Information Technology

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IT438

Communication Technology

Kamal Hamza, PhD

khamza@eelu.edu.eg

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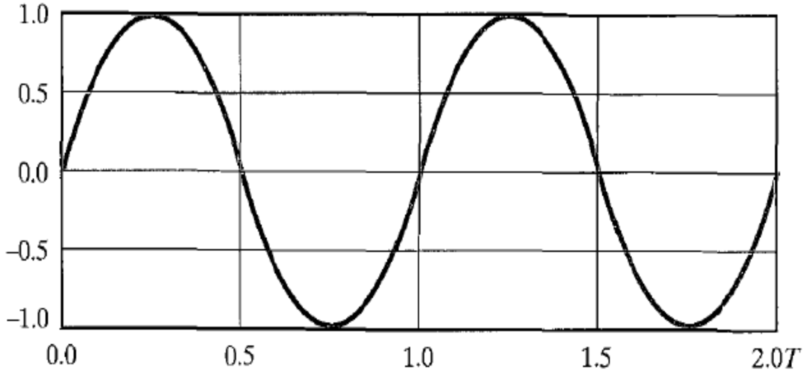
Signal Representation in the Frequency Domain

- In practice, an electromagnetic signal will be made up of many frequencies.
- For example, the signal:

$$s(t) = \sin(2\pi f_1 t) + \frac{1}{3}\sin(2\pi(3f_1)t)$$

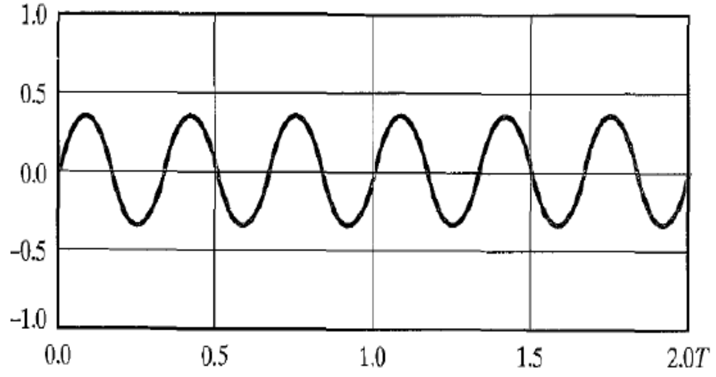
- is made up sine waves of frequencies f1 and 3f1
- The spectrum of a signal is the range of frequencies that it contains.

Signal Representation in the Frequency Domain (cont.)



