Communications

Dr. Michael Melek

Course Contents

- Review on Fourier series and Fourier transform
- Analog modulation
  - Amplitude, frequency and phase (AM, FM and PM)
- Analog to digital conversion
  - Sampling, Quantization, PCM

Intended Learning Outcomes (ILO's)

- To **identify** the function of different components of a **communication system**
- To **recognize** the different types of **modulation** (AM, FM, PM, PAM, PCM) and **demodulation** techniques
- To **calculate** two main communication system parameters: power and bandwidth.
- To **choose** the best modulation/demodulation technique for a practical engineering system and analyze the system

Acknowledgement

- To Dr. Hebat-Allah Mourad
  - For preparing excellent sets of lecture slides and questions that we will be mostly using in this course

Text Book

- B. P. Lathi, “Modern Digital and Analog Communication Systems”
  - Revision: Chapter 2 and 3
  - Main: Chapters: 4, 5, and 6

- Additional reference:

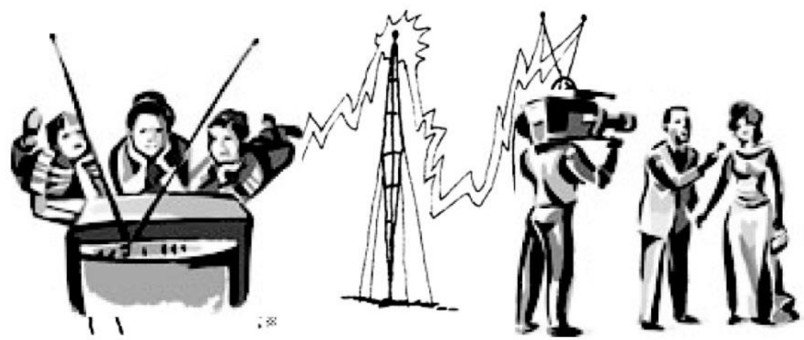
S. Haykin, “Communication systems”

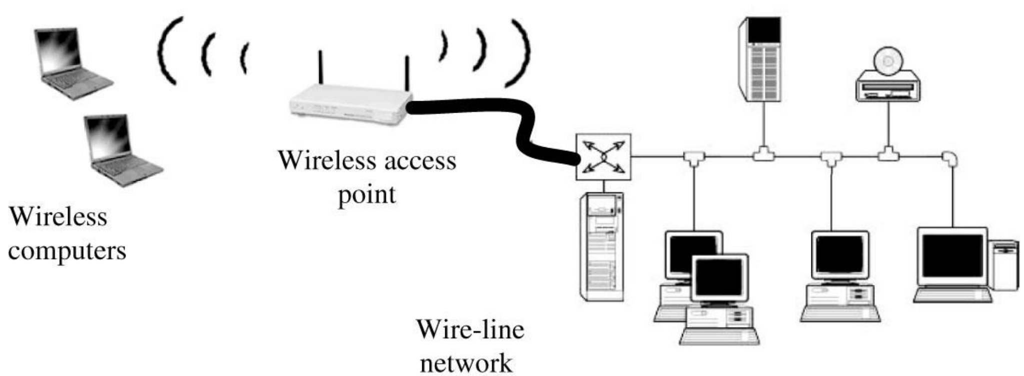
Logistics

- Email: ask_michael@live.com
- Office hours: Thursday 12:00 pm, or by appointment
- Grades:

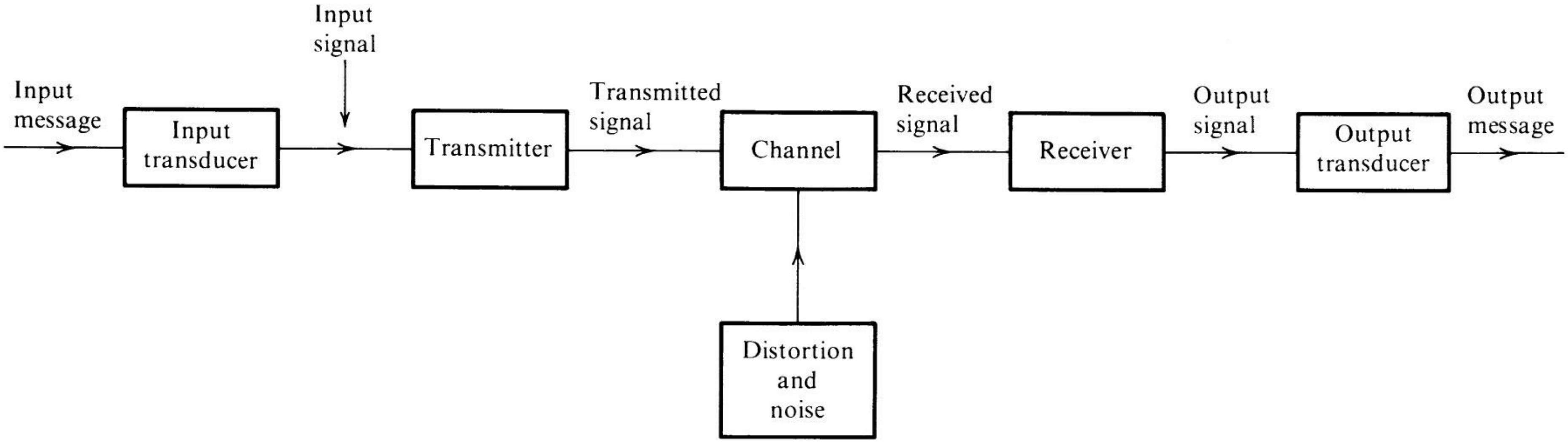
  40: Project, quizzes, labs
  60: Final exam

Communication systems



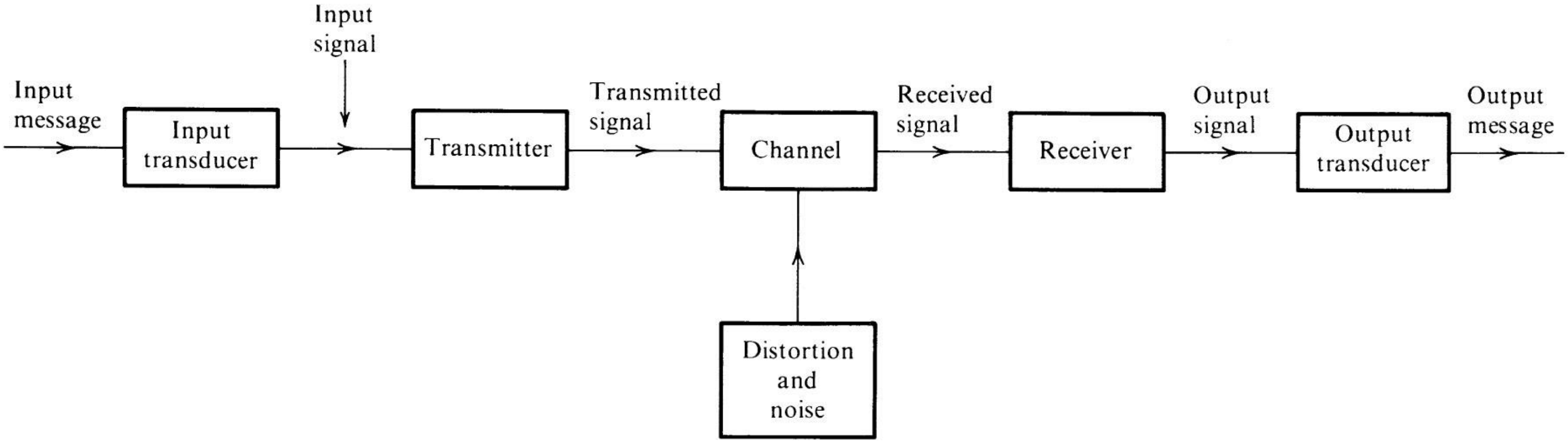


Communication systems



- **Transducer** converts the original message into electrical signal and vice versa
- **Transmitter** modifies the input signal for efficient transmission (modulator, encoder, …)
- **Channel** distorts the signal and adds noise to it
- **Receiver** removes the signal modifications done by the transmitter and channel

