EBU4375: SIGNALS AND SYSTEMS

TOPIC 4-3: SIGNALS AND SYSTEMS APPLICATIONS TO TELECOMMUNICATION SYSTEMS

Queen Mary University of London

ACKNOWLEDGMENT

These slides are partially from lectures prepared by

Dr Jesus Raquena Carrion.

REVISION OF SAMPLING THEORY

1. Why do we need it?
2. ADC pipeline
3. DAC pipeline
4. Nyquist theorem

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WHICH SETTING IS CHANGED TO IMPROVE THE PHOTO?

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https://www.red.com/red-101/cinema-temporal-aliasing

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CAN WE REVERSE TIME?

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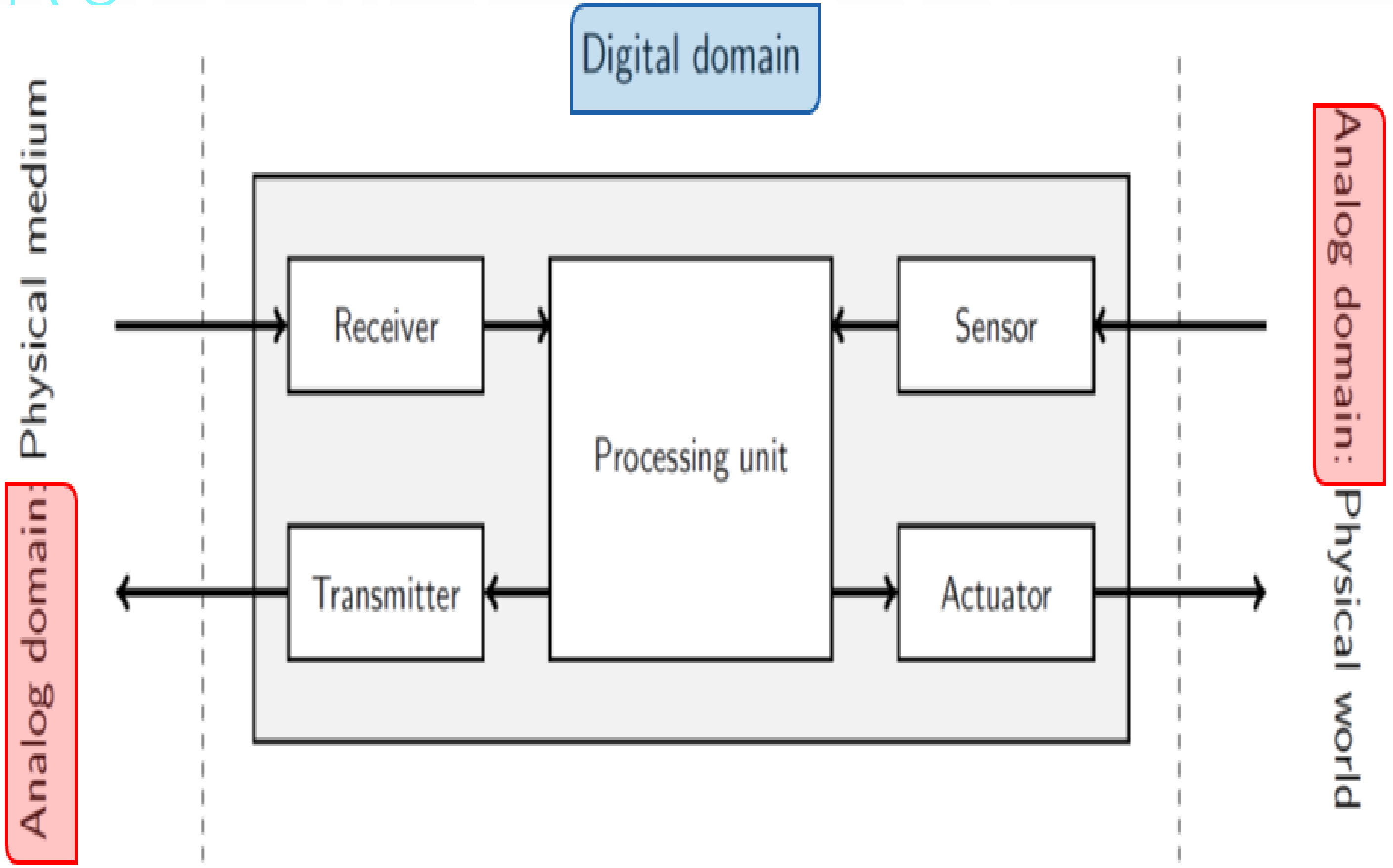
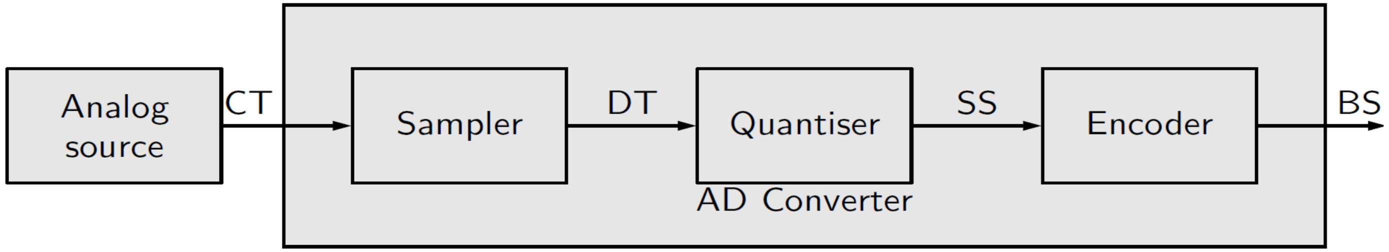
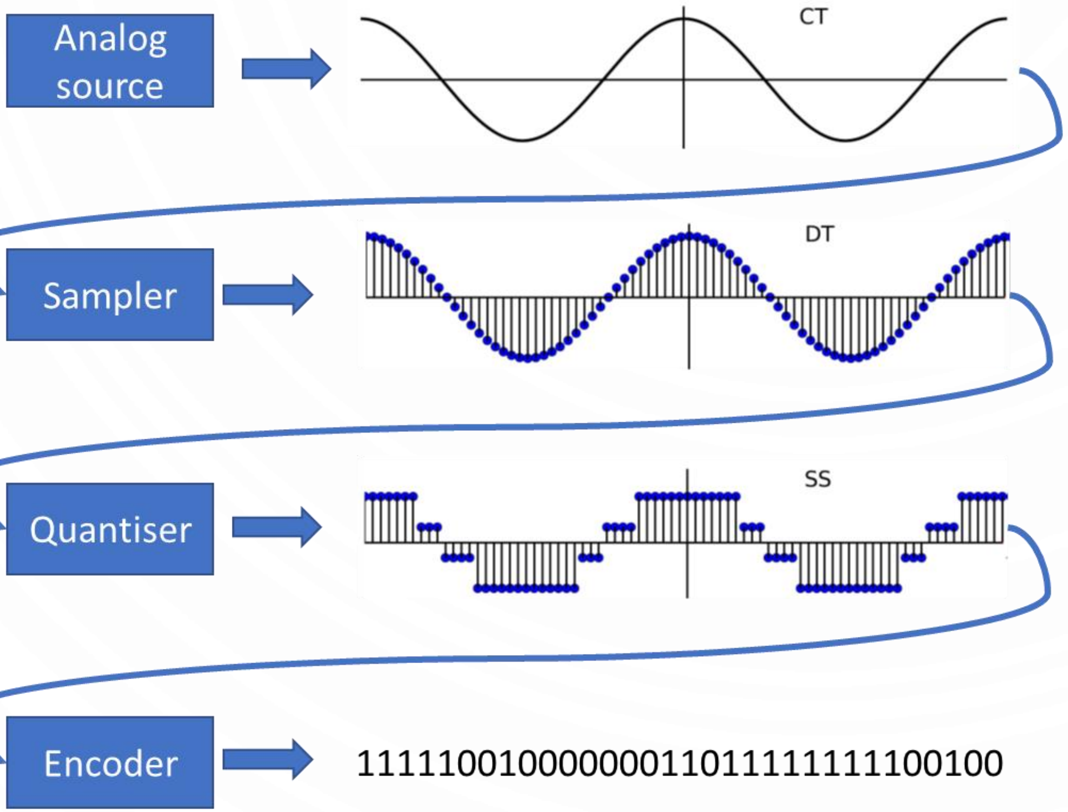
WHY IS CONVERSION TO DIGITAL IMPORTANT?



- Storage of digital information is more efficient
- Signal processing using microprocessors is more precise than analogue electronic systems for analogue signals.
- Digital signals can be regenerated which helps limit the effect of noisy channels.

