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ON THE CROSSTALK IN TRANSMISSION LINES CAUSED BY SPLICES

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Abstract - A model for the crosstalk between two twisted pairs caused by splices, is proposed. The model will allow the crosstalk to be calculated in any case where splices exist in a transmission line. The expressions are then evaluated by measurements on a lab-produced splice and the total influence of the splices on the total crosstalk is evaluated, in order to see if the crosstalk caused by the splices is relevant compared to the standard crosstalk.

Keywords: transmission line, crosstalk, splice.

1. INTRODUCTION

Since the introduction of digital services on the classical telephone lines, crosstalk has always been a major problem to cope with. To improve the quality of transmission, one of the first basics if a good understanding of the quantity of disturbance that is to be expected for a particular transmission system.

As spectral management of access networks relies on good crosstalk models, and because crosstalk cancellation is the basics of current improvements on the ADSL capacity, it is important to take in account all possible causes for it. Splices are one of the factors that seem to have been overlooked for quite some time.

In various sources, e.g. the ADSL telecommunication standard [1] the following expressions for crosstalk are used:

$$NEXT_{PSD} = |E|^2 w^2 K_n \frac{(1-e^{-4aL})}{4a} \quad (1)$$

$$FEXT_{PSD} = |E|^2 w^2 e^{-2aL} K_f L \quad (2)$$

with E the source e.m.f., w the angular frequency, K_n and K_f real constants, a the line attenuation and L the length of the line.

Various attempt have been made to take into account the effects of connecting of two or more lines with different crosstalk coupling constants [2], but what was not taken into account is the physical existence of splices (i.e. the untwisting of pairs in order to be able to connect them). Splices remain an important factor because the existence of a large number of 'bad' splices. This is due to the fact that with POTS (Plain Old Telephone System) metallic contact was sufficient to have a good connection, while nowadays, digital communications require more attention.

1. PROPOSAL AND MEASUREMENTS

Splices can be described as a local pointcoupling in a line, causing an extra amount of crosstalk, which is added to the total crosstalk on the line. Therefore, a simple model is proposed and evaluated, which is based on the supposed transferfunction of such a coupling. The general principle is explained by figure 1.

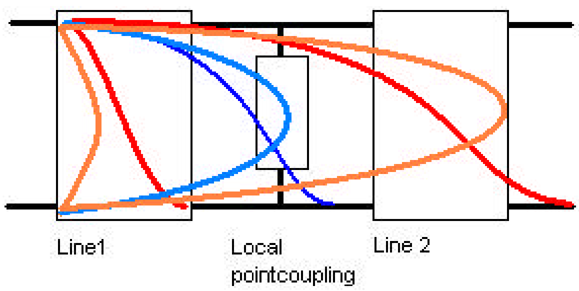

Fig. 1. The proposed model for splices

Due to the short length of the splice, both NEXT (Near End Crosstalk) and FEXT (Far End Crosstalk) are equal, thus the formula proposed to describe the behaviour of the pointcoupling is:

$$NEXT_{PSD} = FEXT_{PSD} = Kw^2 \quad (3)$$

with K the splice coupling constant and w the angular frequency.

A sample splice (0.5mm Belgacom 10-quad, 1m length) was generated in the lab and its parameters were measured and compared to a test cable of the same type and length. Using a simple curve fitting algorithm in Matlab, the parameters K_n and K_f were estimated for the cable and the parameter K for the splice. The results for one of the pairs can be found in figure 2, while Table I shows part of the splice coupling constants matrix. Though we used a different model for splice and reference, the difference in crosstalk caused by both is clearly visible from the figure.

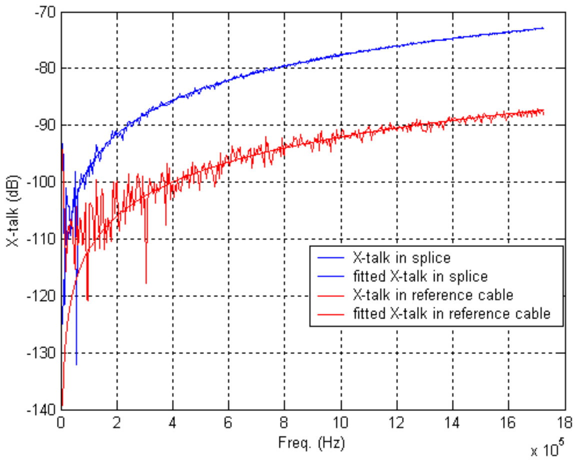

Fig. 2. Identification of the crosstalk on both the splice (upper curves) and the reference cable (lower curves)

