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Alien Crosstalk modeling
**(to search for predominant disturbers,
and estimate boundaries of Alien Crosstalk)**

Prepared for IEEE802.3an 10GBASE-T task group

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Fluke Networks

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This presentation is to be made to the IEEE802.3an task group on 10GBASE-T during the March 2004 meeting in Orlando, Florida.

Comments and suggestions are always appreciated!

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Outline of presentation

- Discussion of a generalized Alien Crosstalk model.
- Measured results with worst case coupling between cable models, both Alien NEXT and Alien (EL)FEXT compared to model predictions.
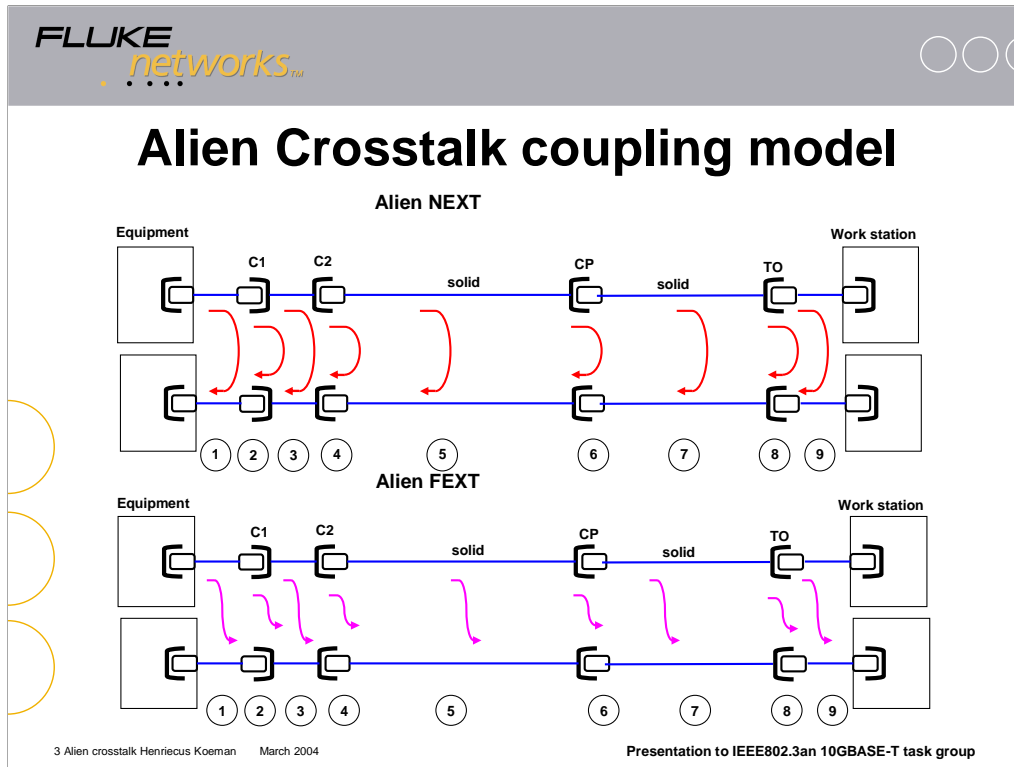- Follow-up work.

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This presentation describes a generalized Alien Crosstalk model. As a first step it is necessary to obtain a model for coupling as a function of length of the distance over which two cables couple.

To validate the Alien Crosstalk models for coupling between cable, an experiment was conducted using two cables taped together over a number of distances. Both Alien NEXT and Alien (EL)FEXT were measured. The results were compared to predicted NEXT and Alien (EL)FEXT.

More work needs to be done to correlate Alien Crosstalk coupling in real installations to determine the Alien Crosstalk margins as a function of the workmanship of the installation. It appears possible with Alien Crosstalk performance assumptions for connecting hardware to predict a worst case boundary of channel Alien NEXT performance.

This slide shows the generic Alien NEXT and Alien FEXT models of two channels. While the diagrams show channels of equal length, that is not intended to be the case.

The highest potential for Alien Crosstalk is present in:

1) The cross connect (C1 & C2, present; or a patch panel (C1).

2) Horizontal cabling (segment 6).

3) Cabling near the consolidation point (CP, if present).

4) The cabling between the CP and the TO (if a CP is present).

5) Multiple TO assemblies, if present.

While the connectors positioning is fixed in a mounting scheme, the cable segment coupling depends a lot on the workmanship and often cables are separated from each other. This can be represented by a "coupling margin" over a worst case test configuration which is expected to defined in cabling standards.

For many components in a channel configuration, the coupling effects are insignificant.

A first modeling attempt is made to establish what the properties are in a test configuration that is expected to provide consistent results.

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Possible alien crosstalk paths (2)

- For other locations, there is a good potential for crosstalk:
  - The connectors of a patch panel in the floor distributor area.
  - The cable near the patch panel in the floor distributor area.
  - If present, the cross-connect connectors.
  - If present, the connectors at a consolidation point (CP), and cable near the CP.
  - If present, telecommunication outlets (TO's) in close proximity.

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The focus therefore has to be on places where there is good potential for Alien Crosstalk. These are shown in this slide.

Alien Crosstalk between Connectors

- The alien crosstalk model between two connectors can easily be described as:

$$ANEXT_{conn,\,freq} = K_{ANEXT,\,conn} - 20 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

$$AELFEXT_{conn,\,freq} = K_{AELFEXT,\,conn} - 20 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

Some reports have been made on Alien Crosstalk in connector assemblies.

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It may be expected that the Alien Crosstalk between connectors (of a patch panel or multiple telecommunications outlets or the connectors of a consolidation point) is well behaved and will show a dependency as a function of frequency that has a 20 dB/decade slope.

For reference measurement purposes, it is essential to create test conditions that provide for consistent test results. In particular, it appears insufficient to use cable ties that do not ensure that the jacket of the cable is touching over the full length of the cable that is tested. It is easily shown that small air gaps will enhance the measured results significantly.

Therefore in the test described in this presentation, the two cables where to be held together were taped in such a way that the jackets were touching. The category 5e cable jackets were fused together by the manufacturer.

The test condition is a practical configuration, but may be highly unrepresentative of real life situations. Reality is that no-one is likely to produce bundled cable, but cable tying two cables together, especially for a specific application using additional cables is a distinct possibility and certainly more likely than a bundled 6 around 1 cable. The bundled pair will be typically worse case in real life.

An "offset" between the 6 disturber cables around 1 disturbed cable and the 1 disturber to 1 disturbed cable have been reported.

Obviously, these test conditions do not reflect the Alien Crosstalk performance in real life installation conditions. There will be a "coupling margin" based on field measurements.

Therefore the Alien Crosstalk model between two cables is not straightforward.

For the purpose of this study, the following assumptions were made.