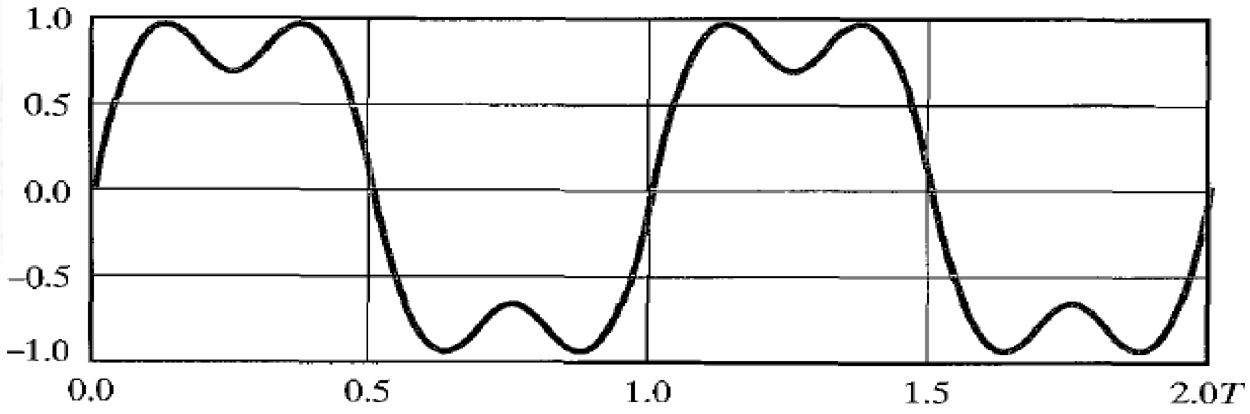
(a) $\sin(2\pi f_1 t)$

+



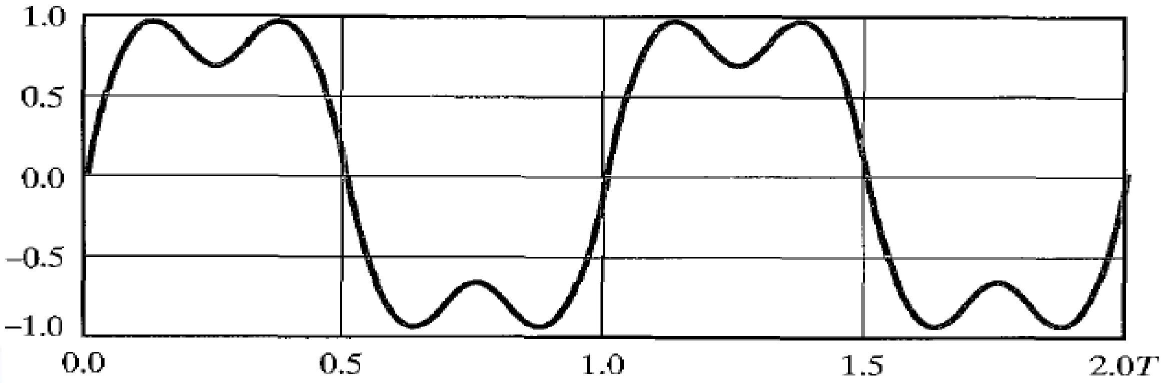
(b) $1/3 \sin(2\pi(3f_1)t)$

=

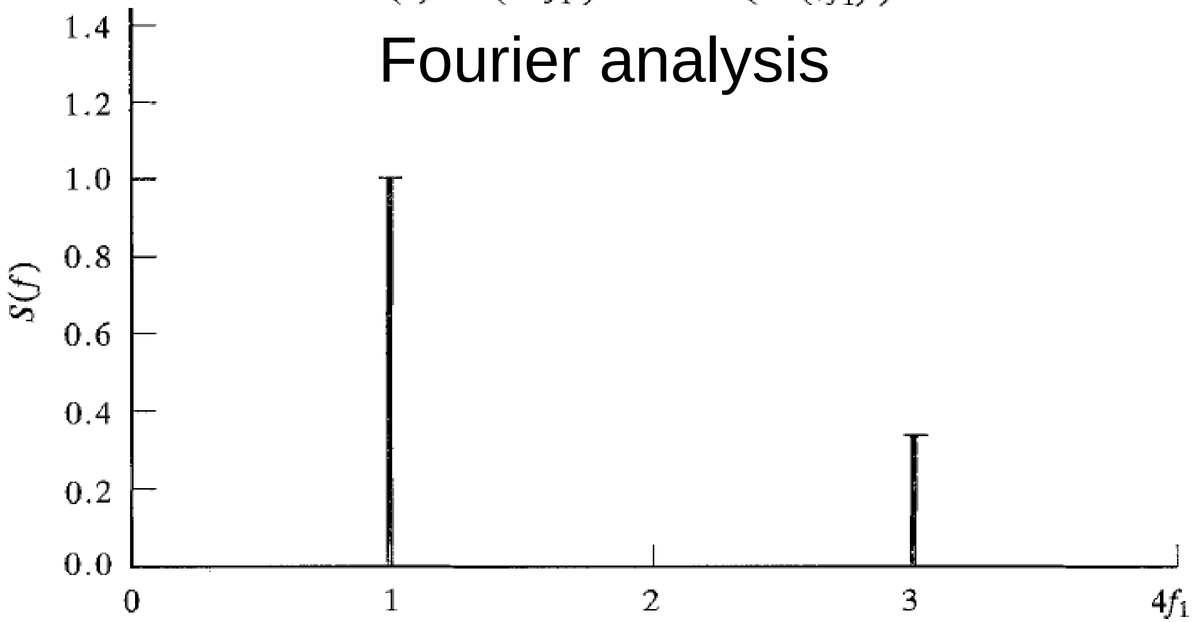


(c) $\sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t)$

Signal Representation in the Frequency Domain (cont.)

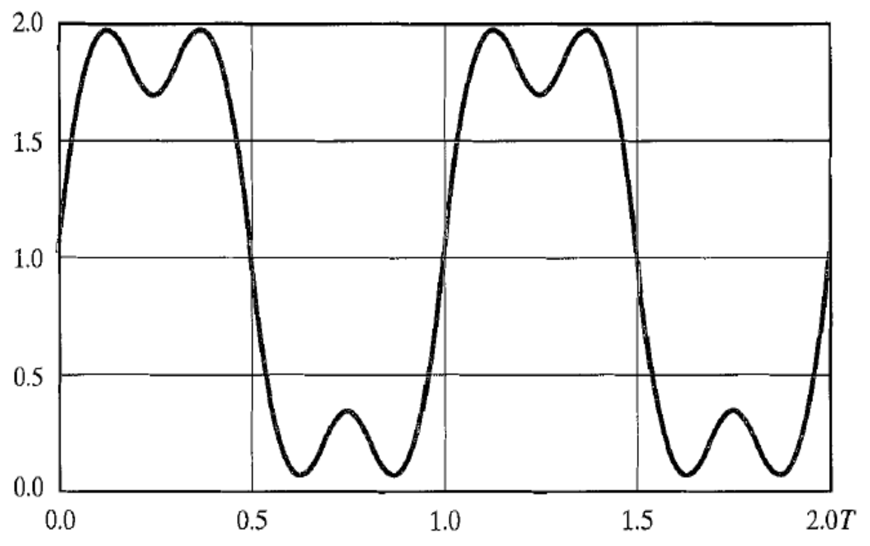


(c) $\sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t)$

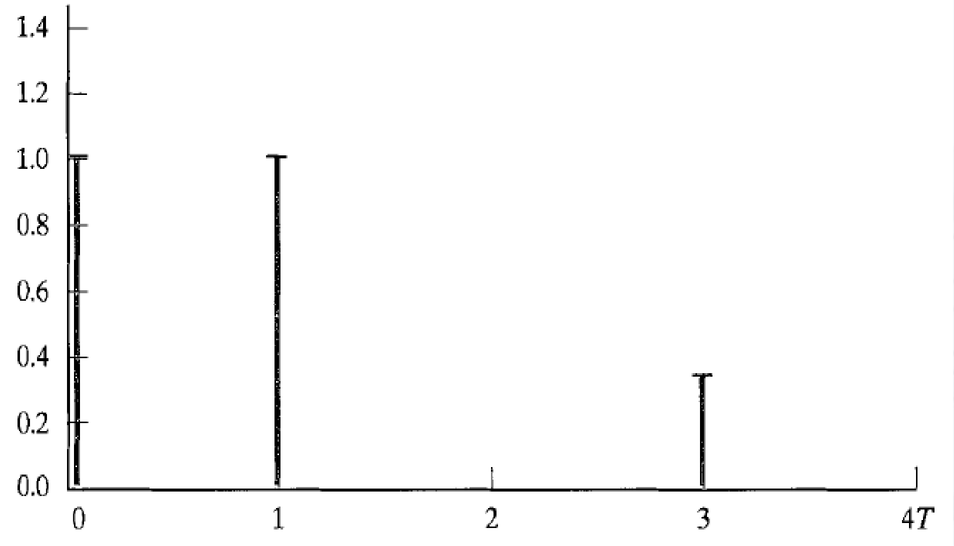


Signal Representation in the Frequency Domain (cont.)

- If a signal includes a component of zero frequency, that component is a direct current (dc) or constant component.



