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Subject: Crosstalk Integration

Date: February 19, 2004

Introduction:

There has been much recent work in IEEE 802.3 to quantify channel capacity of unshielded twisted pair (UTP) media. While internal transmission impairments of UTP media such as Return Loss (RL), Near End CrossTalk (NEXT), and Far End CrossTalk (FEXT) are substantially cancellable with DSP, alien crosstalk (ANEXT) remains a limiting factor for the theoretical channel capacity. Many estimates for channel capacity use an integration of the smooth-line specification limit for ANEXT instead of actual ANEXT. Just as is the case with NEXT, a minimally compliant ANEXT result would only touch the spec limit at one frequency. The integration of ANEXT would therefore be less than the integration of the spec limit. This paper will quantify the difference between the two integrals by considering a Monte Carlo numerical analysis of 225 iterations of 24 pair powersum ANEXT in minimally compliant cable only and minimally compliant two near end connector channel configurations.

Discussion:

A technical contribution entitled ‘Category 6 Alien Crosstalk 6 cable around 1 controlled structure’ was widely presented. The scaled data from that experiment is used here to demonstrate the difference in crosstalk energy (or area) depending on the number of crosstalk contributors in the power sum. The six around one experiment used commercially available Category 6 UTP cables. These cables were bound every few inches to ensure that near perfect longitudinal organization (worst case) was maintained throughout the 100m length.

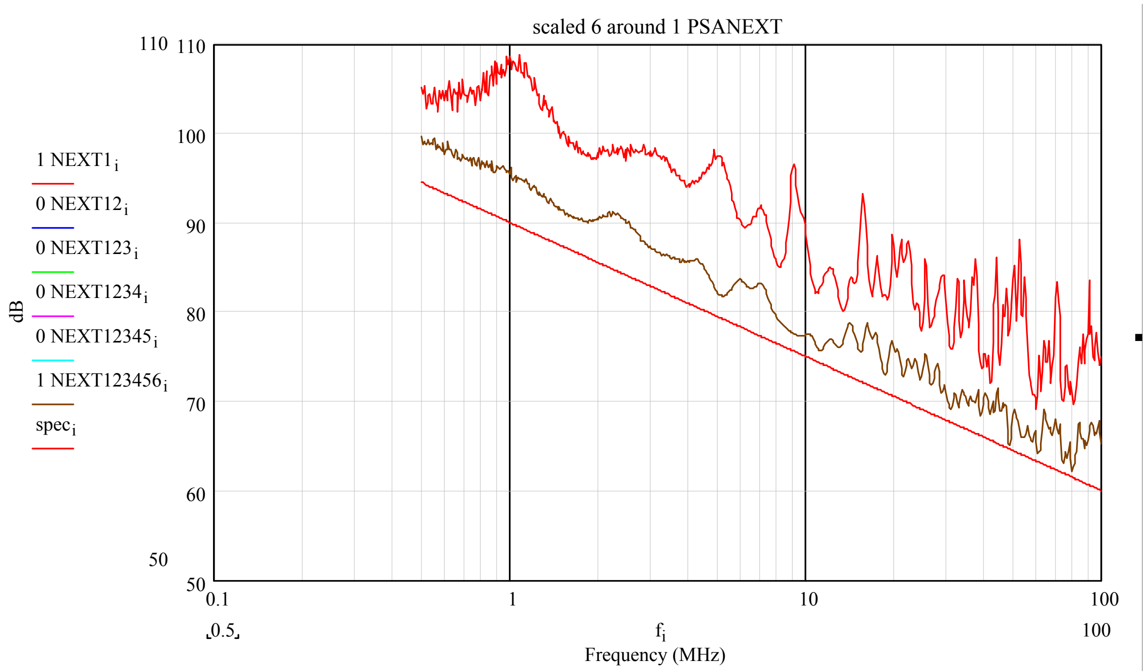

Figure 1: Scaled Power Sum ANEXT from 6 around 1 experiment

Figure 1 illustrates the resulting power sum ANEXT in one pair of the disturbed middle cable. The red trace is the power sum of four disturbing pairs from one adjacent cable into pair 1 of the middle cable. The brown trace is the power sum of a total of 24 disturbing pairs from all six adjacent cables into pair 1 of the middle cable. All cases of incremental cables from 1 through six were considered but not all are shown here to avoid a cluttered graph. The important point is that fewer pairs in the power sum result in “deeper” null structure and less broadband energy. Twenty-four pairs contributing to the power sum is considered worse case and is explained in full detail in the separate contribution. However, it can be seen here from inspection that a minimally compliant 24 pair power sum ANEXT would have less energy than the smooth line spec limit.

