1000BASE-T Technology Overview

Part 1: Design Challenges

What is 1000BASE-T?

A member of the Gigabit Ethernet family of standards.

Supports the CSMA/CD media access control protocol.

Supports full-duplex data transfer at 1000Mbps.

Supports up to 100m of 4-pair unshielded twisted pair (UTP) cable.

Maintains a bit error rate (BER) better than 10^{-10}.

Meets or exceeds FCC Class A requirements.

Roadmap

- 1000BASE-T application environment
  - structured cabling
- 1000BASE-T design principles
  - 5 steps from existing Fast Ethernet technology
- 1000BASE-T noise environment
  - signal-to-noise ratio (SNR)
  - application of digital signal processing (DSP) to improve SNR ratio
  - additional cabling specifications and recommendations

Structured cabling

Defines a generic telecommunications cabling system for commercial buildings.

Specifies the performance of the cable and connecting hardware used in the cabling system.

Why?

- The installation of a cabling system is simpler and cheaper during building construction than after the building is occupied.
- Such a cabling system must have the flexibility to allow the deployment of current and future network technologies.
- A structured cabling standard provides a design target for the developers of new network technologies (like 1000BASE-T).

Structured cabling standards

TIA/EIA-568-A, North America

ISO 11801, International

Scope:

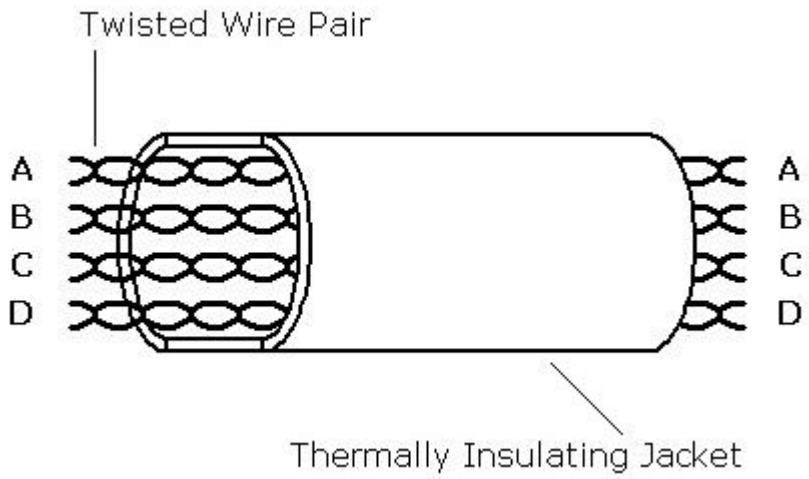
- define performance of unshielded twisted pair (UTP), shielded twisted pair (STP), and fiber optic cables and connecting hardware.
- define how these cables will be used in a generic cabling system.

Both standards define similar distribution systems and performance requirements.

- developers do not have to hit two separate targets

1000BASE-T is designed to operate over 4-pair UTP cable.

Unshielded twisted pair (UTP) cable



The category system

TIA/EIA-568-A defines a performance rating system for UTP cable and connecting hardware:

- Category 3 performance is defined up to 16MHz.
- Category 4 performance is defined up to 20MHz.
- Category 5 performance is defined up to 100MHz.

1000BASE-T requires category 5 or better performance.

Performance parameters for UTP cable

DC resistance

characteristic impedance and structural return loss

attenuation

near-end crosstalk (NEXT) loss

propagation delay

Performance parameters for UTP connecting hardware

DC resistance

attenuation

NEXT loss

return loss

Attenuation

Electrical signals lose power while travelling along imperfect conductors.

This loss, or attenuation, is a function of conductor length and frequency.

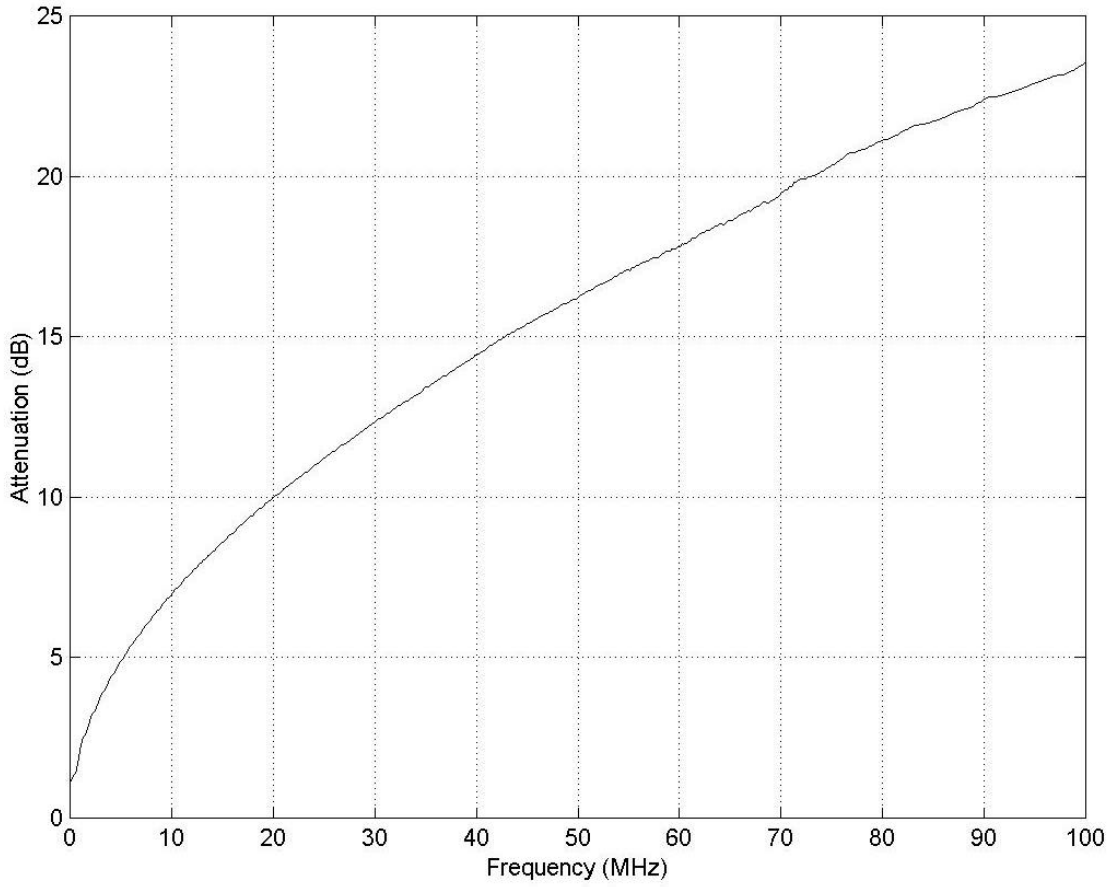
The frequency dependence is attributed to the skin effect.