$s(t) = 1 + \sin + 1/3 \sin(2\pi(3f_1)t)$

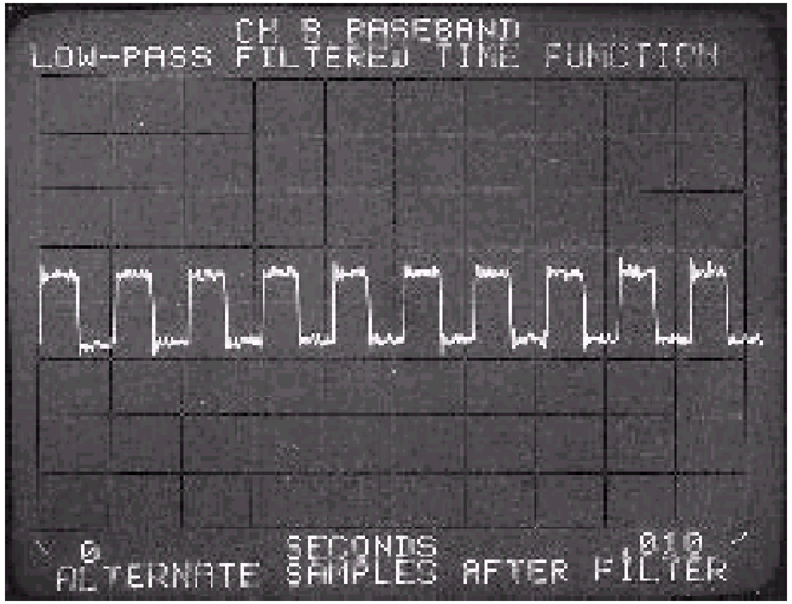


$S(f)$

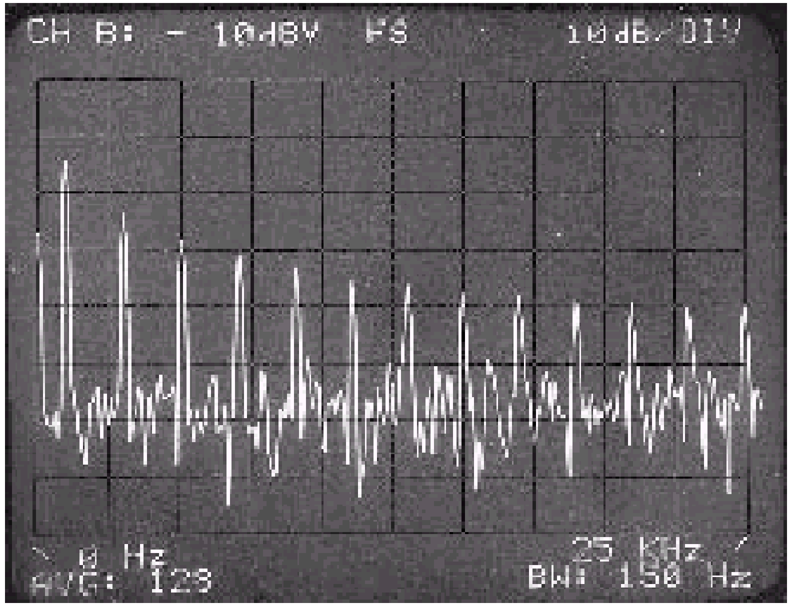
Noise and Interference

- In practical communication systems signals are blurred by noise and interference:

•Time domain

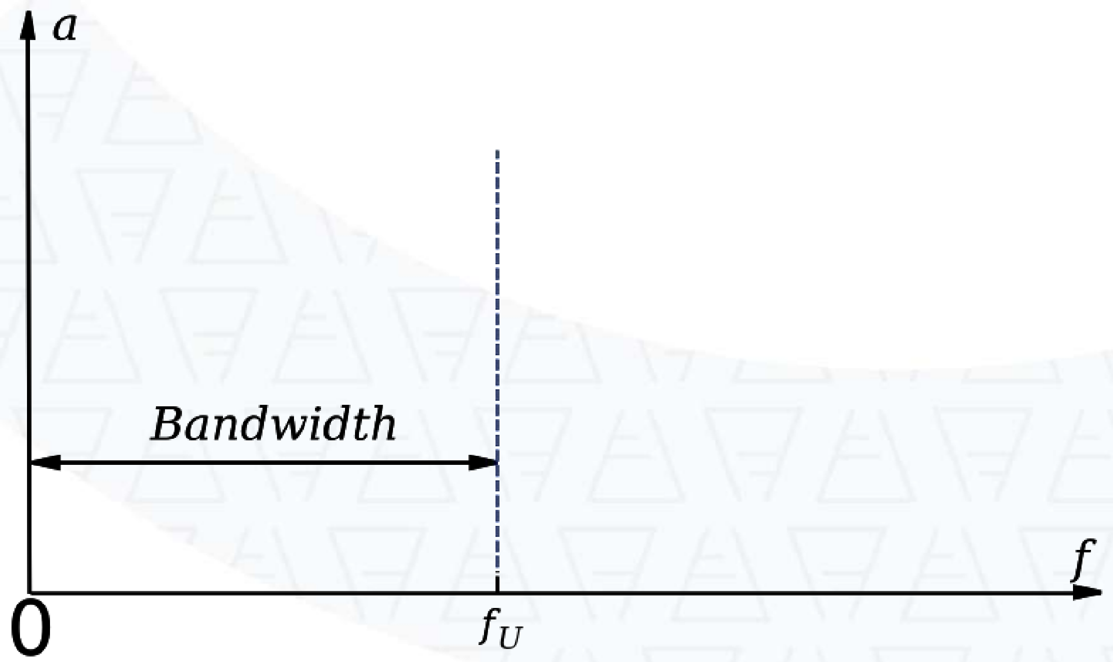


•Frequency domain



Signal Bandwidth (cont.)

Bandwidth is the difference between the upper and lower frequencies in a continuous band of frequencies. It is typically measured in unit of hertz (symbol Hz).



Signal Bandwidth (cont.)

Bandwidth in Different Communication Systems:

1. Telecommunications (Audio):

In traditional telephone systems, the bandwidth is typically limited to 300 Hz to 3400 Hz, which is sufficient for transmitting the human voice. This 3.1 kHz bandwidth filters out both very low and very high frequencies.

2. Radio Broadcasts:

AM radio stations use bandwidths around 10 kHz per channel, while FM radio uses a much larger bandwidth (around 200 kHz) to transmit better quality sound.

Signal Bandwidth (cont.)