• The Alien Crosstalk is independent of the location (homogeneous). Again that condition is generally not satisfied in a real life condition, but it represents a worst case "boundary" of performance. And if it can be proven that the worst case boundary yields satisfactory transmission performance for 10GBASE-T operation, no field testing for Alien Crosstalk will be necessary.

• The insertion loss as expressed in dB exhibits close to a square root of frequency function (this allows for the integral of noise power to be expressed in a simple equation).

The equations shown in this slide are applicable to NEXT within a cable jacket. At first sight there is no reason to question the validity of these equations for Alien NEXT between cables. For NEXT within a cable, a 15 dB/decade slope is applicable. It is the opinion of the author, based on practical measurements, that the Alien NEXT is better approximated with a 10 dB/decade slope. Generally assumed is the 15 dB/decade slope, which provides for some performance margin.

The margin of the NEXT of 100 m when the cable is shorter is expressed by the correction amount. As will be shown, most of the NEXT occurs in the first 10 m to 20 m.
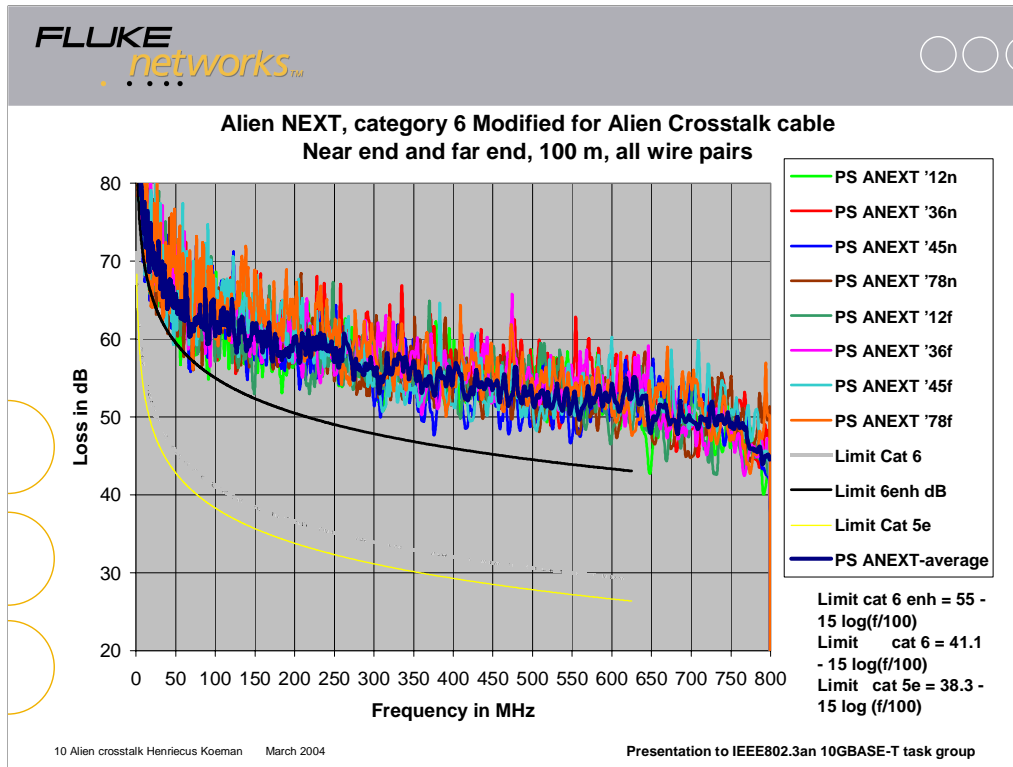
This slide shows the Alien NEXT for two Category 6, modified for Alien Crosstalk, cable (taped together over the full 100 m length), measured from both the near end and far end for all 4 wire pairs. One limit uses the 15 dB/decade slope and an enhanced cat 6 figure of merit (55 dB @ 100 MHz) and the other limit uses the 15 dB/decade slope and the alien crosstalk specification for category 6 cable bundles. The last limit curve uses a 15 dB slope and the alien crosstalk specification applicable to category 5e cable bundles. It is the opinion of the author that a 10 dB/decade slope provides a better "fit". The author cannot explain why the 10 dB/decade slope appears better (also for the cat 5e cable that was tested). Theoretical considerations suggest a 15 dB/decade slope. In any case, the 15 dB/decade slope offers a better performance margin for Alien NEXT between cables.

Alien NEXT, category 5e cable, 100 m, near end and far end, all wire pairs
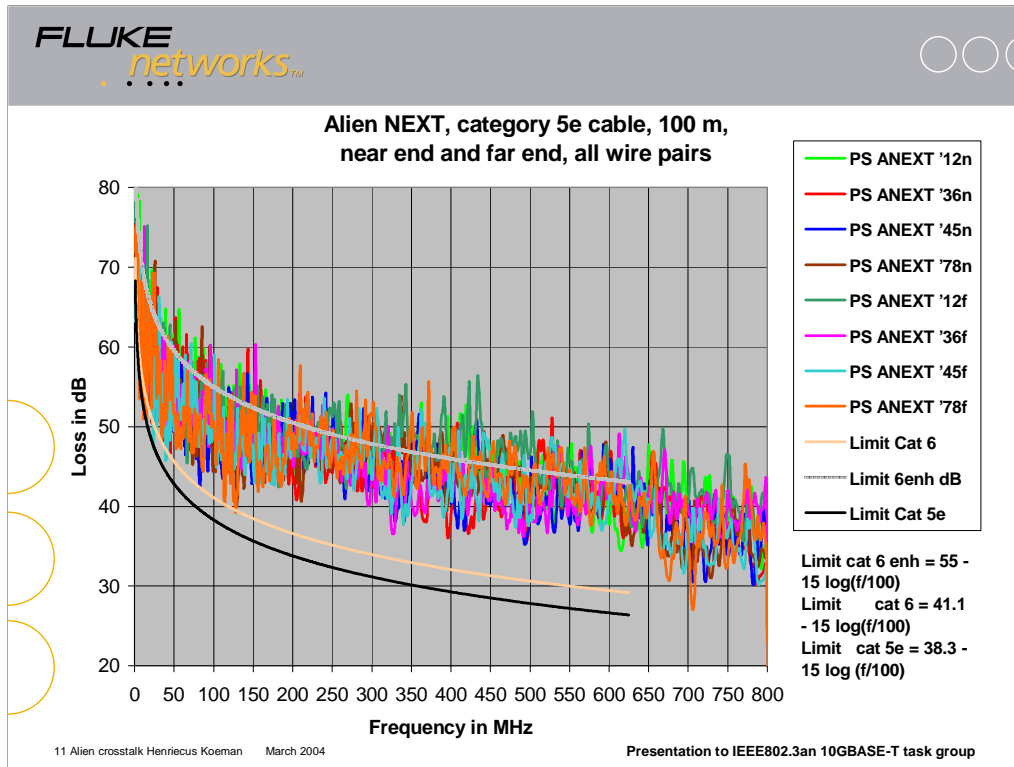
Similar Alien NEXT results were found with the Category 5e cables with fused jackets.

