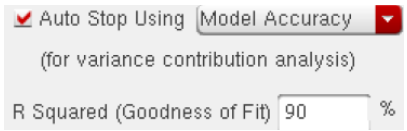
Upper bound of yield estimation < Target Yield

Or

Lower bound of yield estimation > Target Yield

Simulation stops automatically.

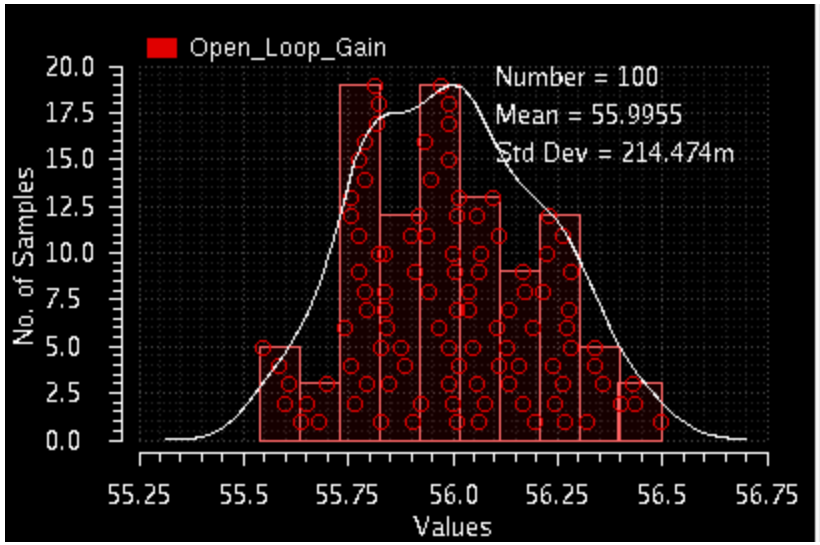


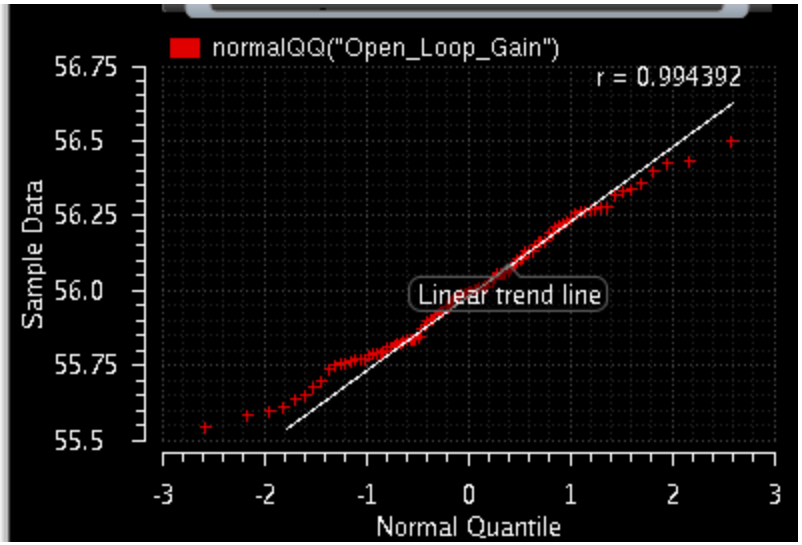


Auto Stop Using Model Accuracy: This option applies a stopping criteria based on the accuracy of the modeling of variation in the outputs, which is due to statistical variation.

How Many Runs Needed: However…

However, in many case, **mean** and **sigma** are of interest.





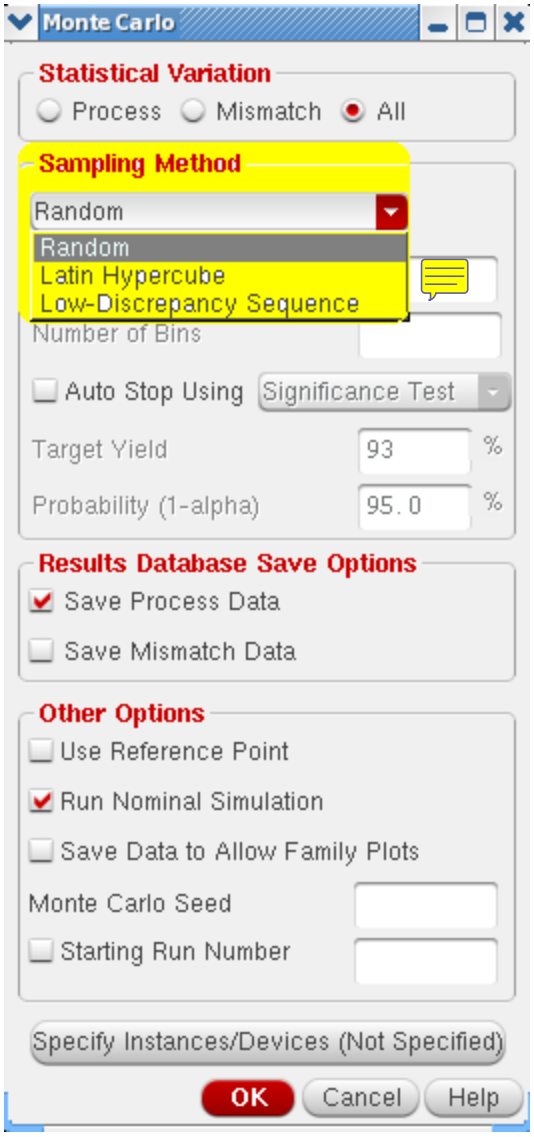
For normal distribution:

Distribution of X	Probability
[Mean-1*Sigma, Mean+1*Sigma]	68%
[Mean-2*Sigma, Mean+2*Sigma]	95%
[Mean-3*Sigma, Mean+3*Sigma]	**99.7%**

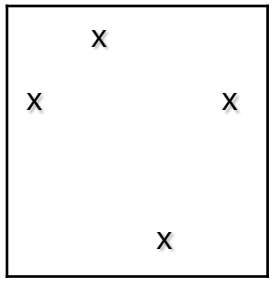
If 3-sigma range is within specification, **99.7% yield** is guaranteed!

cadence

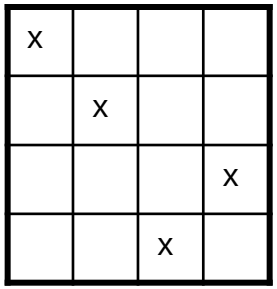
How Many Runs Needed: So…



So, other sampling method could be used to the same distribution with less sampling point.



Standard Random Sampling



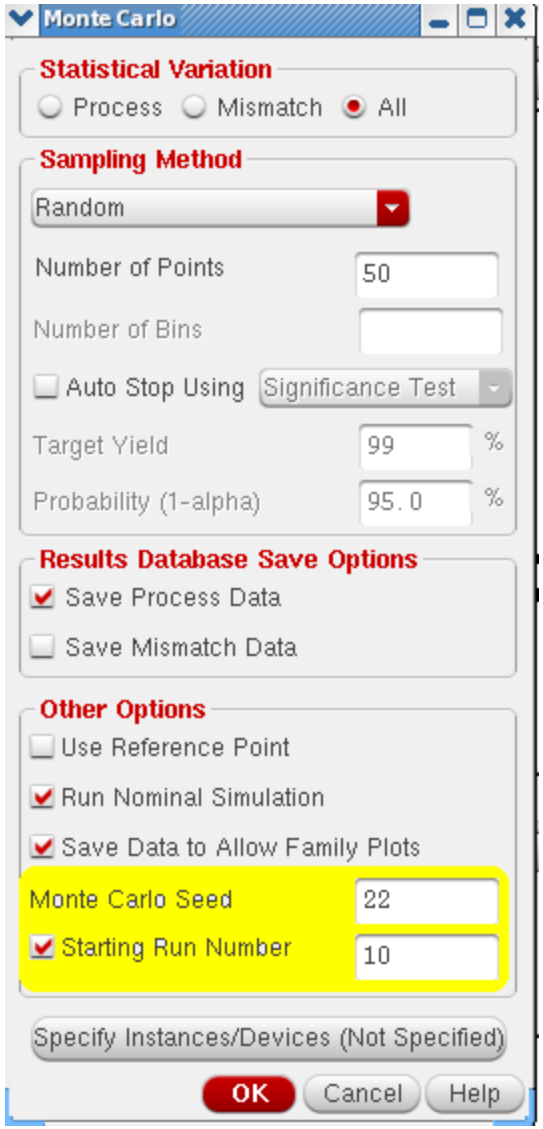
LHS sampling (need to store samples)

Sampling Method	Number of Runs	Sigma
Random	100	16.5687
Random	1000	20.1577
LHS	100	19.8644
LHS	1000	19.7874

LDS:
Mean: slower than LHS; Sigma: faster than LHS.
Could use Target Yield Stopping Criteria.

