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Project:	VDSL
Title:	Longitudinal Signals in DSL: Review and Test Proposal
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Abstract:	The purpose of this contribution is twofold. First, we revisit the longitudinal component (also referred to as common-mode component, asymmetric component or antenna-mode component) occurring at the receive side of a twisted-pair loop. Second, we propose a simple setup for RFI tests that captures reality more accurately than performing differential-mode and common-mode tests separately. In essence, we agree with and support the test environments proposed in [1][2][3]. We stress the fact that differential-mode and common-mode signals should be generated jointly in order to account for their correlation.
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Introduction

The radio frequency interference (RFI) ingress and egress issue has been studied extensively in the past. The focus of most investigations was on the question whether RFI ingress/egress is an issue for European access networks. This contribution elaborates on the fact that differential-mode[1] (DM) and common-mode[2] (CM) ingress are correlated and that their levels exhibit certain relations. Resulting consequences of this property of the CM component and emerging possibilities are discussed.
Regardless of the final decision whether to specify a mandatory RFI test or not, we believe that any kind of test (mandatory or not) should involve both the DM and the CM component in order to better resemble reality. We propose a test setup that is simple and yet fulfills the basic needs.

Properties of the CM signal and consequences

Although the investigations regarding RFI carried out in the past were mostly focused on expected signal levels and analysis of the harm potential imposed by DM ingress (cf. for example [7] and references therein), several contributions considered models, levels and impact of the CM component [8][9][10][11][12][13].
If properly used, the CM component occurring at the receive side of a loop can be beneficial. RFI cancellation methods that use the CM component as a reference to derive a counter-signal in order to mitigate the DM interference have been suggested and evaluated [14][15][16][17]. Increasing the bandwidth of the CM component, the idea has been extended to broadband noise caused by crosstalk [18][19][20][21].
A widely accepted interpretation of the ingress mechanism is the following: the ingress is exclusively of longitudinal nature, i.e., longitudinal currents occur as a consequence of a time-varying electromagnetic field present in the area formed by the two wires of a pair and ground. Subsequently, these CM currents are converted into DM currents due to the imbalance of the cable. In case the ingress is a single tone or a very narrow passband signal (which is usually the case for RFI) the corresponding ingress model can be formulated as

$$d(t) = a_{\mathrm{c2d}}\, c(t - \tau) \qquad (1)$$

where $c(t)$ is the sinusoidal CM ingress component, $\{a_{\mathrm{c2d}}, \tau\}$ specify the CM-to-DM conversion and $d(t)$ is the resulting DM ingress component. The attenuation a_{c2d} is primarily determined by the balance of the cable. Field experience suggests that -30 dB is a reasonable choice for a nominal worst-case value which applies at high frequencies (10 to 30 MHz). Measurement results of the frequency dependence of a_{c2d} are reported in [22][23][24] and references therein.
The choice of the amplitude levels of $c(t)$ could orientate itself on the levels gathered by measurements (such as reviewed in [7] and reported in, for example, [25] or [26]). We agree with [27] that single-shot measurement results should not serve directly as reference values

[1] Cf. International Electrotechnical Vocabulary (IEV) [4] entries IEV 161-04-08 and IEV 161-04-38 for a formal definition of differential-mode voltage and current, respectively

[2] Cf. International Electrotechnical Vocabulary (IEV) [4] entries IEV 161-04-09 and IEV 161-04-39 for a formal definition of common-mode voltage and current, respectively. Cf. [5] and [6] for a definition of and a measurement proposal for balance/unbalance, respectively.

for standardized tests. An alternative to seeking consensus on national or European level for ingress amplitudes could be the definition of a few ingress classes according to which the devices under test are graded.
The value of the time-lag τ influences the performance of CM-based cancellation methods. Since it depends on the ingress scenario, it seems reasonable to choose a few values such that the delay between CM and DM signal corresponds to non-integer multiples of periods.
Reported measurement results of both ingress levels [12] and correlation of DM and CM components [13] strengthen the model (1).
Note that the situation is fundamentally different for the above mentioned case of broadband noise caused by crosstalk:

- The levels of the resulting DM component and the resulting CM component induced on a victim pair due to crosstalk originating from a neighbouring pair in the cable are comparable (in order words, $|a_{\text{c2d}}| \leq 10$ dB is more likely to hold than $a_{\text{c2d}} \leq -30$ dB).
- For the RFI case, the CM ingress is much stronger than the DM ingress—thus the conversion from DM to CM is tacitly neglected. For the crosstalk case, the DM to CM conversion has to be taken into account.

However, broadband noise caused by crosstalk is out of scope of RFI tests and this contribution.

A simple test setup

A simple test injects a sinusoidal or very narrow-band CM signal $c(t)$ longitudinally and derives a DM signal $d(t)$ according to (1) which is injected transversally. Figure 1 schematically depicts an exemplary implementation of the test setup. The longitudinal balance of the balun must exceed a_{c2d} in order to allow a controlled injection of DM/CM interference.

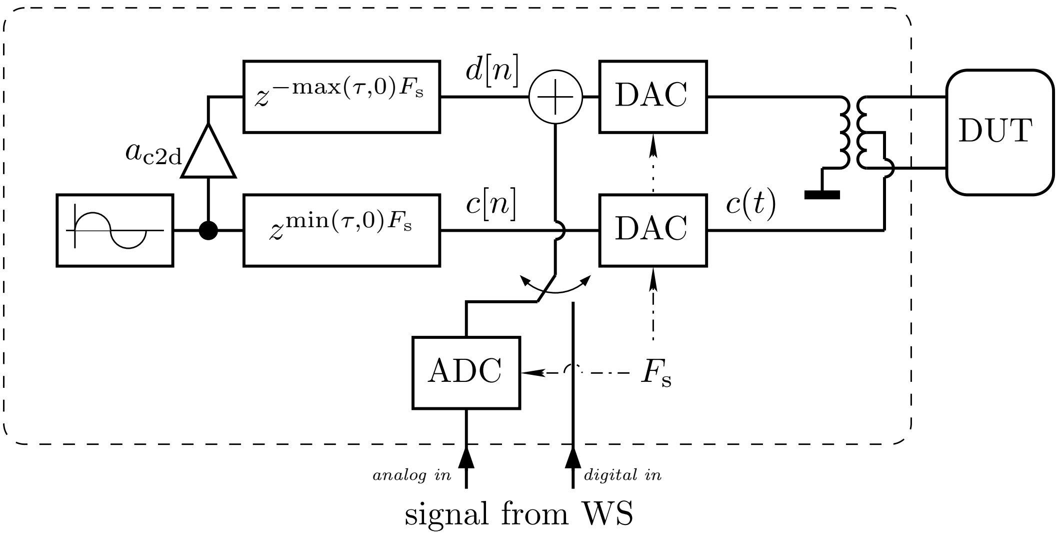

Figure 1: Simple test setup according to the model (1) (ADC: analogue-to-digital converter; DAC: digital-to-analogue converter; DUT: device (modem) under test; WS: wireline simulator).

Conclusions

This contribution reviews origin, amplitude/power levels, negative impacts and possible benefits of the CM component in DSL transmission systems. To conclude, the CM signal is a vital element of the full picture when discussing electromagnetic compliance issues.
A simple setup to integrate the CM component in RFI compliance tests is proposed. Although this test does not represent reality accurately, it resembles reality to a much higher degree than DM-only tests and/or CM-only tests conducted separately, as proposed for example in [28].
We agree with and support the test environments proposed in [1][2][3]. Additionally, we point out that DM and CM signals should be generated jointly in order to implement their correlation.

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