ADC PIPELINE





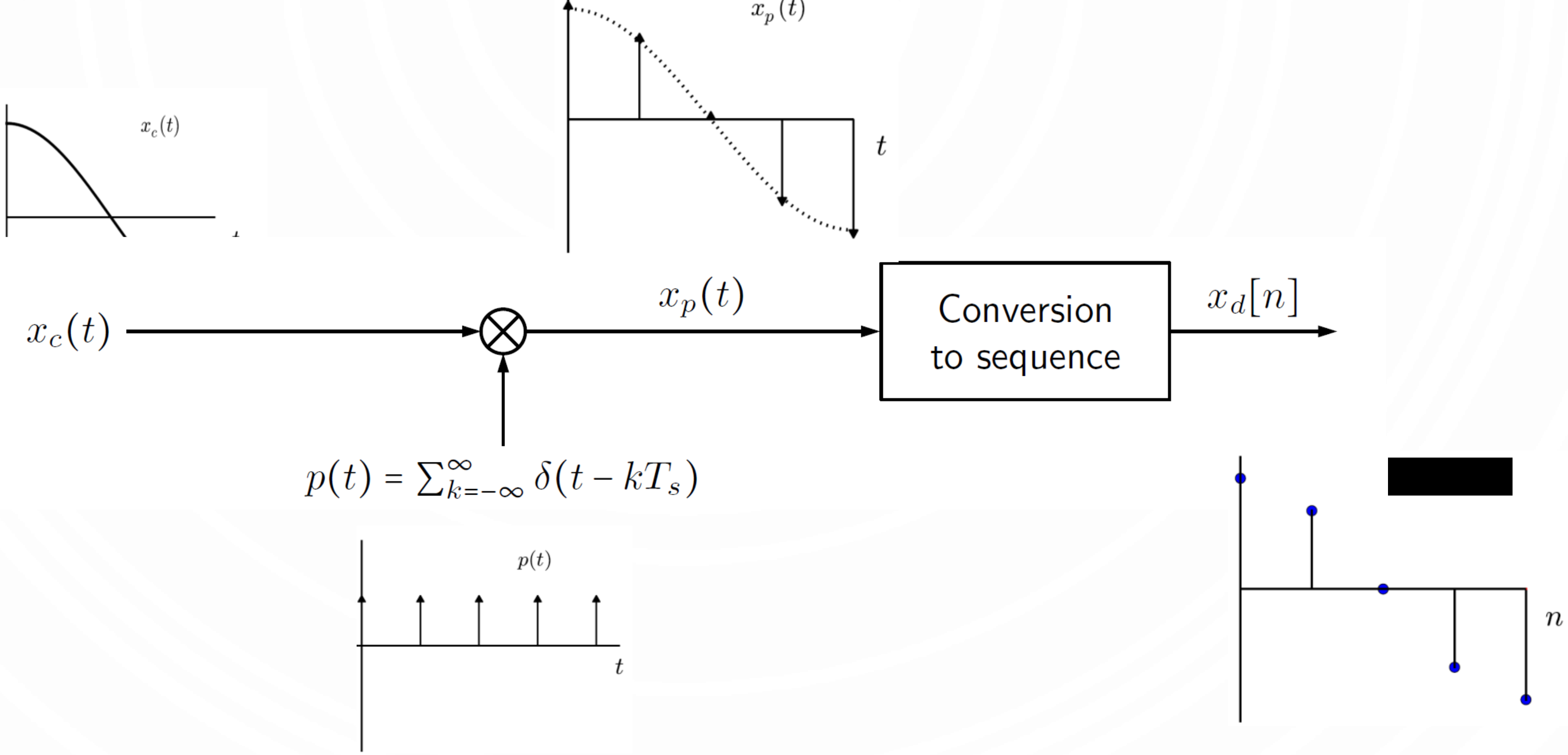
- Continuous time
- Continuous real values