Conclusion on Alien NEXT constants

- For the category 5e rated cable that was tested:

$$ANEXT_{cable,100m,\,freq,\,cat5e} = 38.3 - 15 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

- For the category 6 modified for ANEXT performance rated cable that was tested:

$$ANEXT_{cable,100m,\,freq,\,cat6MAC} = 55 - 15 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

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The conclusions from the cables that were tested:

1) The Alien NEXT assumes a 15 dB/decade slope. It appears that the samples tested are better approximated using a 10 dB/decade slope. This provides for some performance margin.

2) Cable construction will make a lot of difference. For the category 6 cable that was modified for enhanced Alien Crosstalk performance a very significant improvement was determined. Similar results have been reported earlier.

As far as Alien ELFEXT is concerned: a model is adopted that matches the ELFEXT within a cable. It is shown that predictions are that the frequency response is exhibits a 20 dB/decade slope. The response is smooth, unlike NEXT. The only deviation from the predicted slope originates from delay skew and a very few nulls may be present in the response towards the high frequency end.

Theoretical results predict that the ELFEXT for a shorter than 100 m cable segment differs as shown in the correction formula in this slide. Note that it does not decline extremely rapidly with distance. For example for a 10 m section, the enhancement in Alien ELFEXT is only 10 dB; for a 1 m section, the enhancement in Alien ELFEXT is only 20 dB.
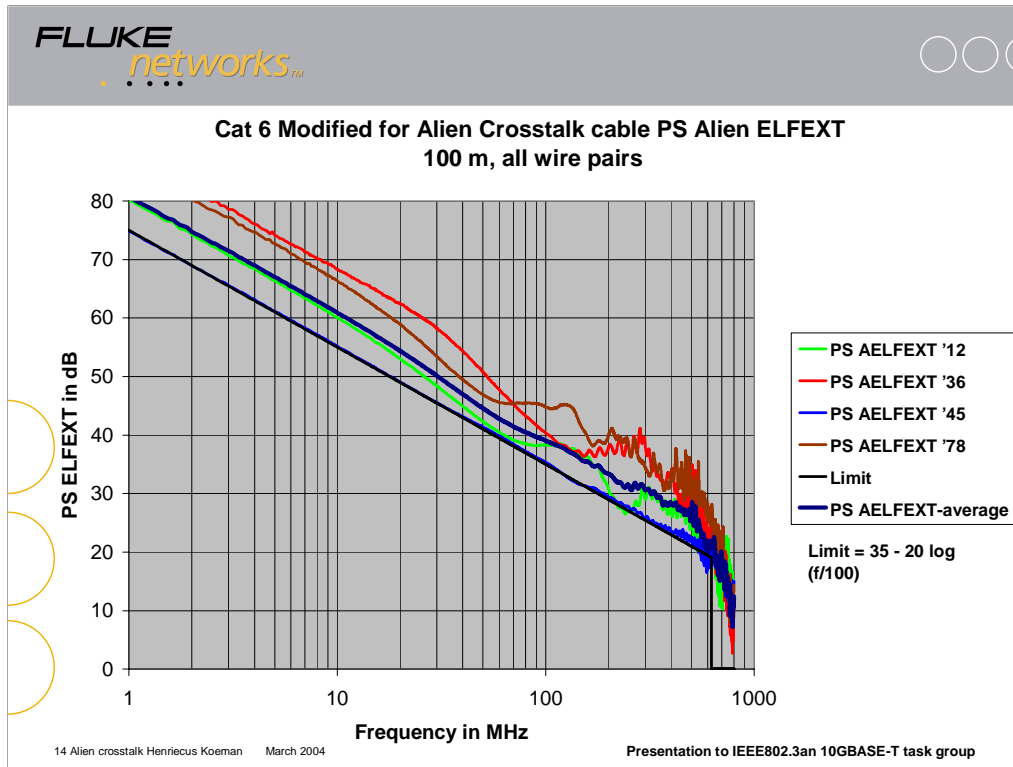
This slide shows the measured Alien ELFEXT results for the category 6 cable with enhanced Alien Crosstalk performance. This measurement took place when two cables were taped together over the full 100 m length.

From a measurement point of view, the ELFEXT was computed from the measured FEXT and insertion loss.

Also shown is the "voltage average" of the Alien ELFEXT of all wire pairs.

Note: this averaging does NOT take place over frequency! It is just the voltage average of 4 wire pairs.

Cat 5e cable, PS Alien ELFEXT, all wire pairs
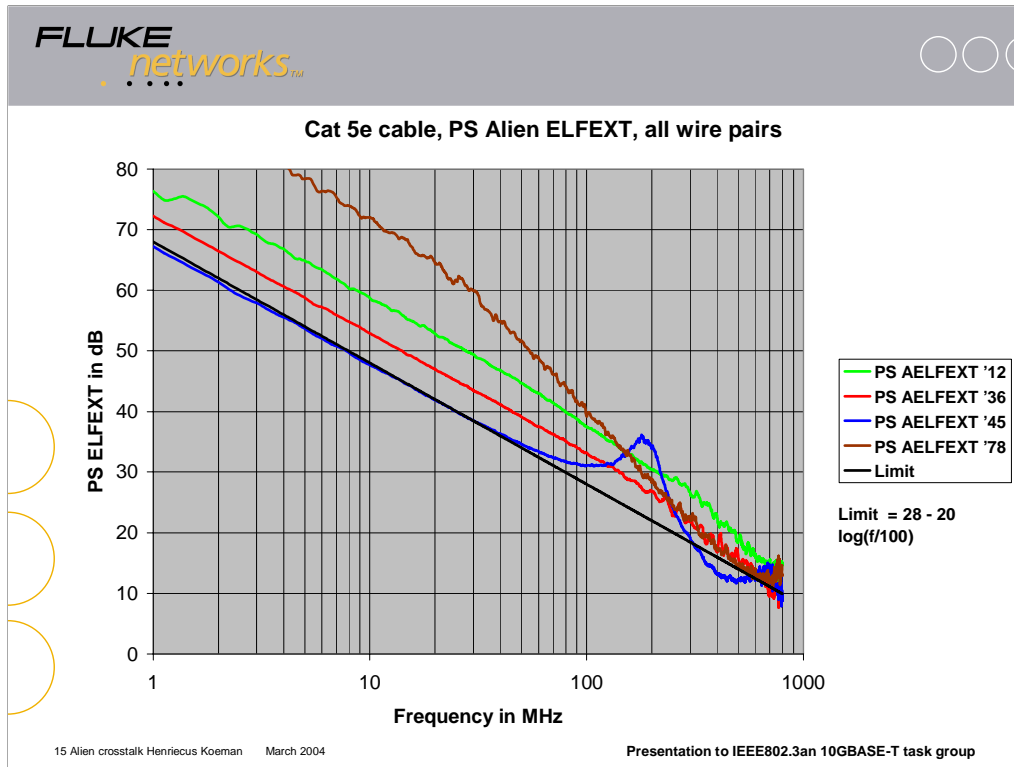
The same Alien ELFEXT measurements were made on the category 5e cable. Note that the Alien ELFEXT performance was not that much worse than the category 6 cable that had enhanced alien crosstalk performance. One will find that for longer channels, the Alien ELFEXT has less influence than Alien NEXT.