In order to quantify the degree of difference between actual power sum ANEXT and smooth-line spec limit integrals, each PSANEXT was scaled to be minimally compliant to the spec limit before integration. In other words, each trace touches the spec limit at its worst point and is better than the limit at all other points. This is illustrated below in figure 2.

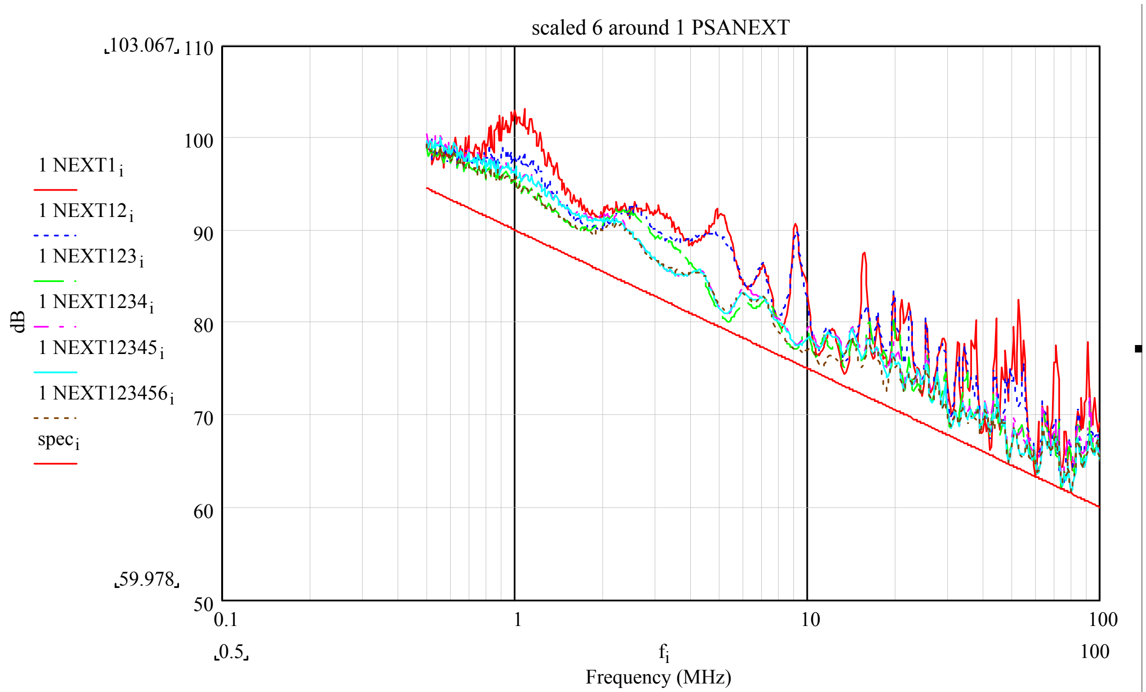

Figure 2: Scaled “minimally compliant” Power Sum ANEXT from 6 around 1 experiment

The integration of each of the traces in figure 2 was performed on the linear voltage ratio. The results are shown in table 1.

	area (unitless)
spec	0.0575
cable 1 to center	0.0262
cables 1 and 2 to center	0.0304
cables 1, 2, and 3 to center	0.0357
cables 1, 2, 3, and 4 to center	0.0336
cables 1, 2, 3, 4, and 5 to center	0.0381
cables 1, 2, 3, 4, 5, and 6 to center	0.0385

Table 1: Linear integration of all traces in figure

A more convenient form to express the data from Table 1 is by converting it to a dB difference of each data trace to the spec limit. This calculation is performed by taking 20*log of the ratio of PSNEXT area to Spec area and is shown in table 2.

	dB
cable 1 to center	6.83
cables 1 and 2 to center	5.54
cables 1, 2, and 3 to center	4.14
cables 1, 2, 3, and 4 to center	4.67
cables 1, 2, 3, 4, and 5 to center	3.57
cables 1, 2, 3, 4, 5, and 6 to center	3.48

Table 2: dB difference of data integrals versus the smooth-line spec integral

Adjusting the smooth-line spec limit by a scalar value in Table 2 would result in identical area. In other words, the area of the spec limit plus 3.48dB would be the same as the six cable PSANEXT result.