- Discrete time
- Continuous real values

- Discrete time
- Discrete finite values

- Digitised signal

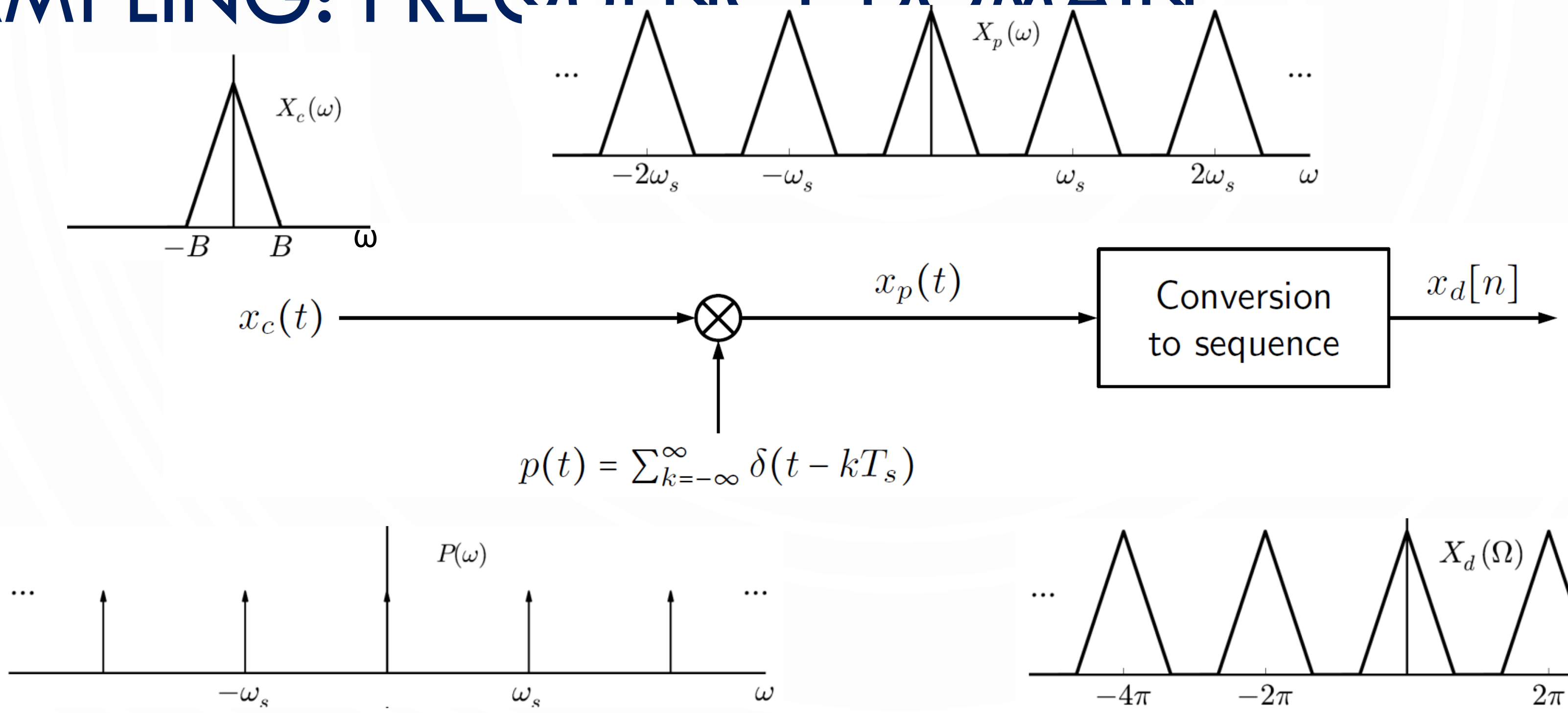
SAMPLING: TIME DOMAIN



Mathematically, sampling can be described as a two step process:

1. Sample extraction: multiplication by a CT impulse train. → $x_p(t)$
2. DT sequence generation: conversion to a DT impulse train. → $x_d[n]$

