IT cables test

Issue:	1
Revision:	0
Reference:	LPHE 2004-009,
Created:	24th August 04
Last modified:	
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ABSTRACT

This note reports results of measurements done on cables suitable for the IT copper link.

DOCUMENT STATUS SHEET

Table 1 Document Status Sheet

1. Document Title: IT cable test			
2. Document Reference Number: LHCb 2004-xxx,LPHE2004-xxx			
3. Issue	**4. Revision**	**5. Date**	**6. Reason for change**
Draft	1	August 04	First version

1. Overview.

The LHCb silicone tracker readout system starts with the Front-end Beetle chip mounted on the hybrid located in the detector box. Each hybrid carries three FE chips and no other active components are foreseen on this hybrid due to radiation levels at this location in the tracking system. Each Beetle chips have four differential outputs and are directly connected to a copper transmission line. The line will carry these signals to the service boxes located under the detector box and sitting outside of the detector acceptance. The distance between the detector box and the service box is around 5 meters. In the service box, the signals are digitized and send to the level one electronic board in the control room via an optical link. The cable used for the transmission must also carry some lvds signals (40MHz clock, reset, trigger) required by the FE chip.
Two types of cables were selected and some measured parameters as attenuation, crosstalk, and pulse response are reported in this note.

2. Cable description.

Cable 1 : 34 shielded twisted pairs round cable (Madison)

The first cable measured is a round 34 shielded twisted pairs. The shield is common for the cable. The length is 5 meter. No inscriptions figure on the cable coat and no specs from the manufactory.
The external jacket is black and the diameter is 9.8mm (0.385inches).
The lineic capacitance is 273pF for 5m: 17 [pf/ft]
The Dc conductor resistance is 1.73 ohms/5m: 0.085[ohm/ft]
Conductor: 30AWG 34 shielded twisted pairs
Impedance: 100 ohms

Cable 2: flat 30AWG flat lousy twisted pairs
The cable is procured at CERN store:

04.21.21.368.5	MT	21.00	2 x 34	425-3016-068	79992-34P-270A

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CONDUCTEUR : Cuivre étamé
         : 0,33 mm (7 x 0,102 mm)
SECTION : 0,057 mm2 (AWG 30)
ENTRE AXE DES CONDUCTEURS (section plate) : 0,635 mm
ISOLATION : Polyoléfine
SPECIFICATIONS :
 TENSION NOMINALE                 : 150 Vcc
 TEMPERATURE D'UTILISATION        : -20 à +90 °C max.
 RESISTANCE (DC)                  : 354 Ohm/km
 IMPEDANCE                        : 110 OHM (GSM)
 CAPACITE                         : 43 pF/m
 INDUCTANCE                       : 0,68 µH/m
 DELAI NOMINAL DE PROPAGATION     : 4,9 ns/m
 COULEUR                          : Multicolore
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There is no shield around the cable. For the tests, the cable is wrapped in a zippered shielded jacket.

3. Insertion loss.

Recent changes in the standards use now the term of “insertion loss” and not attenuation. The insertion loss is the decrease of the signal from one end of the cable to the other. The main causes of the signal attenuation are the combination of impedance (resistance, capacitance and inductance), skin effect and dielectric loss. The skin effect appends at high frequencies.
A differential signal is applied at one side of the cable and the other end is terminated on its impedance. The input amplitude is constant and the frequency is swept from 1[MHz] to 100[MHz]. The amplitude of the differential output is monitored for each frequency value. The insertion loss is expressed in dB.