Skin Effect:

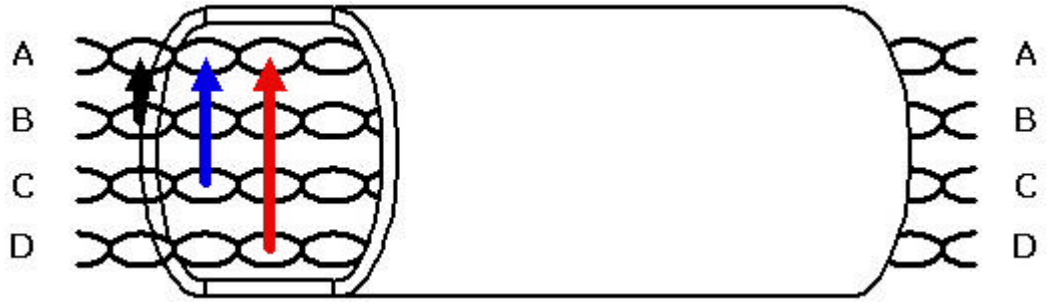
- AC currents tends to ride along the skin of a conductor.
- This skin becomes thinner with increasing frequency.
- A thinner skin results in a higher loss.

Attenuation increases up to 0.4% per degree Celsius above room temperature (20^{o}C).

Attenuation vs. frequency



Near-end crosstalk (NEXT) loss



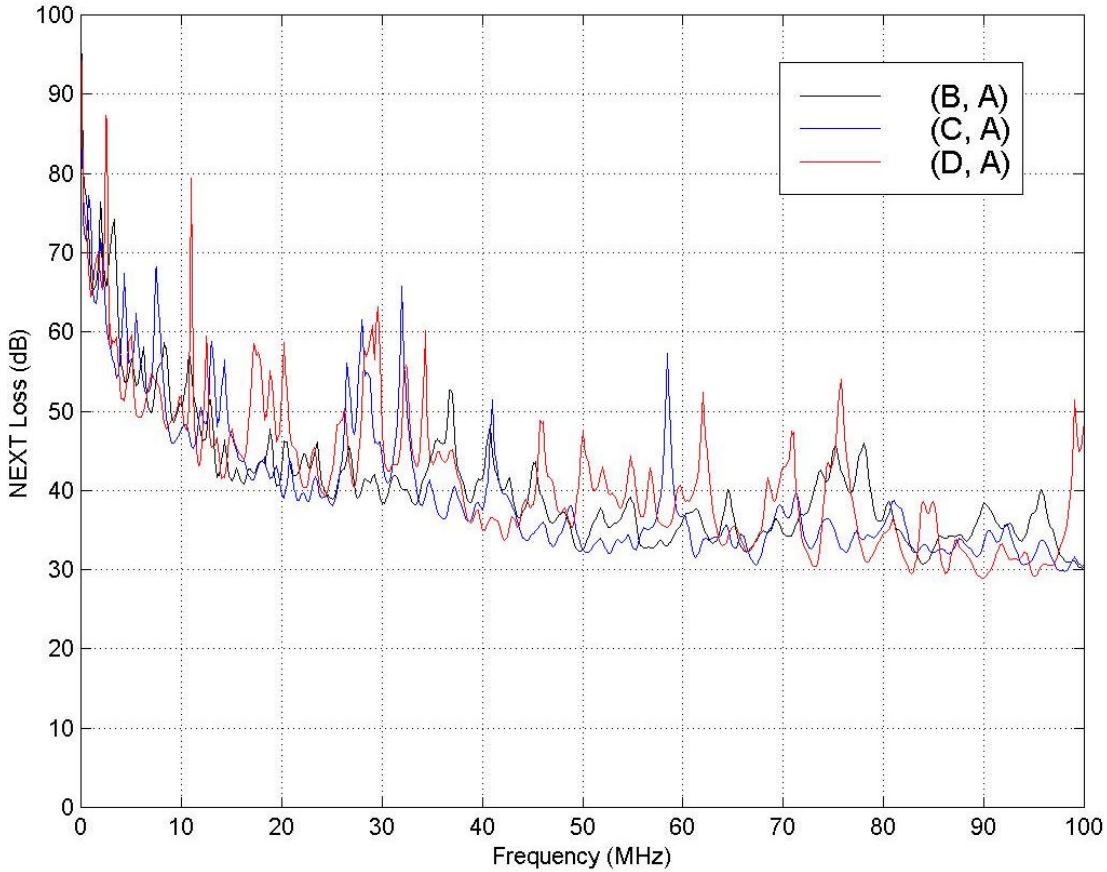
Crosstalk:

- Time-varying currents in one wire tend to induce time-varying currents in nearby wires.

