ERL, COM, and RL with DOE

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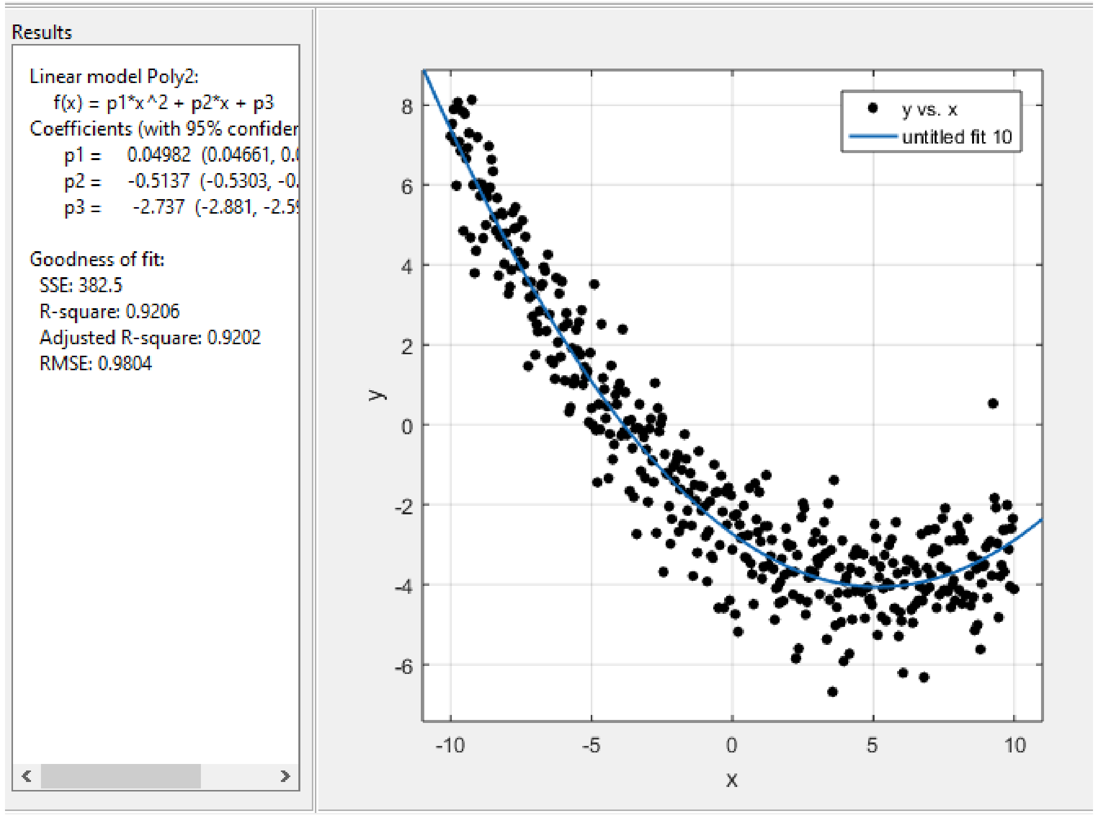
ToC

- ❑ Design of experiment (DOE) for simulation
- ❑ ERL prediction from package parameters
- ❑ DOE for channels with package parameters
- ❑ Analysis of Channel DOE data

Fit example to understand some basic terms in MATLAB

X *is the independent parameters variables*
Y *is the dependent parameter or in our case simulated COM results*



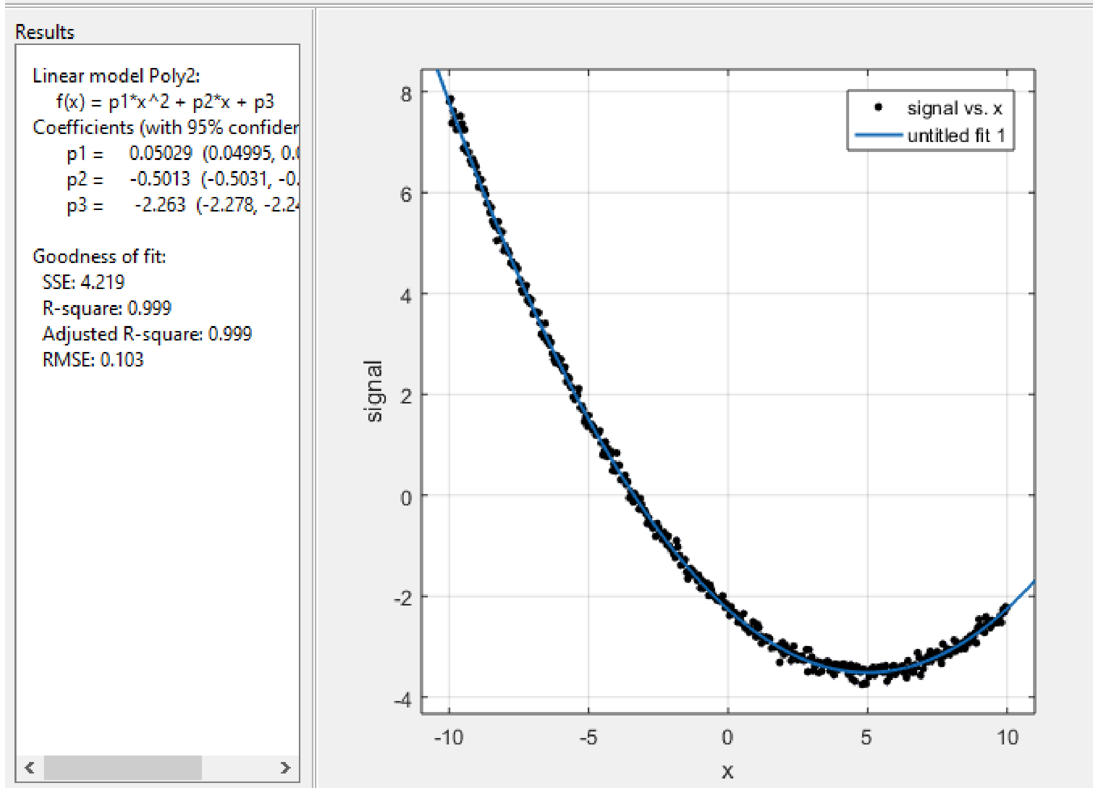
MATLAB Code Example

```
f = @(x) 0.05*(x).^2-.5*(x) -2.2 ;
x=-10:.05:10;
noise = randn(1,length(x)*1) - .5;
signal = f(x)+noise;
cftool(x,signal)
```