Table I. Part of the splice coupling constants matrix

pair/pair	1	2	3	4	5
1	0	8.02E-22	2.47E-23	1.52E-21	2.39E-22
2	8.02E-22	0	8.28E-22	2.73E-21	1.10E-23
3	2.47E-23	8.28E-22	0	2.37E-23	1.56E-23
4	1.52E-21	2.73E-21	2.37E-23	0	8.84E-22
5	2.39E-22	1.10E-23	1.56E-23	8.84E-22	0
6	5.18E-22	2.79E-21	5.64E-22	1.36E-20	1.95E-20
7	1.03E-21	4.02E-22	5.39E-22	3.19E-21	3.50E-24
8	4.02E-21	3.44E-21	1.08E-22	4.57E-21	8.91E-22
9	2.67E-23	6.53E-21	1.53E-21	5.98E-20	8.08E-21
10	2.08E-24	1.23E-22	4.24E-21	1.14E-21	3.21E-21
11	4.46E-23	8.37E-24	2.35E-22	4.83E-22	1.43E-21
12	1.47E-21	8.06E-22	3.59E-22	2.37E-21	7.91E-21
13	4.38E-22	8.32E-24	1.85E-23	2.52E-23	4.01E-21

Figure 2 shows that the matching of the curves is good, so the conclusion can be drawn that the crosstalk in a splice can indeed be described with the proposed model. The noise at the beginning of the crosstalk reference curve is due to the noise-floor of the used equipment.

The intermediate conclusion can be drawn that there is indeed a large difference in the quantity of crosstalk caused by a splice, compared to the same length of cable. In the example this is about 15 dB.

It certainly needs to be noted that the measured splice was produced in the laboratory, resulting in a rather short and dry well-made splice. Splices made in the field are to be expected to give higher coupling constant values. The tested splice was about 40cm in length, while real splices are easily 1m. Hence, for simulation purposes, only the highest values of the coupling constants were used, resulting in larger differences and an overall larger effect.

2. RELEVANCE OF THE RESULTS

It has been shown that the difference between the crosstalk caused by a splice and the crosstalk caused by the same length of cable is significant. However, since it is needed to study those cases that physically appear, a relevance check on the results is needed. A check is needed where splices are calculated in a more realistic environment.

The formulae proposed in [2] for the calculation of crosstalk over multiple segments allow us to make this check:

$$NEXT_{PSD} = e^{-4\sum_{k=1}^{n} a_k L_k} \sum_{i=1}^{n} \frac{NEXT_{PSD,i}}{e^{-4\sum_{k=i}^{n} a_k L_k}} \quad (3)$$

$$FEXT_{PSD} = e^{-2\sum_{k=1}^{n} a_k L_k} \sum_{i=1}^{n} \frac{FEXT_{PSD,i}}{e^{-2a_i L_i}} \quad (4)$$

where n the number of segments, a_k the line attenuation of segment k, L_k the length of segment k, $NEXT_{PSD,i}$ and $FEXT_{PSD,i}$ respectively for the near-end and the far-end crosstalk on segment i. These formulae need to be adapted to include the splices. Furthermore we make use of some coupling constants for those lines proposed in [3] and the ones estimated in part 1.

2.1 Interpretation and adaptation of the formulae

Assuming a perfect match between the different lines, the NEXT summing formula can easily be interpreted as follows: For the first segment, the NEXT formula stays the same as the standard formula (1). For the second segment however, the input source e.m.f. needs to include the attenuation which the signal has due to the transmission through the first segment. Hence a power factor $e^{-2a_1L_1}$ should be included (a_1 and L_1 respectively being the attenuation and the line length of segment 1). Also, the signal needs to propagate back to the beginning of segment 1, so another factor $e^{-2a_1L_1}$ should be taken into account. For segment 3, the same reasoning is followed, resulting in a total factor $e^{-4(a_1L_1+a_2L_2)}$, and so on.