Conclusion on Alien ELFEXT constants

- For the category 5e rated cable that was tested:

$$AELFEXT_{cable,100m,\,freq,\,cat5e} = 28 - 20 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

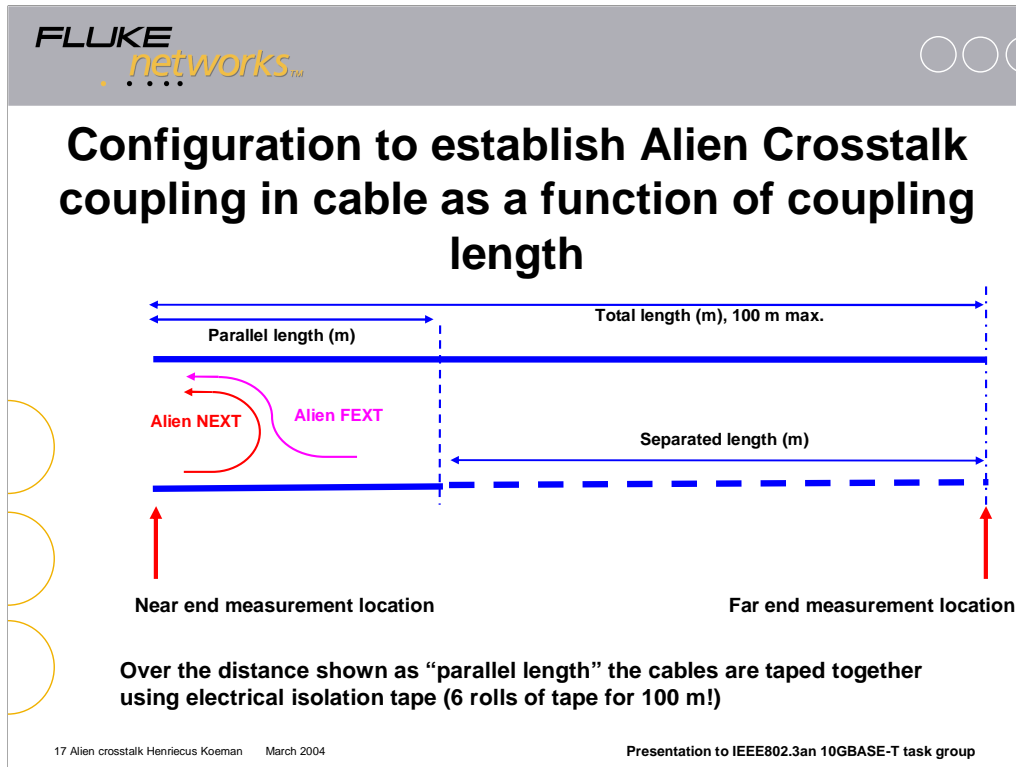- For the category 6 modified for ANEXT performance rated cable that was tested:

$$AELFEXT_{cable,100m,\,freq,\,cat6MAC} = 35 - 20 \cdot \log_{10}\left(\frac{freq}{100}\right)$$

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Conclusions were that the cables that were tested had the properties as shown in this slide. These results can be used for modeling purposes, predictions of the boundary of channel Alien Crosstalk performance.

Configuration to establish Alien Crosstalk coupling in cable as a function of coupling length

Total length (m), 100 m max.

Parallel length (m)

Alien NEXT   Alien FEXT

Separated length (m)

Near end measurement location   Far end measurement location

Over the distance shown as "parallel length" the cables are taped together using electrical isolation tape (6 rolls of tape for 100 m!)

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This slide shows the test configuration of the Category 6 cables with enhanced Alien Crosstalk performance to determine the properties as a function of joint by taping length. This experiment was NOT conducted on the Category 5e rated cable.

The measurement always took place at the ends of the cable segments (no cutting and re-termination!). Over a distance shown on this slide as "parallel length" the cables were held together by using electrical tape. Where not taped together, the separation of the two cables was approx. 30 cm to 50 cm.

How data was processed

- For all Alien Crosstalk results, the volts/volt result was computed for each wire pair. The volts/volt results were averaged and converted back into units of dB to obtain a single "average" Alien Crosstalk result as a function of frequency.

- These measurements were conducted only on the Category 6 cable that had been designed for enhanced Alien Crosstalk performance.

- The "average" Alien NEXT constant was 60 dB @ 100 MHz for the category 6 cable designed for enhanced Alien Crosstalk.

- The "average" Alien ELFEXT constant was 39 dB @ 100 MHz for the category 6 cable designed for enhanced Alien Crosstalk.
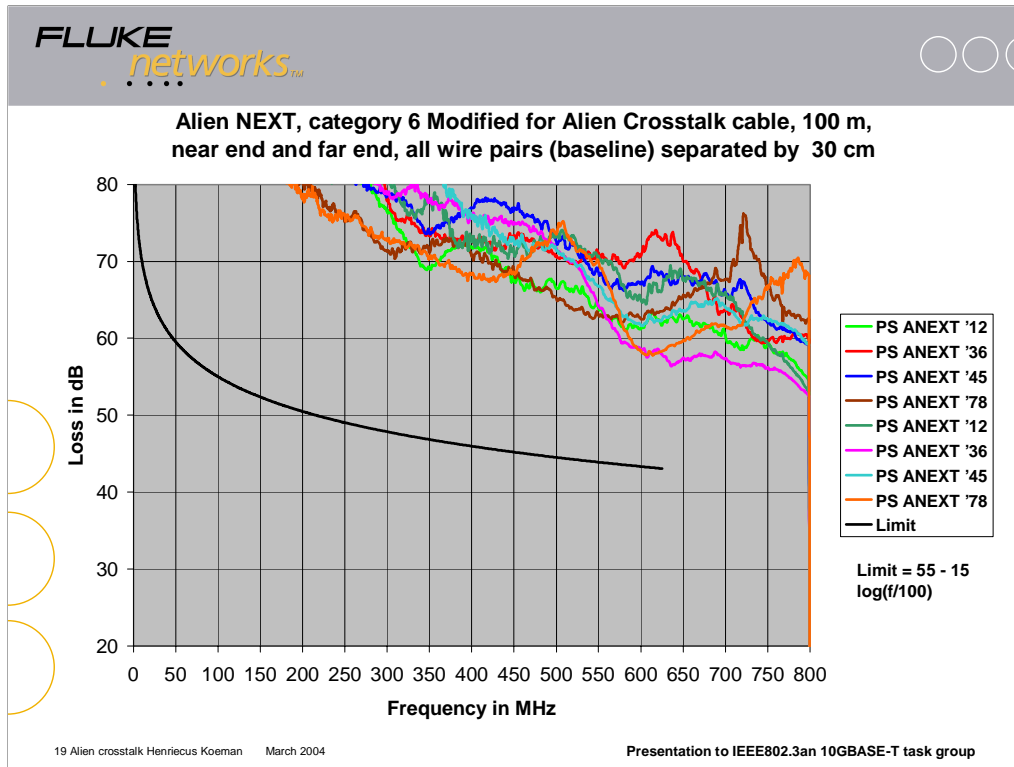
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To reduce the data, the average volts/volt results were computed.