cadence

How to Reproduce: Seed & firstrun

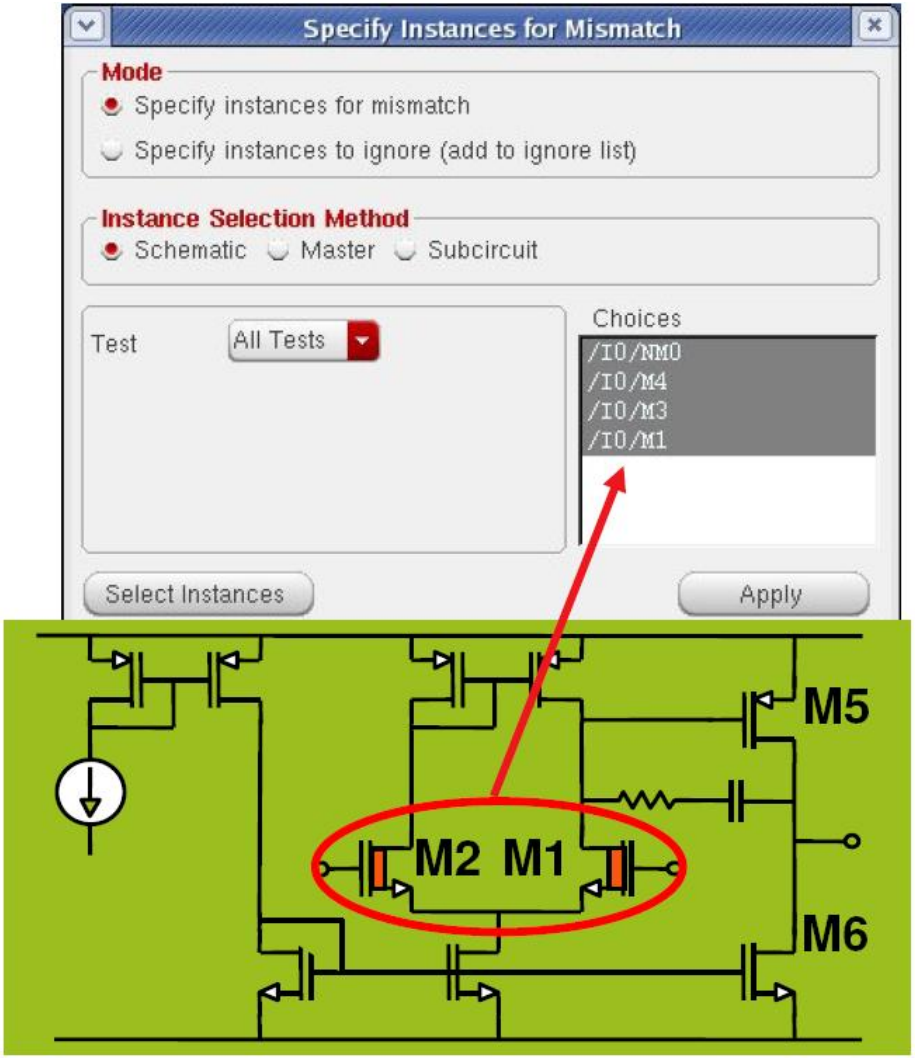


By specifying the same seed, you can reproduce a previous experiment. If you do not specify a seed, the value 12345 is used.

By specifying the first iteration number and the same value for seed, you can reproduce a particular run or sequence of runs from a previous experiment (for example, to examine an outlier case in more detail.)

cadence

Mismatch: All or Selected?



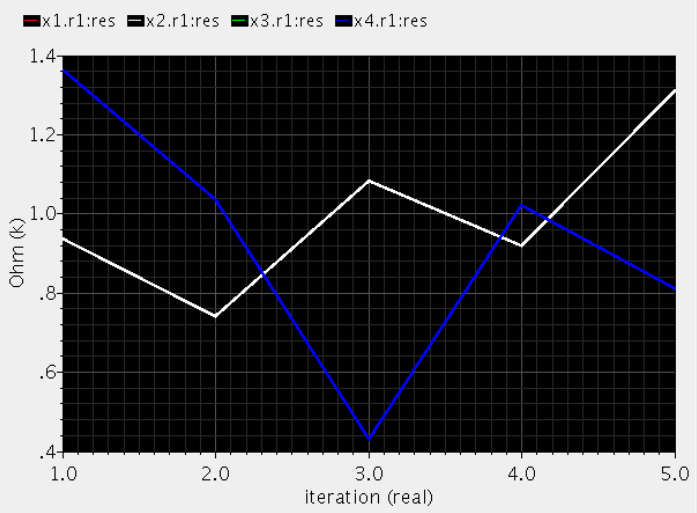
Default, **Mismatch** will be run on **All Instances/Devices**.

Furthermore, **Mismatch** of only **Selected Device/Instance** could be considered or ignored in MC.

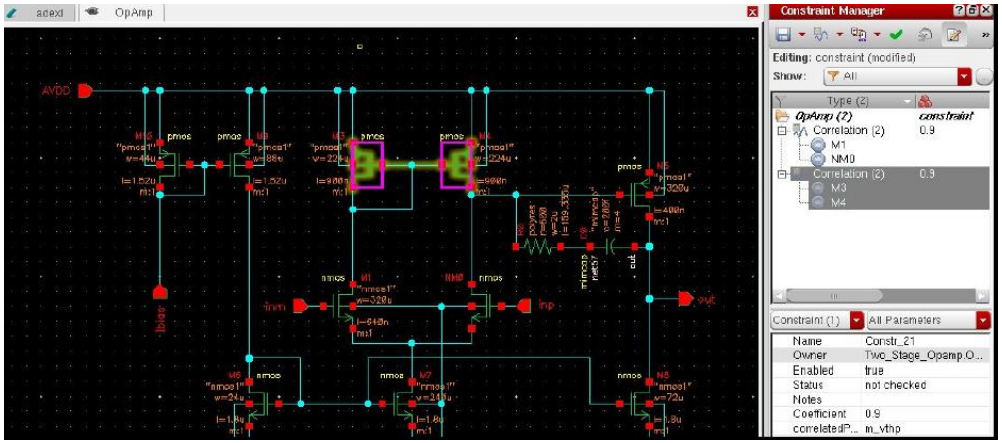
cadence

How to Correlate?: cc=[-1:1]

```
parameters rr=1000
statistics {
mismatch {
vary rr dist=gauss std=20 percent=yes
}
}

statistics {
correlate dev=[x1 x2] param=[rr] cc=1
correlate dev=[x3 x4] param=[rr] cc=1
}

subckt res in out
r1 in out resistor r=rr
ends

x1 1 0 res
x2 2 0 res
x3 3 0 res
x4 4 0 res
```



Res in X1 and X2 are exactly the same;
Res in X3 and X4 are exactly the same;

