

Hands on:

# GigabitEthernet

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1000BASE-T Cable testing



**Trend**Communications

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*Section 1*

## Cable testing for 1000BASE-T

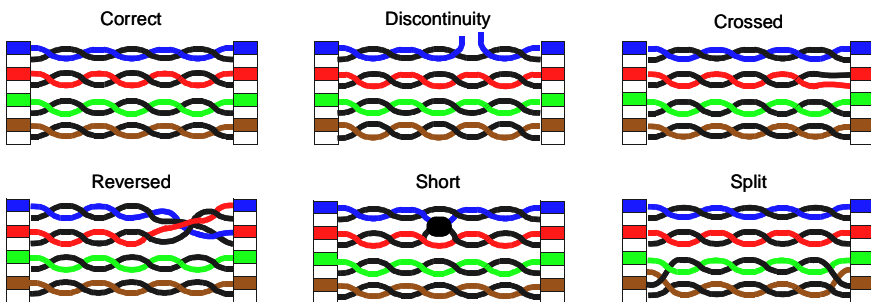
### 1.1 CABLE CATEGORIES

The good news is that Gigabit Ethernet offers a cost effective migration to 1000BASE-T from those installations running 10/100Base-T over Category 5 cabling systems up to 100 meters. The bad news is that you cannot expect a Cat. 5 installation to meet all the requirements, and new performance tests must be run to ensure that the cabling supports the new requirements. New cable categories, such as Cat. 6 or Cat 7, could eventually support Gigabit Ethernet but would require the installation of a new cable system.

In the case of new installations, the category does not matter, it will be necessary to verify the electrical connections in a process often called cable testing. This should be performed before addressing analysis of performance.

### 1.2 CABLE TESTING

The verification of the electrical connections and cabling errors is performed in a process called wiremap testing. Tests on cabling can go further using testers with more sophisticated features such as the ability to measure crosstalk, capacitance, resistance or TDR.



**Figure 1.1** Correctly installed, Reversed, Discontinuity, Short, Crossed and Split pairs of four pairs UTP installations



**Figure 1.2** LinkMaster, a wiremap tester suitable for Cat 5 verification all four twisted pair.

### 1.2.1 Wiremap

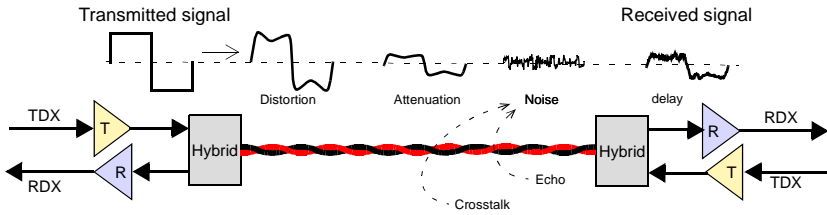
Wiremap is used to identify installation wiring errors. In the case of UTP cabling systems, for each one of the 8 conductors in the link, wire map should indicate:

- *proper pin termination at each end;*
- *continuity to the remote end;*
- *shorts between any two or more conductors;*
- *crossed pairs or polarity swap, split pairs, reversed pairs or pair swap;*
- *shorted pairs and any other mis-wiring.*

### 1.2.2 Advanced cable testing

Using simple analyzers based on LEDs it is possible to detect most wiring errors, however these simple analyzers have certain limitations. For example to detect split pairs it is necessary to connect the tester at the near-end and terminators at the far-end. More sophisticated wiremap testers with capacitance, NEXT or impedance measuring capabilities can perform single-sided tests to detect any wiring errors without using far-end terminators. For example, split pairs can be identified by measuring crosstalk because split pairs cause a high NEXT (over 20dB) that limits the available bandwidth on the installed cabling.

The most advanced cabling testers may include a Time Domain Reflectometer (TDR) to determine the quality of the cables, connectors, and terminations. Some of the possible problems that can be diagnosed include opens, shorts, cable impedance mismatch, bad connectors, and termination mismatch.