When the coupling is between a local transmitter and a local receiver, it is referred to as NEXT.

NEXT increases the additive noise at the receiver and degrades the signal-to-noise ratio (SNR).

NEXT loss vs. frequency (pair A)



Reflections

When a circuit looks into an electrically long cable, it sees the characteristic impedance of that cable.

Characteristic impedance is defined by the structure of the cable.

- An unshielded twisted pair has a characteristic impedance of 100Ω.

Maximum Power Transfer Theorem:

- maximum power is transferred from a source to its load only when the source and load impedances are matched.

When the source and load impedances are not matched, where does the rest of the power go?

- Answer: back to the source (a reflection)

Return loss

The reflection coefficient is the ratio of the reflected voltage to the incident voltage.

The return loss is the magnitude of the reflection coefficient expressed in decibels.

Structured cabling overview I

- Work area
  - for example, an office
- Telecommunications closet
  - focal point of horizontal cabling
  - access to backbone cabling and network equipment
- Equipment room
  - can perform any of the functions of a telecommunications closet
  - generally understood to contain network resources (for example, a file server)
- Entrance facility
  - the point at which the network enters the building, usually in the basement

Structured cabling overview II

- Horizontal cabling
  - from the work area to the telecommunications closet.
  - up to 90m of 4-pair unshielded twisted pair (UTP) cable.
- Backbone cabling
  - between telecommunications closets, equipment rooms, and entrance facilities.
  - up to 90m of 4- or 25-pair UTP cable.
- Flexible patch cords
  - cables use solid conductors making them inflexible and difficult to work with
  - cords use stranded conductors for greater flexibility at the expense of up to 20% more loss than the same length of cable.
  - cords are used at points where the network configuration will change frequently

Structured cabling overview III

Transition point

- connects standard horizontal cable to special flat cable designed to run under carpets.

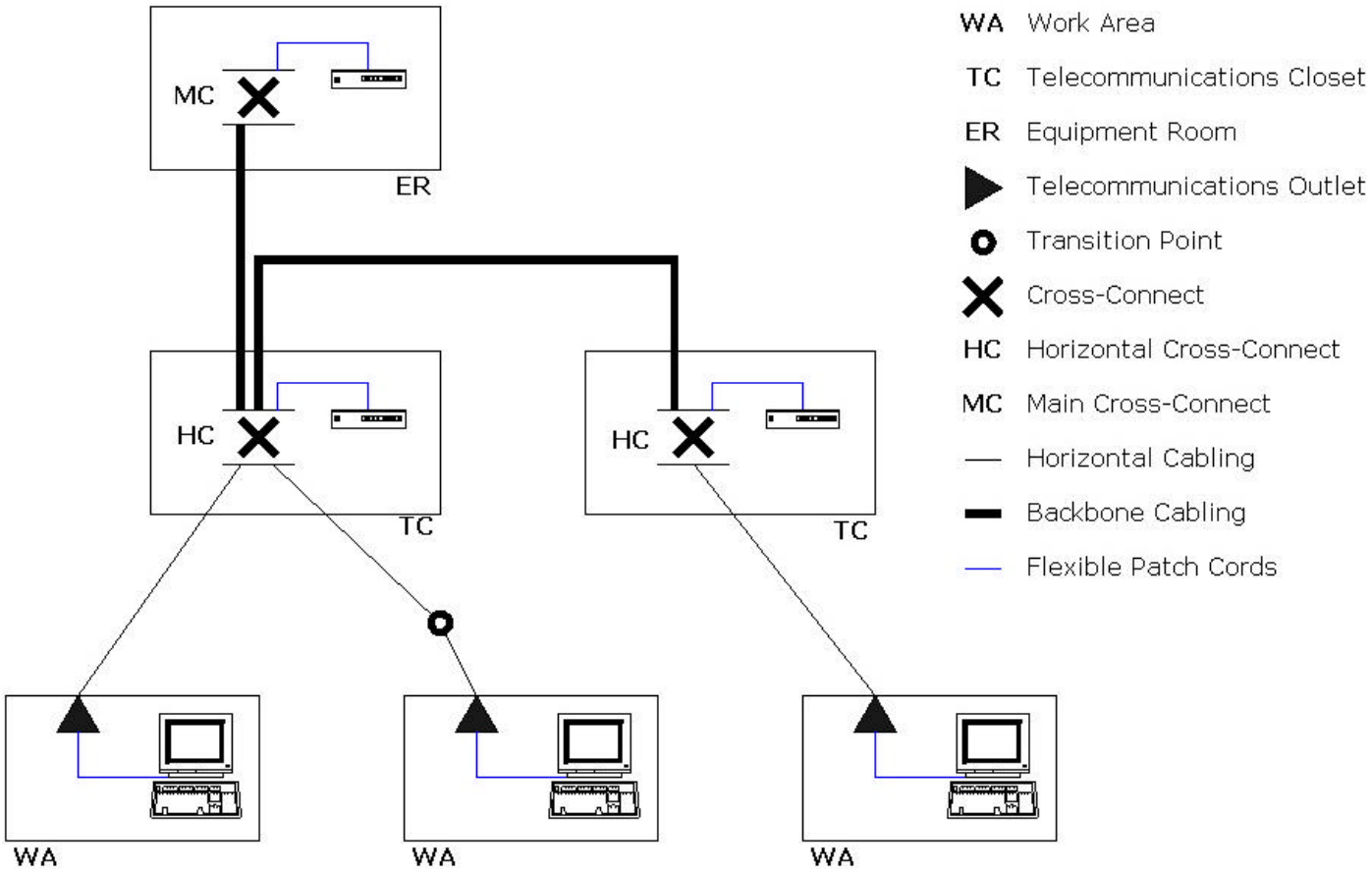
Cross-connect

- a patch between two interconnects
- horizontal and backbone cabling runs end at interconnects
- network equipment may use an interconnect