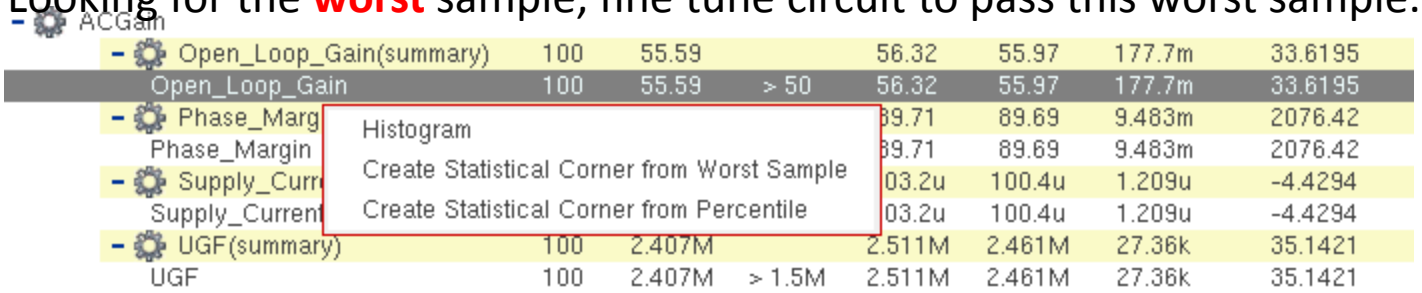


Correlation could also be set in Schematic: (M1, M2), param: vth, coefficient = 0.9;

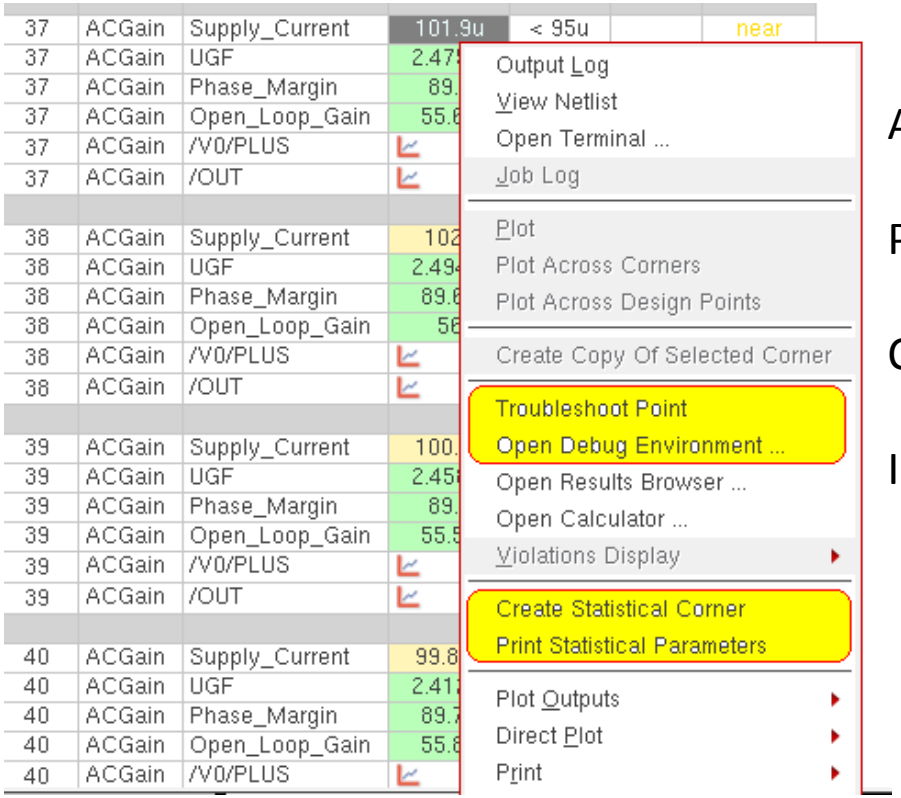
cadence™

How to Simplify: Worst or Specified

Looking for the **worst** sample, fine tune circuit to pass this worst sample.



Percentile is most least worst sample number.



Anyone of MC samples could be **Specified** to:

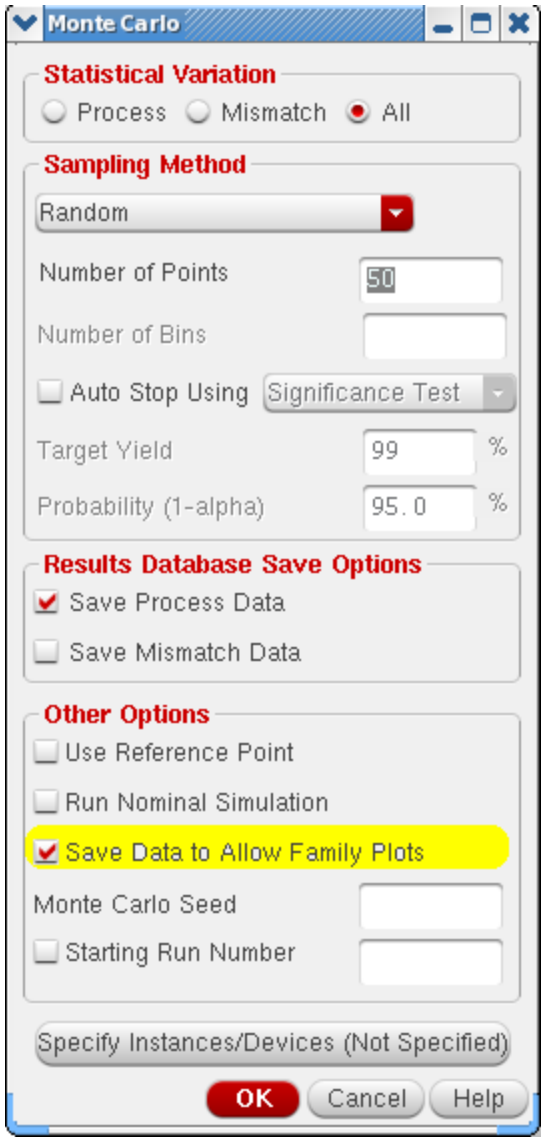
Print the statistical parameter of the corner;