SAMPLING: FREQUENCY DOMAIN

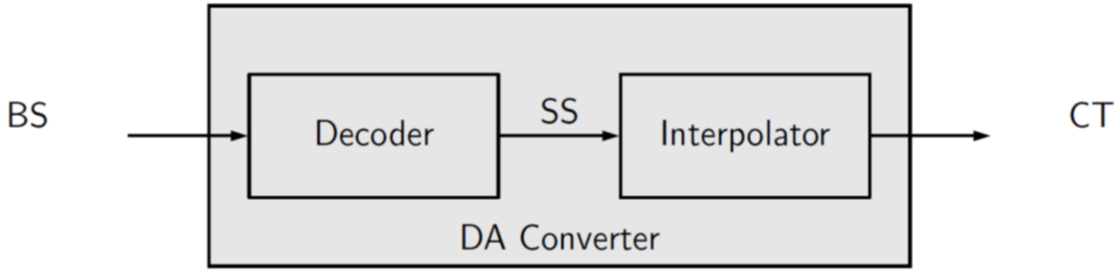


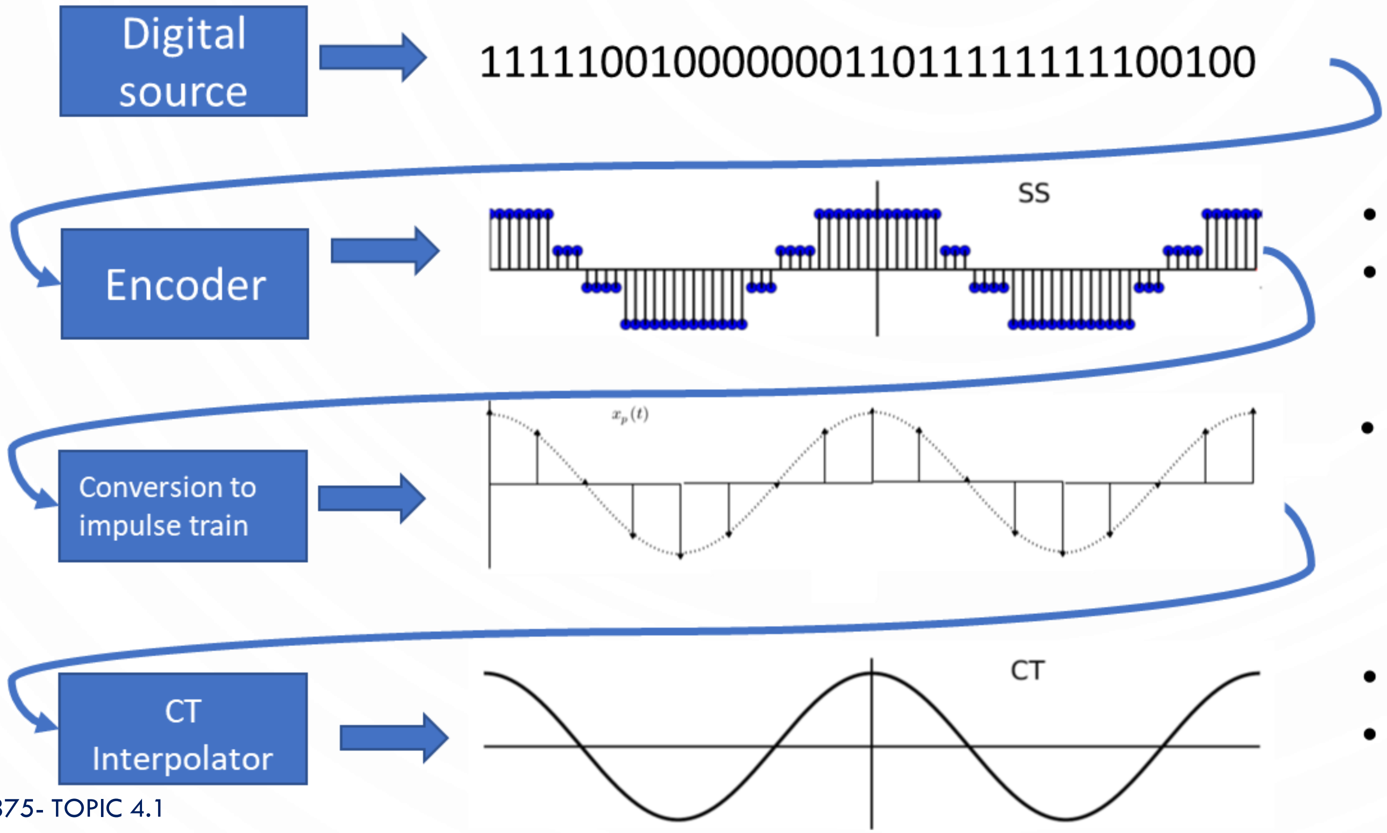
In summary, $X_p(\omega) = X_d(\omega T_s)$ and $X_d(\Omega) = X_p(\frac{\Omega}{T_s})$. Specifically,

$$X_p(\omega_s) = X_p\left(\frac{2\pi}{T_s}\right) = X_d\left(\frac{2\pi}{T_s}T_s\right) = X_d(2\pi)$$

$$\boxed{X_d(\Omega) = \frac{1}{T_s}\sum_{k=-\infty}^{\infty} X_c\left(\frac{\Omega}{T_s} - k\frac{2\pi}{T_s}\right)}$$