If now, in this reasoning, splices are included, the basic formula stays the same (there is no extra attenuation due to the splices), but the sum is extended to:

$$NEXT_{PSD} = e^{-4\sum_{k=1}^{n} a_k L_k} \sum_{i=1}^{n} \frac{NEXT_{PSD,i}}{e^{-4\sum_{k=i}^{n} a_k L_k}} + \sum_{j=0}^{n} w^2 K_j e^{-4\sum_{k=1}^{j} a_k L_k} \quad (5)$$

where K_j is the splice coupling constant for splice j (the splices are numbered from 0 to n. 0 being the splice at the beginning of the transmission system, splice n the last one. See also figure 3).

The same reasoning also leads to the FEXT formula (4). The FEXT caused by the first segment needs to propagate through the rest of the line, resulting in a factor

$e^{-2(a_2L_2+...+a_nL_n)}$. For the other segments a reasoning similar to that of NEXT is followed, the input e.m.f. needs to propagate through the line, causes FEXT and that FEXT needs to be propagated through the rest of the segments.

If the splices are included in the reasoning, this results in an additional term in formula (4):

$$FEXT_{PSD} = e^{-2\sum_{k=1}^{n} a_k L_k} \sum_{i=1}^{n} \frac{FEXT_{PSD,i}}{e^{-2a_i L_i}} + \sum_{j=0}^{n} w^2 K_j e^{-2\sum_{k=1}^{n} a_k L_k} \qquad (6)$$

2.2 Relevance

The topology in figure 3 is now proposed as a test-case to see the influence of the splices on the total crosstalk of a transmission system. A system of three coupled lines of 400m length is considered.

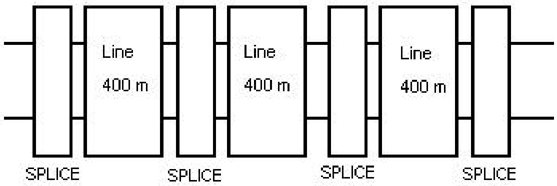

Fig. 3. Simulation topology

First the calculation without using the splices is considered, then the calculation with splices. In figures 2 and 3 an example is shown for non-adjectant pairs. For adjectant pairs, the overall effect is greatly diminished because the coupling constants of the lines themselves are much bigger.

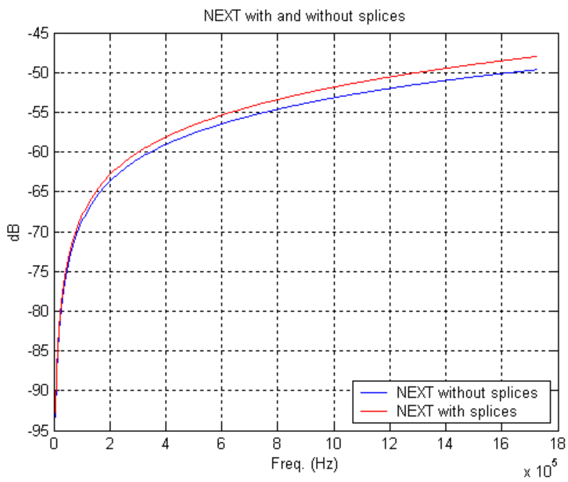

Fig. 4. The NEXT calculations with (upper curve) and without (lower curve) considering splices

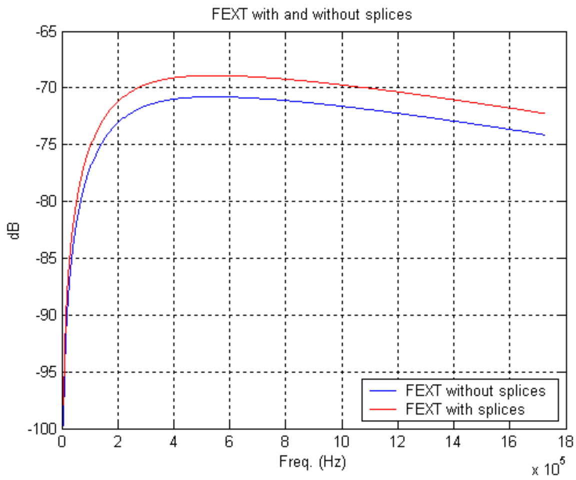

Fig. 5. The FEXT calculations with (upper curve) and without (lower curve) considering splices

As can be seen from figures 4 and 5, the contribution to NEXT and FEXT is not to be neglected. In this case, the following values for K_n, K_f and K were used:

K_n	$1.05e^{-21}$
K_f	$2.61e^{-22}$
K	$4.24e^{-20}$

This resulted in a 1.5dB difference for NEXT and a 1.9dB for FEXT. Of course, the more splices are added, the bigger the difference.

