Media

	Attenuation	Repeater spacing
Twisted pair	10-12 dB/km at 1MHz	2 km
Coaxial cable	7 dB/km at 10 MHz	1–9 km
Optical fibre	0.2 dB/km	100 km

conniq.com provides an excellent tutorial on physical media.

Twisted pair

consists of two copper wires that are twisted together to reduce interference. Its main advantage is cost; otherwise, it is the least attractive medium in wide use.

The most common variant is the Unshielded Twisted Pair Category 5, usually called UTP-5 or UTP CAT 5. Its latest version is CAT 5e (“enhanced”). CAT 6 and CAT 7 were recently introduced—they are capable of handling the 10Gb switched Ethernet. CAT 7 is not unshielded; a screen surrounds the wires; it is a form of the previously unpopular STP cables (some experts predict that all cables will be shielded in the future; other disagree).

CAT 5e is used in Gigabit Ethernet when the segment distance does not exceed 100m (some optimists say 350m).

Several variations exist in how the cables are arranged. The standard way is a bundle of 4 pairs of wires, each pair made of 2 insulated copper conductors in a common sheath. The conductors can be stranded (many wires per conductor) or solid (one thick wire), used for short cabling (flexibility) and long cabling (electrical properties), respectively.

Inside the UTP bundle there are 4 physical pairs although the network only uses 2 of them (the other 2 are either wasted or used for something else). One pair is used to send information and the other pair is used to receive information.

In a LAN, the pair on pins 1 and 2 (green pair) of the connector send information, while the pair on pins 3 and 6 (orange pair) receive the information. That means we need a crossover cable, where input sent on pins 1 and 2 appears on pins 3 and 6.

Pin	Name	Description
1	A+	green
2	A-	green
3	B+	orange
4	C+	blue
5	C-	blue
6	B-	orange
7	D+	brown
8	D-	brown

8P8C

A crossover cable can be recognised as having a different order of colours at one end (orange–blue, green, brown).

The main problems of UTP are interference, especially **crosstalk**[a] and its fragility during installation (when a UTP is “pulled” it is common that the twisting pattern is damaged which results in much greater interference).

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[a] from other UTP cables in the same bundle.

UTP Solid Cable Specifications Comparison				
	CAT 5	CAT 5e	CAT 6	CAT 7
Bandwidth	100 MHz	350 MHz	550 MHz	600 MHz+
Insertion loss	22 dB	22 dB	21.3 dB	19.9 dB
Reflection Loss	16.0 dB	20.1 dB	20.1 dB	20.1 dB
NEXT	32.3 dB	35.3 dB	39.9 dB	42.3 dB
PS-NEXT	?	32.3 dB	42.3 dB	
ELFEXT	?	23.8 dB	27.8 dB	24.8 dB
PS-ELFEXT	?	20.8 dB	24.8 dB	
Delay Skew (Max. per 100 m)	?	45 ns	45 ns	

All measurements are for a 100 MHz transmission.

- NEXT Near End Cross Talk.
- ELFEXT Equal Level Far End Crosstalk.
- PS is a “power–sum” method of calculating crosstalk that takes into account all 4 pairs in a bundle.
- Delay skew is the difference in arrival times caused by different lengths of the two wires in a pair.
- Insertion and Reflection loss: these occur at the entry point to a transmission line.

Coaxial cable

A form of shielded (non–twisted) pair. It is widely used in cable television hence it became a popular medium for high–speed MANs although it is getting competition from fibre–based telephony and from power (electrical) lines. Coax can handle up to 600–700 Mb/s and is being abandoned in favour of optic fibre (cheaper and has much higher bandwidth ceiling).

Coax has few weaknesses of its own. However, one major externally introduced weakness is that coax–based networks are deployed over existing cabling which was meant for TV; as a result, the user at the low end of the cable gets much less bandwidth than the one close to the head end.

Optical fibre

is made of a very thin glass cylinder (**core**) designed to carry light along its length wrapped by a layer of glass called cladding which in turn is surrounded by a jacket (which can be made of one or two hollow cylinders).

The signal (in the form of light) is introduced into one end of the core as a laser beam, It propagates through the core eventually reaching the other end where an optical photodetector receives it. It is impossible to lay a fibre cable perfectly straight, so the light occasionally hits the cladding; it is reflected by it back into the core and continues on (there is considerable science behind this).

The bouncing of light introduces significant decoding problems because it creates a number of complex phenomena, including **chirp**.

