Physical level

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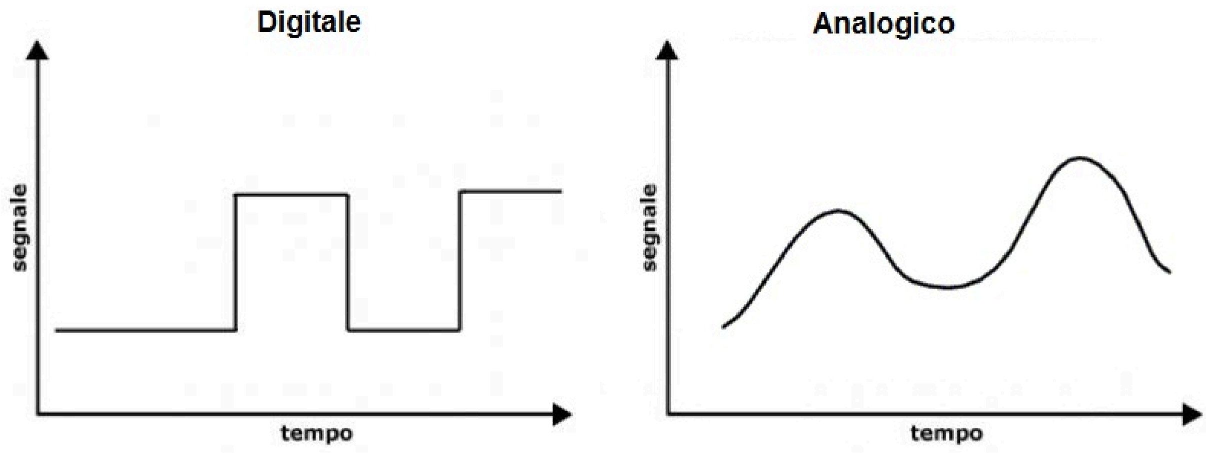
The physical layer is the lowest layer of the network stack. It handles the transmission of bits through a physical medium, such as a copper cable, an optical fiber, or the space through which radio waves propagate (International Organization for Standardization [ISO], 1994; Institute of Electrical and Electronics Engineers [IEEE], 2022).

At this layer, data is no longer considered as packets or frames, but as sequences of bits to be represented by physical signals. The task of the physical layer is therefore to convert 0s and 1s into signals that can travel through the transmission medium and then be correctly interpreted by the receiver (ISO, 1994; IEEE, 2022).

The transmission media used to create a channel in a network are usually divided into three categories, depending on the physical phenomenon used to transmit the bits:
- Electrical media: transmission relies on the ability of metals to conduct electrical energy (such as telephone twisted pairs) (IEEE, 2022).
- Optical media: transmission uses light (as in optical fibers) (International Telecommunication Union [ITU], 2024a).
- Wireless media ("without cables"): transmission uses electromagnetic waves (such as microwave radio transmissions and satellite radio transmissions). In this case, the transmission medium can be considered free space, or the environment, through which electromagnetic waves propagate (IEEE, 2025).

The physical layer must encode data so that it can be carried by the transmission medium (IEEE, 2022, 2025).
The encoding method depends on the characteristics of the transmission medium being used: for example, to transmit information over a copper wire, a physical variable such as voltage or current is modulated (IEEE, 2022).
For this reason, there must be a network device that converts bits into signals suitable for the medium being used. This conversion can be performed by different components, such as an Ethernet network interface card, a Wi-Fi module, a modem, or an optical converter (IEEE, 2022, 2025; ITU, 2024a).
The signal transmitted through the medium can be of two types:
- An analog signal varies continuously over time and can take on many intermediate values (ITU, 1993).
- A digital signal, by contrast, represents information using a limited set of distinct values, for example two voltage levels associated with 0 and 1 (ITU, 1993).

The type of signal depends on the medium and the technology: some encoding schemes transmit bits as a digital signal, using distinct voltage or light levels; in other cases, such as a modem on a telephone line, the bits are converted into an analog signal (the modem takes its name from this process of modulation and demodulation) (ITU, 1993; IEEE, 2022).



Example
A common example of encoding bits using a voltage signal is NRZ (Non-Return-to-Zero) encoding. In this encoding, each binary value is associated with a fixed voltage level, maintained for the entire duration of the bit:
- “1” is encoded with a high voltage level, for example +5 volts.
- “0” is encoded with a low voltage level, for example 0 volts.