It is clear that predicted channel capacity is greater if actual minimally compliant alien NEXT is considered instead of a smooth-line spec limit. It is not yet clear the degree of benefit that can be "banked on". This data would indicate that about 3.5dB less ANEXT is present than the smooth-line spec for the worst case 24 pair power sum scenario. However, it should be expected that this number will vary from case to case and may be different for channel configurations. In order quantify the expected variation, a numerical Monte Carlo simulation was performed. A model was developed to compute 225 iterations of a 24 pair powersum alien NEXT disturbed pair. In each iteration, the 24 pair PSANEXT was scaled to be minimally compliant and then the integration was performed and compared with the spec limit as shown before. The model takes approximately fifteen hours of execution time and was run with 100 meter cable only and 100 meter with two near end connector channel configurations. The channel placed a connector at 1m and 2m positions from the near end. There were six "worst case" pairs disturbing the connector from adjacent connector ports. Their ANEXT was 75-20log(f/100). Figure 3 illustrates a typical channel coupling function for a given alien NEXT pair combination.

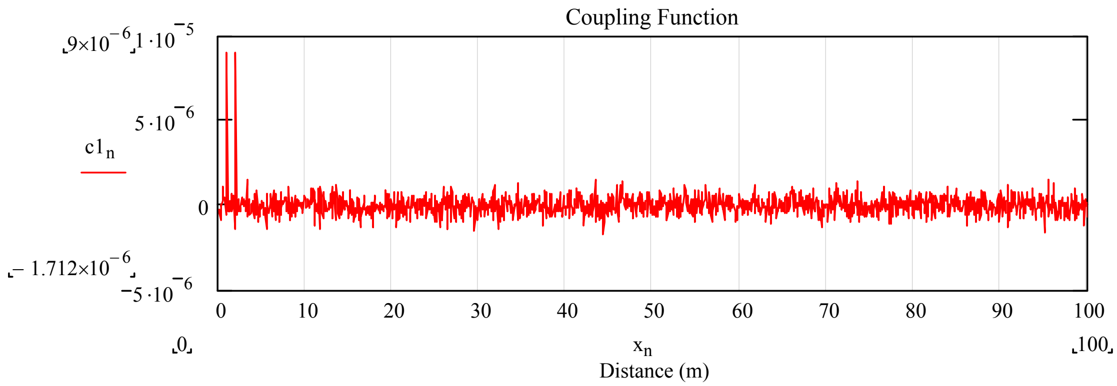

Figure 3: Typical channel ANEXT coupling function

Figures 4 and 5 illustrate a typical modelled individual pair combination ANEXT in cable only and channel configurations respectively.