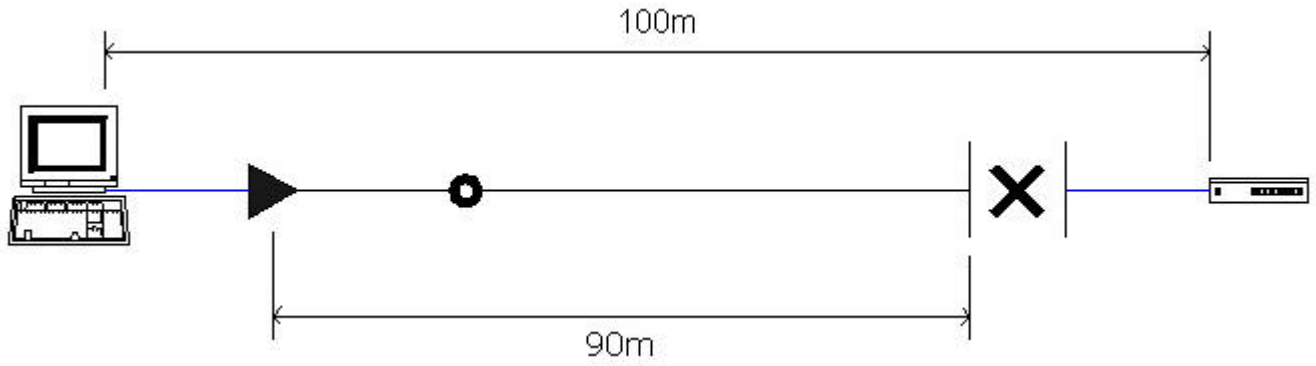
For UTP cabling systems, horizontal and backbone runs are always terminated in the telecommunications closet and equipment room.

- for example, you cannot cross-connect a horizontal run to a backbone run.

Structured cabling system example



TIA/EIA-568-A channel definition



90m of horizontal cable

10m of flexible cords

4 connectors

ISO 11801 channel definition does not include a transition point (3 connectors).

The channel definition is the developer s design target.

1000BASE-T design principles

Begin with existing Fast Ethernet technology, type 100BASE-TX

- Supports full-duplex transmission at 100Mbps.
- Supports up to 100m of 4-pair category 5 UTP cable (uses 2 pairs, one to transmit and one to receive).
- 4B5B block encoding and MLT-3 encoding result in the transfer of 3-level symbols at 125Mbd.
- Complete digital signal processing (DSP) implementations are commonplace.

Five steps to 1000BASE-T

Remove 4B5B encoding (125Mbps).

Transmit on all four twisted pairs simultaneously (500Mbps).

- technology derived from Fast Ethernet, type 100BASE-T4

Simultaneously transmit and receive on each twisted pair (500Mbps full-duplex).

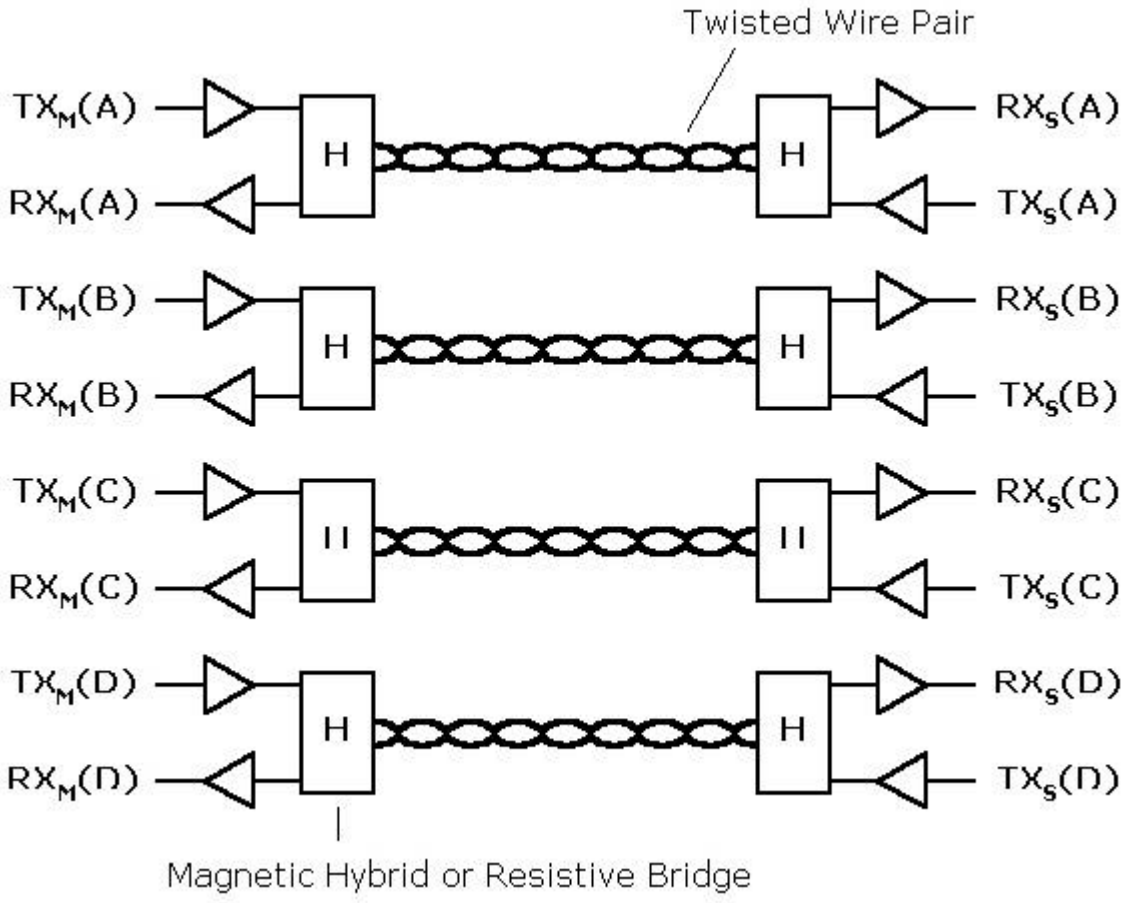
- technology derived from Fast Ethernet, type 100BASE-T2

Use 5-level symbols rather than 3-level symbols and encode 2 bits per symbol (1000Mbps full-duplex).