Bandwidth in Different Communication Systems (Cont.):

3. Video and TV Transmission:

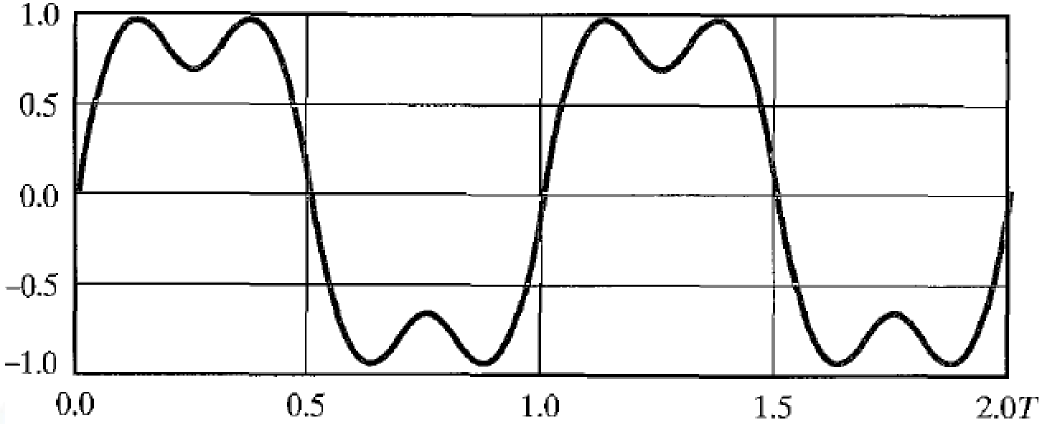
Analog TV signals use bandwidths around 6 MHz. Digital video signals (e.g., HD video) use even more bandwidth, which is why they rely on advanced compression techniques.

4. Wi-Fi and 5G:

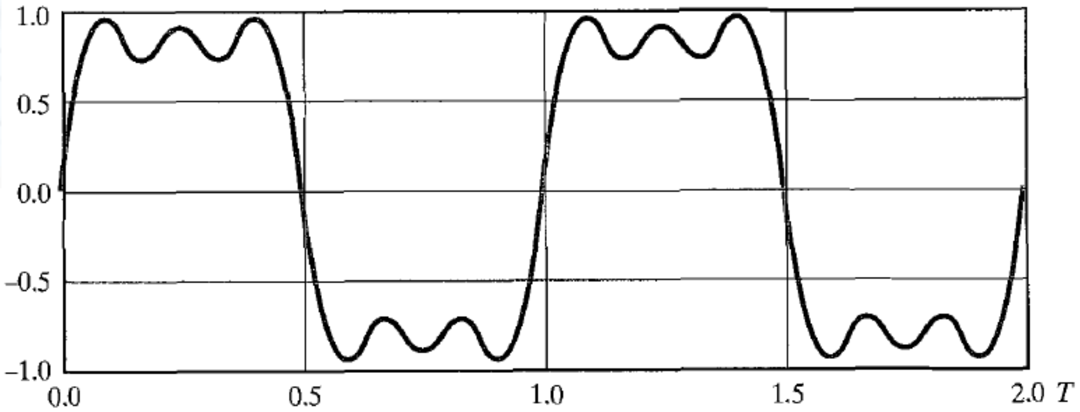
a) Wi-Fi operates in the 2.4 GHz or 5 GHz frequency bands, with bandwidths typically ranging from 20 MHz to 160 MHz. Higher bandwidth means faster internet speeds.

b) 5G technology operates at frequencies between 3 GHz and 100 GHz, with very large bandwidths available (up to several GHz), allowing it to carry massive amounts of data.

Signal Bandwidth (cont.)

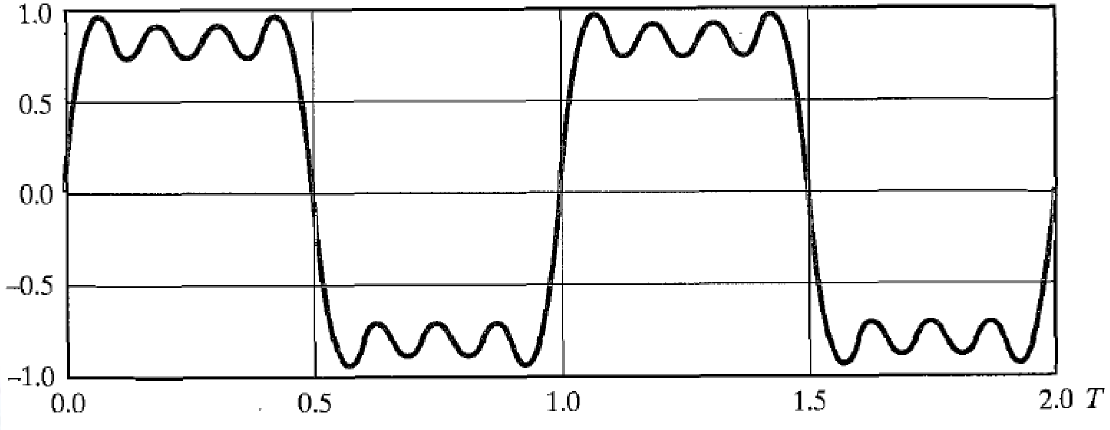


$\sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t)$

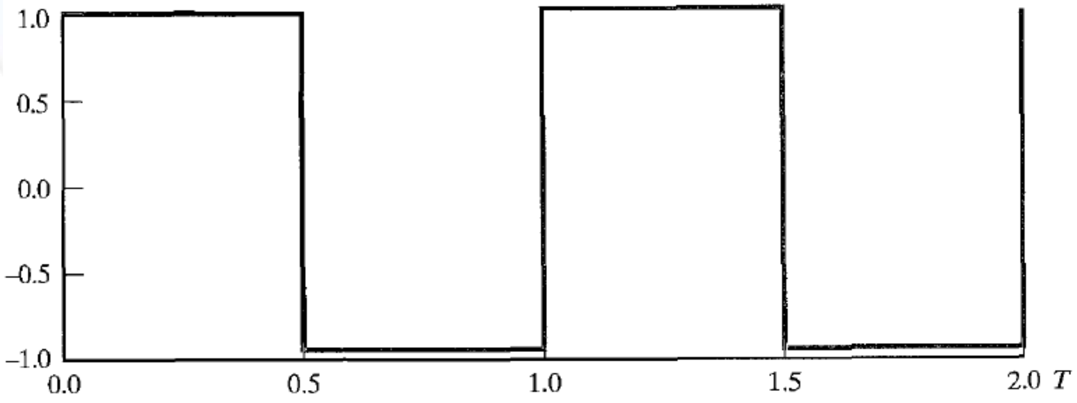


$\sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t) + 1/5 \sin(2\pi(5f_1)t)$

Signal Bandwidth (cont.)



$$\sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t) + 1/5 \sin(2\pi(5f_1)t) + 1/7 \sin(2\pi(7f_1)t)$$



$$s(t) = A \times \sum_{k \text{ odd},\, k=1}^{\infty} \frac{1}{k} \sin(2\pi k f_1 t)$$