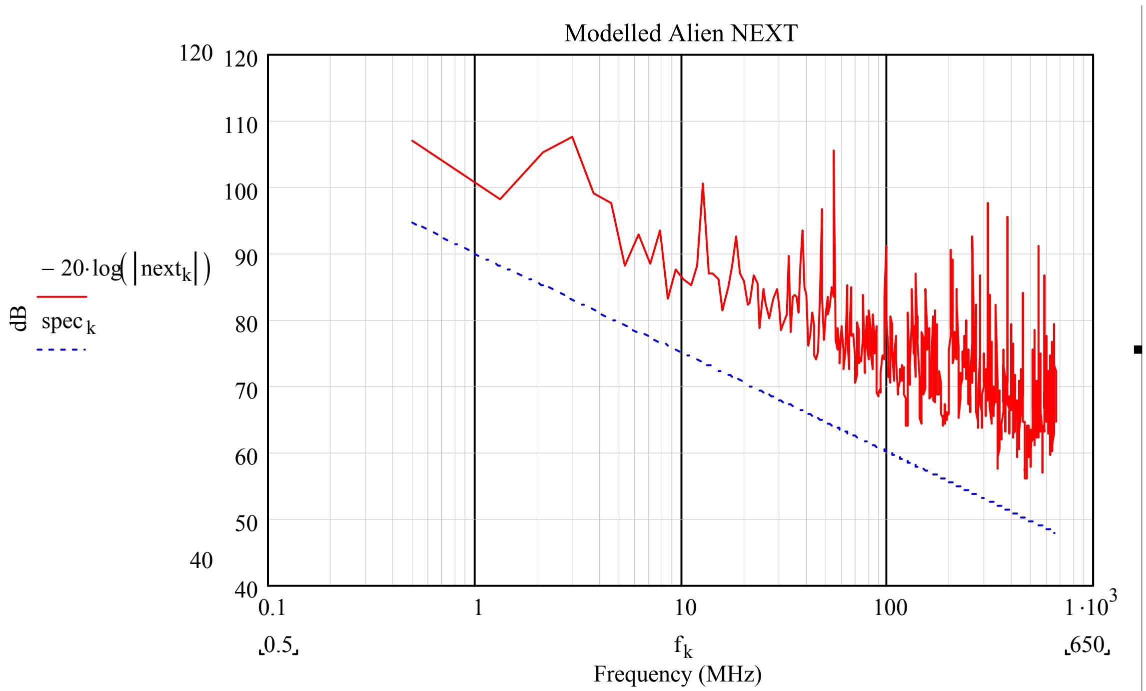

Figure 4: Typical Modelled Individual Pair Combination Cable Only ANEXT

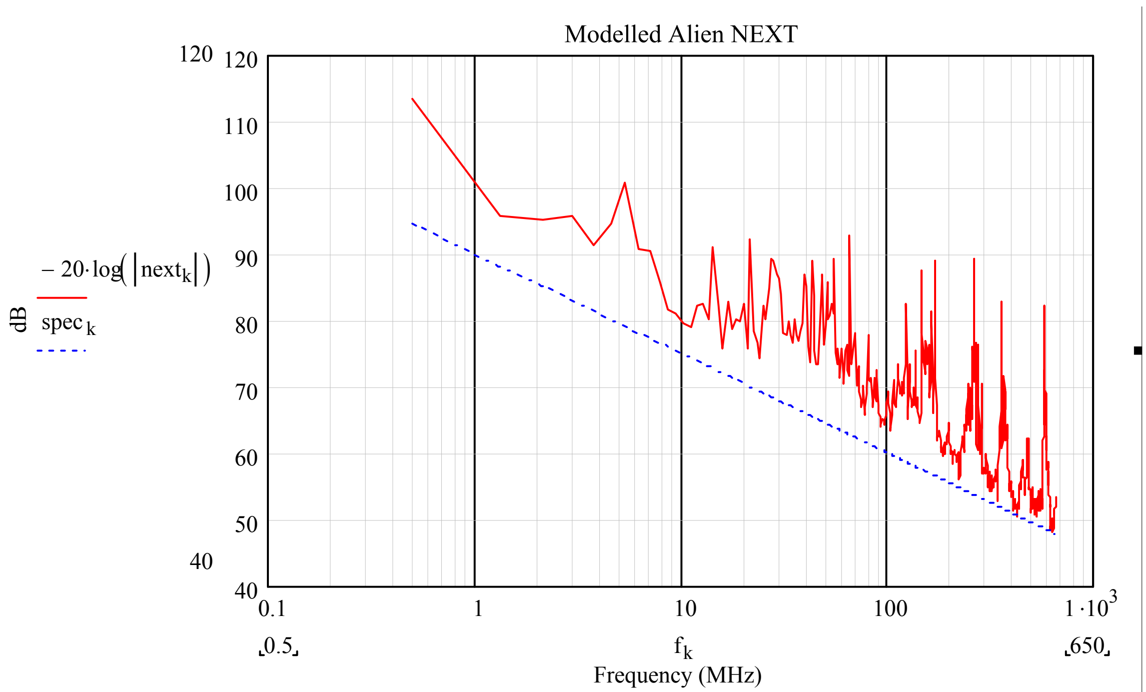

Figure 5 Typical Modelled Individual Pair Combination Channel ANEXT

As mentioned previously, twenty-four of these individual ANEXT results were power summed and then scaled to be minimally compliant. This process was repeated for 225 iterations and the integral difference for each result was captured. These results are plotted in histogram form below in Figures 6 and 7.