Communication systems



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CT Fourier Series

$$a_k = \frac{1}{T}\int_T x(t)e^{-jk\omega_0 t}\,dt$$

Time Domain

$\boldsymbol{x(t)}$

- Periodic
- Continuous

Analysis equation

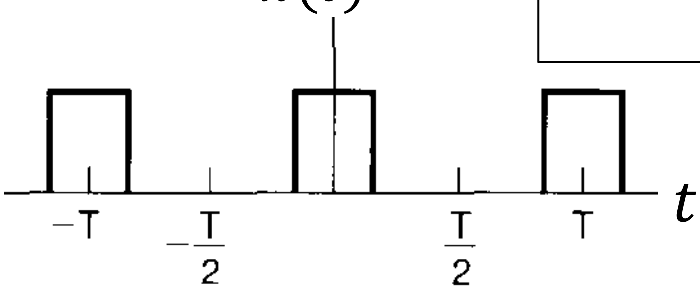
Synthesis equation

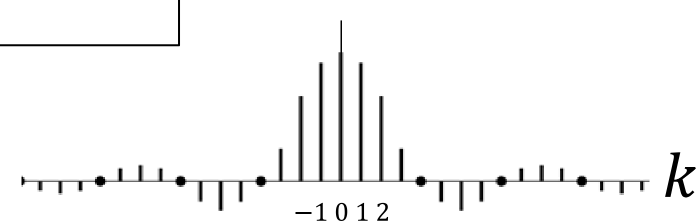
Freq. Domain

$\boldsymbol{a_k}$

- Discrete
- Aperiodic

$$x(t) = \sum_{k=-\infty}^{\infty} a_k e^{jk\omega_0 t}$$



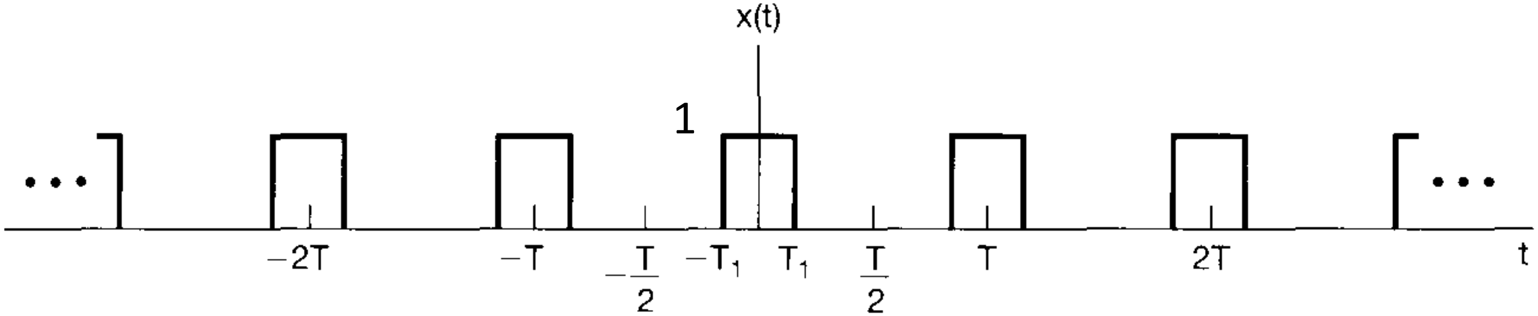


$$\omega = k\omega_0$$

$$\omega_0 = \frac{2\pi}{T}$$

Example

Obtain Fourier series coefficients for $x(t)$



$$a_k = \frac{1}{T}\int_{-T_1}^{T_1} e^{-jk\omega_0 t}\,dt = -\frac{1}{jk\omega_0 T} e^{-jk\omega_0 t}\Big|_{-T_1}^{T_1}$$

$$a_k = \frac{2\sin(k\omega_0 T_1)}{k\omega_0 T} = \frac{\sin(k\omega_0 T_1)}{k\pi},$$