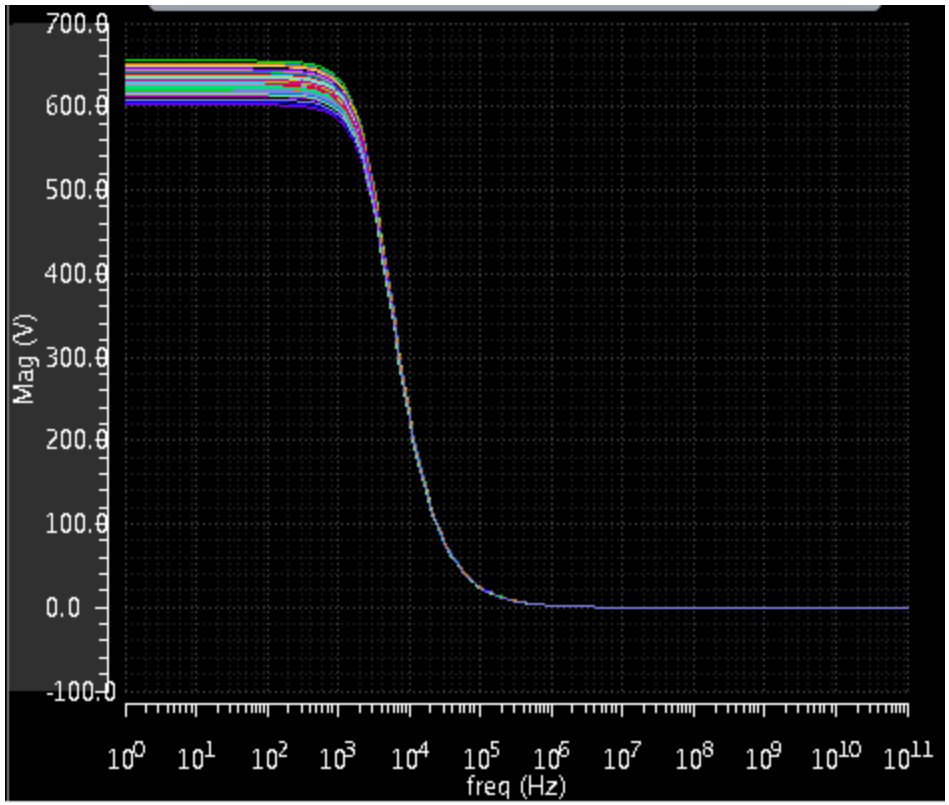
Create this MC sample to a single coner;

In-line debug this corner.

