Optimizing Calibration Error Using Two Points Calibration Method

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Abstract

When calibrating the radiated path loss for a RF setup using a correlation unit the result will tend to have a huge error if the unit was not generated properly. This paper describes how we define correlation errors, and how to generate proper reference units using two point's calibration method. Two points calibration method is a method of calibration by first, defining a good reference units using statistical averaging and second, by using two reference units (one as calibrator and another as verifier) to ensure that errors stemming from calibrating the station is minimize. This method is use in CT2 handset and some paging product's system test station to calibrate the radiated path loss for receiver sensitivity measurement. The result is quite encouraging.

Introduction

One of the classical ways of calibrating radiated receiving path loss for a RF chamber is to take the receiver sense of a pager measurement in the crawford cell. Then used the reading to offset the transmitted signal strength setting that injected to the chamber to obtain the similar reading. The offset of the signal strength basically is used as the receive path loss of the radiated measurement.

For a while, this method seems to work fine. However, sometimes the error seems to be huge if the calibration unit is not generated properly. This paper describes a statistical method to generate a calibration unit to optimize the calibration error. This method of generating calibration unit basically is used in CT2 handset system test for calibrating the radiated receive path loss in receiver sensitivity measurement. The procedure to calibrate the system is call the two point calibration because it uses two reference units instead of one to calibrate a fleet of test stations.

Two point calibration

Two-point calibration is a calibration method used to ensure calibration done in a test station is maintained within a certain error limit. Basically a reference unit (golden unit) is used to calibrate the station. After calibrating the station, a second reference unit (silver unit) is used to verify calibration has been done properly. A set of statistical data will have to be generated in order to select the reference unit for calibration and correlation. Before we look into how to generate the reference unit, let's break down the problem in detail.

Defining the problem and looking into the errors

When using the classical way of calibration to calibrate the chamber, due to the fact that a bad reference unit is selected, measurement errors as huge as 6-7 dB can be obtained from station to station. This makes calibration errors unpredictable and can create a situation of over accepting or over rejecting production units. Let us look into the analysis of this problem:

Basically we can defined two major error in the measurement when calibrating the stations with reference to crawford cell. One of the errors is the error caused by the calibration between crawford cell and station. The other is the variation reading between station to station.

In general we can formulate the problem using the following two equations:

$$y = x + \Delta x \qquad (1)$$

Where

- y = measurement obtain from a particular station
- x = measurement obtain from crawford cell
- Δx = the error between crawford cell and station.

$$z = y + \Delta y \qquad (2)$$

Where

- z = measurement obtain from any station
- y = measurement obtain from a particular station
- Δy = error between station to station

Combining equation (1) and (2) we get:

$$z = x + (\Delta x + \Delta y) \quad (3)$$

From equation (3), we see that in order to optimize the measurement error, we should try to optimize both Δx and Δy.

In general the error between crawford cell and station is around +/- 1.5 dB and the error cause by station to station reading is around +/- 1.5 dB. Overall the total error should be around +/- 3 dB. However, if the calibration is done biased at one end, the error can be as big as +/-4.5 dB with reference to crawford cell.

Fig-1 can be used to reflect the importance of the reference unit. In order to select a reference unit that does not deviate between station to station, we are actually selecting a fine line to draw the reference across the station.

Fig-1a shows a fine line x that represents an ideal reference unit where the reading does not deviate from one station to another station.

Fig-1b shows a fat line that represents a reference unit that has large deviation between station. If the fat line is use to draw out the reference across the station the error can be as huge as ($\Delta x + \Delta y$).

Fig-1c shows that if the reference deviated too far from the normal average unit, calibration will be over calibrate or under calibrate.

Fig-1d show the combination of Fig1b and Fig-1c, which is the worse case. In general this situation will either over reject units and over accept units.