CT Fourier Transform

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}\,dt$$

Time Domain

$\boldsymbol{x(t)}$

- Aperiodic
- Continuous

Analysis equation (FT)

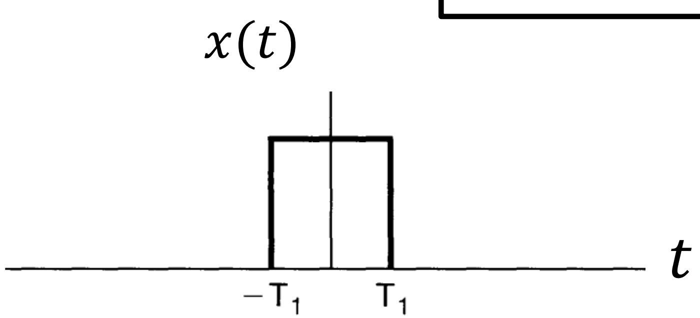
Synthesis equation (IFT)

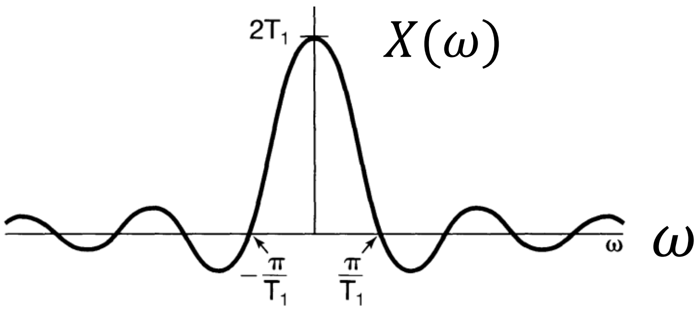
Freq. Domain

$\boldsymbol{X(\omega)}$

- Continuous
- Aperiodic

$$x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{j\omega t}\,d\omega$$

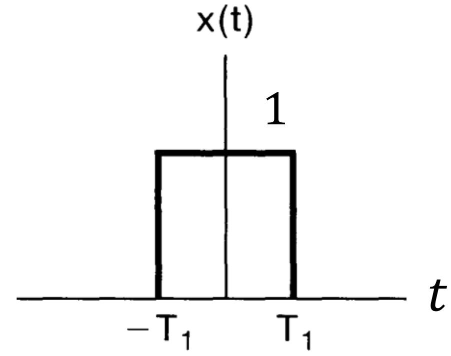




Example

Obtain FT of the rectangular pulse

$$x(t) = \begin{cases} 1, & |t| < T_1 \\ 0, & |t| > T_1 \end{cases}$$

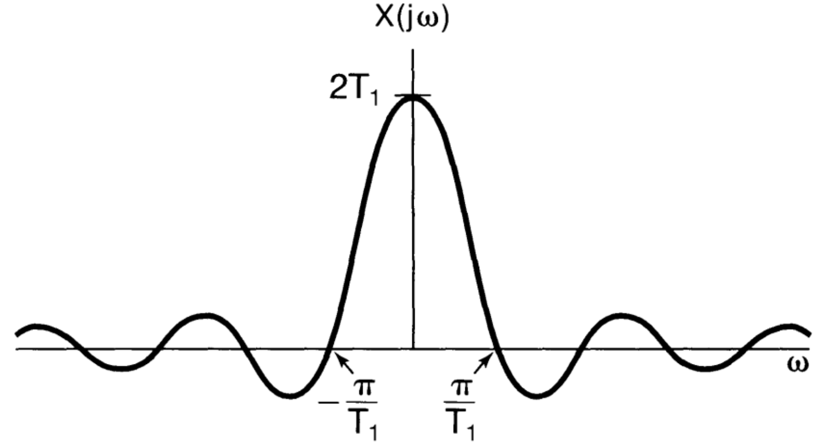


Solution:

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}\,dt$$

$$= \int_{-T_1}^{T_1} 1e^{-j\omega t}\,dt$$

$$= \frac{2\sin(\omega T_1)}{\omega}$$



Fourier transform

- Time domain: $x(t), y(t), h(t), \ldots$

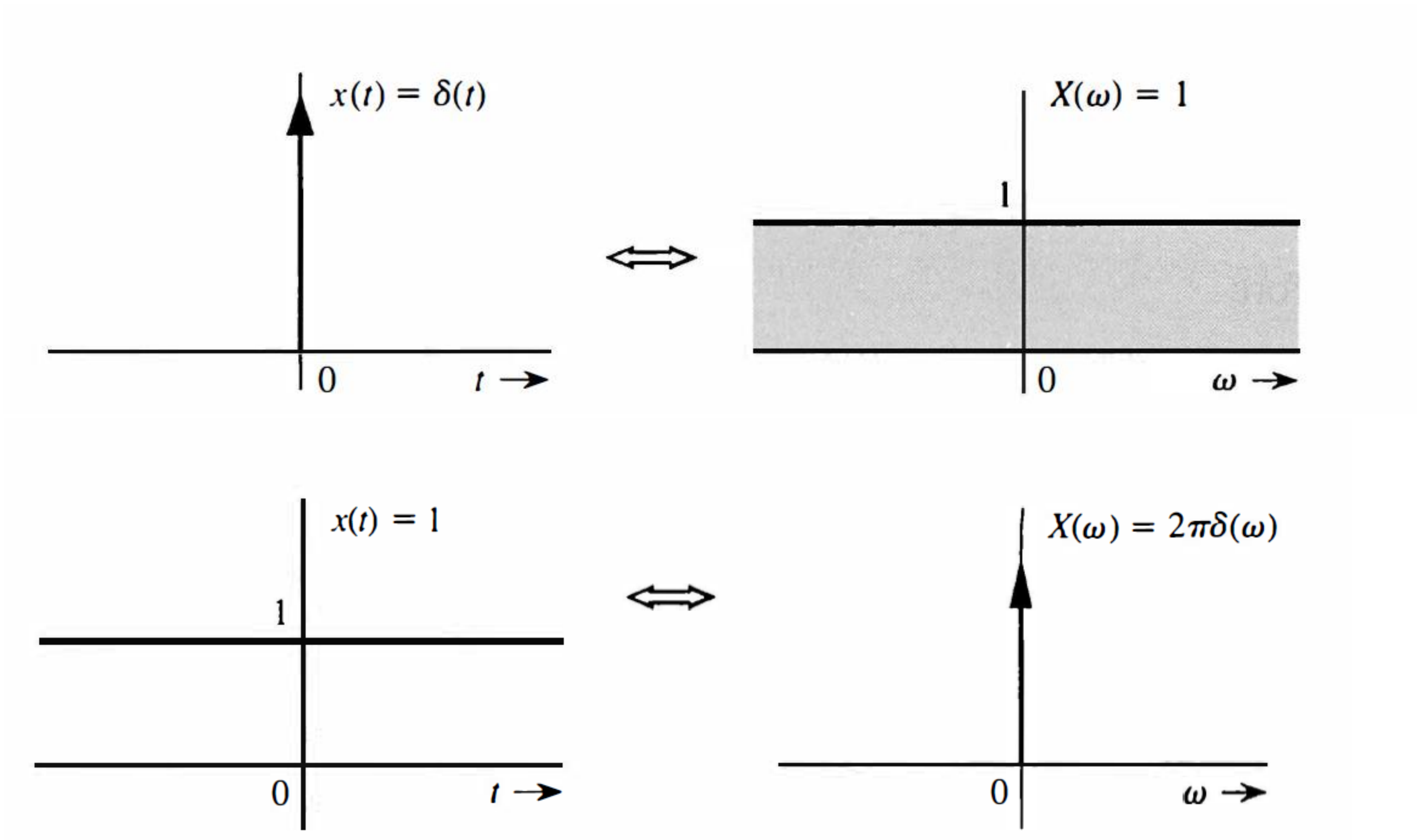
  Freq. domain: $X(\omega), Y(\omega), H(\omega), \ldots$
- $X(\omega)$ is FT of $x(t)$, $x(t)$ is IFT $X(\omega)$,