Fibre modes

Optical fibre exists in three variants:

Single mode fibre has a very narrow core (8–10 μm which reduces the effects of bouncing. It uses infrared light and can handle a bandwidth in the Tb/s range (recently 14 Tb/s but a bandwidth of about 25 Tb/s is theoretically achievable). Due to the use of optical amplifiers, the length of a single mode fibre cable is practically unlimited.

Multi mode fibre has a much wider core (50–100 μm and its maximum bandwidth is much lesser, Additionally, it introduces much more distortion. Its use is limited to relatively short distances (it has cheaper receivers/transmitters, but the cable itself is more expensive).

Plastic core is another possibility. It is not much more than a curiosity at this time, but has potential.

Sources of error

There are 4 basic sources of signal impairment:

- Attenuation.
- Limited bandwidth.
- Delay distortion.
- Noise.

Attenuation

As a signal propagates along the link its amplitude decreases, a phenomenon called **signal attenuation**. To reduce its effect, the link is split into **segments** connected by **amplifier**s (analog) or **repeater**s (discrete).

In analog transmissions, attenuation increases with frequency causing distortion. Amplifiers try to compensate for this by amplifying frequencies in a non–uniform manner (“equalise”).

Attenuation increases with temperature at a rate of about 0.4% per degree centigrade.

Attenuation and amplification are measured in **decibel**s. Assuming that the sender sends a signal of P_1 watts, the nearest amplifier receives it at power level P_2 watts and retransmits it at power level P_3 watts:

$$Attenuation = 10 \log_{10} \frac{P_1}{P_2} dB$$

$$Amplification = 10 \log_{10} \frac{P_3}{P_2} dB$$

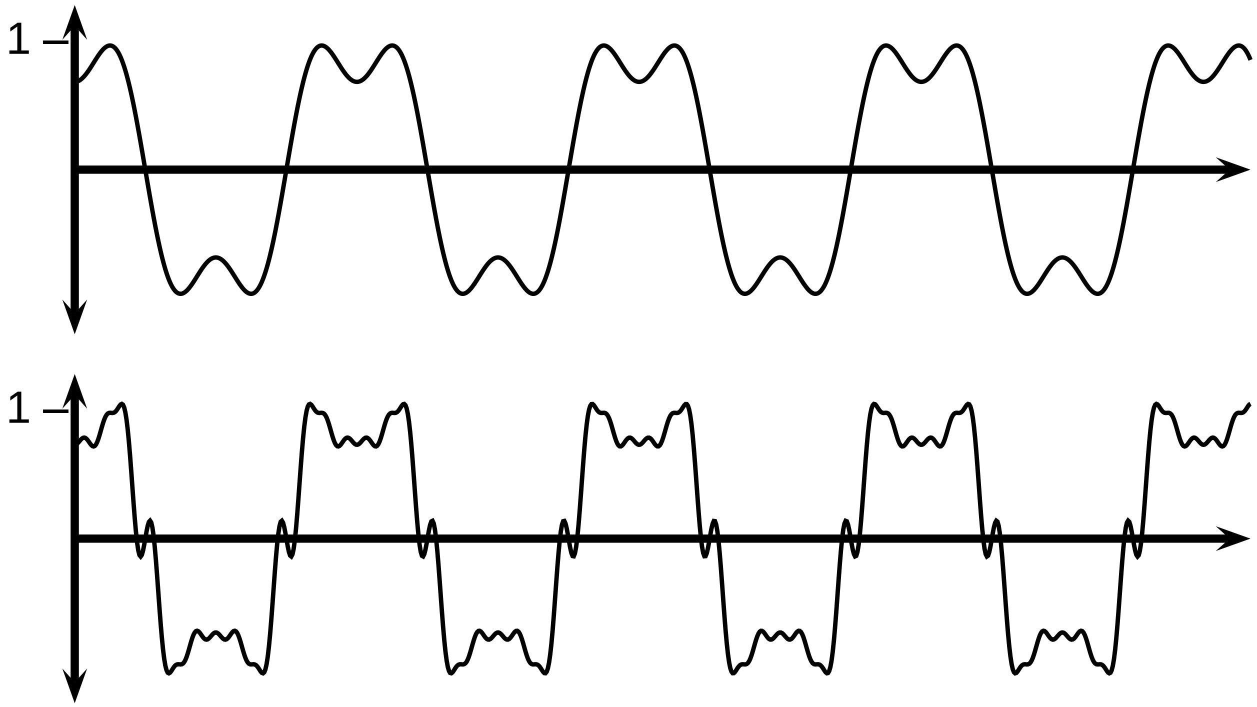
Example

A link is made of 2 segments with an amplifier in between. If the attenuations for the segments are 16dB and 10dB and the **gain** (amplification by the amplifier) is 20dB, a signal of 400mW will be received at the level of $100.5mW$ ($P_2 = 10.0475mW$, $P_3 = 1000.475mW$, P_3 attenuated by 10 dB is $100.0475mW$).