As can be observed, the average Alien NEXT constant for the Category 6, enhanced for Alien Crosstalk cable was 60 dB @ 100 MHz.

The Average Alien ELFEXT constant was 39 dB @ 100 MHz.

Alien NEXT, category 6 Modified for Alien Crosstalk cable, 100 m, near end and far end, all wire pairs (baseline) separated by 30 cm
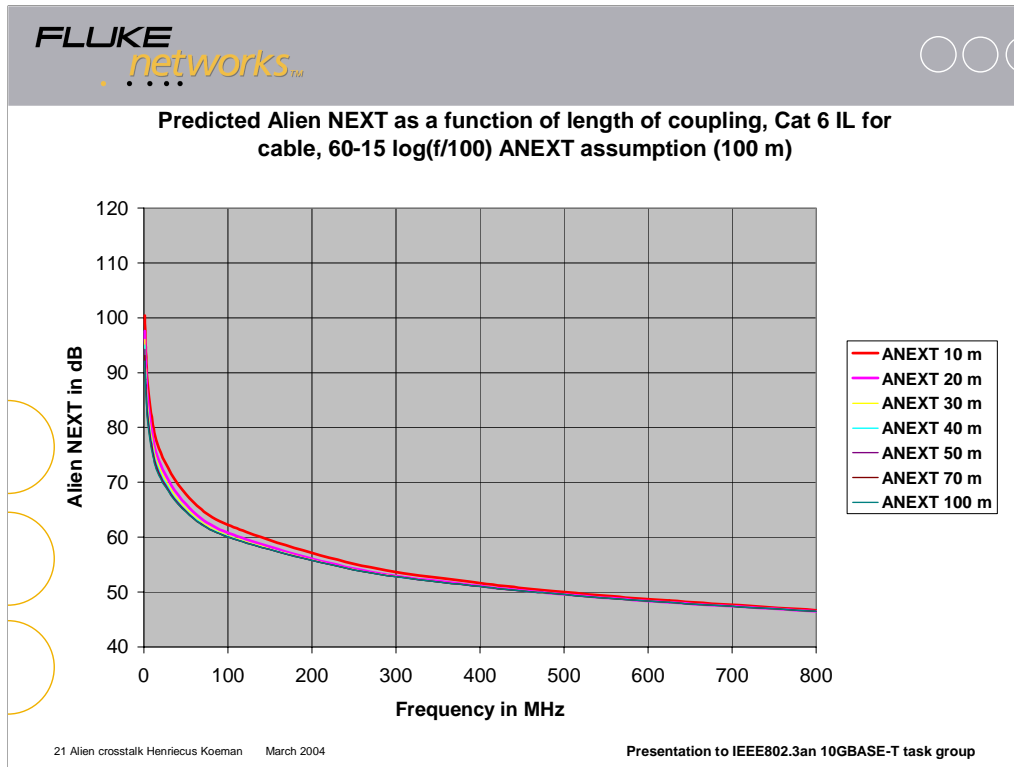
This slide indicates the measurement floor. In this test conditions, the two cables were separated over the full 100 m length by between 30 cm and 50 cm.
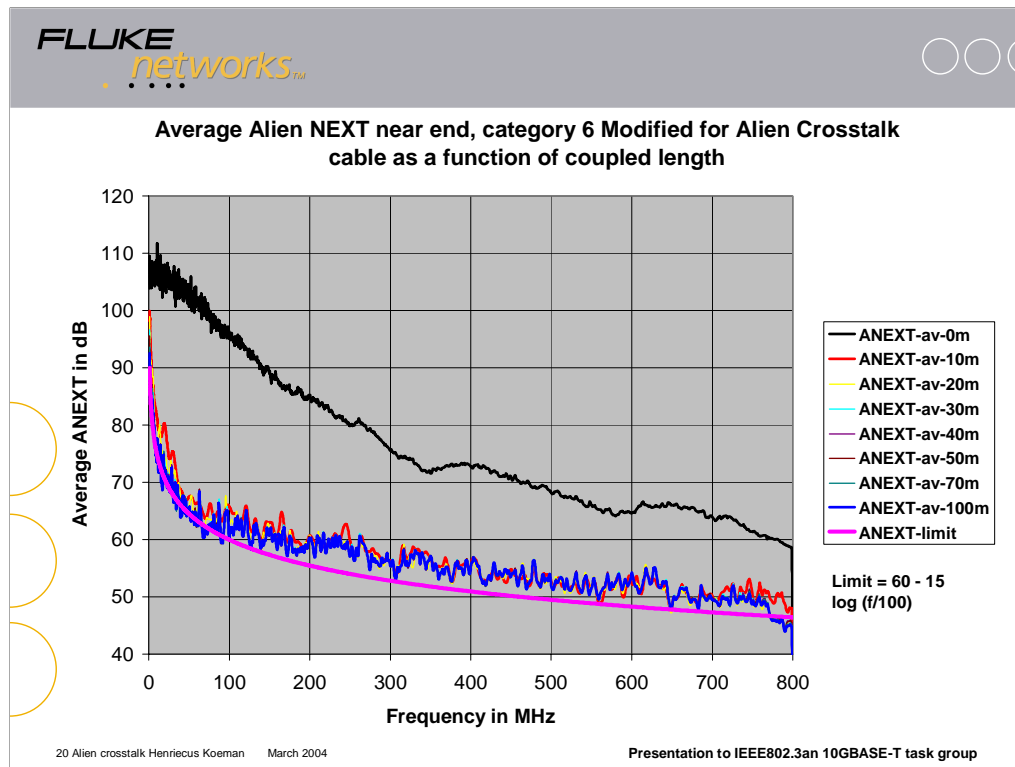
This slide shows the average Alien NEXT, as measured from the near (=taped together) end as a function of taped length.

Note that by far most of the effect is in the first 10 m. At 100 MHz, the difference between Alien NEXT for 10 m and 20 m is only a few dB at a 60 dB level.