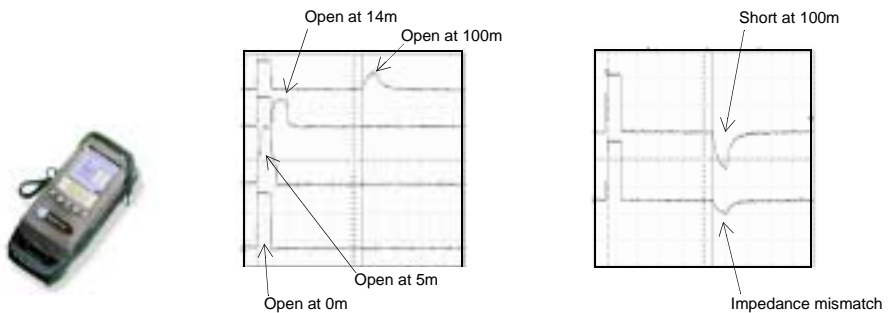
**Figure 1.4** Effects of attenuation, distortion, and noise on transmission. It is remarkable that impairments are typically reflected as noise.

### 1.3 PERFORMANCE PARAMETERS

Wiremap is a basic test, and does not guarantee that the cabling is capable of supporting Gigabit Ethernet; it is necessary to verify bandwidth performance which relies on frequency-dependent parameters.

Appendix 1 to 5 of ANSI/TIA/EIA-568B and the technical system bulletin (TSB) is the reference that taken over from ANSI/TIA/EIA-568A (1995) to ensure that a Category 5 cabling provides a reliable medium for 1000BASE-T. These documents define a transmission model with a characteristic impedance and a number of parameters. They include the limits of limiting power loss, crosstalk, and delay (see Figure 1.4):

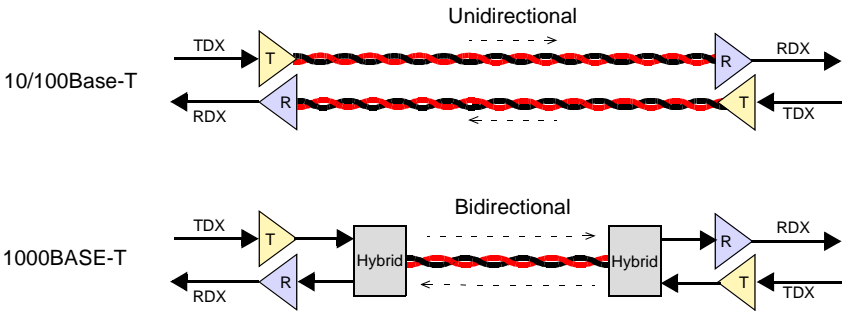
- *Characteristic Impedance ( $Z_0$ )* of a line is the resistance it would exhibit if it were infinite in length. Because it is a pure function of parasit capacitance and inductance distributed along the line, then  $Z_0$  reduces with increasing frequency.



**Figure 1.3** Aurora Tango Gigabit Ethernet has a TDR embedded for UTP cable testing.

- *Power Loss.* Not all the power transmitted by the source arrives at the destination, a portion is reflected back to the source because of impedance mismatch, another portion is lost as cable losses. The first effect is called Return Loss (RL) and the second Insertion Loss (IL) or attenuation.
- *Crosstalk (XT)* is the noise induced by a disturbing transmitter pair in a victim receiver pair due electromagnetic coupling. Several parameters characterize XT such as Near End Crosstalk (NEXT), Far End Crosstalk (FEXT) and Equal Level Far End Crosstalk (ELFEXT).
- *Delay* is the time a signal needs to arrive at the far-end. Delay skew is the difference in delay between the four pairs transmitting signals simultaneously.

Return Loss and ELFEXT measurements were not required when qualifying links for 10/100Base-T, but are now because 1000BASE-T transmission is bidirectional on a single pair (see Figure 1.5).



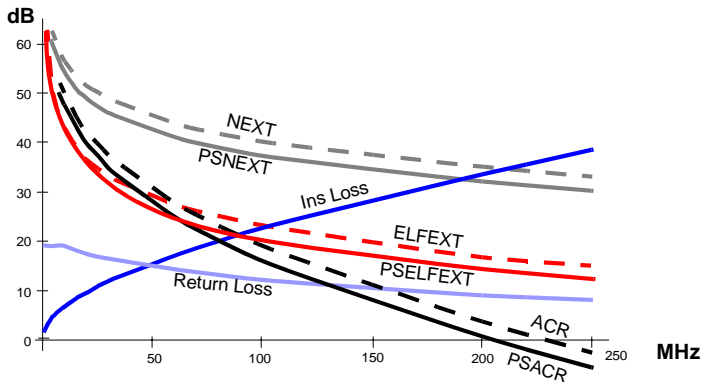
**Figure 1.5** Bidirectional and unidirectional transmission.