- R-squared is used determent the quality of correlation
  - It is called the "coefficient of determination"
  - R^2 = 1 is the best
  - It is the proportion of the x variable variance which is predictable.
  - In this example R^2 is 0.9206
  - i.e. data is 92% correlated to the fit
- RMSE is the RMS error
  - one way to interpret is:
    - The equation is, on the average, +/- 0.9804 accurate
    - The fit is predicting signal values between 8 and -6.
- The fit is an equation called f(x) at left
  - With fitted p1, p2, and p3 coefficients when are nearly the same as in the MATLAB code above

Better fit does not have zero uncertainty

***X** is the independent parameters variables*
***Y** is the dependent parameter or in our case simulated COM results*

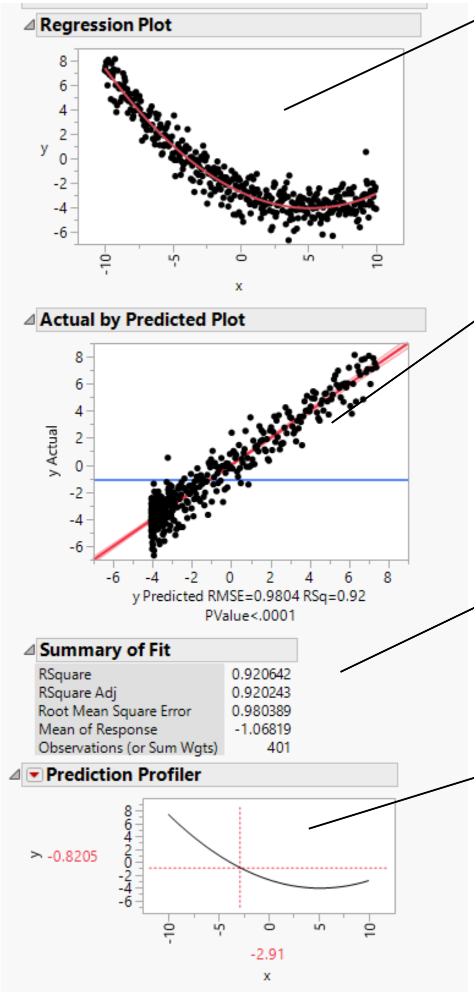


<u>MATLAB Code Example</u>

```
f = @(x) 0.05*(x).^2-.5*(x) -2.2 ;
x=-10:.05:10;
noise = randn(1,length(x)*1) - .5;
signal = f(x)+noise*0.1;
cftool(x,signal)
```

- ❑ Noise in the experiment is reduced by a factor of 10
  - In the case 99.9 % correlated to the fit
- ❑ RMSE is not zero!
  - one way to interpret is:
    - The equation, is on the average, +/- 0.1 accurate
    - The fit is predicting signal values between 8 and -6.

View the same data in JMP



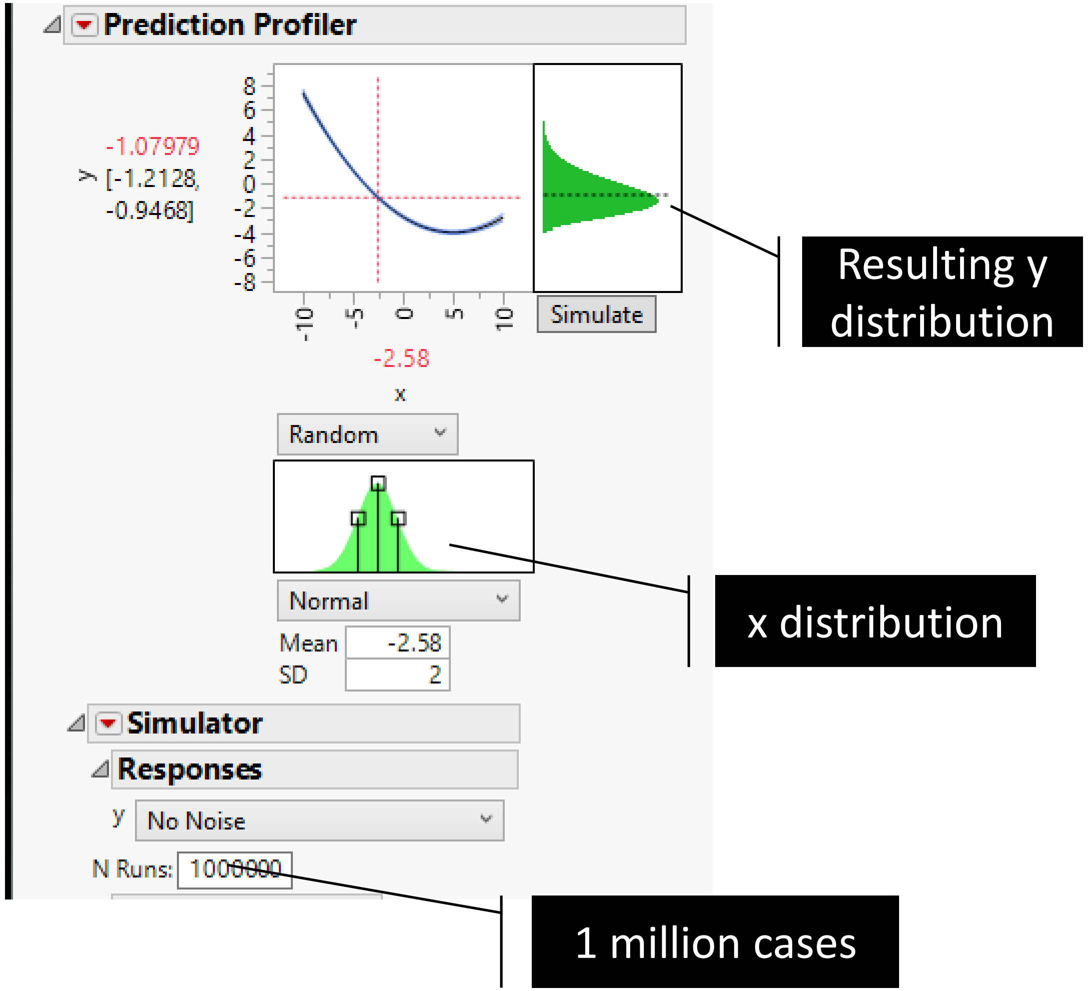
- ❑ Fit equation (red) plotted with data
- ❑ This equation is complicated for more than 1 “x” variable