Predicted Alien NEXT as a function of length of coupling, Cat 6 IL for cable, 60-15 log(f/100) ANEXT assumption (100 m)

This slide shows the prediction of Alien NEXT when the length over which the coupling takes place is less than 100 m. An "average" Alien NEXT limit is used for comparison purposes.

The measured results pretty much are in agreement with expectations.

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Conclusions Alien NEXT dependency as a function of coupling length

- By far most of the coupling occurs in the first 10 m and just a little bit more beyond 10 m.
- Any mitigation should focus on the first 10 m (randomizing the cable bundle, adding some patch cordage).

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Therefore the conclusion is that one must be most concerned about Alien NEXT coupling opportunities in the first 10 m from either end of the channel.

Mitigation includes randomizing the cable bundle, and possibly adding some patch cordage.
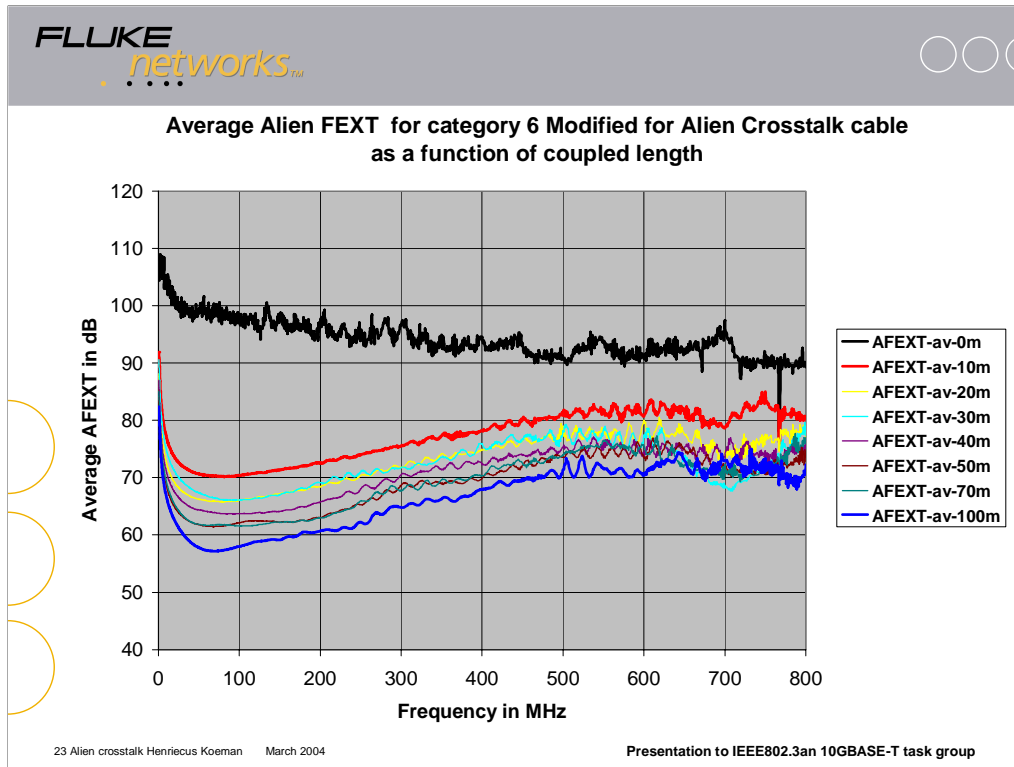
This slide shows the actually measured FEXT data (rather than ELFEXT data which has the insertion loss subtracted).

Of note are the signal levels at which the measurements are taking place. Note that one easily approaches the noise floor of a Agilent 8753ES network analyzer.
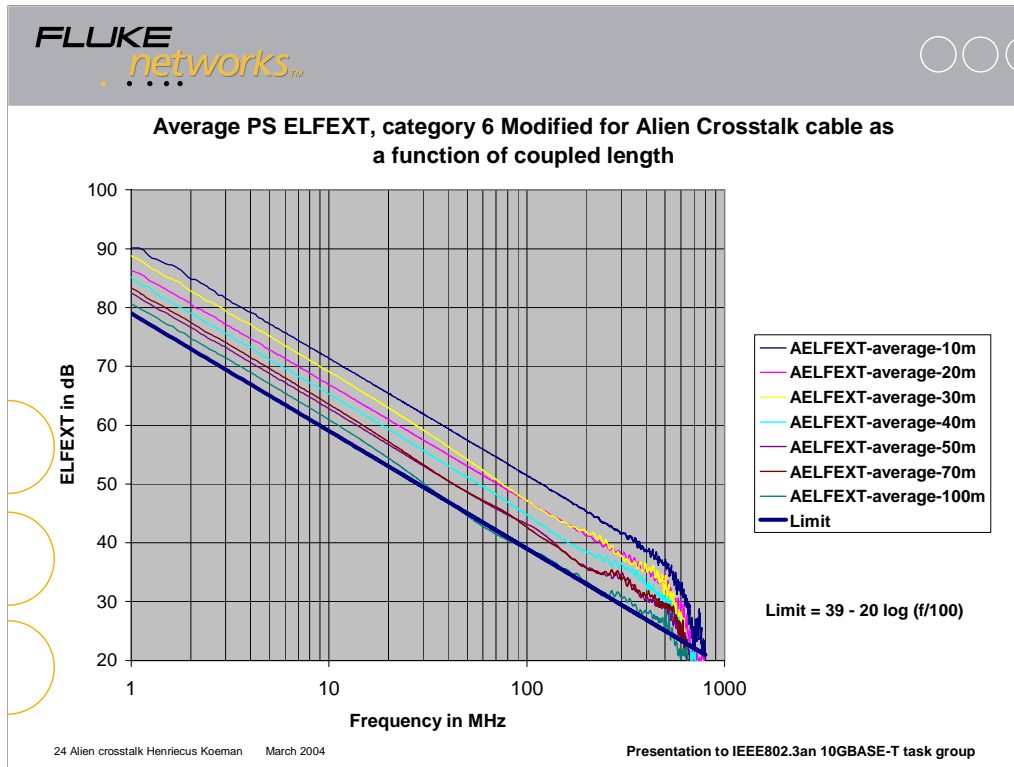
The ELFEXT result which was computed from the FEXT and insertion loss results is shown in this slides. It is obvious that the slope remains 20 dB/decade.
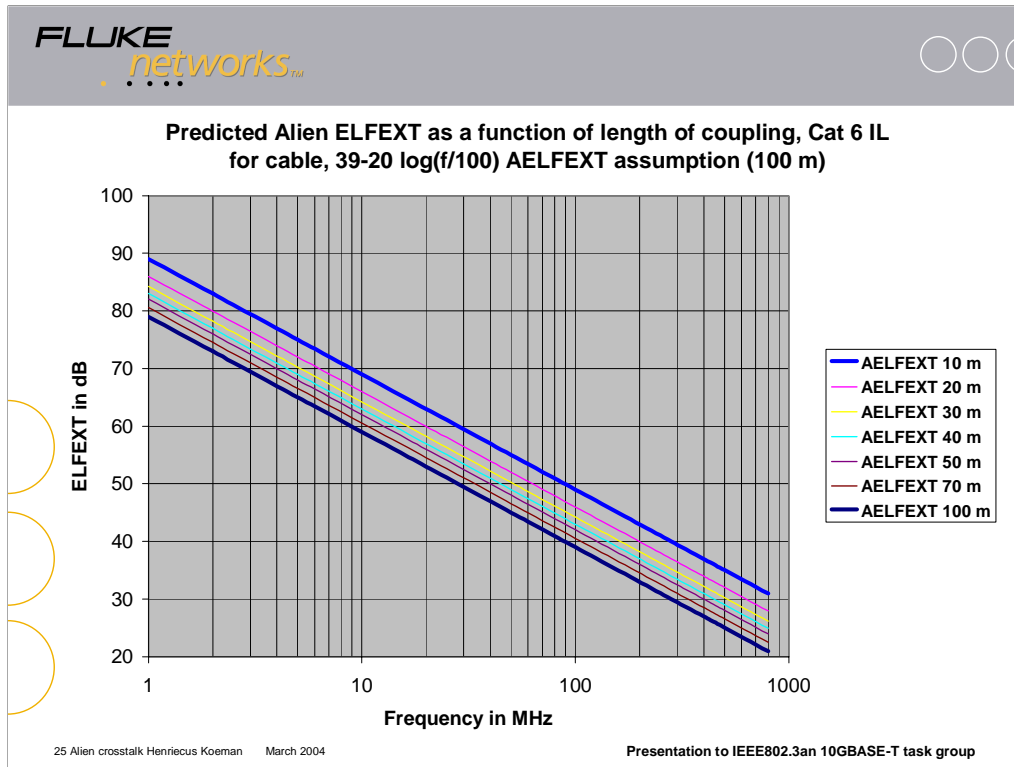
This slide shows the prediction of Alien ELFEXT as a function of the length over which coupling takes place. The same "average" Alien ELFEXT value is used as a reference. Again the measured results are pretty much in agreement with predicted values.