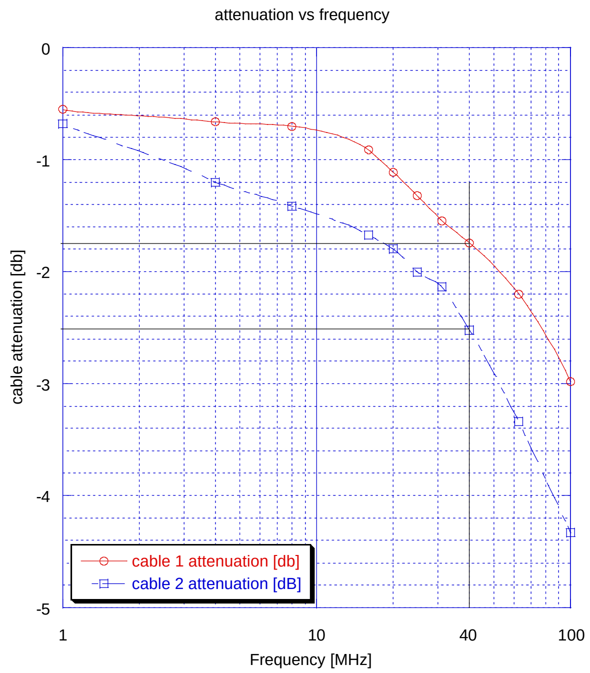


Fig.1 : attenuation vs frequency

Cable 1 introduces less attenuation versus frequency than cable 2. At 40MHz the attenuation with cable 1 is -1.74dB which means that the output signal is reduced by 18%.
The attenuation at 40MHz with the cable 2 is -2.52dB, which corresponds to a factor of 25.2%.

4. Crosstalk.

When a current flows through a wire, an electromagnetic field is created which can interfere with signals on adjacent wires. As frequency increases, the effect becomes stronger. This is crosstalk. Telecommunications standards define several crosstalk and interpretation ways:

NEXT (Near End Crosstalk): this crosstalk is measured at the same side of the cable where signal in injected into the cable. This crosstalk is an important parameter where transmission is bidirectional. Its characteristic versus frequency looks like a roller coaster going up hill. That is it varies up and down while increasing in magnitude. This is because twisted pair coupling becomes less effective for high frequencies.

ACR (Attenuation to Crosstalk ratio): it is the difference between NEXT and the attenuation for pair in the link under test. Due to effects of attenuation, signals are at their weakest at the receiver end of the link. However, is also where NEXT is the strongest. Signals that survive attenuation must not get lost due to effect of NEXT. This combined effect is characterized by the ACR. It is the difference between the attenuation and the NEXT. ACR is a good figure of merit of the transmission quality and can be assimilated to a kind of signal to noise ratio, excluding effects coming from external noise that may affect the signal transmission. It provides a measure of how much headroom is available, or how much stronger the signal is than the background noise. The greater ACR, the better.

Power Sum NEXT (PSNEXT): it is not a measurement but a calculation. It is derived from the summation of the individual NEXT effects on each pair by the other pairs. Typically, PSNEXT results are around 3 dB lower than the worst case NEXT result.

FEXT (Far End Crosstalk): it is similar to NEXT, except that the signal is sent from the local end and crosstalk is measure at the other end of the cable.

Equal Level Far End Crosstalk (ELFEXT): it is derived by subtracting the attenuation of the disturbing pair from the FEXT this pair induces in an adjacent pair. ELFEXT is a good figure of merit of the transmission quality and can be assimilated to the ACR at the far end cable.

Power Sum Equal Level Far End Crosstalk (PSELFEXT): it is derived from the algebric summation of the individual ELFEXT effects on each pair by the other pairs. Typically, PSELFEXT result is around 3dB lower than the worst case ELFEXT result.

5. Crosstalk measurements.

During all measurements, all the pairs are terminated at both ends on their characteristic impedance. The crosstalk is measured on the adjacent exciting pair, which is the worst case talking about interferences. The signal injected in the disturbing pair is a differential sine wave.

NEXT :

The NEXT versus frequency of both cable are represented in the figure 2. The attenuation is also represented on the same plot. The difference between the attenuation and the NEXT curve is the cable ACR.

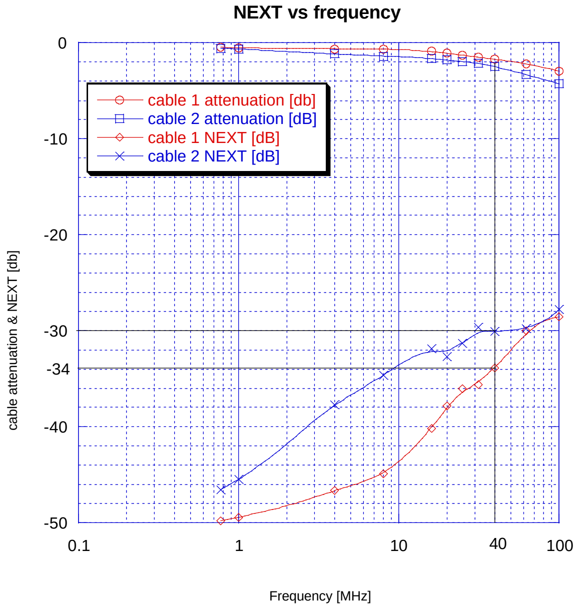


Fig.2 : NEXT vs frequency

The NEXT for cable 1 at 40MHz is at -34dB, which represents a crosstalk of 1.99% from the adjacent pair.
The NEXT for cable 2 at 40MHz is at -30dB, which represents a crosstalk of 3.16% from the adjacent pair.
The distance between the attenuation and the NEXT at a known frequency is the ACR.
The PSNEXT curve for both cables would be 3dB lower from the NEXT curve.