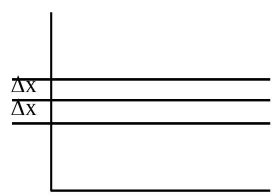

Fig-1a

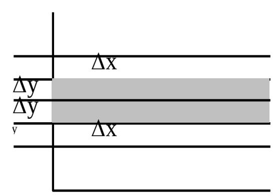

Fig-1b

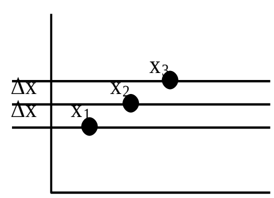

Fig-1c

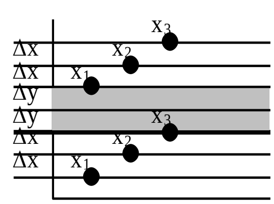

Fig-1d

In order to select a proper reference unit for calibration, we need to make sure that the selected unit does not deviate between crawford cell and station and also does not deviate between station to station. This is actually a unit that has an optimal Δx and Δy. Basically this unit can be sort out by some kind of averaging method from a set of pagers.

Experiment on averaging method

An experiment was conduct using 10-unit pager to sort out the reference unit that has an optimum Δx and Δy. Before begin the experiment, all station are calibrated using the classical method.

The process begins by taking data for all pagers in crawford cell. We then uses a single unit to re-calibrate the stations and data are collect for the remaining units for the second time, this can be formulate as shown in equation (4). We then take the average offset from n number off units as the path loss offset to re-calibrate all the station and data are collect for the third time.

$$y_{pathloss} = x_{ref} - y'_{ref} \tag{4}$$

The path loss offset can be obtain from average offset using equation (5).

$$y_{pathloss} \equiv \frac{1}{n}\sum_{i=1}^{n}(x_i - y'_i) \tag{5}$$

Where

y' = initial reading taken from the station. (Raw reading without offset)

x = reading taken from crawford cell.

With the path loss we obtain from equation (5) we can re-generate the first approximation data using equation (7).

Since

$$y = y' + y_{pathloss} \tag{6}$$

$$\Rightarrow y_i \equiv y'_i + \frac{1}{n}\sum_{i=1}^{n}(x_i + y'_i) \tag{7}$$

Where

y' = measurement taken before offset

y = measurement taken after offset

x = measurement taken from crawford cell

From the first approximation data, we can now look across the station to station reading and pick up a unit that have the least deviation across the station as reference unit. Using this reference unit to recalibrate all the station will basically optimize the calibration error.

The re-calibrated result can be predict using equation derive from the following equation.

Since

$$y_{pathloss} = y_{ref} - y'_{ref} \tag{8}$$

$$z = y' + y_{pathloss} \tag{9}$$

$$\Rightarrow \quad z = y' + y_{ref} - y'_{ref} \tag{10}$$

where

z = measurement taken from any station.

y' = measurement taken before offset

y = measurement taken after offset

With equation (7) and (10), by assuming $y_{ref} = y_{avg}$ we can now derive an equation to model the whole calibration process as follow:

$$z = y' + \frac{1}{m}\sum_{j=1}^{m}\left[y'_{ref,j} + \frac{1}{n}\sum_{i=1}^{n}\left(x_i - y_{i,j}\right)\right] - y'_{ref} \tag{11}$$

Where

m = number of station

n = number of pager unit use for generating the reference unit

Fig-2a, 2b and 2c shows the Rx sens power measurements for the crawford cell and four other stations using 10 handset units.

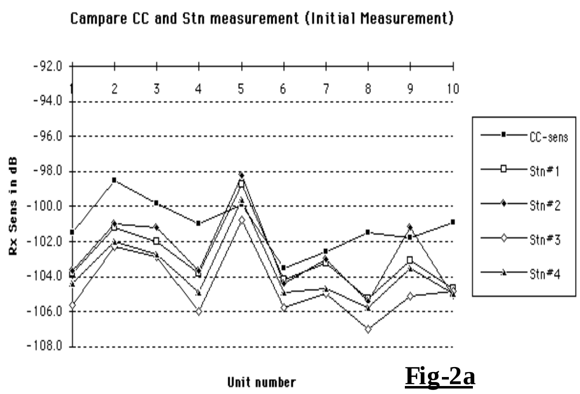

Fig-2a

<u>Fig. 2a - Initial Measurement using classical method</u>

The results from classical method show that the readings for the various stations on a particular handset unit are rather scattered and deviation from the crawford cell reading is large.