- incurs 6dB SNR penalty relative to 100BASE-TX

Use forward error correction (FEC) to recover 6dB.

1000BASE-T topology



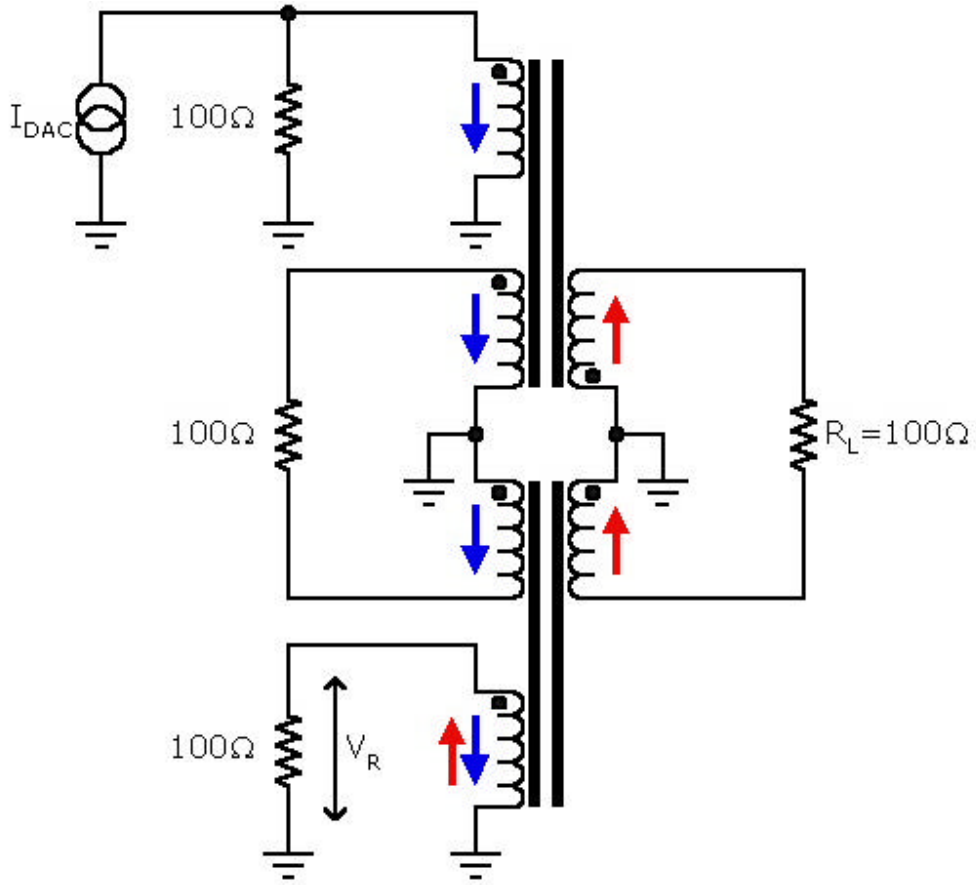
Magnetic hybrids

Facilitates simultaneous bi-directional transmission on a twisted pair by performing echo cancellation.

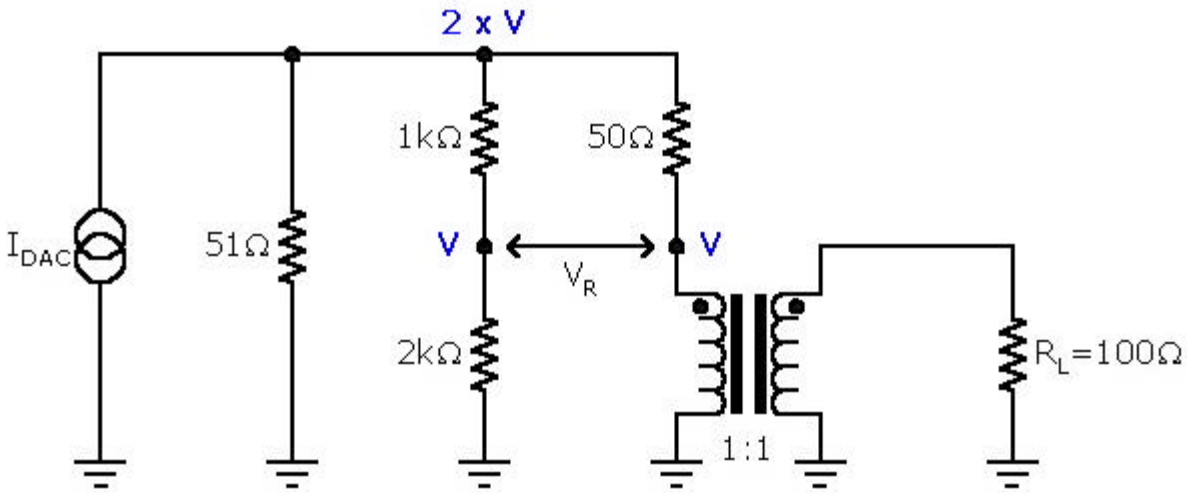
- make V_R due to I_{DAC} as small as possible

Also electrically isolates the cable from the network equipment.