FEXT:

The disturbing sine wave is injected at one end, and the FEXT is measured at the other one. The attenuation and NEXT for both cables are represented in figure 3. The ELFEXT is the distance between the attenuation and the NEXT curves.

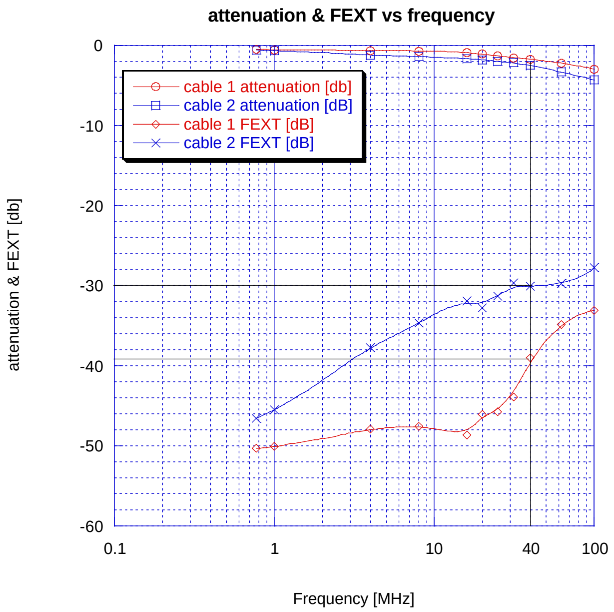
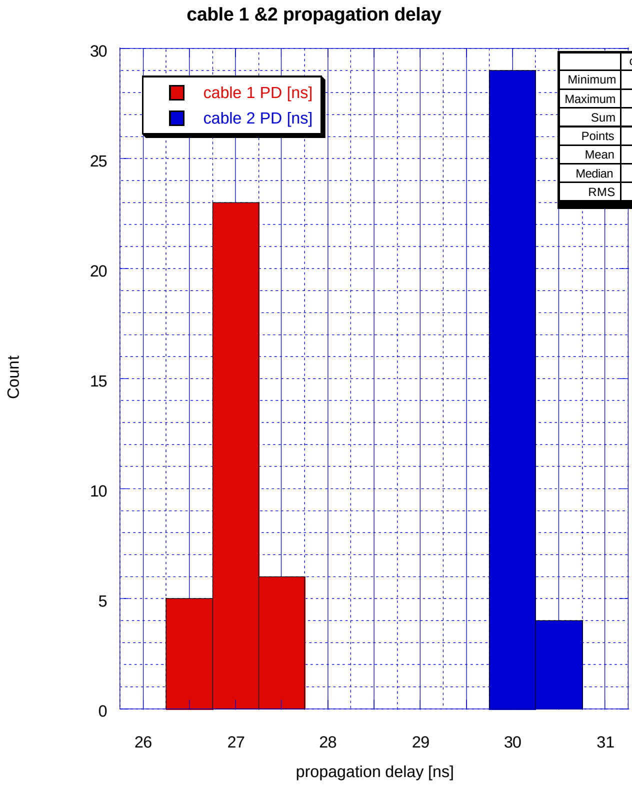


Fig. 3 : insertion loss & FEXT vs frequency

The FEXT for cable 1 at 40MHZ is -39dB, which corresponds to a crosstalk of 1.12% from the adjacent pair. The FEXT for cable 2 at 40MHZ is -30dB, which corresponds to a crosstalk of 3.16% from the adjacent pair.

6. Propagation delay (PD) and propagation delay skew (PDS).

This is the measure of the time required for a signal to propagate from one end of the cable to the other end. The delay is measured in nanoseconds. One 25ns pulse is sent on each pair and the delay is measured at the other end. The propagation delay skew (PDS) is the difference between the fastest and the slowest pair in the cable. The skew is important because if the delay on one or more pairs is significantly different from any other, signals were arrive at significantly different times at the receiver which can introduces some problem in digitizing.
The maximum delay skew allowed for the IT system must be less than 5ns.
The figure 4 shows the propagation delay distribution for respectively cable 1 and 2.



	cable 1 PD [ns]	cable 2 PD [ns]
Minimum	26.299999	29.799999
Maximum	27.5	30.299999
Sum	918	992
Points	34	34
Mean	27	30.060606
Median	27.1	30.1
RMS	27.00147	30.060908

Fig.4: cable 1 & 2 propagation delay

Cable 1: the propagation delay is 27ns and the PDS is 1.21ns for a cable length of 5m.
Cable 2: the propagation delay is 30 ns and the PDS is 0.5ns for a cable length of 5m.