- ❑ Fit equation plotted vs data is graphic representation for the ability to predict results base on new x data
- ❑ A perfect plot would be a 45 degree line

- ❑ Fit quality data as shown in previous slides

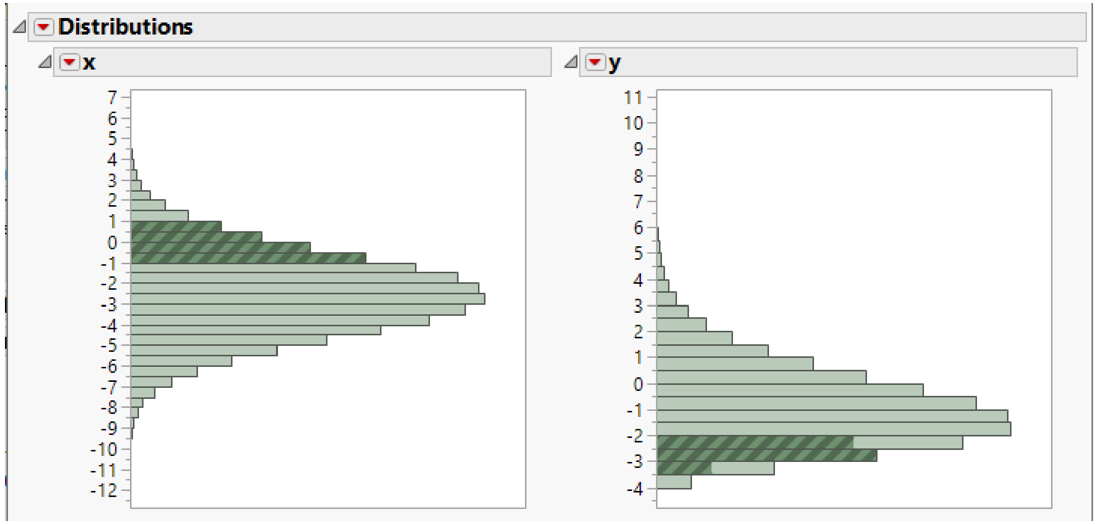
- ❑ Plot of predicted y verses the new “x” values
- ❑ Normally there are number of x valuables
- ❑ The graph is useful for interactively or by inspection determining the effect of moving an “x” variable one way or another

Predicting simulation for millions of combinations of “x” values



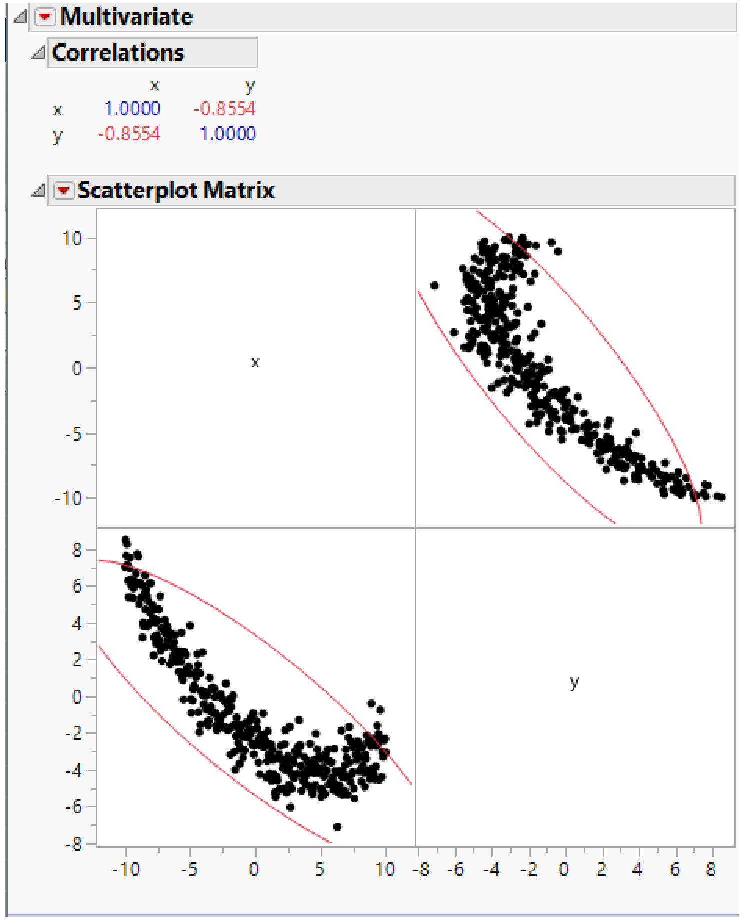
- ❑ From the last slide we have a prediction formula for y as function of x.
- ❑ If we assign a distribution of for “x” we can determine the resulting y distribution
- ❑ In this case we are doing a 1 million cases

We use linked distributions to determine the effect of the range of x on y



- In this case the all the value of x are between -1 and 1 are selected
- The dark areas in y correspond the selected cases of x

Multivariate plots are a rough first step



- ❑ The diagonal is the variable name
  - In this case x and y
- ❑ The off diagonal is x plotted vs y and vice versa.
  - For more variables all possible plots (linearly) taken 2 at a time are plotted
- ❑ The red ellipses are the linear correlation factors
- ❑ Multivariate plots can suggest what to investigate