Suppose we want to transmit the bit sequence “101010”.
With NRZ encoding, the voltage signal takes the following values in sequence:
+5 V, 0 V, +5 V, 0 V, +5 V, 0 V.

Note: this is a simplified example. In real technologies, such as Ethernet or Wi-Fi, physical-layer encoding schemes are much more complex.

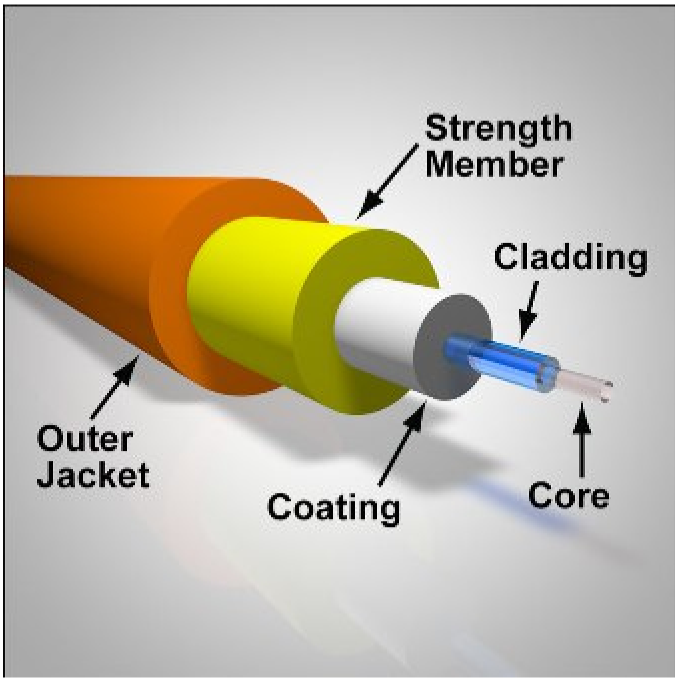
Optical fiber

Optical fiber is a data transmission technology that uses light pulses to send information through a cable made of glass or plastic fibers (ITU, 2024a).
It is one of the most important and high-performance transmission media in modern networks, thanks to its high speed, large data-carrying capacity, and resistance to electromagnetic interference (ITU, 2024a; IEEE, 2022).
In simplified terms, we can imagine digital data being represented as follows:
- 1 = presence of a light pulse.
- 0 = absence of a light pulse.

In real technologies, however, light encoding and modulation systems can be more complex (IEEE, 2022).

Because the optical fiber itself is very thin and delicate, a fiber-optic cable is made up of several protective layers; specifically, its structure is as follows (International Electrotechnical Commission [IEC], 2023):

- Core: the glass (or plastic) center through which the light travels.
- Cladding: the layer surrounding the core.
- Coating: plastic protection against scratches, microbends, moisture, and dust.
- Strength member: provides mechanical strength. In particular, it withstands tensile forces (for example, during installation), bending, compression, impacts, and environmental stresses.
- The outer jacket: the outermost sheath that covers and protects the entire fiber-optic cable. It is the part you see and touch when handling a fiber cable (IEC, 2023).



How does it work?

An optical fiber is an extremely thin strand (thinner than a human hair) capable of guiding light inside it thanks to a physical principle called **total internal reflection** (Ling et al., 2016; ITU, 2024b).

Total internal reflection causes a light ray, when it strikes the interface between the core and the cladding at a sufficiently large angle, not to exit but to be completely reflected (Ling et al., 2016).

Total internal reflection works because the core and the cladding have different refractive indices (Ling et al., 2016; ITU, 2024b).