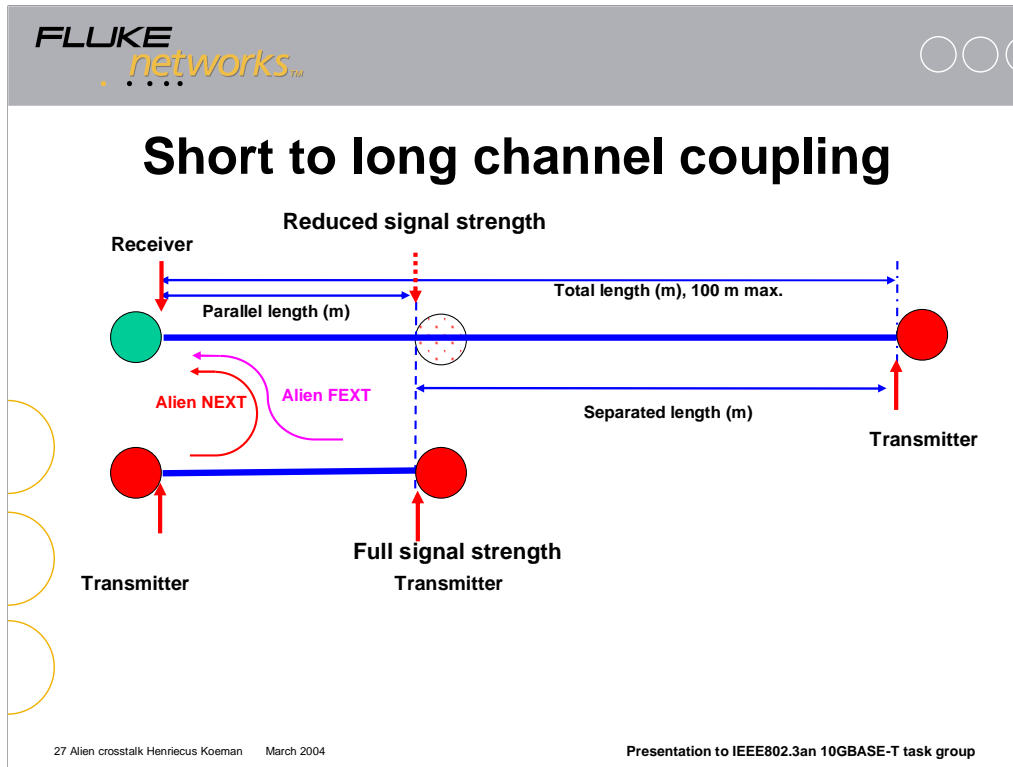**Conclusions Alien ELFEXT dependency as a function of coupling length**

- The length dependency for Alien ELFEXT behaves exactly as predicted.
- Note the 10 dB shift between the 10 m and 100 m coupling length Alien ELFEXT results.
- Alien FEXT can become a concern when a short channel runs along a long channel (see the slides that follow), but generally is not a problem and can be mitigated easily.

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The length dependency for ELFEXT was confirmed in this experiment and can be used for channel modeling purposes.

Note however that Alien FEXT can become a concern when a short channel runs in parallel along the last portion of a long channel. Mitigation is generally easy. See the slide that follows.

Short to long channel coupling

Reduced signal strength

Receiver

Parallel length (m)

Total length (m), 100 m max.

Alien NEXT   **Alien FEXT**

Separated length (m)

Transmitter

Transmitter

Full signal strength
Transmitter

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This slide shows the potential trouble from (EL)FEXT coupling when a short channel runs in parallel with a long channel.

The location of transmitters that influence the signal and noise at the location of the receiver are shown.

The desired signal is the signal from the transmitter of the long channel. It is reduced over the full length of the cable.