Using DOE methods to perform simulation prediction

- Determine x parameters
- Determine collection of values for x parameter
- Simulate y parameters for the collection of x parameters
- Perform a fit for the collection of x parameters and simulated y parameters (determine fit equation)
- Use fit equation to predict performance for a much larger range of x parameter values

Checking expectations

Determine x parameters

Determine collection of values for x parameter

Simulate y parameters for the collection of x parameters

Perform a fit for the collection of x parameters and simulated y parameters (determine fit equation)

Use fit equation to predict performance for a much larger range of x parameter values

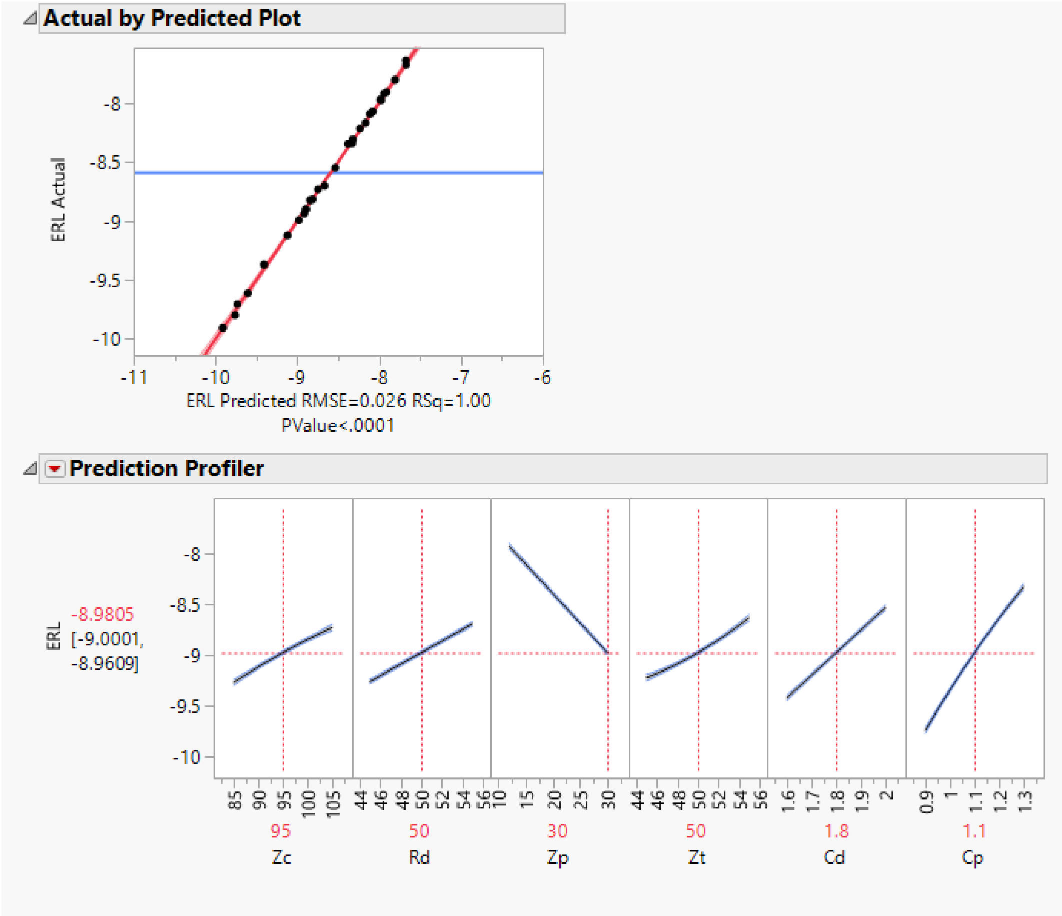
Do the results make sense?

Effective Return Loss Experiment

- X variables are COM package parameters centered on D2.1 COM table
- Y is the computed ERL for the specified Zt
- From mellitz_060717_3cd_02_adhoc

x						y
Zc Ohms	Rd Ohms	Zp Ohms	Zt Ohms	Cd 1e-10 F	Cp 1e-10 F	ERL dB
95	50	30	50	1.8	1.1	-9.0
95	50	30	50	1.8	1.1	-9.0
96	51	30	50	1.8	1.1	-8.9
96	51	30	50	1.8	1.1	-8.9
94	48	30	50	1.8	1.1	-9.1
94	48	30	50	1.8	1.1	-9.1
85	45	12	55	2	0.9	-7.9
95	55	30	55	1.6	1.3	-8.2
95	45	30	50	1.6	0.9	-10.5
85	45	30	55	2	1.3	-8.0
105	45	12	45	1.6	1.3	-8.6
105	55	12	45	2	1.3	-6.9
85	50	30	55	1.8	0.9	-9.7
105	55	30	45	2	0.9	-8.8
105	45	30	45	1.8	1.1	-9.4
85	45	12	45	1.6	0.9	-9.9
85	55	12	55	2	1.3	-6.4
85	55	12	45	2	0.9	-8.1
85	45	30	45	2	0.9	-10.2
105	50	12	55	2	1.1	-7.0
105	45	12	45	2	0.9	-8.8
95	50	30	45	2	1.3	-8.2
85	45	30	45	1.6	1.3	-9.6
105	55	30	50	1.8	1.3	-7.8
105	45	30	55	1.6	1.3	-8.3
105	55	12	55	1.6	0.9	-8.3
85	50	12	50	1.6	1.3	-7.9
95	55	21	55	2	0.9	-8.1
85	45	21	55	1.6	1.1	-8.9
105	45	30	55	2	0.9	-8.9
105	45	21	50	2	1.3	-7.6
95	55	12	45	1.6	1.1	-8.3
85	55	12	55	1.6	0.9	-8.7
85	55	30	50	2	1.1	-8.5
105	50	21	45	1.6	0.9	-9.8
85	55	21	45	1.8	1.3	-8.0
95	45	12	55	1.8	1.3	-7.2
85	45	12	45	2	1.3	-7.7
85	55	30	45	1.6	0.9	-10.5
105	45	12	55	1.6	0.9	-8.7