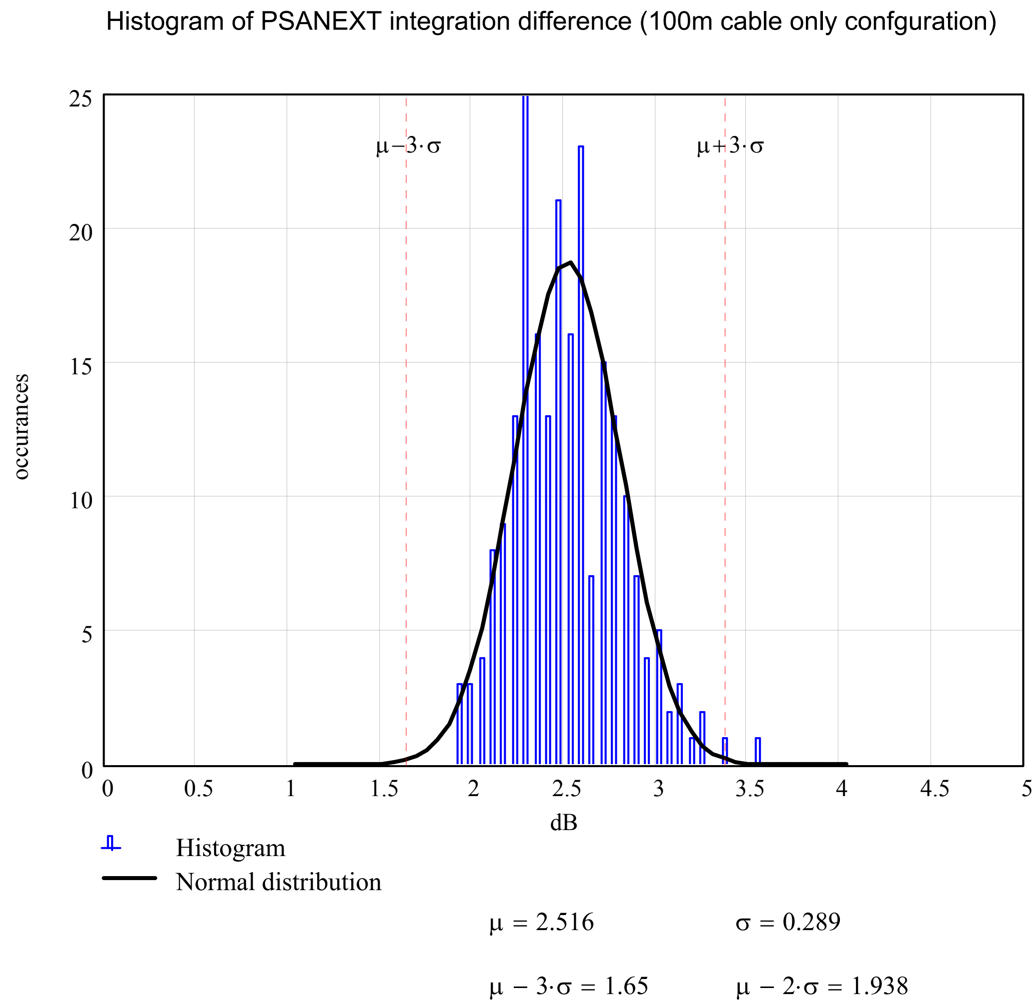

Figure 6: Histogram of PSANEXT integration difference for cable only configuration