One could compute the result directly using the aggregated attenuation of $10 - 20 + 16 = 6dB$ and solving

$$6 = 10\log_{10}\frac{400}{P_4} = 26.0206 - 10\log_{10} P_4$$

The bandwidth of a channel being limited, only the lower harmonics are transmitted properly.



Digital signal of rate 500 b/s is to be transmitted over a link. Derive the minimum bandwidth required (in Hz).

The worst case is the sequence of alternating 0's and 1's which has a fundamental frequency of 250 Hz (2 bits per period). The harmonics are: 750 Hz, 1250 Hz, 1750 Hz, etc.

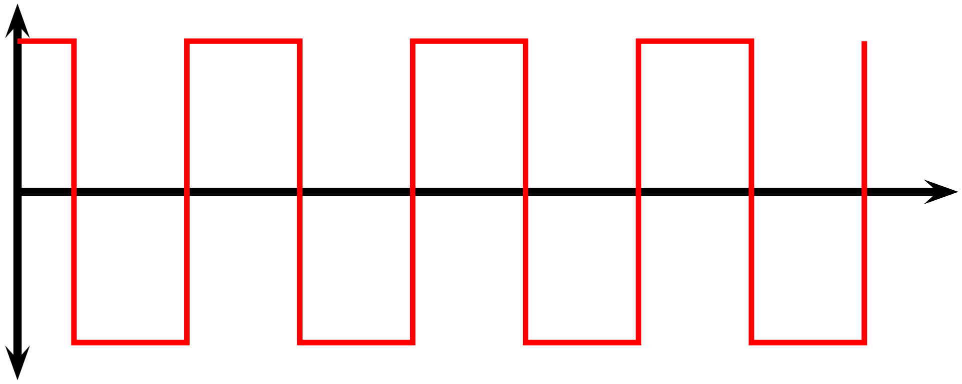
Hence the minimum bandwidth is 0–250 Hz for the fundamental frequency only, 0–1250 Hz for the $\omega_0 - 3\omega_0 + 5\omega_0$, etc.

Delay distortion

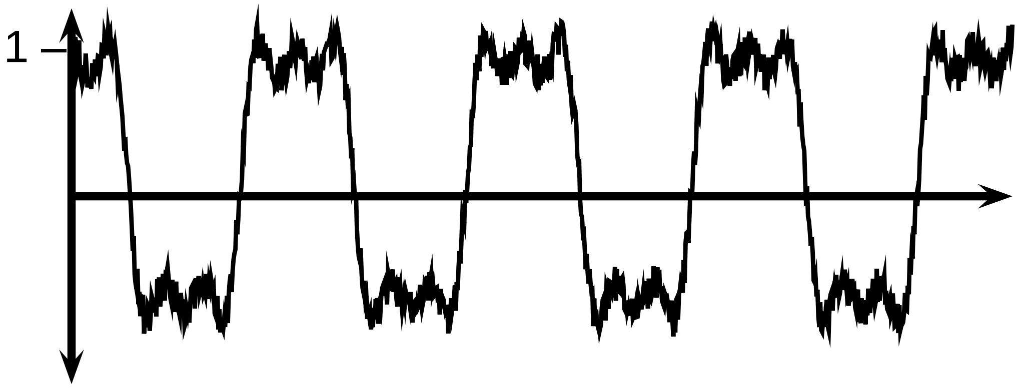
The rate of propagation of a signal varies with frequency. Consequently, the various frequency components arrive at different times, causing delay distortion of the signal. This is particularly relevant to fibre links because higher frequencies have to be used in high–rate transmissions. The higher frequency components may arrive at the same time as the low–frequency component of the previous symbol, resulting in an incorrect decoding (**chirp**).