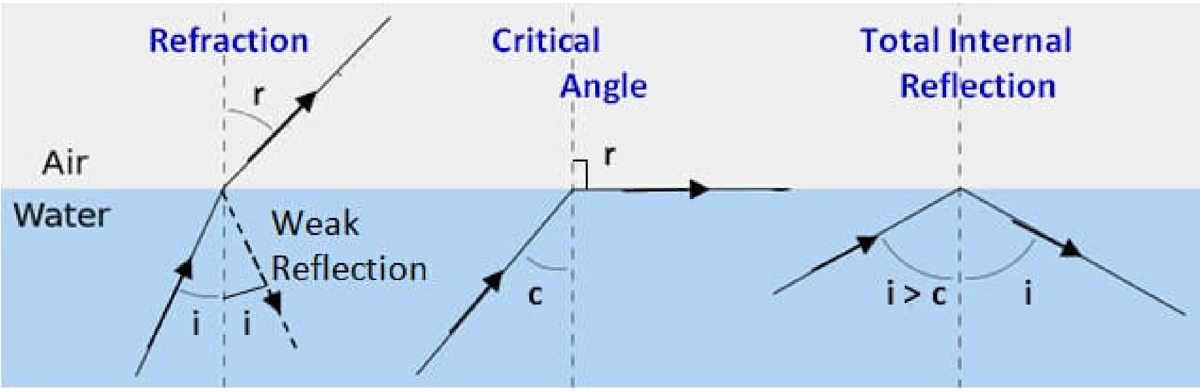
The refractive index indicates how much light slows down when it passes through a material: the higher the index, the more the light is slowed (Ling et al., 2016).

In an optical fiber, the core has a higher refractive index than the cladding (Ling et al., 2016; ITU, 2024b).

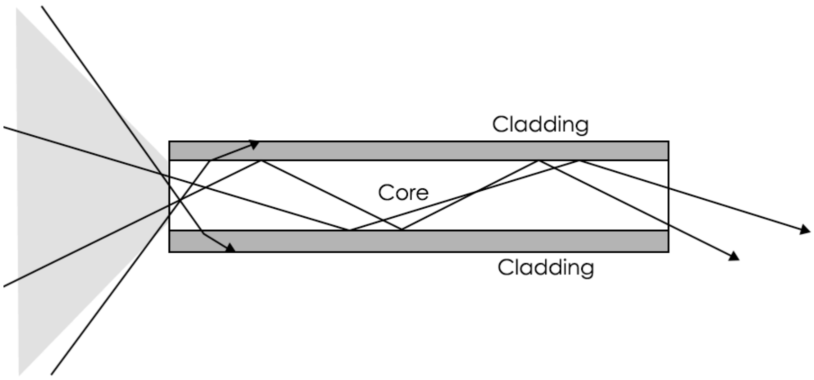
When light travels through the core and reaches the boundary with the cladding, it tends to change direction.

Because it is passing from a material with a higher refractive index to one with a lower refractive index, the light bends away from the perpendicular to the boundary between the two materials (Ling et al., 2016).

If the angle at which the light strikes the boundary is large enough, the light would enter the cladding in a direction almost parallel to the boundary. Beyond a certain angle, called the critical angle, there is no longer a possible direction in which the light can propagate through the cladding. For this reason, the light does not leave the core but is completely reflected back inside it (Ling et al., 2016).



In this way, the light pulses remain guided inside the fiber and can travel long distances (Ling et al., 2016).



This effect guides the light along the entire fiber, even over very long distances (Ling et al., 2016).

As a metaphor, we can imagine the fiber as a tunnel of mirrors: the light is guided along the path and is able to reach the other end of the fiber.

Supplementary materials

Key points

- **The physical layer** transmits bits through a physical medium.
- It converts 0s and 1s into **electrical**, **optical**, or **radio** signals.
- Transmission media can be **electrical**, **optical**, or **wireless**.
- The conversion of bits into signals can be performed by network interface cards, modems, Wi-Fi modules, or optical converters.
- Signals can be **analog**, if they vary continuously, or **digital**, if they use distinct values.
- ***NRZ*** encoding represents 0 and 1 using different voltage levels.
- **Optical fiber** transmits data using light pulses through strands of glass or plastic.
- Fiber offers high speed, large capacity, and resistance to electromagnetic interference.
- The cable consists of a **core**, **cladding**, **protective coatings**, and **strength members**.
- Light remains in the core thanks **to total internal reflection**, caused by the different refractive indices of the core and the cladding.

Exercises

Converting bits into signals
A computer must transmit the following sequence of bits through an electrical cable:
1 0 1 1 0 0 1
To simplify, the system uses the NRZ encoding described in these materials:
- 1 = +5 V
- 0 = 0 V

Answer the following questions:
- Write the sequence of voltage levels that must be transmitted through the cable.
- Explain what task the physical layer is performing in this situation.
- Explain why, at this layer, it is no longer important to know whether the bits represent a web page, an image, or a message.
- Identify the physical phenomenon used to carry the information in this example.
- Explain why there must be a component capable of converting bits into signals suitable for the transmission medium.
- Now imagine replacing the cable with an optical fiber. Explain which physical quantity would be used instead of voltage.
- If the communication took place over Wi-Fi instead, indicate the physical phenomenon through which the bits would be transmitted.
- Use the three cases to explain why the same sequence of bits can be represented physically in different ways depending on the medium being used.