7. Pulse response.

Cables distortion will affect transmitted data. The rise and fall time of a pulse increase as the signal travels down the line. This effect will tend to affect timing of recovering the signal. The high frequency components of a step input are attenuated and delayed more than the low frequency components. This attenuation is inversely proportional to the frequency. This effect is more significant for fast rise and fall times.

A differential 25ns pulse in injected on both cable and rise and fall time are measured at the cable end. The differential magnitude of the input pulse is 2V. The figures 5 and 6 shows the differential signal output for respectively cable 1 and 2.

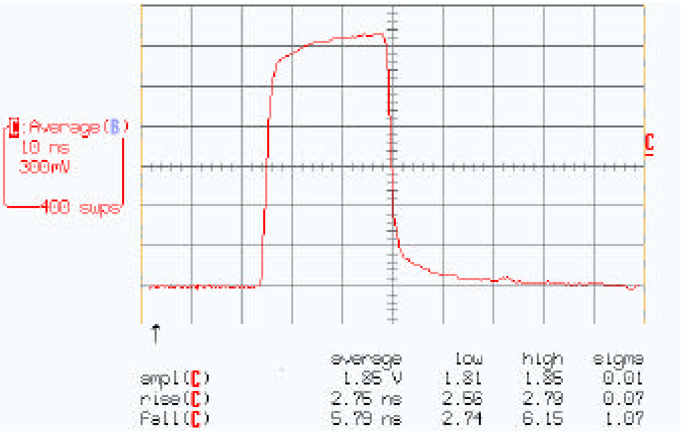


Fig. 5 : cable 1 : 25ns pulse response

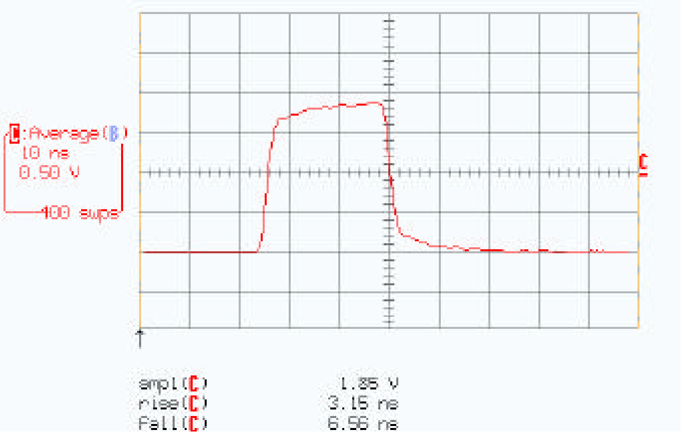


Fig.6: cable 2: 25ns pulse response

Cable 1: the rise time is 2.75ns and the fall time is 5.79ns for a cable length of 5m.
Cable 2: the rise time is 3.15ns and the fall time is 6.56ns for a cable length of 5m.

8. Crosstalk factor CF.

The fall time is typically bigger than the rise time. The analogue data stream send on the cable are digitized every 25ns. If some residual voltage, due to large fall time, is present in the next sample at the digitizing instant, it will introduce distortion amplitude in the sample. This effect can be considered as a crosstalk.
The crosstalk factor CF is defined as the fraction of sample n that persists in the amplitude of sample n+1. As the persistence decays exponentially, this factor is slightly dependent of the exact moment (ADC clock trailing edge) on which the samples are taken. This crosstalk can be view as an additional noise, which is tolerable as long as it stays bellow the noise already present in signal itself (S/N).