cadence

Results: Family Plot

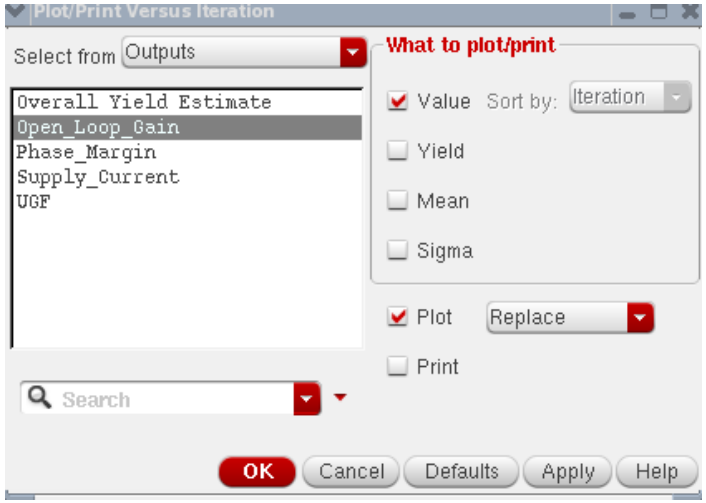


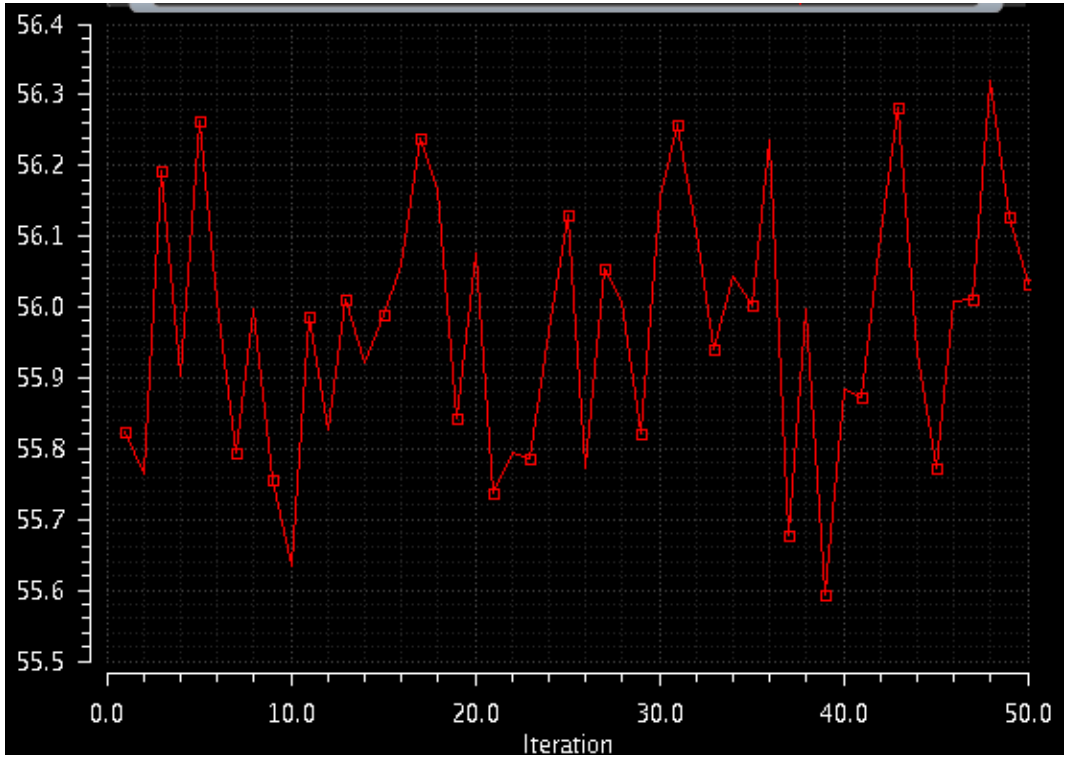


cadence™

Results: Plot/Print Versus Iteration

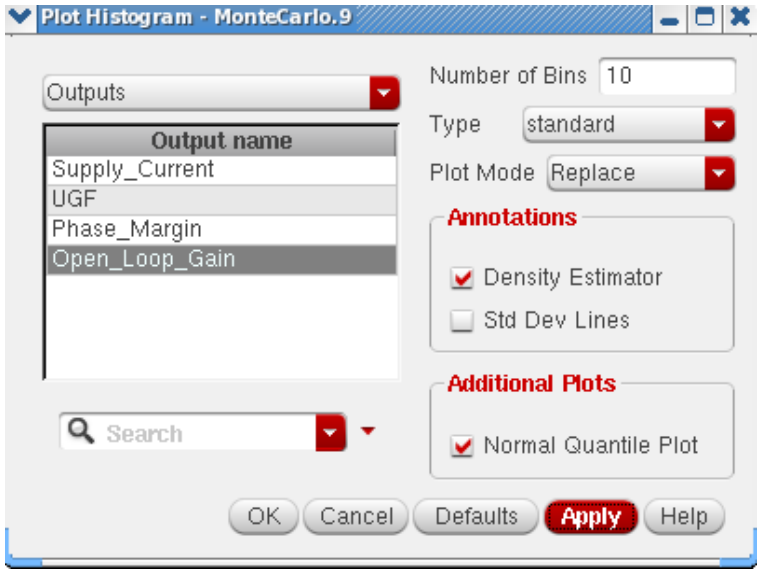
You can print/plot outputs and parameters Vs iterations. In addition, you can also plot or print the mean and sigma values for outputs.