Choosing the transmission medium
A company needs to create three different connections:

- Connect two computers in the same room using a cable.
- Connect two distant buildings where many electrical devices may generate electromagnetic interference.
- Temporarily connect several tablets without using cables.

For each situation:
- Choose the solution you consider most appropriate among electrical, optical, and wireless media.
- Justify each choice by referring to the characteristics described in these materials.
    - For the electrical connection, explain what type of physical phenomenon carries the information.
    - For the optical connection, explain what type of signal travels through the medium.
    - For the wireless connection, explain why space itself can also be considered part of the transmission medium.
- Identify which of the three technologies is particularly resistant to electromagnetic interference.
- Explain why choosing the physical medium does not necessarily mean changing the original data: what changes is the way the bits are represented and transmitted.

Why does light stay inside the fiber?
A technician must explain to a customer why a light signal can travel through an optical fiber without continuously escaping from the strand.
The cable used contains a core, cladding, coating, strength member, and outer jacket.

Answer the following questions:
- Indicate in which part of the fiber the light mainly travels.
- Explain the function of the cladding in relation to the core.
- Explain why the core and the cladding must have different refractive indices.
- Indicate which of the two must have the higher refractive index according to the operation described in these materials.
- Explain what happens when the light reaches the boundary between the core and the cladding at a sufficiently large angle.
- Define the principle of total internal reflection in your own words.
- Explain the role of the critical angle.
- Describe why this phenomenon allows light to travel long distances inside the fiber.
- Also match the coating, strength member, and outer jacket to their respective protective functions.
- A technician removes all the outer layers, leaving only the core and the cladding. Explain why the optical principle could still work, but the cable would become much less suitable for real-world use.
- Finally, use the “tunnel of mirrors” metaphor from these materials to explain intuitively how light is guided along the fiber.

Bibliography

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International Telecommunication Union. (2024a). *Characteristics of a single-mode optical fibre and cable* (Recommendation ITU-T G.652). https://www.itu.int/rec/T-REC-G.652-202408-I/en

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Further reading

- James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 9th ed., Pearson, 2026 — Introduces physical transmission media and access-network technologies, explaining how copper cables, optical fiber, and wireless channels carry data and how the physical layer fits into the broader Internet protocol stack.
- Andrew S. Tanenbaum, Nick Feamster, and David J. Wetherall, Computer Networks, 6th ed., Pearson, 2022 — Provides a systematic treatment of the physical layer, including guided and wireless transmission media, digital communication, copper wiring, optical fiber, radio transmission, and the physical technologies underlying modern computer networks.
- Behrouz A. Forouzan, Data Communications and Networking with TCP/IP Protocol Suite, 6th ed., McGraw Hill, 2022 — Dedicates an entire chapter to the physical layer and is particularly useful for exploring signals, digital transmission, encoding and modulation, bandwidth, transmission media, and the conversion of bits into electrical, optical, or wireless signals.
- William Stallings, Data and Computer Communications, 10th ed., Pearson, 2022 — Provides a broader telecommunications perspective on physical transmission,

covering analog and digital signals, signal encoding, transmission impairments, guided and wireless media, modulation, data rates, and the fundamental principles of data communication.

- Govind P. Agrawal, Fiber-Optic Communication Systems, 5th ed., Wiley, 2021 — Provides a specialized and more advanced treatment of optical-fiber communication, including optical fibers, light propagation, transmitters and receivers, modulation, and the physical principles that allow information to be transmitted over long distances using light.

Editorial notes

In producing these materials, I have used generative artificial intelligence tools to support the writing process, particularly to improve the form of the text, reorganize content, refine wording, and speed up certain editorial tasks.

As I work independently on the production of these materials, I try to automate any activities that can reasonably be automated, so that I can devote more time to research, design, and content development.

However, artificial intelligence does not determine the content of this work: the choice of topics, structure, ideas, interpretations, examples, and teaching approach are developed by me. AI is therefore used primarily as a tool to support production and formal revision, while authorship and responsibility for the design and content remain mine.