Hybrid transformer circuit diagram



A resistive bridge performs the same function



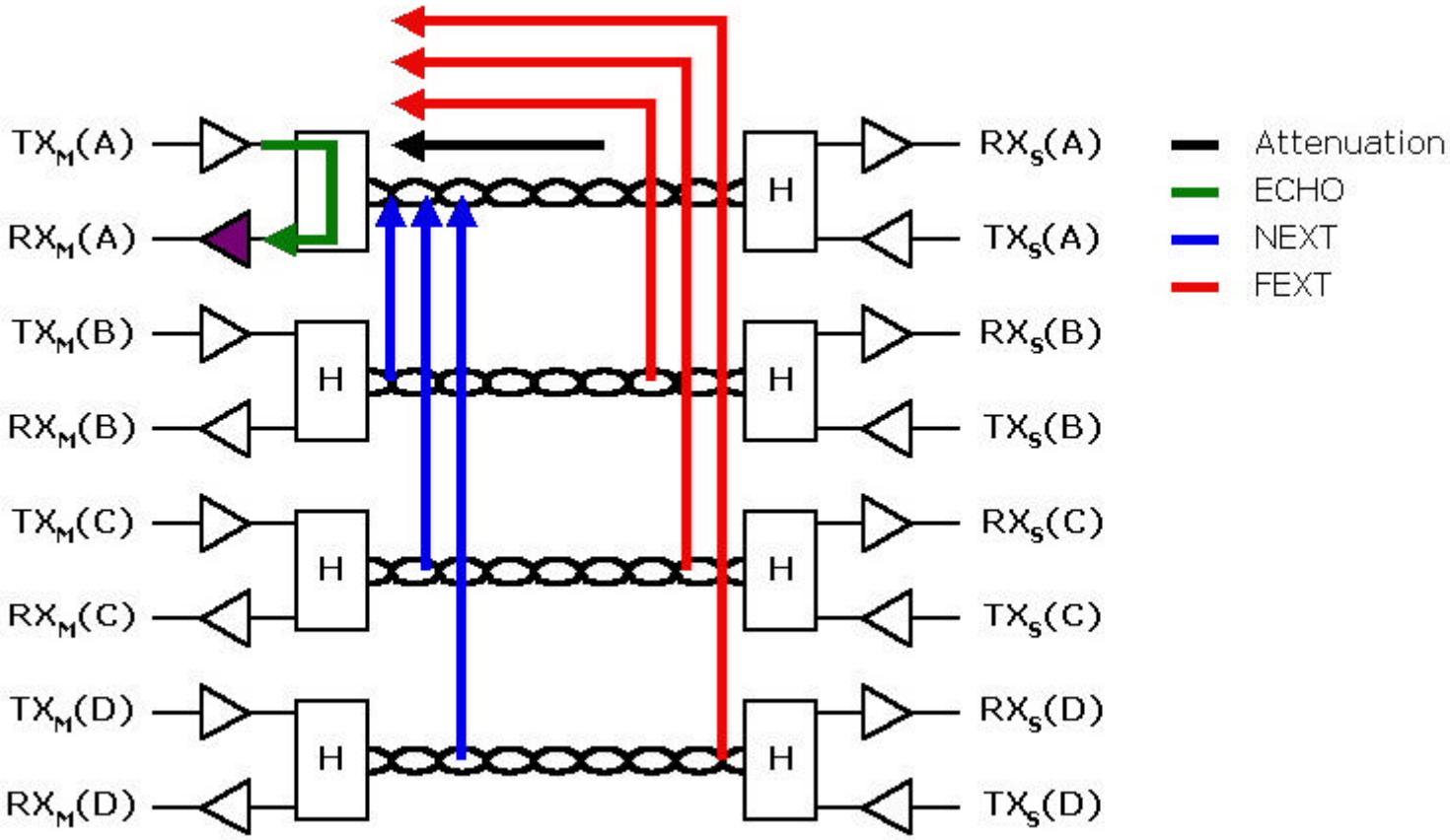
Signal-to-noise ratio (SNR) definition

Signal power is decreased by channel attenuation.

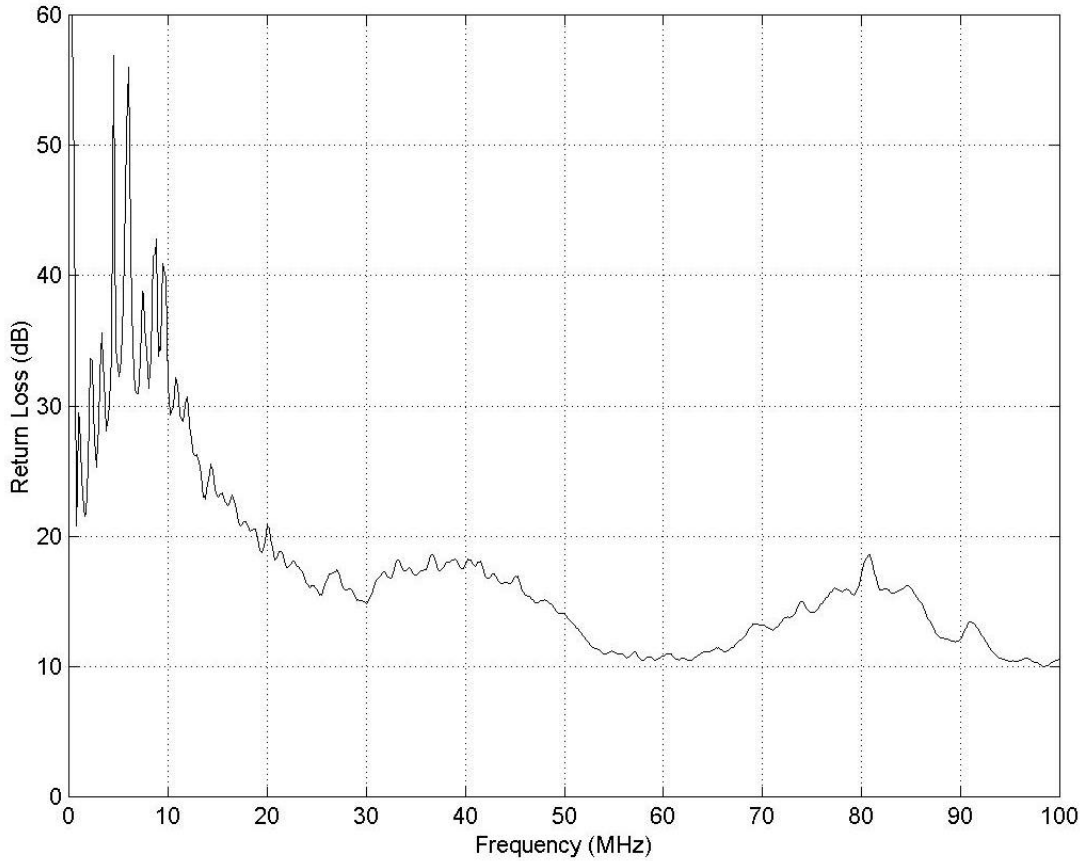
Noise power is the sum of the following (and more):