ERL fit is very closely tied to package parameters . RMS err is 0.026 dB



ERL Prediction Equation

(-22.9371813122759) + 0.0180921056094042 * Zc + 0.0568325927712985 * Rd +-0.0589245893510021 * Zp + 0.0680408952372635 * Zt + 2.29551955640816 * Cd+3.2956494591755 * Cp + (Zc - 94.5) * ((Zc - 94.5) * -0.000232738951785374) + (Zc - 94.5) * ((Rd - 49.575) * 0.000677332168959554) + (Zc - 94.5) * ((Zp-22.125) * 0.00111325213652863) + (Zc - 94.5) * ((Zt - 49.875) *0.000238892775679064) + (Rd - 49.575) * ((Zt - 49.875) * -0.00396965785082018) + (Zp - 22.125) * ((Zt - 49.875) * -0.00103701659658663) + (Zt - 49.875) * ((Zt-49.875) * 0.00196432071730769) + (Zc - 94.5) * ((Cd - 1.805) *-0.0153551291854686) + (Rd - 49.575) * ((Cd - 1.805) * 0.0130086172404367) + (Zp - 22.125) * ((Cd - 1.805) * -0.00883864973187424) + (Zt - 49.875) * ((Cd - 1.805) * -0.00345591899210246) + (Zc - 94.5) * ((Cp - 1.095) * -0.0130281234843095) + (Rd - 49.575) * ((Cp - 1.095) * -0.00811355551678069) + (Zp - 22.125) * ((Cp -1.095) * 0.0321656771693624) + (Cd - 1.805) * ((Cp - 1.095) * -0.841281482352236) + (Cp - 1.095) * ((Cp - 1.095) * -1.47094118647978)

What is ERL for the COM Package

- For 30 mm package (Zp) ERL is 9 dB (ERL dB is negated here)
- For 12 mm package (Zp) ERL is 7.9 dB
- A simple RL spec could be ERL > 7.9 dB
  - But is this good enough alone?
  - Or is it even helpful?

So all we can say so far is

- ERL can be accurate predicted for COM package parameters
- Good for determine incremental device/package design improvements because ERL is number not a vector or numbers
- ERL is tightly correlated to physical interconnect design choices
- Next let's look at COM and ERL for package and channels
  - Note: Av is adjusted for transmitter parameters
    - Av and Afe = 0.004.*Rd+.215;
    - Ane = 0.006.*Rd+.304;

Channel Key for KR

number	Channel designator
1	'5F3N--Ch1_10_5F3N_t
2	'TEC_STRADAWhisper11p75in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper11p75in_THRU_G14G15-07212016
3	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_Nom_thru
4	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_HzLzHz_thru
5	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_LzHzLz_thru
6	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_Nom_thru
7	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_HzLzHz_thru
8	'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_LzHzLz_thru
9	'5F3N--Ch4_20_5F3N_t
10	'TEC_STRADAWhisper27in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper27in_THRU_G14G15_07202016
11	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_Nom_thru
12	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_HzLzHz_thru
13	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_LzHzLz_thru
14	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_Nom_thru
15	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_HzLzHz_thru
16	'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_LzHzLz_thru
17	'5F3N--Ch8_30_5F3N_t
18	'TEC_STRADAWhisper40in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper40in_THRU_G14G15_07202016
19	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_Nom_thru
20	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_HzLzHz_thru
21	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_LzHzLz_thru
22	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_Nom_thru
23	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_HzLzHz_thru
24	'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_LzHzLz_thru
25	'20dB_HghZ--20dB_HighZ_thru
26	'20dB_HghZ_Nom_HighZ--20dB_HighZ_Nom_HighZ_thru
27	'30dB_HighZ--30dB_HighZ_thru

“X” table for each of the 27 channels

Zc Tx	Zc Rx	Rd Tx	Rd Rx	Cp	Cd	Zt	Zp
105	105	45	55	1.1	1.8	50	30
95	95	45	55	1.1	1.8	50	30
95	105	50	50	1.1	1.8	50	30
105	85	55	50	1.1	1.8	50	30
105	85	45	55	1.1	1.8	50	30
85	105	45	55	1.1	1.8	50	30
105	105	55	45	1.1	1.8	50	30
85	85	55	45	1.1	1.8	50	30
85	85	45	50	1.1	1.8	50	30
105	95	45	45	1.1	1.8	50	30
105	85	50	45	1.1	1.8	50	30
85	105	55	45	1.1	1.8	50	30
85	85	50	55	1.1	1.8	50	30
95	85	45	45	1.1	1.8	50	30
95	85	55	55	1.1	1.8	50	30
105	95	51.05	55	1.1	1.8	50	30
105	105	45	45	1.1	1.8	50	30
85	105	55	55	1.1	1.8	50	30
85	105	45	45	1.1	1.8	50	30
105	105	55	55	1.1	1.8	50	30
85	95	55	50	1.1	1.8	50	30
95	95	50	50	1.1	1.8	50	30
94	94	49	49	1.1	1.8	50	30
96	96	51	51	1.1	1.8	50	30
94	94	51	51	1.1	1.8	50	30
96	96	49	49	1.1	1.8	50	30