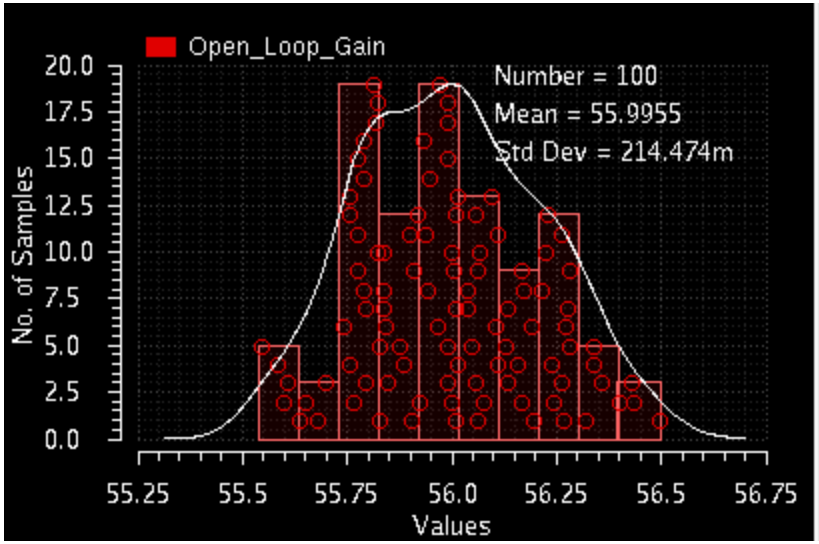


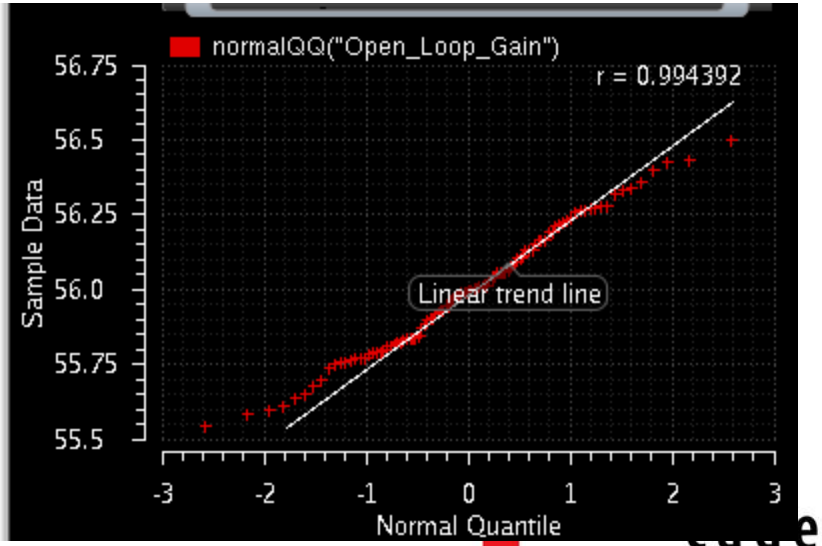
cadence

Results: Histograms



Histograms and Normal Quantile for the outputs and statistical parameters from Monte Carlo results can be ploted.





Results: Print Correlations

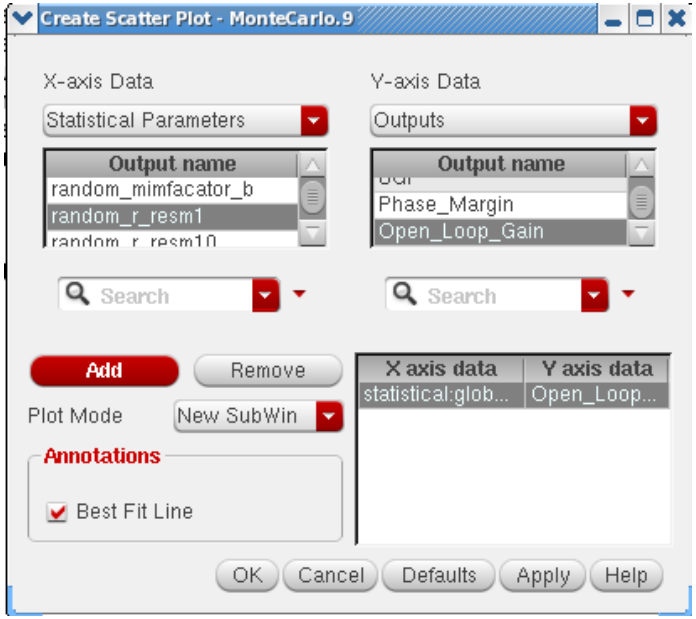
To print a table showing the correlation coefficients of each parameter with each of the other parameters sorted from most correlated to least correlated for each combination of parameters, do one of the following:

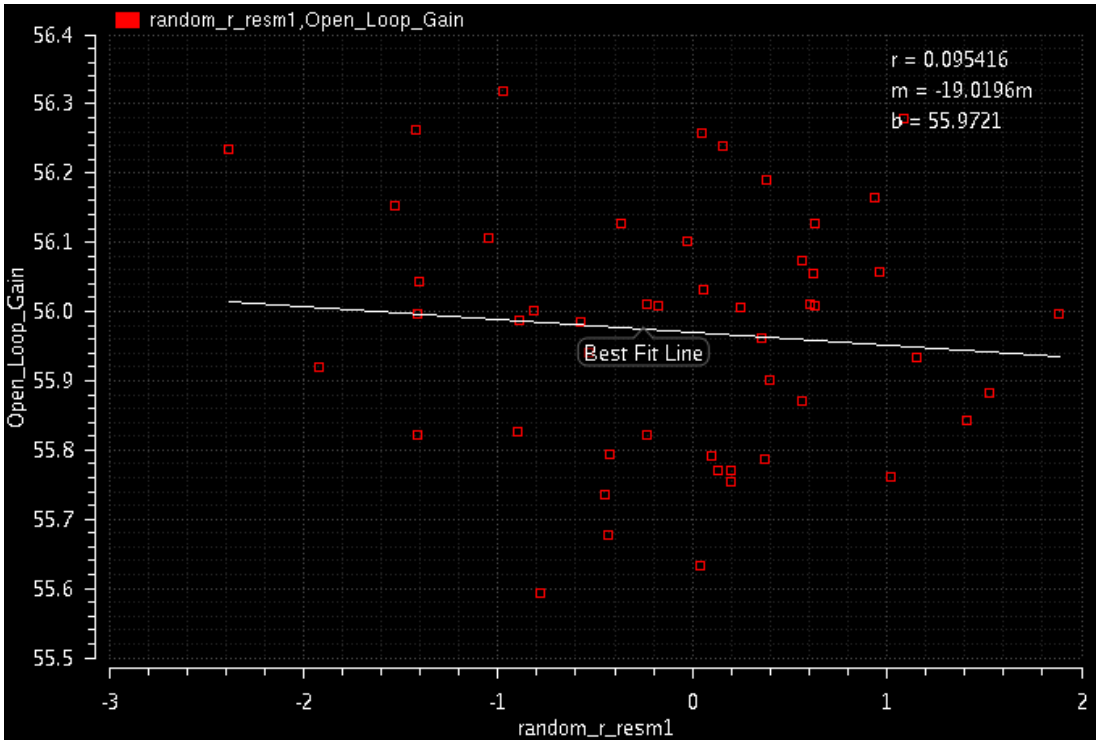
param #1	param #2	corr-coef	mean1	stdev1	mean2	stdev2	size
Open_Loop_Gain	Phase_Margin	-8.8258e-01	5.5974e+01	1.7769e-01	8.9690e+01	9.4828e-03	50
Phase_Margin	Open_Loop_Gain	-8.8258e-01	8.9690e+01	9.4828e-03	5.5974e+01	1.7769e-01	50
Phase_Margin	UGF	-5.8355e-01	8.9690e+01	9.4828e-03	2.4614e+06	2.7358e+04	50
Supply_Current	UGF	5.6272e-01	1.0035e-04	1.2087e-06	2.4614e+06	2.7358e+04	50
UGF	Phase_Margin	-5.8355e-01	2.4614e+06	2.7358e+04	8.9690e+01	9.4828e-03	50
UGF	Supply_Current	5.6272e-01	2.4614e+06	2.7358e+04	1.0035e-04	1.2087e-06	50
random14	random_mimfacator_b	-5.4720e-01	-4.6825e-02	1.0441e+00	1.8636e-01	1.0370e+00	50
random_mimfacator_b	random14	-5.4720e-01	1.8636e-01	1.0370e+00	-4.6825e-02	1.0441e+00	50