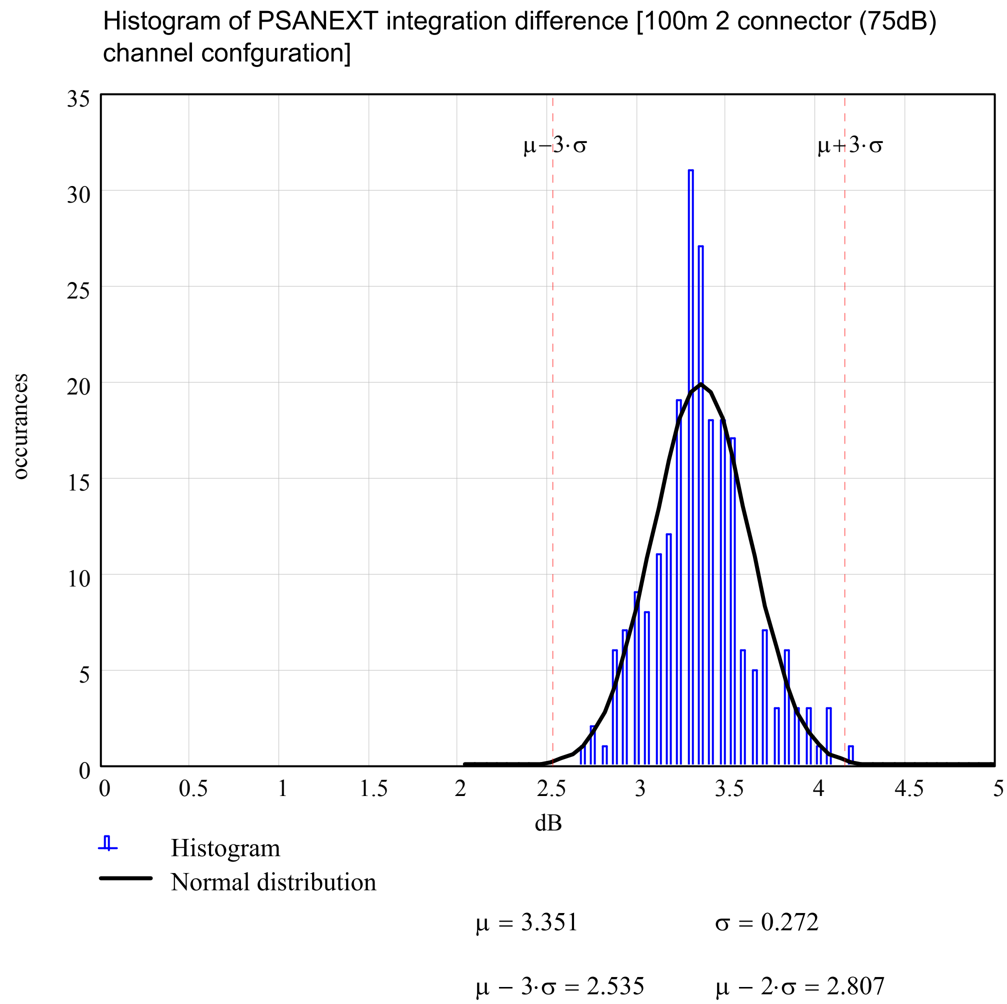

Figure 7: Histogram of PSANEXT integration difference for channel configuration

It is observed that the 24 pair PSANEXT result from table 2 is at the upper end of the cable only numerical simulation distribution. The explanation for this observation is that the measured data in the 6 cable experiment had a 10dB/decade slope starting at about 80MHz due to a small separation between adjacent cables at the near end connecting to the test set. This departure from the spec limit from 80MHz to 100MHz results is a bigger difference of integration in that band.

Conclusions:

This paper reviewed and quantified the difference between the integration of a smooth-line specification and actual PSANEXT. It is proposed that for purposes of conservatively estimating channel capacity that a smooth-line spec plus 2.5dB be used. This offset was arrived at by considering the minimum expected difference (lower 3 sigma value) between the smooth-line spec and actual worst case channel PSANEXT data.

Appendix 1: Alternate integration technique

Based on some feedback presented to the author, it appears that an alternate technique of computing average crosstalk margin on a dB basis may be beneficial. This appendix will compute the average dB margin for a typical minimally compliant single pair combination of ANEXT, a typical minimally compliant 24 pair power sum ANEXT, and the 225 iteration Monte Carlo simulation. In each case, the same two connector channel model will be used as previously discussed.