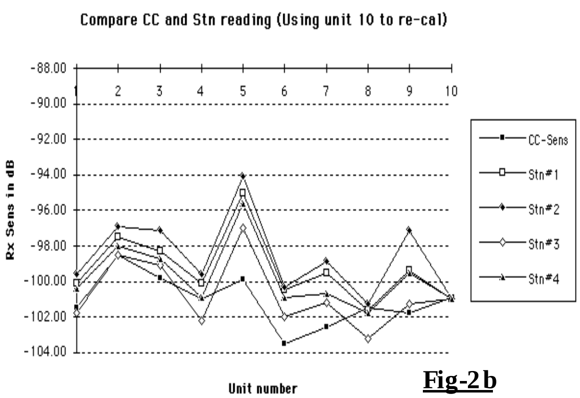

Fig-2b

<u>Fig. 2b - Results using unit #10 (random unit) to recal</u>

Assume random selection of a unit to recalibrate the station and unit #10 has been chosen as that unit.

Unit #10 (now used as a reference unit) is use to recalibrate the test stations. From the results obtained here, it can be observed that the readings are scattered and not close to the crawford cell reading.

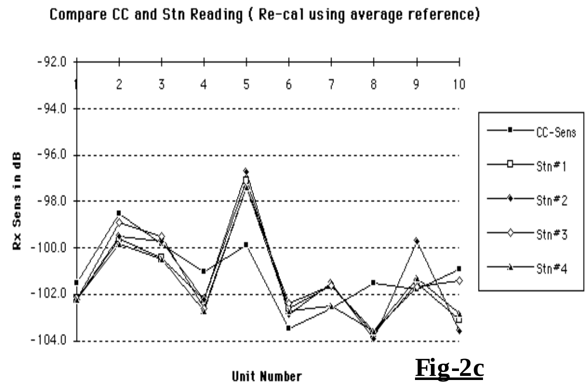

Fig-2c

<u>Fig. 2c - Results using an averaged reference unit (golden unit) to recal</u>

Using the method describe in "experiment on averaging method", a golden unit or averaged reference unit is obtained.

This golden unit is then used to recalibrate the test stations (just as in 2b). The results now show that the scatter between readings from station to station is much less and the deviation from crawford cell reading is reduced.

Fig-3 shows the station reading errors, which is the difference in readings from crawford cell and each test station.

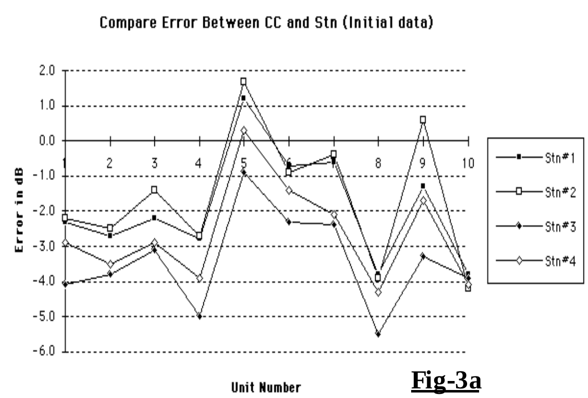

Fig-3a

<u>Fig. 3a - Errors from using classical method</u>

We can see from the graph that the errors using the classical method are ad hoc and widely distributed for a particular handset unit. This will yield an unpredictable and less accurate result during measurement.

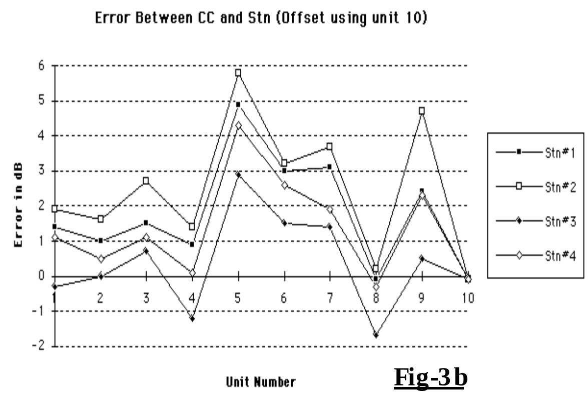

Fig-3b

Fig. 3b - Errors from using unit #10 (random unit) to recal

Errors in using unit #10 as the calibrating unit also shows large deviations from station to station. Not much improvement is found compared to Fig 3a.