  $x(t) \Leftrightarrow X(\omega)$
- Other form:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j\,2\pi f\,t}\,dt$$

$$x(t) = \int_{-\infty}^{\infty} X(f) e^{j\,2\pi f\,t}\,df$$

Examples



Fourier Transform for Periodic Signals

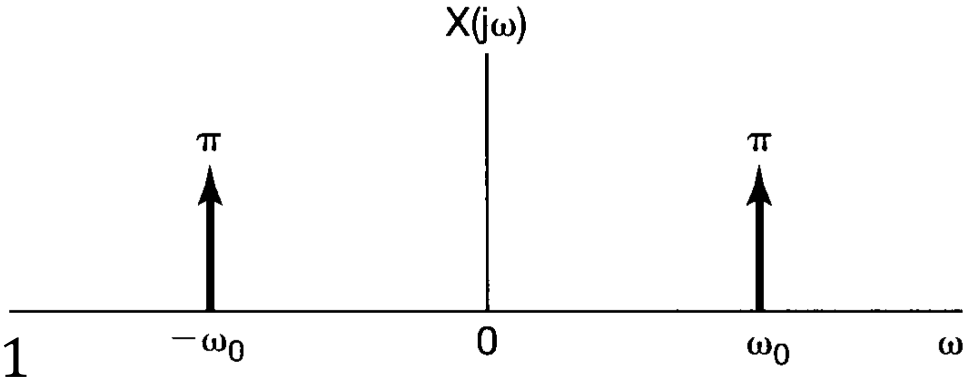
For a periodic $x(t)$ with FS coefficients $\{a_k\}$

$$X(\omega) = \sum_{k=-\infty}^{\infty} 2\pi a_k \, \delta(\omega - k\omega_0)$$

- **Example**

$x(t) = \cos(\omega_0 t)$

$a_1 = a_{-1} = \frac{1}{2}, a_k = 0, k \neq \pm 1$



$$X(\omega) = \pi\delta(\omega - \omega_0) + \pi\delta(\omega + \omega_0)$$

Fourier Transform Properties

$$x(t) \leftrightarrow X(\omega)$$

Time Shifting (same sign)

$$\boxed{x(t - t_0) \leftrightarrow e^{-j\omega t_0} X(\omega)}$$

Frequency Shifting (opposite sign)

$$\boxed{e^{j\omega_0 t} x(t) \leftrightarrow X(\omega - \omega_0)}$$

Time domain	Frequency domain
Shift	**×complex exp. (phase shift)**
×complex exp.	**Shift**