Fiber Optics Communication Technology

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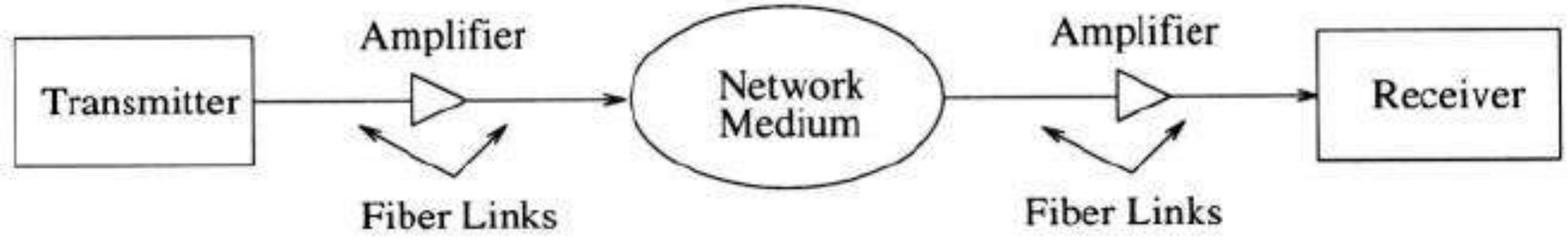
Optical Transmission System



- Main components of an optical transmission system are:
  - Optical fiber links
  - Transmitters
  - Receivers
  - Amplifiers
  - Network medium

Optical Fiber Links

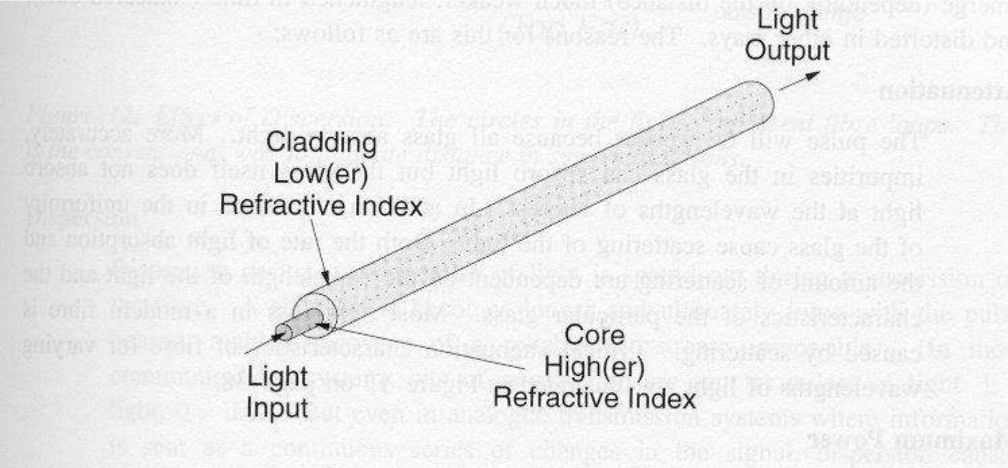
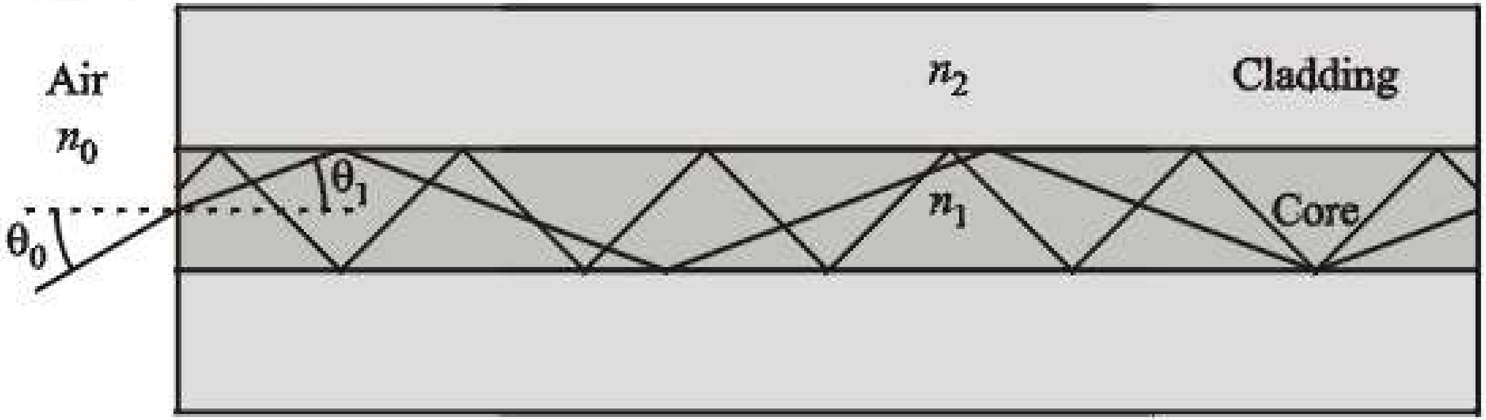


Figure 11. Basic Principle of Light Transmission on Optical Fibre

- Light propagates by total internal reflection



Optical Fiber Links (cont.)

Advantages of fiber optical links:

1. High Bandwidth Capacity

- **Fiber optics can carry more data**: Unlike copper cables, fiber optic cables have much higher bandwidth, which means they can transmit more data over longer distances without degradation.
- **Speed**: Modern fiber systems can easily handle data rates of 100 Gbps and higher.

2. Low Signal Attenuation (Loss)

- **Long-distance transmission**: Signals transmitted over fiber optic cables experience much less loss compared to copper cables.
- **Improved efficiency**: fiber optics are particularly suitable for large-scale communication networks, including long-distance telecommunication and undersea cables.

Optical Fiber Links (cont.)

Advantages of fiber optical links (cont.):

3. Immunity to Electromagnetic Interference (EMI)

- **Interference-free transmission**: Fiber optic cables are immune to electromagnetic interference (EMI) because they transmit light instead of electrical signals.
- **No cross-talk**: In copper wires, nearby cables can interfere with each other, causing signal distortion.