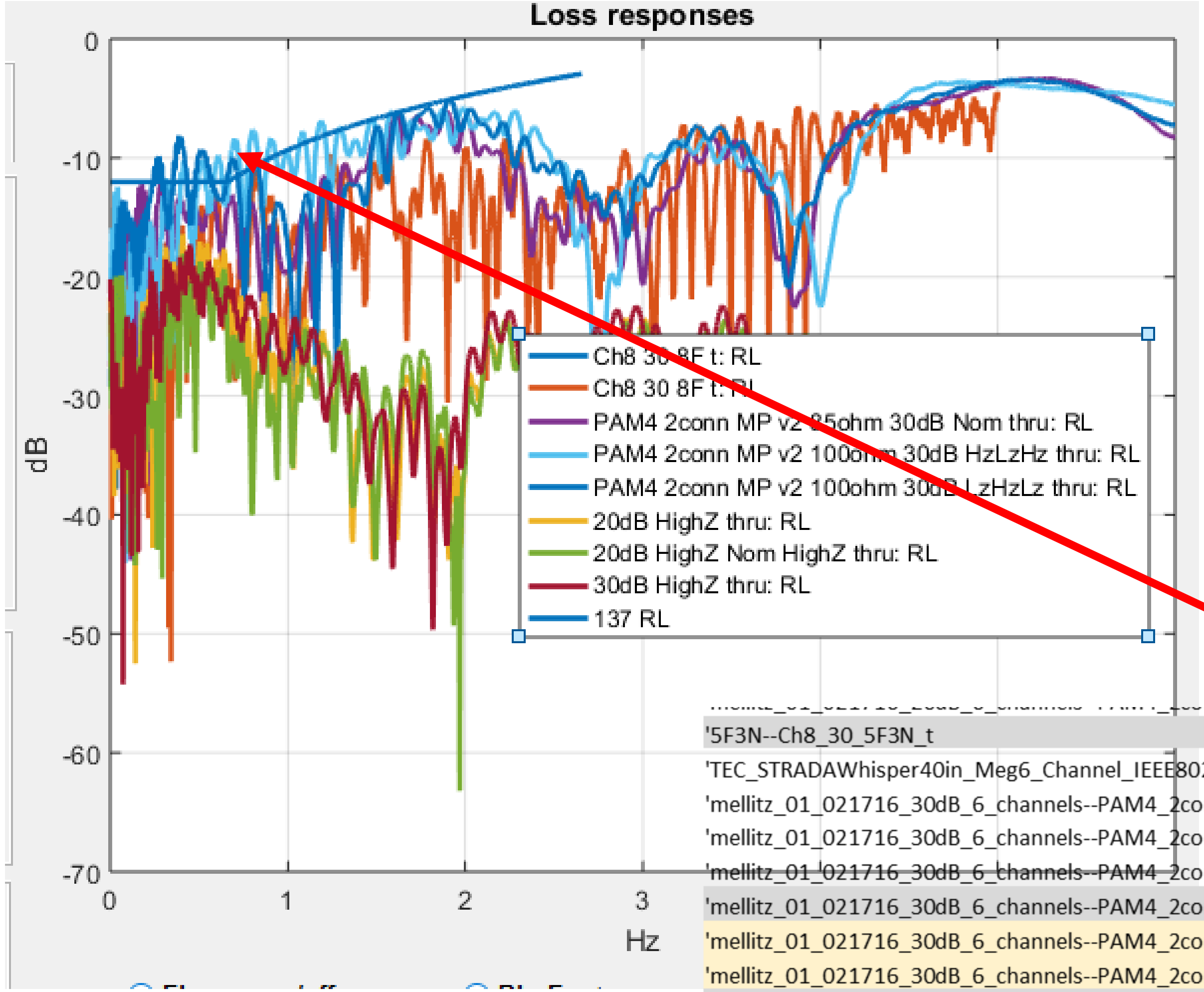
Highlight COM between 3dB and 4 dB and channel ERL > 8 dB

Channel	COM	ERL11	ERL22	com min from D2.1 delta
'5F3N--Ch1_10_5F3N_t	6.07	-10.69	-11.62	0.49
'TEC_STRADAWhisper11p75in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper11p75in_THRU_G14G15-07212016	6.75	-13.76	-13.34	0.23
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_Nom_thru	5.25	-8.79	-5.68	0.47
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_HzLzHz_thru	5.53	-8.98	-5.36	0.56
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_100ohm_10dB_LzHzLz_thru	4.57	-7.11	-4.94	0.61
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_Nom_thru	7.19	-10.45	-7.39	0.53
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_HzLzHz_thru	6.67	-9.03	-6.01	0.51
'mellitz_01_021716_10dB_6_channels--PAM4_2conn_MP_v2_85ohm_10dB_LzHzLz_thru	6.64	-8.28	-6.07	0.72
'5F3N--Ch4_20_5F3N_t	5.60	-10.31	-13.27	0.34
'TEC_STRADAWhisper27in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper27in_THRU_G14G15_07202016	4.78	-14.48	-13.71	0.15
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_Nom_thru	5.87	-10.81	-7.25	0.53
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_HzLzHz_thru	5.37	-11.29	-6.67	0.35
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_100ohm_20dB_LzHzLz_thru	5.27	-9.19	-6.37	0.66
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_Nom_thru	6.71	-12.33	-8.33	0.46
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_HzLzHz_thru	6.20	-10.74	-7.10	0.43
'mellitz_01_021716_20dB_6_channels--PAM4_2conn_MP_v2_85ohm_20dB_LzHzLz_thru	5.99	-10.48	-7.00	0.50
'5F3N--Ch8_30_5F3N_t	3.07	-11.25	-13.76	0.28
'TEC_STRADAWhisper40in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper40in_THRU_G14G15_07202016	1.68	-14.90	-14.08	0.18
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_Nom_thru	2.76	-11.35	-7.40	0.51
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_HzLzHz_thru	2.58	-11.86	-6.89	0.39
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_LzHzLz_thru	2.58	-9.91	-6.54	0.70
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_Nom_thru	3.41	-13.07	-8.56	0.43
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_HzLzHz_thru	3.06	-11.35	-7.43	0.29
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_LzHzLz_thru	3.19	-11.32	-7.19	0.57
'20dB_HghZ--20dB_HighZ_thru	3.15	-17.17	-16.71	0.37
'20dB_HghZ_Nom_HighZ--20dB_HighZ_Nom_HighZ_thru	3.27	-18.95	-18.45	0.40
'30dB_HighZ--30dB_HighZ_thru	3.16	-17.34	-17.08	0.25

Failing channel are failing if COM decreases

Channels passing with great margin are not interesting here.