Fourier Transform Properties

Conjugate symmetry

Time domain	Frequency domain
Real	Magnitude is even Phase is odd

Convolution and multiplication

Convolution property

$$\boxed{x(t) * h(t) \leftrightarrow X(\omega)H(\omega)}$$

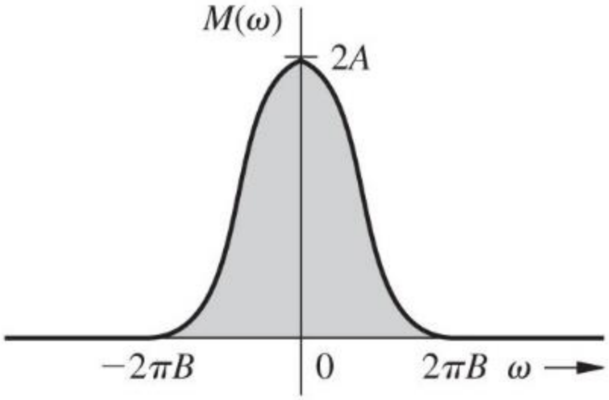
Multiplication property

$$\boxed{s(t)p(t) \leftrightarrow \frac{1}{2\pi} S(\omega) * P(\omega)}$$

Time domain	Freq. domain
Convolution	Multiplication
Multiplication	Convolution

Example

- Given that $M(\omega)$ is the FT of $m(t)$. Plot the spectrum of $m(t) \cos \omega_c t$. $\omega_c \gg 2\pi B$



LTI systems

In time domain:

$$x(t) \longrightarrow \boxed{h(t)} \longrightarrow y(t) = x(t) * h(t)$$

In freq. domain:

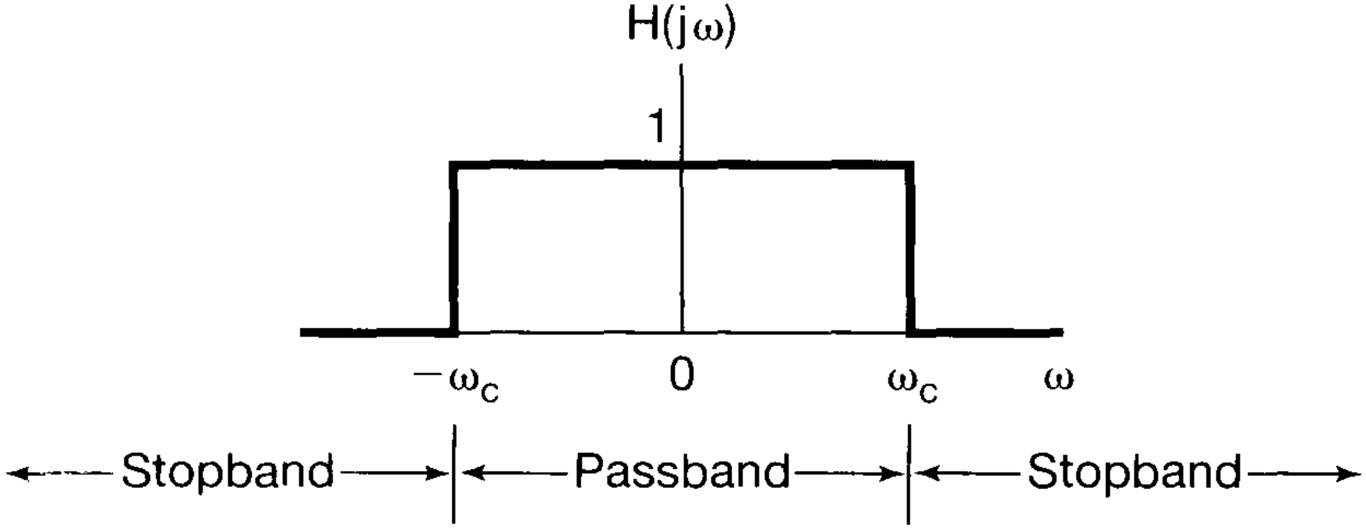
$$X(\omega) \longrightarrow \boxed{H(\omega)} \longrightarrow Y(\omega) = X(\omega)H(\omega)$$