The bidirectional transmission results in disturbing echo signals that must be removed by the hybrids, to prevent them being mixed with the local received signals. As result of this performance meters now include Insertion Loss, Return Loss, NEXT, ELFEXT, Delay and Delay Skew. All of them are a function of frequency and proportional to the cable length.

**Table 1.1** Cabling Systems

	Category 5	Category 5e	Category 6	Category 7
<i>Bandwidth</i>	100MHz	100MHz	250MHz	600 MHz
<i>Standard</i>	ANSI/TIA/EIA 568A: 1995	TIA/EIA-568-A Addendum 5	TIA TR 42.7.1 and ISO/IEC/SC25/WG3	In development by ISO/IEC/SC25/WG3
<i>Testing</i>	TIA/EIA TSB 67, TIA/EIA TSB 95	Includes return loss and FEXT		

When qualifying UTP cabling system a field tester should compare successive readings across the frequency range against a typical pass/fail line. If the measurement line crosses the pass/fail curve (often called a mask) at any point, then the link does not meet the stated requirement see Figure 1.6 and Figure 1.9.



**Figure 1.6** Cat 6 cabling mask up to 250 MHz. Includes Parameters Insertion Loss (IL), Return Loss (RL), Near End Cross Talk (NEXT), Power Sum Next (PSNEXT), Attenuation to Cross Talk Ratio (ACR), Power Sum ACR (PSACR), Equal Level Far End Cross Talk (ELFEXT) and Power Sum ELFEXT (PSELFEXT).

### 1.3.1 Characteristic Impedance

Characteristic impedance ( $Z_0$ ) corresponds to the input impedance of a uniform transmission line of infinite length. It also corresponds to the input impedance of a transmission line of finite length that is terminated with its own characteristic impedance.

$Z_0$  is a function of the frequency of the applied signal, and is unrelated to the cable length. At very high frequencies, the characteristic impedance asymptotes to a fixed value which is resistive. For example, coaxial cables have an impedance of 50 or 75 Ohms at high frequencies. Typically, twisted-pair lines used in local loops have an impedance above 600 Ohm for telephony, and below 150 Ohms when they are used for xDSL (see Figure 1.8).

For 1000BASE-T the characteristic impedance of each link, which includes cable cords and connecting hardware, is 100 Ohm for all frequencies between 1 MHz and 100 MHz [1]. This means that tests should be conducted using source and load impedances of 100 Ohms.

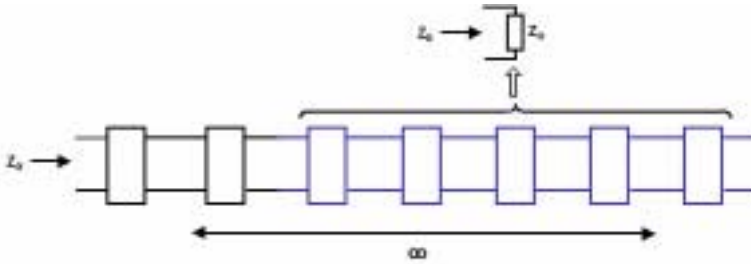


Figure 1.7 Characteristic impedance of a transmission line.

The major influence on characteristic impedance is the capacitance, which is largely determined by the type of dielectric used. For high frequencies, it can be stated in terms of the physical dimensions of the cable:

$$Z_0 = 276 \log D/r \quad (Ohm)$$

*D*: is the spacing between the centers of two conductors pair  
*r*: is the radius of each conductor

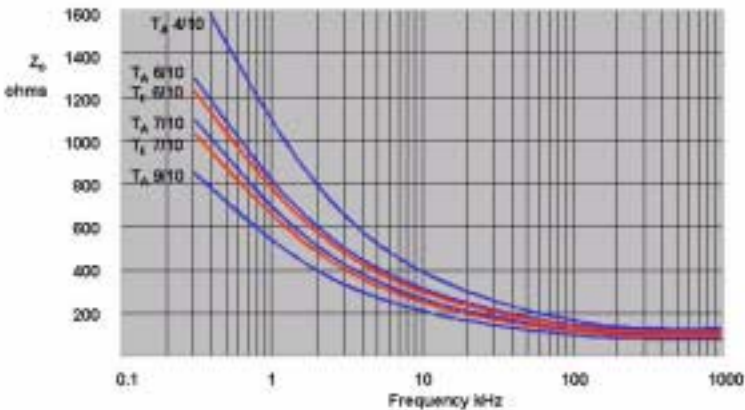


Figure 1.8 Characteristic impedance of twisted pairs of difference gauge.