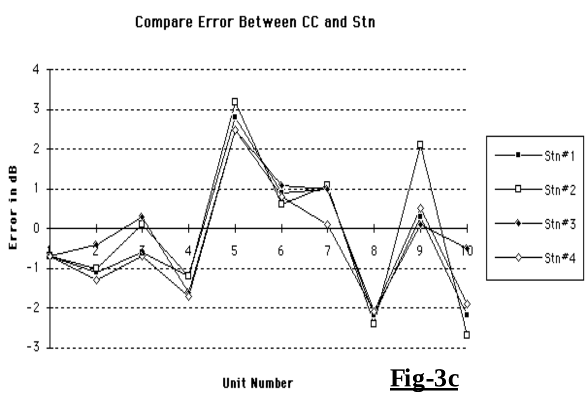

Fig-3c

Fig. 3c - Errors from using an averaged reference unit (golden unit) to recal

Using the golden unit to calibrate, the errors are more predictable and less ad hoc as illustrated in the graph.

The deviation errors are hence minimized for each station and readings are hence more consistent from station to station.

From this experiment we learn that the averaging method is much better compare to the classical method. It is not ad hoc and overall the errors are more predictable

A more practical approach

For a more practical approach, 3 units are used rather than 10 units to generate the reference unit. However, more judgement and manual fine-tuning are required in order to set the proper reference. Appendix A shows a particular case in generating the reference unit.

From the data, we see that after offset the path loss with the average error, unit 2 has the smallest deviation compare to the rest of the unit. Using this unit as reference and set the reference similar to the average (since this average and the crawford cell reading are within a reasonable range), we obtain a set of simulated result which is listed in " Using unit#2 as reference at -104db" section. The simulated results show that the overall result is bounded by +/- 1dB except an extreme case, which has -2.23dB.

Using the selected reference unit, we performed the actual calibration. The result are record down for further validation. From the result, we found that it is quite close to the simulated result. Base on this reading we set unit 2 as the calibration unit and unit 1 as a correlation unit to verify the calibration are done properly and maintain within a certain error limit.

IMPACT

The 3-unit approach is basically used in generating correlation unit for CT2 handset system. The two-point calibration method is also implemented there to ensure calibration done for the station is maintained with the accepted level. Correlation units generated by the averaging method are used to correlate the station everyday to ensure the station is in tiptop condition. After implementing this calibration method, there are not much ad hoc cases happen in the line which we used to see in the pass when classical calibration were implemented. Overall this calibration method had increase the quality of the station measurement.

Future Plans & Recommendation

The averaging method used in generating the reference unit can be use to generate a more reliable correlation unit. The two-point calibration method can use to save guide on the calibration procedure. In future the equation in (1), (2) and (3) can be used as a starting point for further evaluation and study

CONCLUSION

The classical method is good if the calibration error between stage to stage is small and not critical. However, when use to calibrate radiated measurement, which have a huge uncertainty from stage to stage, the method seem to be ad hoc. When randomly pick up a unit to use as a calibration unit, it is questionable on how reliable the selected unit is. The averaging method is a more appropriate approach to generate the reference unit. With two-point calibration we further improve the confident level for the calibration procedure.

REFERENCES

[1] Athanasios Papoulis, Probability, Random Variables, and Stochastic Process, Mc Graw Hill, Inc. 1984.