Return loss for selected channel (3 dB to 4 dB COM)

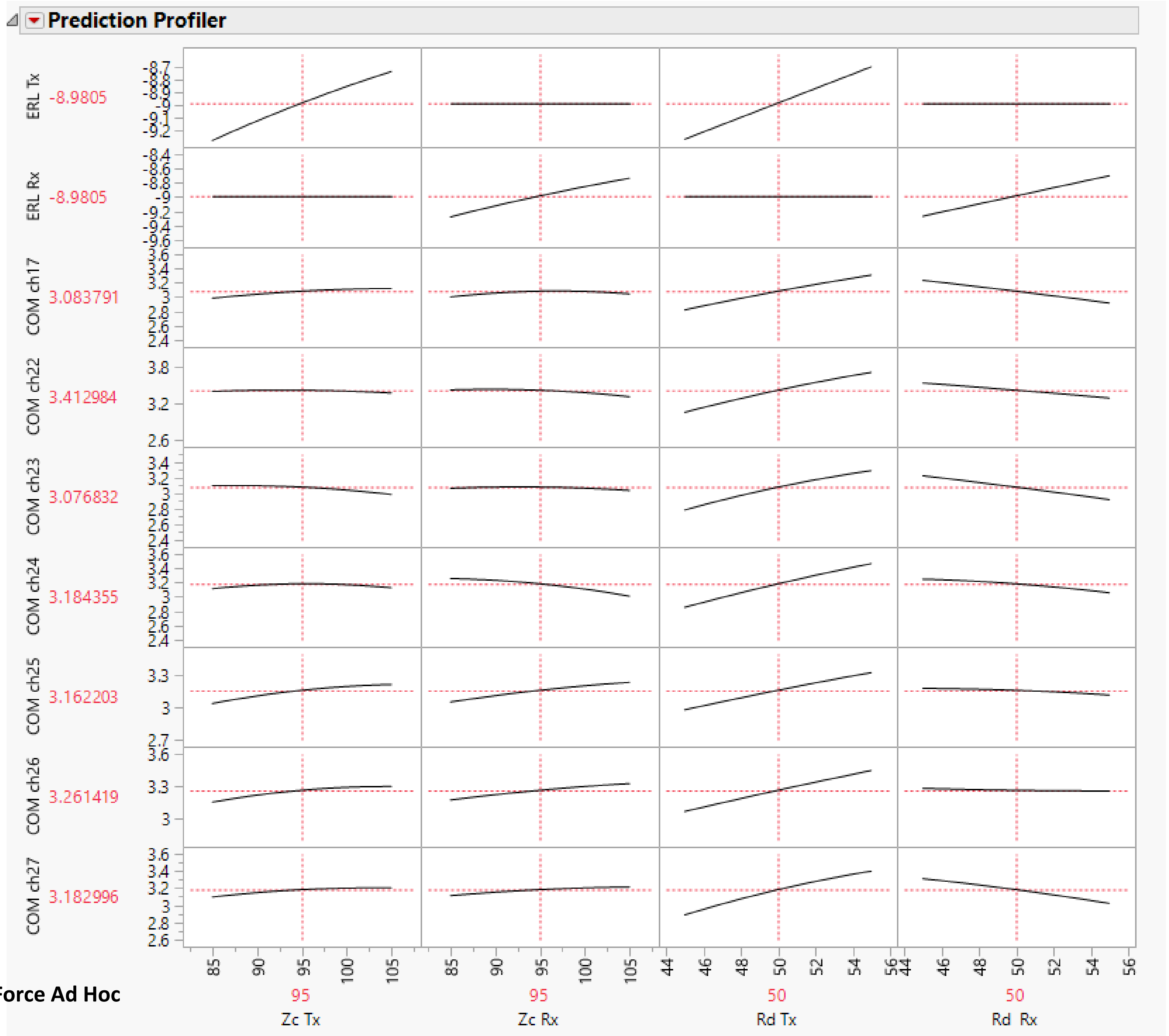


2 channels correspond to limit crossing pass com

'5F3N--Ch8_30_5F3N_t	3.07	-11.25	-13.76	0.28
'TEC_STRADAWhisper40in_Meg6_Channel_IEEE802_3_cd_Cu_07282016--TEC_Whisper40in_THRU_G14G15_07202016	1.68	-14.90	-14.08	0.18
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_Nom_thru	2.76	-11.35	-7.40	0.51
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_HzLzHz_thru	2.58	-11.86	-6.89	0.39
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_100ohm_30dB_LzHzLz_thru	2.58	-9.91	-6.54	0.70
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_Nom_thru	3.41	-13.07	-8.56	0.43
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_HzLzHz_thru	3.06	-11.35	-7.43	0.29
'mellitz_01_021716_30dB_6_channels--PAM4_2conn_MP_v2_85ohm_30dB_LzHzLz_thru	3.19	-11.32	-7.19	0.57
'20dB_HghZ--20dB_HighZ_thru	3.15	-17.17	-16.71	0.37
'20dB_HghZ_Nom_HighZ--20dB_HighZ_Nom_HighZ_thru	3.27	-18.95	-18.45	0.40
'30dB_HighZ--30dB_HighZ_thru	3.16	-17.34	-17.08	0.25