White noise

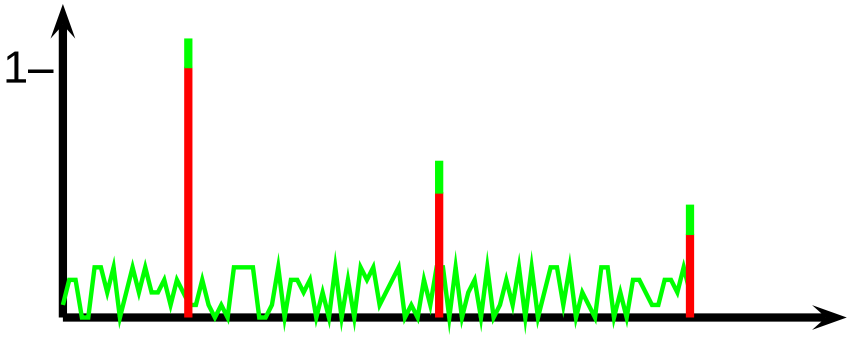
Original signal:



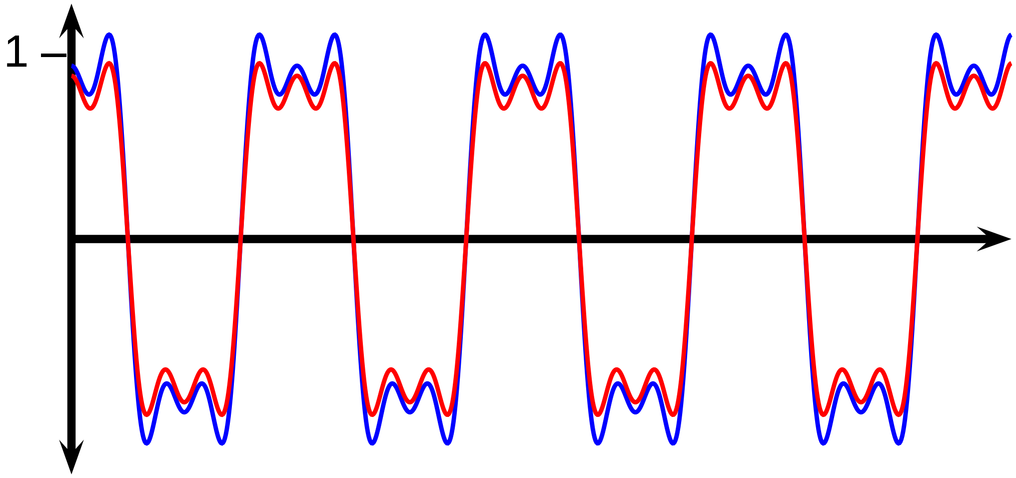
1^{st}, 3^{rd} harmonics plus white noise.



Frequency domain:



Reconstructed signal after filtering:



There are several types of noise and each type has several names:

White noise also known as **thermal noise**.

Intermodulation noise

Crosstalk

Impulse noise

The level of noise is measured either in decibels as a relative **Signal–to–Noise Ratio**:

$$SNR = 10 \log_{10} \frac{S}{N}$$

or as an absolute quantity measured in Watts or in dBW:

$$N = 1.38 \times 10^{-23} \times T \times B \;\; W$$

$$N = -228.6 + 10 \log_{10} T + 10 \log_{10} B \;\; dBW$$

Where T is the temperature in$^\circ K$, B is the transmission bandwidth in Hz and the magic number is *Boltzmann's constant* (and its logarithm).

White noise

is due to agitation of electrons carrying the signal (thermal agitation is proportional to the temperature in $^\circ K$).

Example:

A receiver connected to a 100 MHz link and operating at $300^\circ K$ ($+27^\circ C$) will experience a white noise of

$$-228.6+10\log_{10}3\times10^2+10\log_{10}10^8=-139dBW$$

Intermodulation noise

Most transceivers show some degree of non–linear behaviour: the output is not an exact copy of the input (multiplied by a constant). If a non–linear transmitter uses more than one frequency, e.g. f_1 and f_2, some non–zero energy will appear at frequency $f_1 + f_2$ possibly corrupting traffic at that frequency.

Non–linear behaviour is particularly acute when the signal is stronger than anticipated.

Crosstalk

Crosstalk occurs when two (or more) links interfere with one another. If the signal on one link is much stronger than the other, the weaker signal can become severely distorted by the stronger signal.

Crosstalk is common in UTP links; it occasionally happens when a aerial antenna (e.g. microwave) picks signals not wanted, such as reflections of signals intended for another tower.

Impulse noise

is non–continuous, consisting of irregular short spikes of high amplitude. I.N. is harmless in analog communication, but is very harmful in high–rate digital transmission: a spike of 1 ms will destroy 100,000 bits in a 100 Mb/s line.