cadence

Results: Scatter Plot

A scatter plot could depict the relationship between the pairs of outputs or parameters in the Monte Carlo results.





r shows the correlation coefficient. The value of **r** ranges between -1.0 and 1.0.

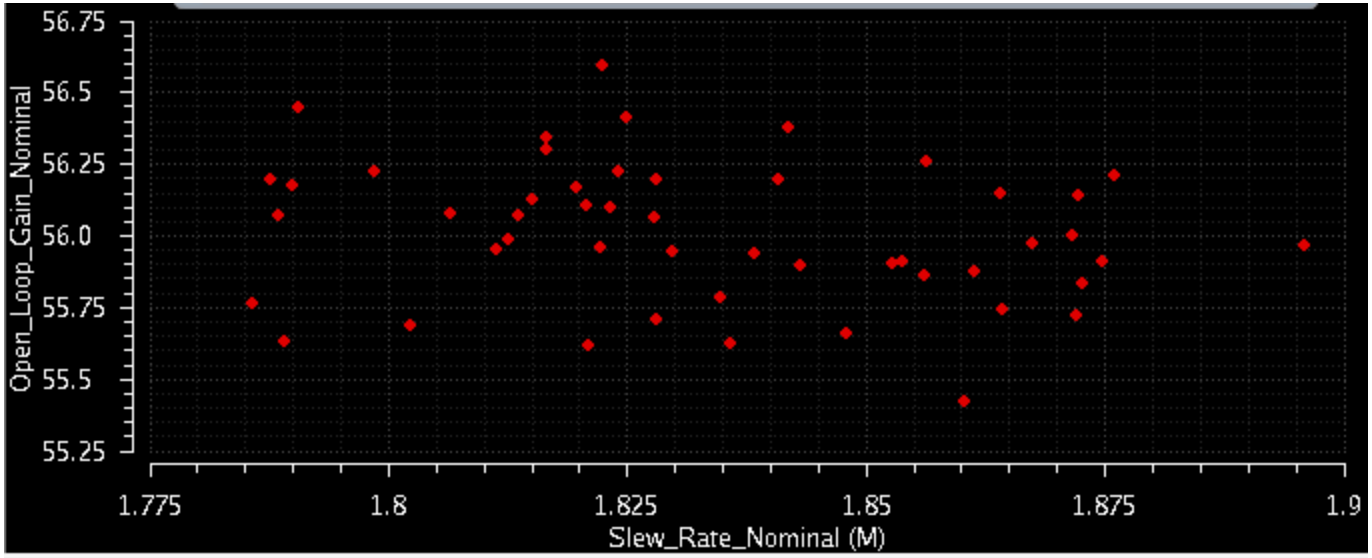
b is the constant value and **m** is the value of slope in the linear equation describing the best fit line of the plotted data. The linear equation that is used to find the best fit line is $y = \mathbf{b} + \mathbf{m}x$.

cadence

Results: Sensitivity

	Average(Mag)	Slew_Rate Nominal (Top 100.0%)	Supply_Current Nominal (Top 100.0%)	UGF Nominal (Top 100.0%)	Phase_Margin Nominal (Top 100.0%)	Open_Loop_Gain Nominal (Top 100.0%)
Slew_Rate_Nominal	1		N.A.	N.A.	N.A.	N.A.
Open_Loop_Gain_Nominal	0.67211	N.A.				
Phase_Margin_Nominal	0.67723	N.A.				
UGF_Nominal	0.66554	N.A.				
Supply_Current_Nominal	0.52186	N.A.				

Sensitivity Tab could be used to creat scatter-like plot between specs from 2 different testbenches. For example: “Slew_Rate” comes from “Slew_Rate” testbench, “Open_Loop_Gain” comes from “ACGain” testbench. Double-clicking the boxes in the table, scatter-like plot can be got.



cadence

Use Machine Farms

- ADE XL distributes Monte Carlo on a farm of machines or processors based on
  - # of tests
  - # of corners
  - # of Monte Carlo samples
- Example: 2 tests, 3 corners (+nominal), 100 samples, 20 processors
  - Total sims: 800
  - Sims / machine: 40 simulations

END