4. Security

- **Enhanced data security**: Fiber optics offer greater security because it is difficult to tap into or intercept the light signals without disrupting the transmission.
- **Tamper detection**: Any attempt to physically tap into a fiber optic cable will cause noticeable disruption to the light transmission, which can be detected easily.

Optical Fiber Links (cont.)

Advantages of fiber optical links (cont.):

5. Lightweight and Thin

6. Durability and Longevity

7. Reduced Latency

8. Scalability

9. Environmental Benefits

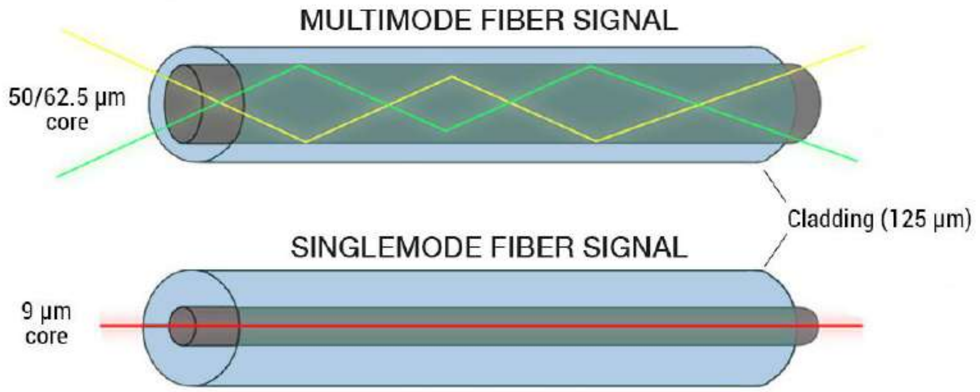
10. High Reliability

Optical Fiber Links (cont.)

Types of optical fiber:

1. Single-mode fiber (SMF)

2. Multimode fiber (MMF)



Feature	Single-mode Fiber (SMF)	Multimode Fiber (MMF)
Core Size	Small (8-10 microns)	Larger (50-62.5 microns)
Light Propagation	Single light mode (direct path)	Multiple light modes (bounces inside the core)
Distance	Long distances (up to 40 km or more)	Short distances (up to 550 meters)
Bandwidth	Higher bandwidth, supports higher data rates	Lower bandwidth, supports moderate data rates
Cost	More expensive to install and maintain	Cheaper, simpler installation
Application	Long-haul telecom, WAN, high-speed data links	LAN, data centers, short-range communication
Attenuation/Dispersion	Lower attenuation and dispersion	Higher attenuation and modal dispersion

Attenuation

- Attenuation in optical fiber leads to a reduction of the signal power as the signal propagates over some distance.

$$\text{Attenuation (dB)} = \alpha \times L$$

Where:

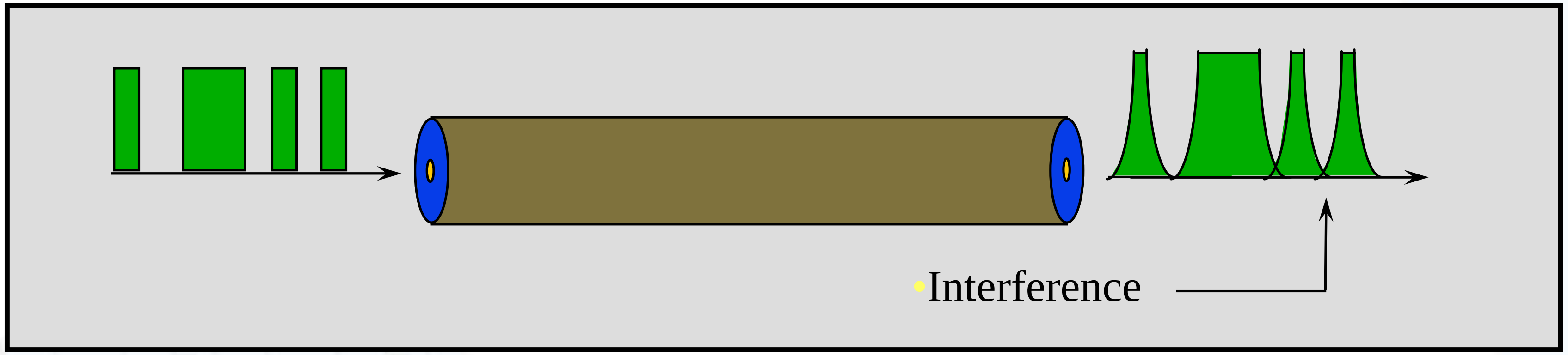
α = **Attenuation coefficient** (measured in dB/km).

L = **Length** of the fiber (in kilometers).

- Attenuation must considered when determining the maximum distance that a signal can propagate.
- Caused by the **fiber material**, which absorbs and scatters light energy.