- echo from the transmitter that shares the twisted pair with the receiver (due to the finite isolation of the hybrid and the return loss of the channel)
- NEXT from 3 local transmitters
- FEXT from 3 remote transmitters
- inter-symbol interference due to the dispersive properties of the twisted pair medium (phase response is not linear).
- alien crosstalk: crosstalk coupling of signals in adjacent cables

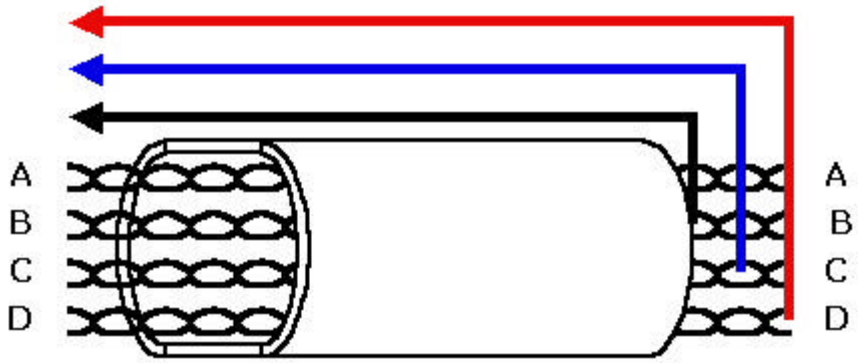
1000BASE-T noise environment



Echo vs. frequency



Far-end crosstalk (FEXT) loss



Crosstalk coupling between a local receiver and remote transmitters.

FEXT

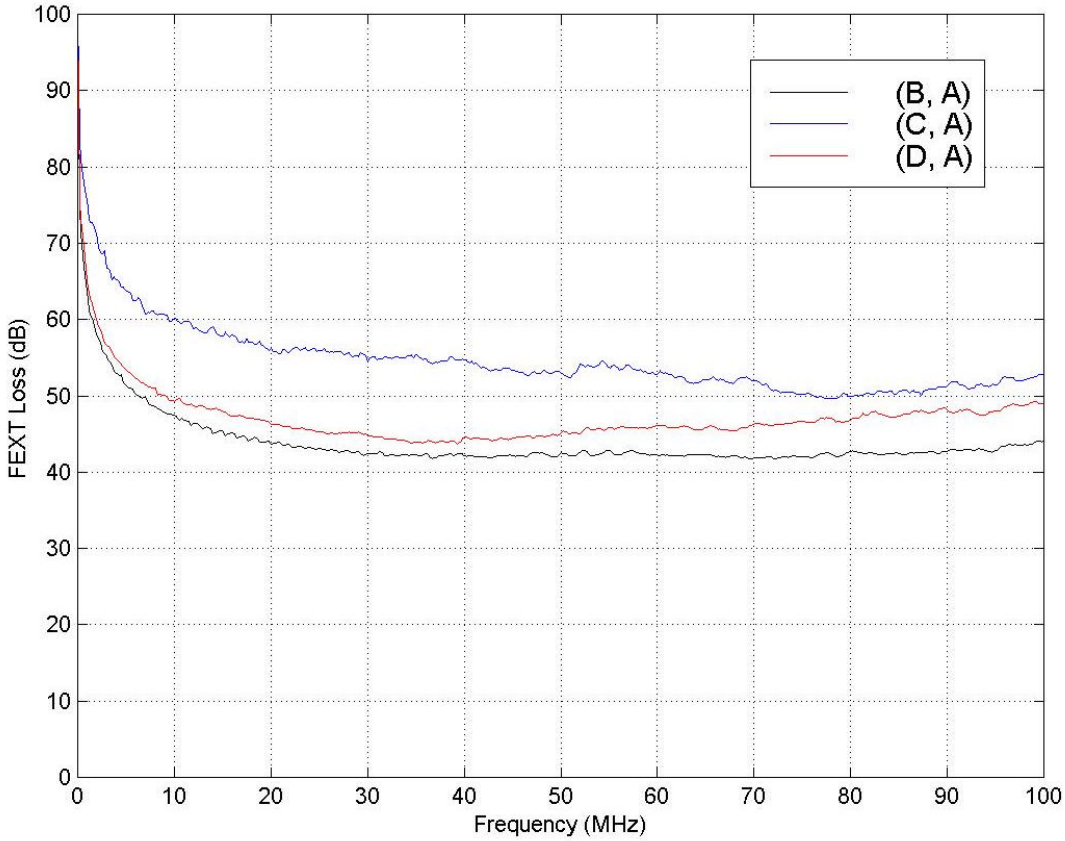
the ratio of voltage output by the remote transmitter to the voltage present at the local receiver.