Characteristic impedance is of prime importance for good transmission. Maximum power transfer occurs when the source has the same impedance as the load. Thus for sending signals over a line, the transmitting equipment must have the same characteristic impedance as the line in order to put the maximum signal into the line. At the other end of the line, the receiving equipment must also have the

same impedance as the line in order to be able to get the maximum signal out of the line. Cat 5e segment testing must be conducted using source and load impedances of 100 Ohm.

### 1.3.2 Insertion Loss or Attenuation

When an electrical signal is inserted into a transmission line, only one part of the power arrives at the receiver. One part of the power is reflected to the transmitter; another part turns into ohmic losses; and another part is lost due to outward radiation, especially for very high frequencies.

*Insertion Loss (L)* of a line is a measure of the reduction in signal power due to cabling losses. The simplest way to characterize attenuation is by means of a parameter called attenuation,  $L$ , that is obtained from the relationship between the power of the transmitted,  $P_T$ , and the received,  $P_R$ , signal:

$$L = \frac{P_R}{P_T}$$

However, 1000BASE-T transmission uses sinusoidal signals, and insertion loss is a function of frequency. Insertion Loss is therefore to be measured over the frequency range 1 MHz to 100 MHz.

Excessive length is the most common reason for problems with attenuation, but it can also be caused by poorly terminated connectors/plugs or impurities in the copper cable. If only one or two pairs have high attenuation, this suggests an installation issue. If all pairs have high attenuation, check for excess length. Connection problems and impurities typically happens on one pair only.

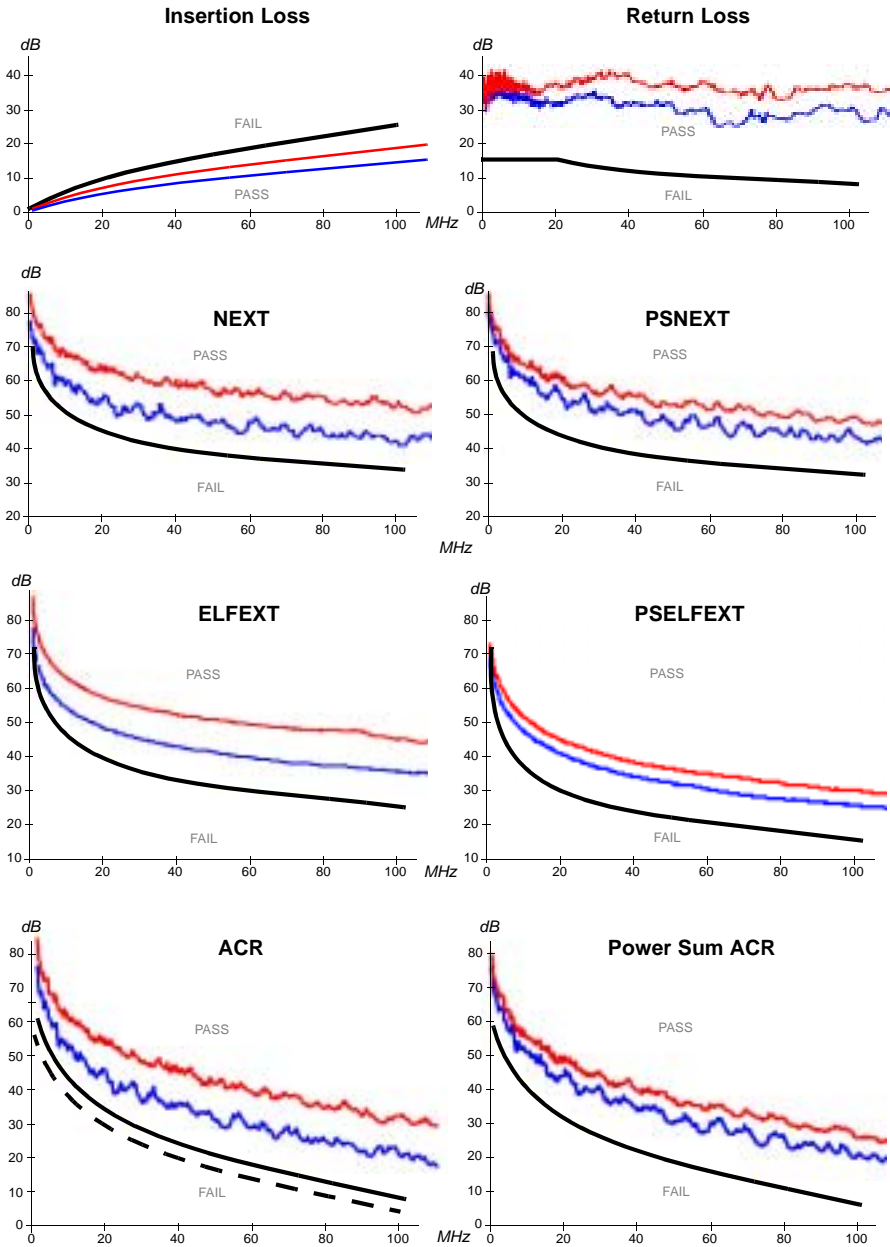
The standard for 1000BASE-T [1] states link insertion loss shall be less than:

$$InsertionLoss(f) < 2.1f^{0.529} + 0.4/f \quad (dB)$$

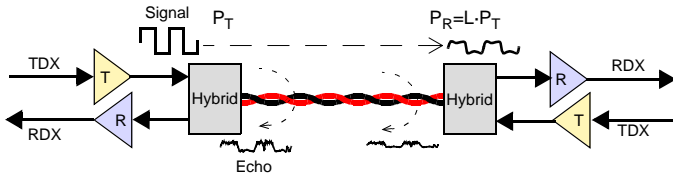
### 1.3.3 Return Loss

Where line and transmitter impedances do not match, some of the signal is reflected back towards the source as echo that disturbs the receiver reflected signal; this causes problems and is therefore undesirable.

*Return Loss (RL)* of a line is a measure of all reflections caused by impedance mismatches. It is calculated as the ratio of the power reflected back from the line to the power transmitted into the line.



**Figure 1.9** Cat 5e mask (black color) and measurement plots (blue worst case, red average). Parameters Insertion Loss (IL) and Return Loss (RL), Near End Cross Talk (NEXT), Power Sum Next (PSNEXT), Equal Level Far End Cross Talk (ELFEXT) and Power Sum ELFEXT (PSELFEXT), Attenuation to Crosstalk Ratio (ACR), Power Sum ACR (PSACR)



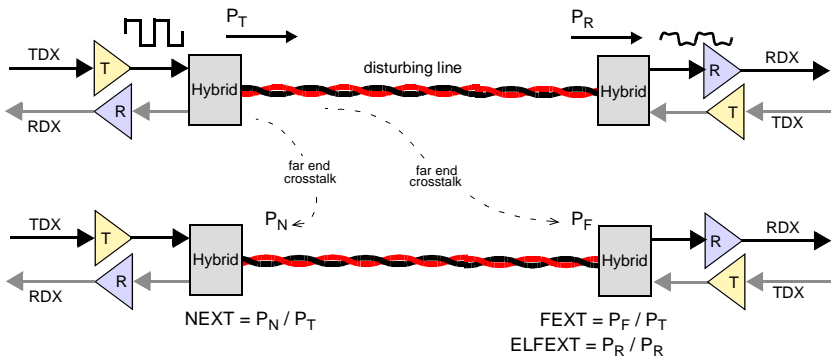
**Figure 1.10** Echo and attenuation in Bidirectional Transmission Systems.

The standard for 1000BASE-T [1] states link requirements for return loss limits

$$ReturnLoss(f) > \begin{cases} 15 & [1, 20MHz] \\ 15 - 10\log(f/20) & [20, 100MHz] \end{cases} \quad (dB)$$

### 1.3.4 Crosstalk

Crosstalk is analyzed by means of many parameters in which the signal power received at one end is compared to the disturbing power. A disturbing signal generates crosstalk at both ends of the victim line. The end where the power is inserted is called *Near End* the opposite is the *Far End* (see Figure 1.13).