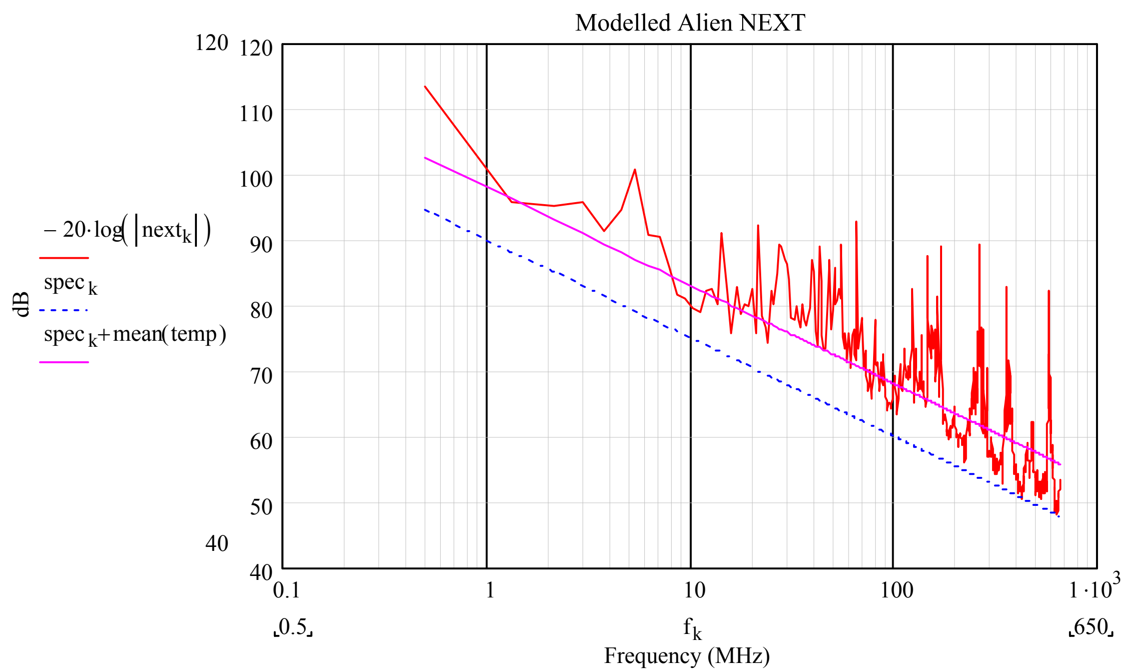

Figure 8: Alternate method – Average margin computed on dB basis individual Pr-Pr ANEXT (8.0dB avg)

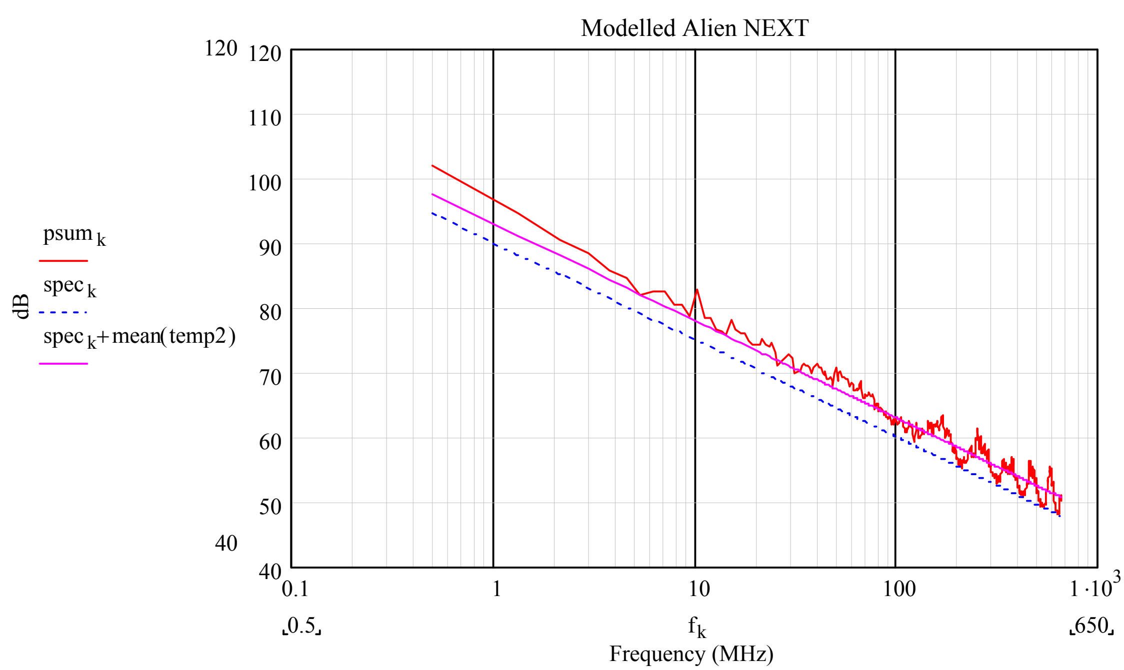

Figure 9: Alternate method – Average margin computed on dB basis 24 disturber PSUM ANEXT (2.9dB avg)