APPENDIX A

DATA	C.CELL	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5
Unit#1	-105.50	-100.50	-112.70	-110.00	-110.90	-102.30
Unit#2	-104.00	-99.00	-111.10	-109.50	-110.40	-101.80
Unit#3	-104.50	-100.50	-111.80	-109.50	-110.50	-104.50

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5
Unit#1	5.00	-7.20	-4.50	-5.40	3.20
Unit#2	5.00	-7.10	-5.50	-6.40	2.20
Unit#3	4.00	-7.30	-5.00	-6.00	0.00
Range	1.00	0.20	1.00	1.00	3.20
Average	4.67	-7.20	-5.00	-5.93	1.80

After Offset With Average Error

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5	Average	Deviation	Range
Unit#1	-105.17	-105.50	-105.00	-104.97	-104.10	-104.95	0.52	1.40
Unit#2	-103.67	-103.90	-104.50	-104.47	-103.60	-104.03	0.43	0.90
Unit#3	-105.17	-104.60	-104.50	-104.57	-106.30	-105.03	0.76	1.80

Error After Offset

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5	Min	Max
Unit#1	0.33	0.00	0.50	0.53	1.40	0.00	1.40
Unit#2	0.33	0.10	-0.50	-0.47	0.40	-0.50	0.40
Unit#3	-0.67	-0.10	0.00	-0.07	-1.80	-1.80	0.00
min	-0.67	-0.10	-0.50	-0.47	-1.80	-1.80	-0.10
max	0.33	0.10	0.50	0.53	1.40	0.10	1.40

Using Unit#1 As Reference At -104.9 dB

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5	Average	Deviation	Range	Max	Min
Offset	5.00	-7.20	-4.50	-5.40	3.20					
Unit#1	-104.95	-104.95	-104.95	-104.95	-104.95	-104.95	0.00	0.00	-104.95	-104.95
Unit#2	-104.00	-103.90	-105.00	-105.00	-105.00	-104.58	0.58	1.10	-103.90	-105.00
Unit#3	-105.50	-104.60	-105.00	-105.10	-107.70	-105.58	1.23	3.10	-104.60	-107.70

Error						Max	Min
Unit#1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unit#2	0.00	0.10	-1.00	-1.00	-1.00	0.10	-1.00
Unit#3	-1.00	-0.10	-0.50	-0.60	-3.20	-0.10	-3.20
Average	-0.33	0.00	-0.50	-0.53	-1.40		

Using Unit#2 As Reference At -104.0

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5	Average	Deviation	Range	Max	Min
Offset	5.03	-7.07	-5.47	-6.37	2.23					
Unit#1	-105.53	-105.63	-104.53	-104.53	-104.53	-104.95	0.58	1.10	-104.53	-105.63
Unit#2	-104.03	-104.03	-104.03	-104.03	-104.03	-104.03	0.00	0.00	-104.03	-104.03
Unit#3	-105.53	-104.73	-104.03	-104.13	-106.73	-105.03	1.12	2.70	-104.03	-106.73

Error						Max	Min
Unit#1	-0.03	-0.13	0.97	0.97	0.97	0.97	-0.13
Unit#2	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
Unit#3	-1.03	-0.23	0.47	0.37	-2.23	0.47	-2.23
Average	-0.36	-0.13	0.47	0.44	-0.43		

Using Unit#3 As Reference At -105.0

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5	Average	Deviation	Range	Max	Min
Offset	4.53	-6.77	-4.47	-5.47	0.53					
Unit#1	-105.03	-105.93	-105.53	-105.43	-102.83	-104.95	1.23	3.10	-102.83	-105.93
Unit#2	-103.53	-104.33	-105.03	-104.93	-102.33	-104.03	1.12	2.70	-102.33	-105.03
Unit#3	-105.03	-105.03	-105.03	-105.03	-105.03	-105.03	0.00	0.00	-105.03	-105.03

Error						Max	Min
Unit#1	0.47	-0.43	-0.03	0.07	2.67	2.67	-0.43
Unit#2	0.47	-0.33	-1.03	-0.93	1.67	1.67	-1.03
Unit#3	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53	-0.53
Average	0.14	-0.43	-0.53	-0.46	1.27		

Using Unit#2 As Calibration Unit (-104db) and Unit#1 As Correlation Unit(-105dB

	Stn#1	Stn#2	Stn#3	Stn#4	Stn#5
Unit#1	-105.00	-105.90	-104.40	-105.30	-105.00
Unit#2	-104.00	-104.00	-104.00	-104.00	-104.00
Unit#3	-105.60	-104.60	-104.20	-105.70	-106.00