2.3 Influence of the number of splices in a line

As is to be expected from the formulae (5) and (6), both NEXT and FEXT will raise with the number of splices added. In the case of NEXT, however, the effect of adding more splices is insignificant, since the further away from the source the splices are, the less they will add to the overall effect. For FEXT, the effect is cumulative, the more splices there are, the bigger the effect, as is shown in figure 6.

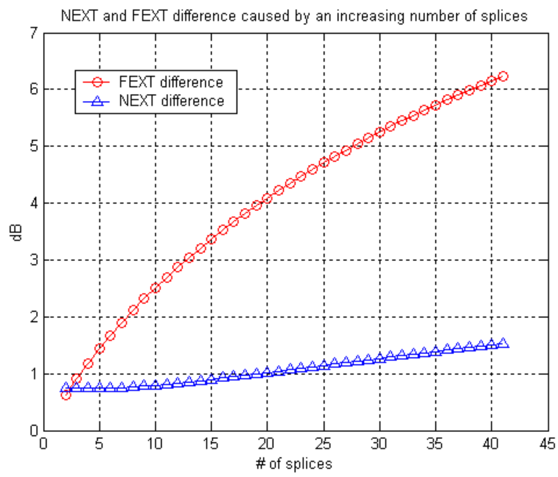

Fig.6. NEXT and FEXT difference at 5kHz due to an increasing number of splices

Figure 6 shows the simulated values for a line of 5km length with up to 41 splices at frequency 5kHz. It should be considered though, that in reality, the real number of splices will be closer to 15 or maybe 20, still giving approximately 4dB difference over such long distance.

The total curves for some of the simulation points in figure 6 can be found in figure 7.

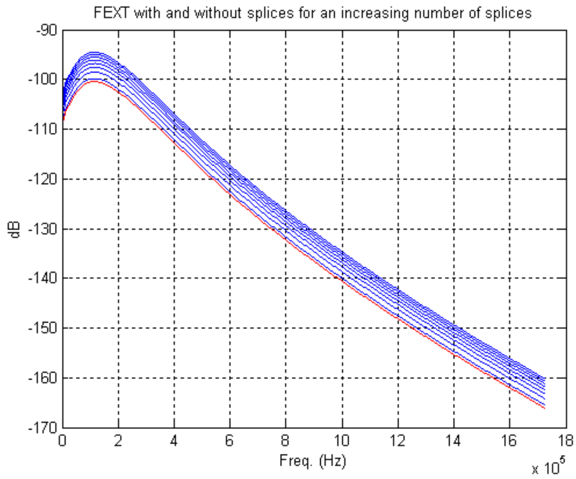

Fig.7. Total FEXT curves for different numbers of splices on a 5km line

3. CONCLUSIONS

Splices are certainly a factor to be considered in accurate estimations of the overall crosstalk. More specific in the following cases the crosstalk will be most relevant: if the first splice is located close to the Central Office side of the transmission line, the NEXT will be primarily caused by the first splice, otherwise, it will mostly be covered by the currently used models which do not consider splices. In the case of a large number of splices, more and more FEXT will occur, adding to the significance of the inclusion of splices in the calculations. The effect is clearest in non-adjectant pairs, since there, the difference in value between the coupling in the line and in the splice is the largest.

REFERENCES

[1] ANSI T1.413 Issue 2 1998, “Asymmetric Digital Subscriber Line (ADSL) Metallic Interface”

[2] P. Boets, M. Zekri, L. Van Biesen, "On the Multi Disturber Crosstalk on a Loop which Consists of Multiple Segments", unpublished

[3] P.Boets, "Frequency Domain Identification of Transmission Lines from Time Domain Measurements", Ph. D. Thesis, Free University of Brussels, May 1997

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