**Figure 1.11** Near-End Crosstalk (NEXT), Far-End Crosstalk (FEXT) and Equal-Level Far-End Crosstalk (ELFEXT).

- *Near-end Crosstalk (NEXT)*, which is the relationship between the power transmitted by the disturbing line and the power received by the victim line at the same end where the signal is inserted. NEXT is independent of line length.



**Figure 1.12** LANTEK 7 cable tester compliant with Categories 3/5e/6 and 7/ISO F standards, with a frequency range up to 750 MHz.

- *Far-end Crosstalk (FEXT)*, which is the relationship between the power transmitted by the disturbing line and that received by the victim line at the end opposite to where the disturbing signal is inserted. FEXT depends on the line length.
- *Equal Level Far-end Crosstalk (ELFEXT)* is defined as the relationship between the power received by the disturbing line, and the FEXT power received by the victim pair. Unlike Next, FEXT depends on the length of the pairs in question, the longer the pairs, the less FEXT there is. However, this may be misleading, as the useful signal is also affected by the same attenuation factor.

$$NEXT = \frac{P_N}{P_T} \quad FEXT = \frac{P_F}{P_T} \quad ELFEXT = \frac{P_F}{P_R} = \frac{P_F}{LP_T} = \frac{FEXT}{L}$$

$P_T$ : power of the transmitted signal

$P_R$ : power of the signal received at the far-end

$L$ : attenuation

$P_N$ : disturbing power received by the victim pair at the near-end

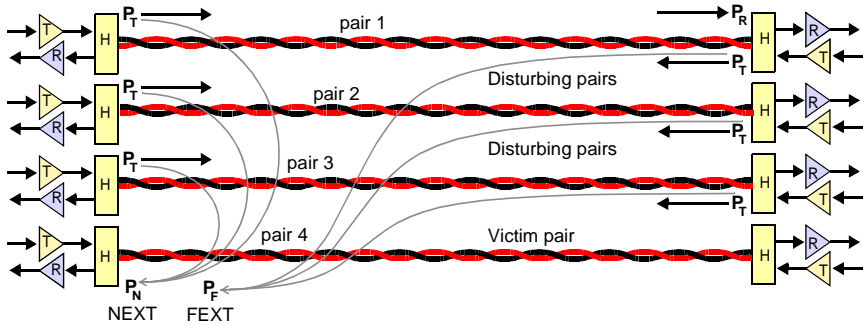
$P_F$ : disturbing power received by the victim pair at the far-end of the transmitter

Note that FEXT is not a required parameter for Cat5e but it allows the calculation of ELFEXT.

### 1.3.4.1 Near-end crosstalk (NEXT)

NEXT varies significantly with frequency, it is therefore important to measure it across a range of frequencies, typically 1 – 100 MHz.

Often, excessive crosstalk is due to poorly twisted terminations at connection points. Since NEXT characteristics are unique to each end of the link, six NEXT results should be obtained per line and  $6 \times 4 = 24$  per UTP link! Nevertheless testers can simplify the qualification task by reporting the worst case of NEXT, the average and the Power Sum (PSNEXT) (see Figure 1.11).



**Figure 1.13** Due to electromagnetic coupling not only the line receives the signal power at the far end, but the victim lines as well, both at the same end where the disturbing power is inserted (NEXT) and at the opposite end (FEXT).

The first thing to do in the event of a NEXT failure is to use the field tester to determine at which end the NEXT failure occurred. Once this is known, check the connections at that end and replace or re-terminate as appropriate. If this does not appear to be the problem, check for the presence of lower Category patch cords. Another possible cause of NEXT failures is split pairs (see Section 1.2). These can be identified automatically with the wiremap function of your field tester.

A tester with TDR capabilities gives the ability to show the fault by distance, pinpointing the problem. This diagnostic function clearly identifies the cause of the NEXT failure, whether it is the patch cord, connection, or horizontal cable.

The standard for 1000BASE-T [1] states link requirements for NEXT loss between a pair and the other three should be at least:

$$NEXT(f) > 27.1 - 16.8 \log_{10}(f/100) \quad (dB)$$

#### 1.3.4.2 Equal Level Far-End Crosstalk (ELFEXT)

ELFEXT loss is critical when two or more wire-pairs carry bi-directional signals in the same direction because it is a kind of indication of Signal-to-Noise-Ratio (SNR).