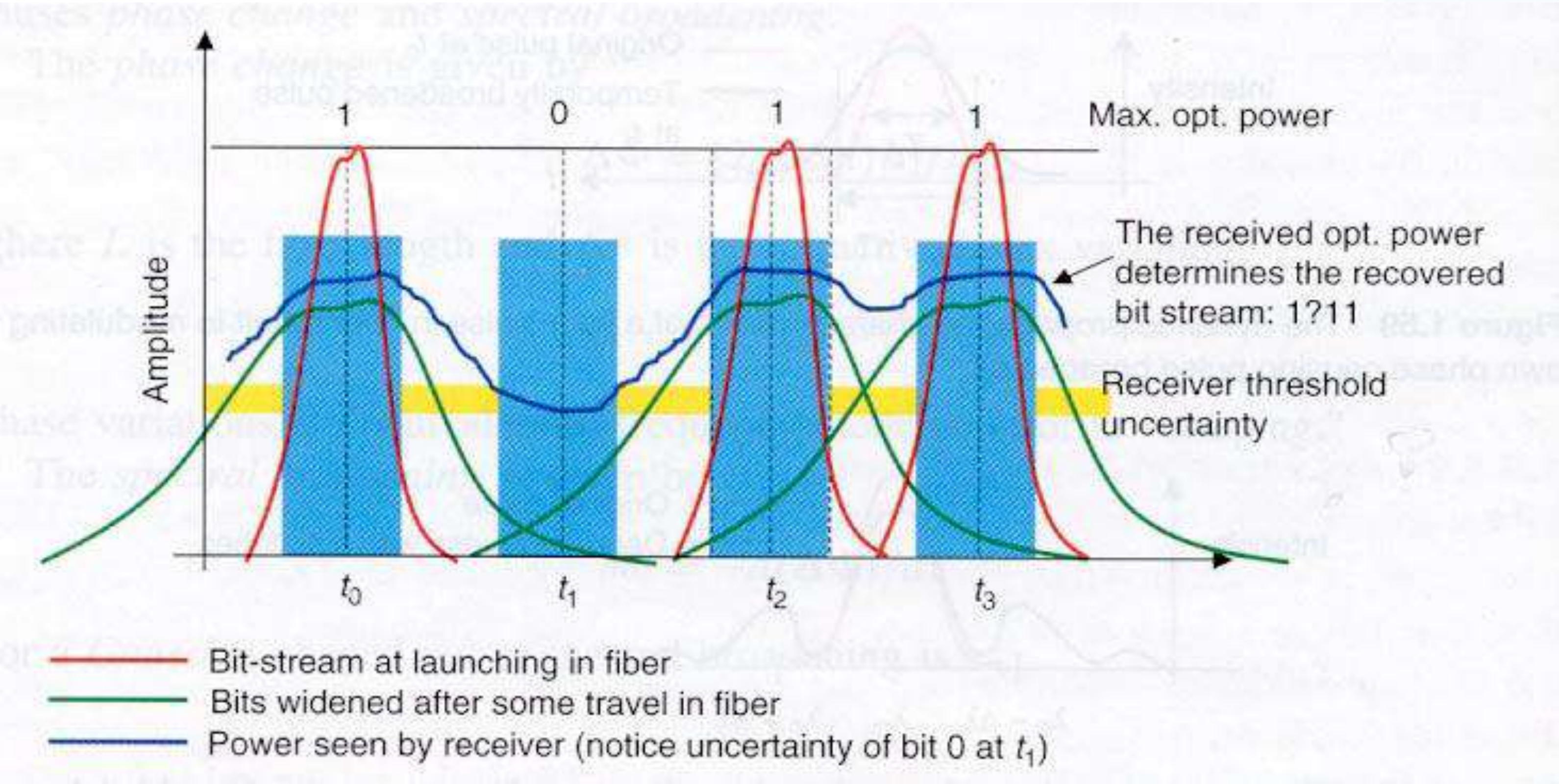
Dispersion

- Dispersion is the widening of a pulse duration as it travels through a fiber.



- Different components of the light pulse arrive at the destination at different times.
- Affects the **clarity and timing** of the signal, limiting the **data rate** and causing errors when pulses overlap due to broadening.

Effect of Dispersion



- As a pulse widens, it can broaden enough to interfere with neighboring pulses (bits) on the fiber, leading to ISI.

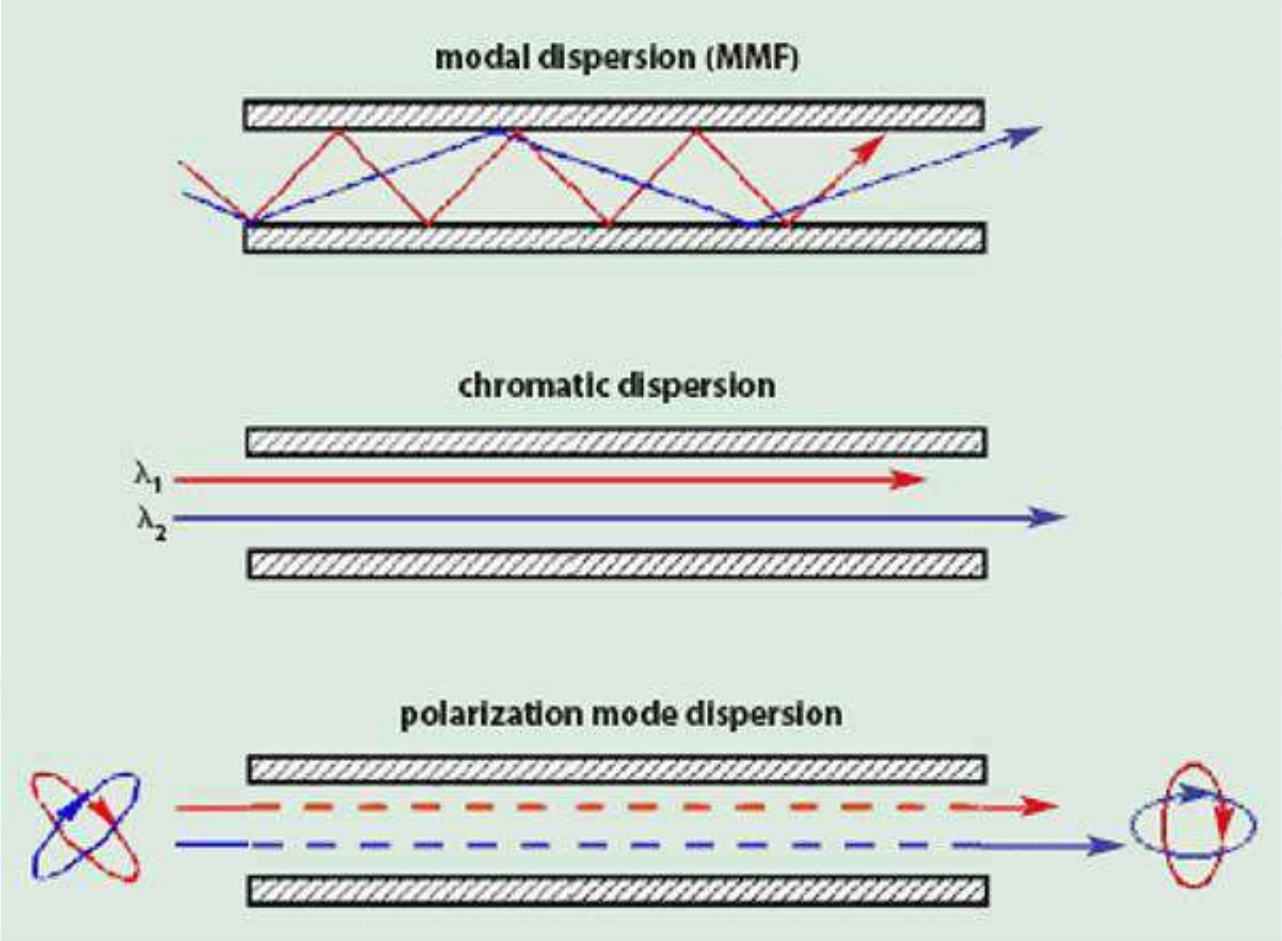
Types of Dispersion

1. **Modal Dispersion**: Occurs in multimode fibers when different light paths (modes) travel at different speeds, causing pulse broadening. Mitigated by single-mode fibers or graded-index fibers.