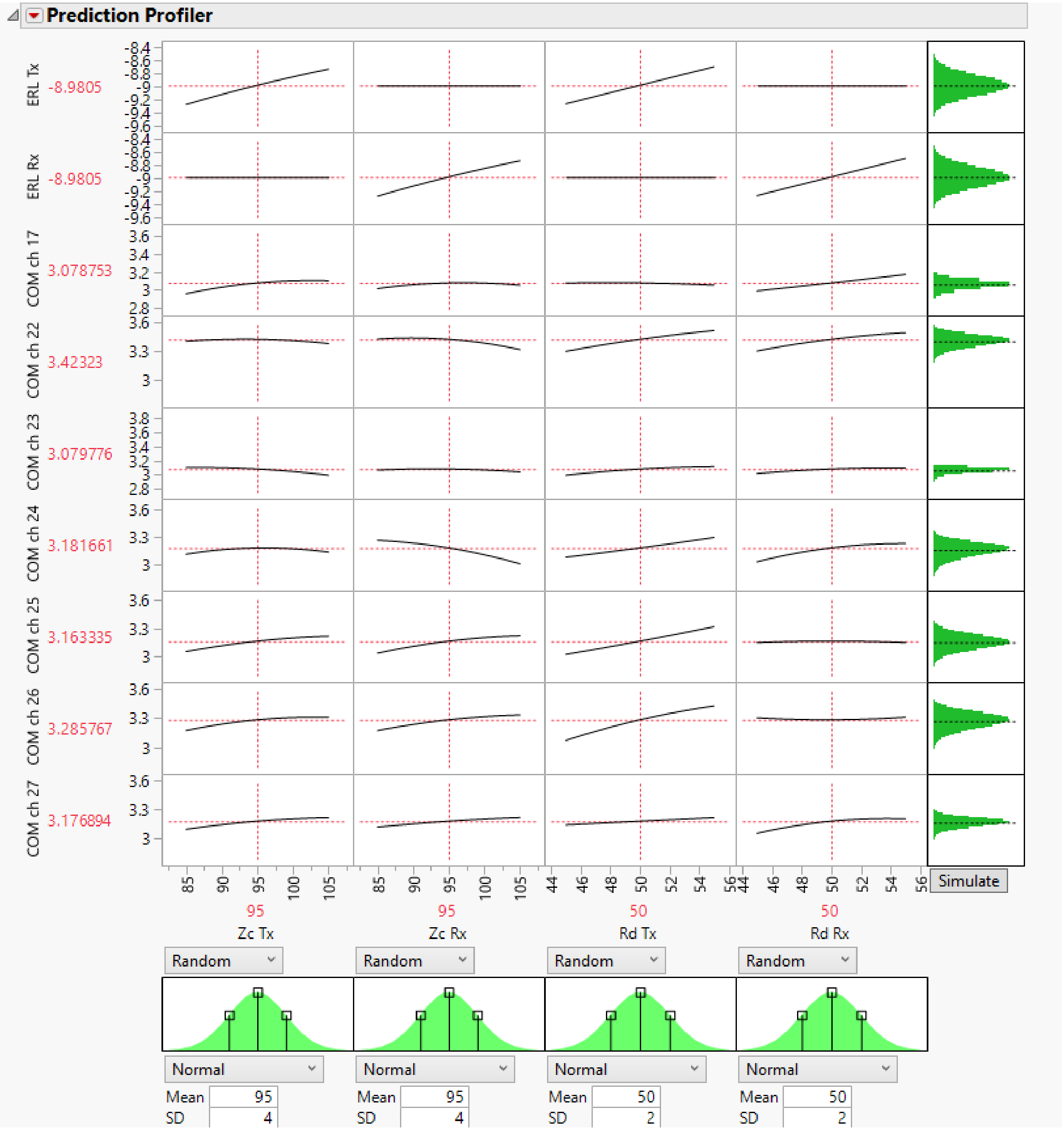
Results have interesting results

- ERL and COM in dB are the individual y axes.
- Zc and Rx (ohms) are the individual x axes.
- Does this make sense?
- No
- Further investigation found a problem with bifurcation of Tx and Rx Rd in the COM MatLab
- Does not affect any computation made with COM table used in standards so far

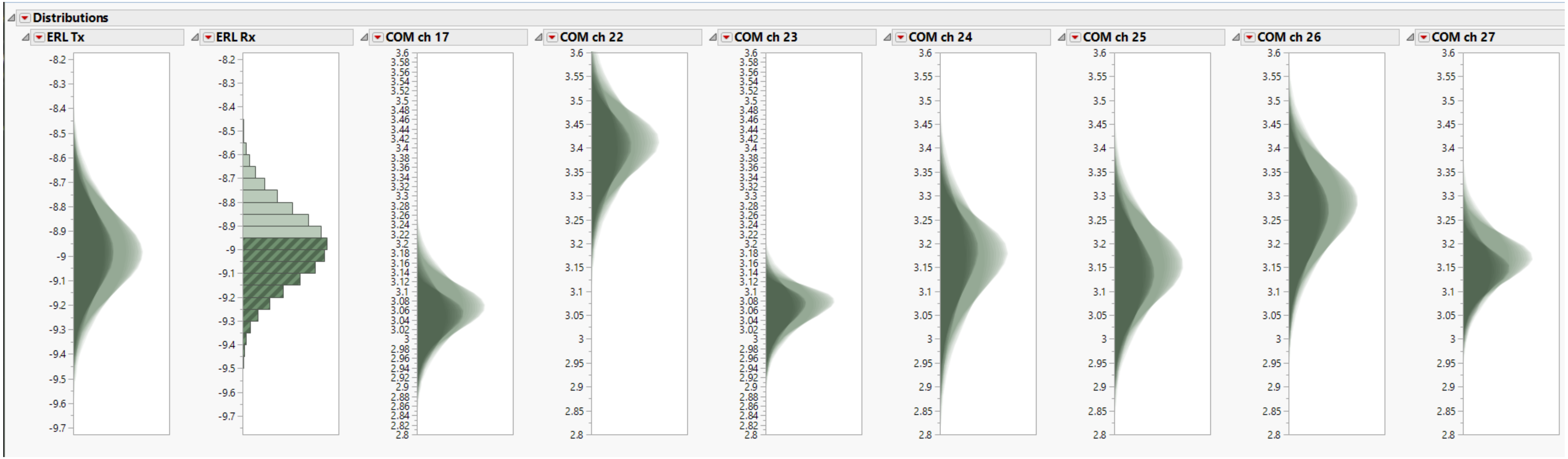


COM 2.0b results rectifies problem

- ❑ Variability still exists irrespective of return loss or ERL



1 Million combination of Rd and Zc



- ❑ Limiting ER does not affect downward COM distribution limit very much

Conclusion

- ❑ Return loss and/or ERL should not be used for channels
- ❑ Return loss and/or ERL should not be used for devices
- ❑ Suspected reason:
  - Return loss can have a constructive or destructive impact
- ❑ Something like VSWR (voltage standing wave ratio) might be a better discriminator.