The example in figure 8 is a single pair combination of alien NEXT. The data was scaled to be minimally compliant and the average margin was 8.0dB. The depth of the nulls diminishes as the number of pair combinations included in the power sum is increased. This is evident in figure 9. The example in figure 9 is a 24 disturbing pair combination power sum alien NEXT. The data was scaled to be minimally compliant and the average margin was 2.9dB. Figure 10 below is the result of the repeated Monte Carlo numerical simulation for a two connector channel. In this case, the average dB margin was captured for each observation instead of the integrated area.

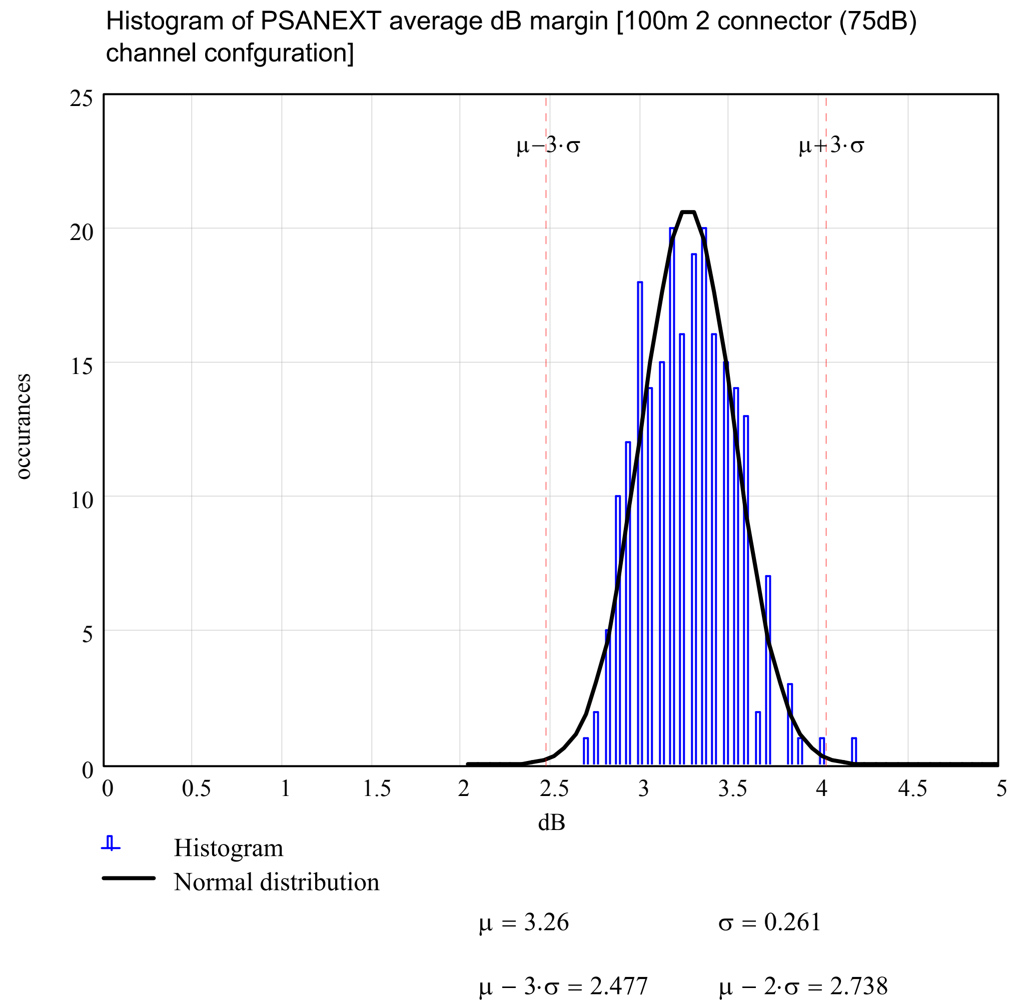

Figure 10: Histogram of PSANEXT average dB margin for channel configuration