Convolution $\Leftrightarrow$ Multiplication

Filtering

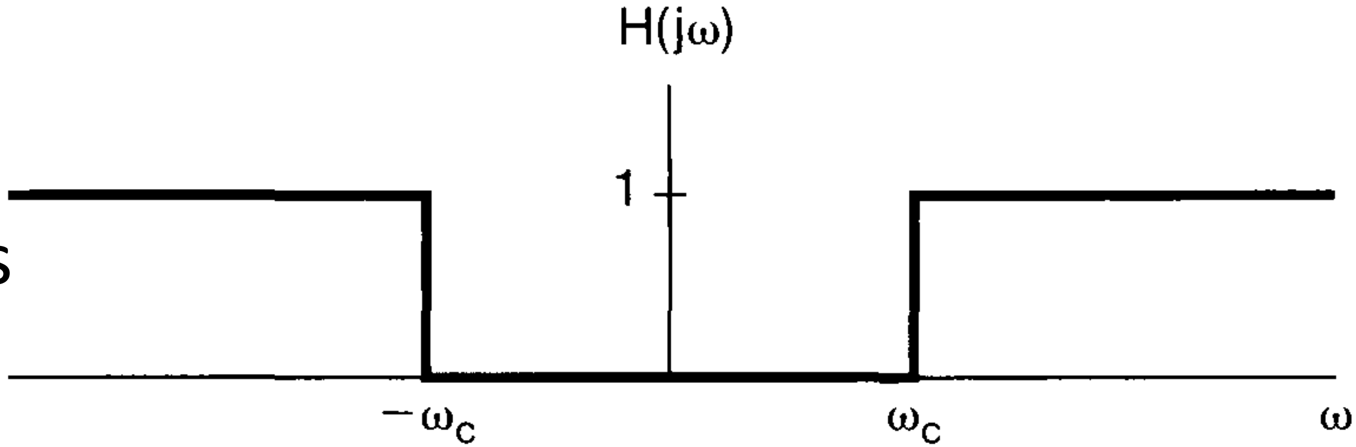
Ideal Filters

Ideal lowpass filter

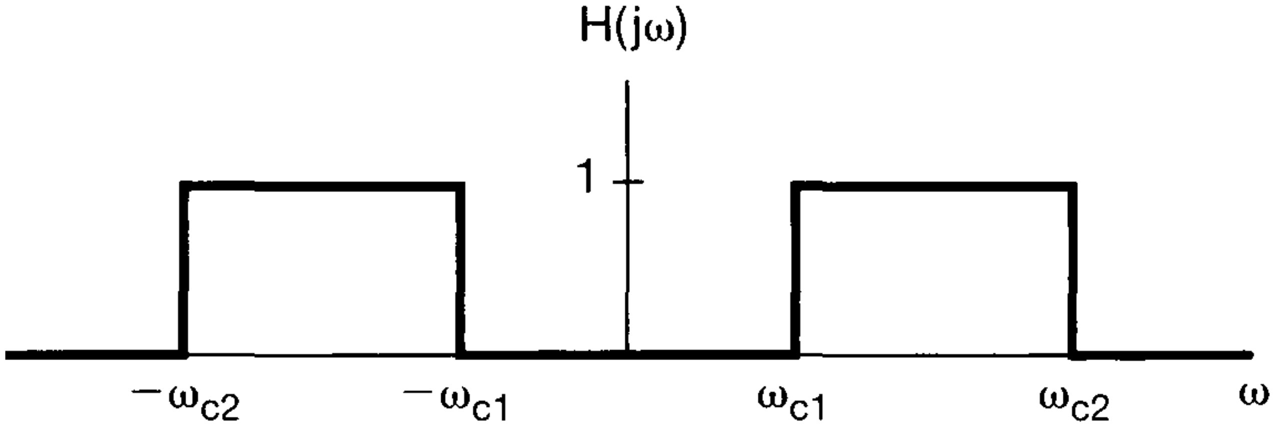


Filtering

Ideal highpass filter



Ideal bandpass filter



Bandwidth

- It is the difference between the **highest significant** frequency and the **lowest significant** frequency in the signal spectrum (in positive frequencies)

Energy and Power

Energy $$E = \int_{-\infty}^{\infty} |x(t)|^2 dt$$

Power $$P = \lim_{T \to \infty} \frac{1}{T} \int_T |x(t)|^2 dt$$

Parseval's theorem

Aperiodic $$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} |X(\omega)|^2 d\omega$$

Periodic $$P = \frac{1}{T} \int_T |x(t)|^2 dt = \sum_{k=-\infty}^{\infty} |a_k|^2$$