A full strength signal amplitude transmitter is near the long channel at the last portion of its cable run. It injects FEXT over this last distance. It is stronger in amplitude by the loss of signal represented by the difference in lengths of the two cables. It is clear that the influence of that transmitter can be reduced by reducing the signal to the short channel.
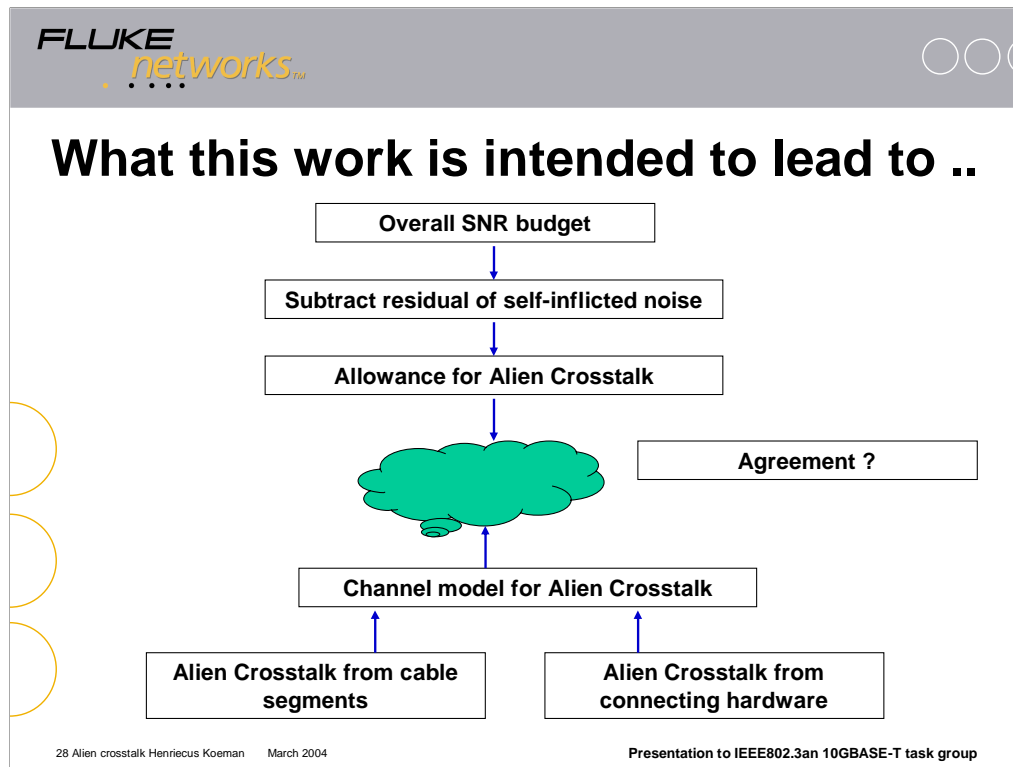
There are two elements this work is intended to contribute to.

First of all, to put the basis for modeling of Alien Crosstalk. It is impossible to model all channel configurations. Instead, if reliable models can be constructed, it will be possible to predict channel Alien Crosstalk from its configuration.

Of course, the budget for Alien Crosstalk has to be in harmony with the Alien Crosstalk properties of the components that make up the channel, as well as the workmanship that was used during the installation.

This study is just the initial step of further research.

1) We need to develop a better understanding of how much these worst case results are enhanced in practical installations (as represented in a "coupling margin").

2) The modeling may provide also a "boundary" of absolutely worst case Alien Crosstalk performance. If the transmission performance for 10GBASE-T can be assured by this boundary performance, there is absolutely no need to test for Alien Crosstalk.

3) When "looking for trouble" in real life installations for Alien NEXT one should concentrate on what happens in the first 10 m from either end of the channel and for Alien (EL)FEXT one should concentrate on short channels running in parallel over a short last distance with long channels.
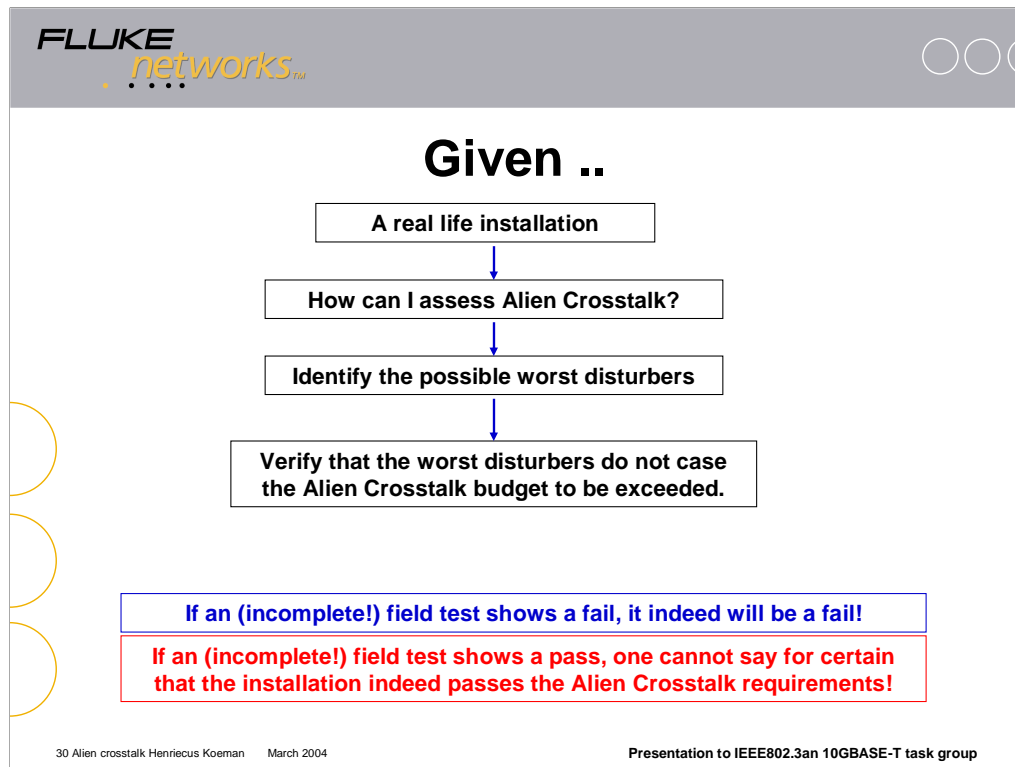
I is agreed that it is rather impractical to measure all possible combinations of Alien Crosstalk. But, the recognition of what the possible worst disturbers are, a reasonable assessment of Alien Crosstalk may be possible.

Of note is that if an (always incomplete) Alien Crosstalk field test shows a fail, it is indeed a FAIL. On the contrary, a PASS condition cannot be fully assured to be indeed a PASS!

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Develop an overall Alien Crosstalk model for installed cabling

- Existing cabling models can be used.
- Length dependency properties of Alien Crosstalk coupling have been pretty well established.
- What is totally lacking is information on typical Alien Crosstalk margins in installed cabling. It is anticipated that these will be substantial and allow 10GBASE-T to work in many circumstances, while predictions using worst case conditions will suggest that satisfactory operation is impossible.

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This work suggests that existing cable models can be applied to Alien Crosstalk predictions.

The length dependency equations were confirmed in this experiments.

As commented before, we are lacking a lot of knowledge on "coupling margins", which will depend on the workmanship and installation guidelines.

The matter of Alien Crosstalk measurement has been brought up numerous times. One cannot go about this kind of testing in a random manner since the number of combinations is practically prohibitive.

However, it may be possible to achieve an assessment of Alien Crosstalk by focusing attention on the cabling components that have potential to contribute the most to Alien Crosstalk. This is part of on-going research and we need many parties to participate in this effort.

Alien Crosstalk measurements are difficult and time consuming.