The standard for 1000BASE-T states link requirements for ELFEXT in order to limit the crosstalk at the far end and meet the BER objectives. The worst pair ELFEXT loss should be greater than

$$ELFEXT(f) > 17 - 20 \log(f/100) \quad (dB)$$

ELFEXT is a calculated result, rather than a measurement. It is derived by subtracting the attenuation of the disturbing pair from the Far End Crosstalk (FEXT) that this pair induces in an adjacent pair. This normalizes the results for length.

To ensure that the total FEXT coupled into a pair is limited, multiple disturber ELFEXT loss is specified as the power sum (PSELFEXT) of the three adjacent disturbers which shall be:

$$PSELFEXT(f) > 14.4 - 20\log(f/100) \quad (dB)$$

Consider if the FEXT is equal to 45 dB and attenuation equal to 11 dB then:

$$ELFEXT = 45 - 11 = 34 \quad (dB)$$

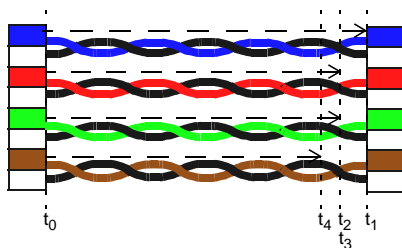
### 1.3.4.3 Power Sum Crosstalk (PSACR)

Every pair receives, simultaneously with its data signal, NEXT and FEXT from the other three pairs (see Figure 1.13). Power Sum Crosstalk (PSACR) is the combination of all the interferences received in a pair and measured at both ends. To meet Cat 5e requirements the worst PSACR shall be limited (see Figure 1.15) according to the TIA/EIA 568-A.

## 1.3.5 Delay parameters

### 1.3.5.1 Delay

It is necessary to guarantee that the data, which has been divided and sent separately across four channels, can be properly reassembled at the receiver side.



**Figure 1.14** Skew is important because Gigabit Ethernet, use all four pairs in the cable. If the delay on one or more pairs is very different to recover the original signal.

The propagation delay of the single channels and variation of the delays between

the four channels must be limited. The delay limit for frequencies between 2 and 100MHz shall not exceed [1]:

$$Delay(f) < 570ns$$

This also guaranties Collision Detection (CD) if half duplex transmission is used. This is because round trip delay is important to guarantee that Collision Detection functions properly.

### 1.3.5.2 Propagation Delay Skew

Different types of insulation materials on each pair produces variation in delays. Propagation Delay Skew is the difference between the delay in the fastest and slowest pairs in a UTP cable. Reception buffers re-synchronize the four signals, however there is a limit that cannot be broken over 100 m links [1]:

$$DelaySkew < 50ns$$

## 1.4 COUNTERING TRANSMISSION IMPAIRMENTS

The transmit signals in 1000BASE-T are subject to impairments introduced by the cabling and external noise sources (see Figure 1.4). In order to operate reliably, the impairments to the transmit signal need to be controlled. The ratio between the impairments, which are generally manifested as noise, and the transmit signal, shall be maintained to achieve an acceptable bit error rate (BER).

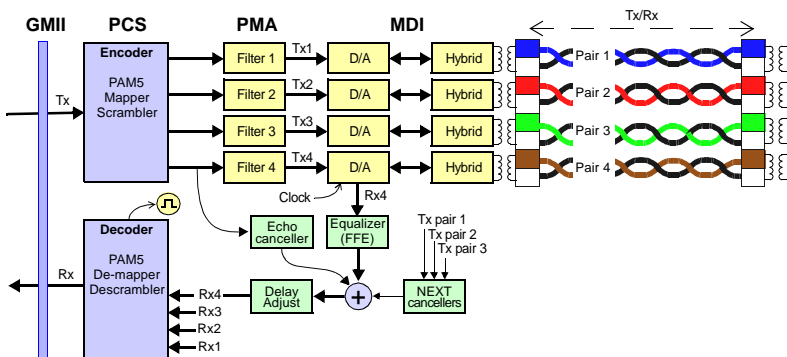


Figure 1.15 1000BASE-T circuits to counter transmission disturbances.

1000BASE-T uses several technologies to reduce disturbances. Digital Signal Processing (DSP) is used to cancel crosstalk and echo (return loss). To overcome attenuation and distortion each band of frequencies of the signal must be equalized or amplified. Attenuation is compensated at the receiver by the equalization of the signal. Delay skew can be cancelled using buffers (see Figure 1.15).

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