A 25ns differential pulse is sent in the cable and the amplitude is measured at the middle of the duration. The sample n+1 is digitized 25ns later. The amplitude of the sample n rises from 0 to 4V and the residual voltage is monitored in the sample n+1,i.e. 25ns after the mid of the sample n duration.
The residual voltage in sample n+1 versus the amplitude of sample n is then plot. The CF is the slope of the linear fit. The figure 7 shows the CF for cable 1 and 2:

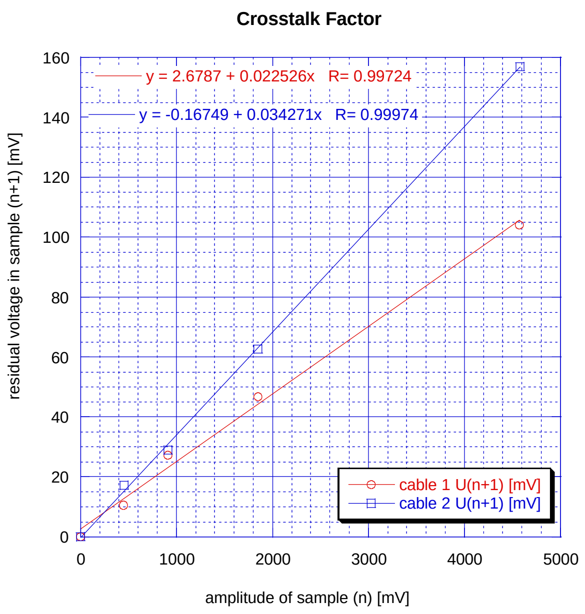


Fig. 7: cable 1 & 2 Crosstalk Factor

The cable 1 crosstalk factor is 2.25%.
The cable 2 crosstalk factor is 3.42%.
The residual voltage in the next sample depends strongly on the digitizing instant. Positioning of the ADC clock edge on the second half of the duration will reduce the effect.

9. Shield.

A cable shield is required to prevent EMI.
The cable 1 has basically a tape shield. The shield is an aluminium polyester laminated tape used in conjunction with a drain wire applied directly adjacent to the aluminized side of the tape. For frequencies up to 400MHz, it is effective as a braid copper shield since it provides a 100% coverage. This kind of shield reduces the flexibility of the cable and introduces some mechanical stress on connectors if cable is not attached.

There is no shield with the cable 2 and all the pairs are lousy. A way to shield the cable is to wrap one or a bundle of cables in a braid zippered cable shielding. Braids shielding are a trade off between flexibility and ideal tubular tubes. The lower resistance of the braids results in good shielding effectiveness up to a certain point. The small holes between the cross over of the braid strands become large at some frequencies. Braids are specified by the percent of coverage. Coverage of 70% to 80% will be effective for audio frequencies. For higher frequencies (3 to 30 MHz), coverage of 85% to 95% is necessary to give an adequate protection. Two layers of braid can be specified fro still greater effectiveness, but all at the expense of flexibility.

10. Alien crosstalk.

When cables are adjacent to each other, emissions from one cable can affect pairs in the other cables. This effect is called Alien crosstalk. Practically, unshielded cables that are closely bundled together for a distance of more than 15 meters can be concerned. Measurements of Alien crosstalk are difficult because it requires synchronizing several sets of test instruments.

11. Summary.

All the measured parameters are summarized on the following table:

item	cable 1	cable 2
insertion loss @40MHz	-1.7dB (81.9%)	-2.52dB (74.8%)
NEXT @40MHz	-34dB (2%)	-30dB (3.1%)
FEXT @40MHz	-39dB (1.1%)	-30dB (3.1%)
Propagation Delay	27ns	30ns
Propagation Delay Skew	1.21ns	0.5ns

25ns pulse response		
rise time	2.75ns	3.15ns
fall time	5.79ns	6.56ns
Crosstalk Factor	2.25%	3.42%
shield	common	no

The two types or cables are suitable for the inner tracker copper transmission between the detector and service box.
However, flat cable is relatively not expensive to terminate. Connectors are available in configurations with insulation displacement contacts for flat cable termination. Lousy pairs allowed more freedom in routing cables and does not limit the cable flexibility to a single plane. Commercial double braid shielding jacket around a bundle of cables can provide EMI immunity, but uses more routing cross section.
The round cable uses less routing cross section and each cable has its own shield. The bend radius is quite big in front of lousy twisted pairs and introduces some mechanical stress on connectors if they are not fixed to a solid structure. Mounting connectors on this type of cable is not an easy task and can improve the cost.

The main parameter for choosing the cable for the IT transmission is the total radiation length of cable with connectors. This is outside of the scope of this note.

12. Conclusion.

In this paper, results on cables measurements are reported. The crosstalk between adjacent pairs can be consider can be considered as negligible, but the crosstalk from sample to sample depends on the digitizing ADC clock edge time position. No individual pair shielding is needed. Bundle cables can be wrapped in a shielding zipped jacket to prevent EMI. Important points for choosing the cable are budget material, mounting facilities, flexibility.