2. **Chromatic Dispersion**: Affects both single-mode and multimode fibers as different wavelengths of light travel at different speeds, causing pulse spreading. Mitigated by lasers and dispersion-compensating fibers.

Types of Dispersion (cont.)

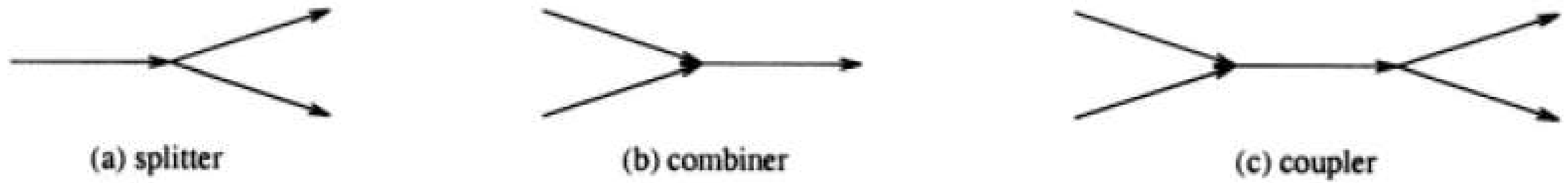
3. **Polarization Mode Dispersion (PMD)**: Occurs in single-mode fibers when different polarization states travel at different speeds due to fiber imperfections. Mitigated with high-quality fibers or polarization-maintaining fibers.



Nonlinearities in Fiber

- Nonlinearities in fiber occur when the light intensity in the fiber becomes high enough to cause the fiber's refractive index to change or to induce other non-linear effects.
- It may lead to attenuation, distortion, and cross-channel interference.
- **E.g.: Four-Wave Mixing (FWM)**
  - **Cause**: When multiple wavelengths of light interact within the fiber, new wavelengths are generated due to the non-linear mixing of signals.
  - **Effect**: This creates additional wavelengths that interfere with the original signals, causing crosstalk and signal degradation.

Optical Couplers



- A coupler is a general term that covers all devices that combine light into or split light out of a fiber.
- Enabling signal sharing between different channels or users without the need for active electronics.
- A Splitter (1×N coupler) takes an input signal from one fiber and splits it into N output fibers.
- A Combiner (N×1 coupler) combines optical signals from multiple input fibers into a single output fiber.

Optical Couplers *(cont.)*

Coupling ratio :

- describes how the input optical power is divided between the output ports of an optical coupler.
- **Formula for Coupling Ratio:**

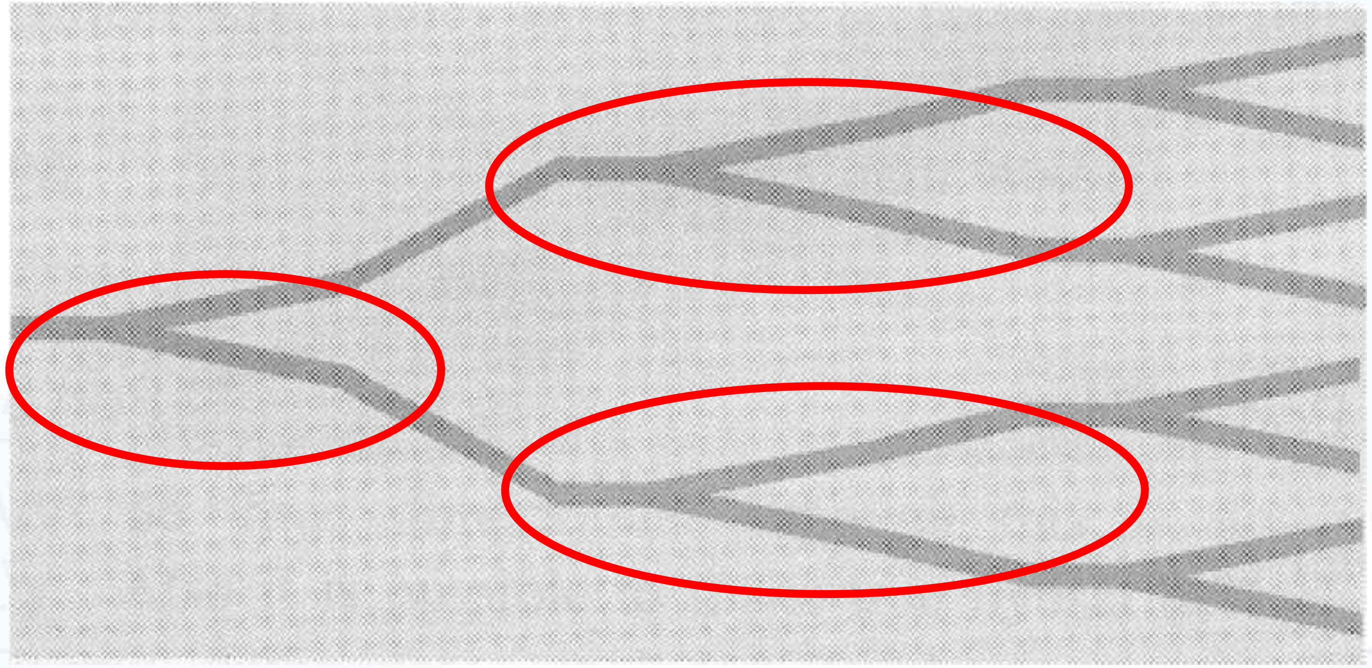
For a simple 1x2 optical coupler, the coupling ratio is defined as:

$$\text{Coupling Ratio } (\square) = \frac{P_1}{P_1 + P_2} \; or \; \frac{P_2}{P_1 + P_2}$$

Where:

- P_1 = Power at output port 1.
- P_2 = Power at output port 2.

Optical Couplers *(cont.)*



- How to design a 1xN splitter?

- Couplers (2x1) can be used to design an 8-port splitter.

THANKYOU

QUESTIONS?

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