Equal-level far-end crosstalk (ELFEXT)

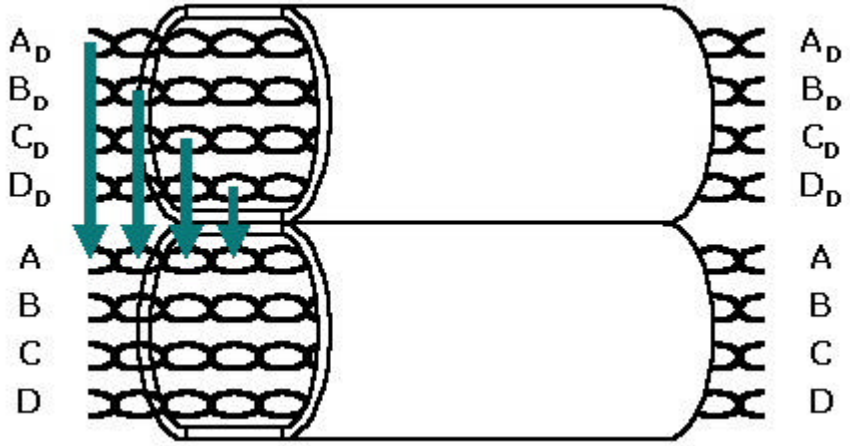
the ratio of the voltage arriving at other local receivers to the voltage present at the local receiver

ELFEXT Loss = (FEXT Loss channel attenuation)

FEXT loss vs. frequency (pair A)



Alien crosstalk



Horizontal cable runs are usually pulled in bundles.

for example, an office may require 2 voice grade cables and 2 data grade cables.

rather than pulling each of the four cables separately, they are bundled together and pulled at that same time.

Coupling between cables in the bundle increases as the bundle gets tighter.

Signal-to-noise ratio (SNR) margin

SNR is related the bit error rate (BER).

- a higher SNR allows you to maintain a lower BER

SNR margin

- the amount of additional signal loss or noise that the system can tolerate before the BER increases above a given level.

The system described to this point has a negative SNR margin for a BER of 10^{-10}.

Improving SNR margin

Some noise components can be cancelled.

- digital signal processing (DSP) techniques can be used to create adaptive filters
- adaptive filters can be used to cancel inter-symbol interference (ISI), echo, NEXT, and FEXT
- ISI cancellers, or adaptive equalizers, are currently used in 100BASE-TX applications
- echo and NEXT are easier to cancel because the source symbols are readily available
- alien crosstalk cannot be cancelled because the source symbols cannot be reliably represented

Further increase SNR margin by imposing additional cabling guidelines.

1000BASE-T cabling guidelines

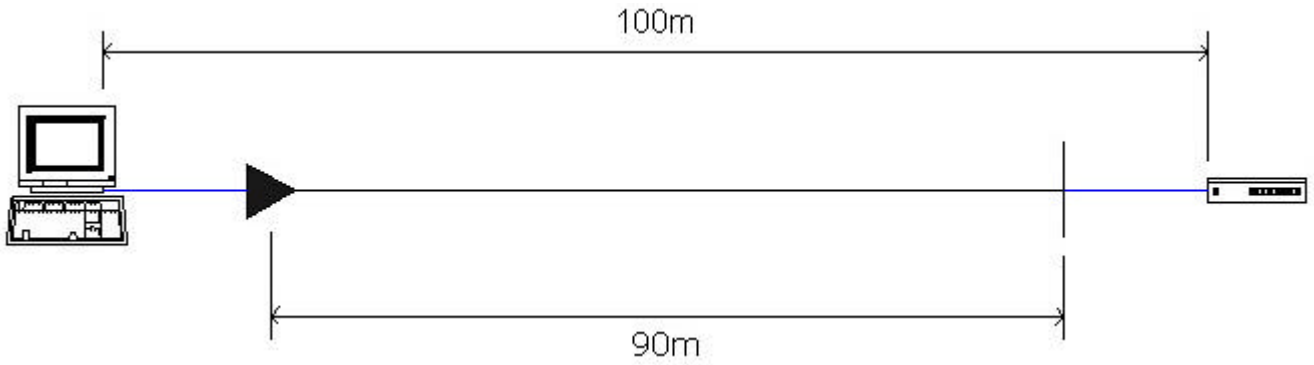
Begin with TIA/EIA-568-A category 5 channel.

Introduce additional performance specifications for:

- FEXT loss
- return loss
- compatible specifications will be adopted by TIA/EIA-568-A and ISO 11801

Impose a limit on the crosstalk allowed adjacent cables in a bundle (i.e limit alien crosstalk)

1000BASE-T recommended channel



What if an existing installation does not meet the new performance requirements?

- remove the transition point connector
- transform the cross-connect to an interconnect
- in effect, decrease NEXT and FEXT by removing two connectors

Other guidelines

25-pair UTP backbone cables are not supported.

- backbone cables support up to six 4-pair UTP channels
- similar to a bundle of 6 cables except the coupling is much higher (alien crosstalk)

1000BASE-T is intended for use in the horizontal run.

Conclusions

To support the horizontal cabling run at a BER better than 10^{-10}, each 1000BASE-T receiver requires:

- an adaptive equalizer
- an echo canceller
- 3 NEXT cancellers
- that is 5 adaptive filters per receiver, for a total of 20 adaptive filters (a lot of chip real estate)

1000BASE-T is the motivation for the specification of three additional performance requirements by TIA/EIA and ISO.

- FEXT loss
- return loss
- crosstalk between bundled cables

More conclusions

Current category 5 cable installations may not meet these new specifications.

- current category 5 installations will need to be re-certified

1000BASE-T offers additional cabling guidelines to help support cable installations that don t make the grade.