DAC PIPELINE





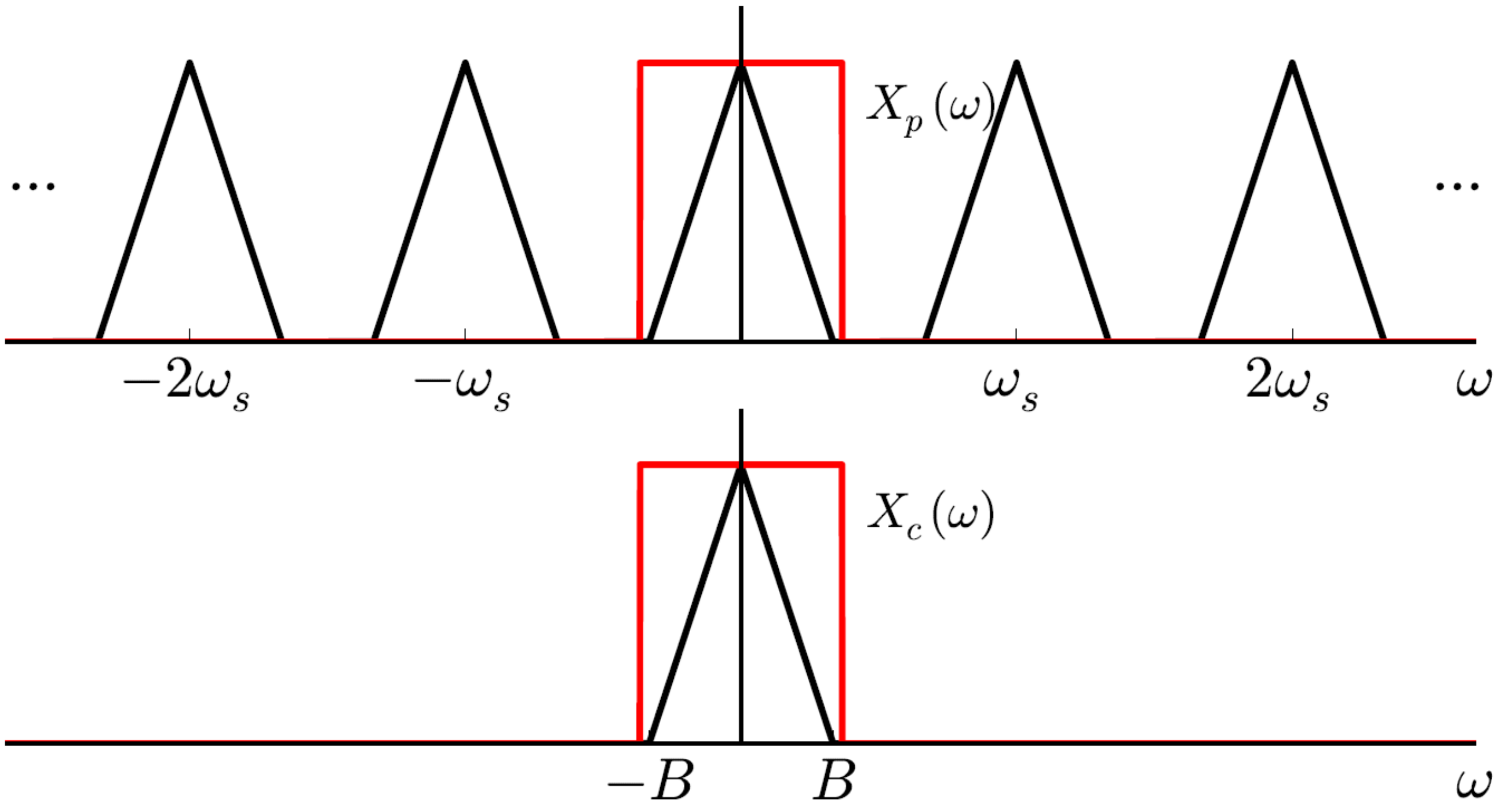
- Discrete time
- Discrete finite values

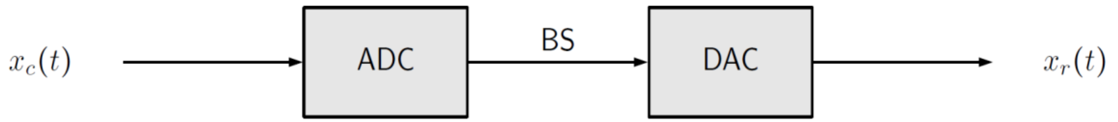
- Continuous time

$$x_p(t)$$

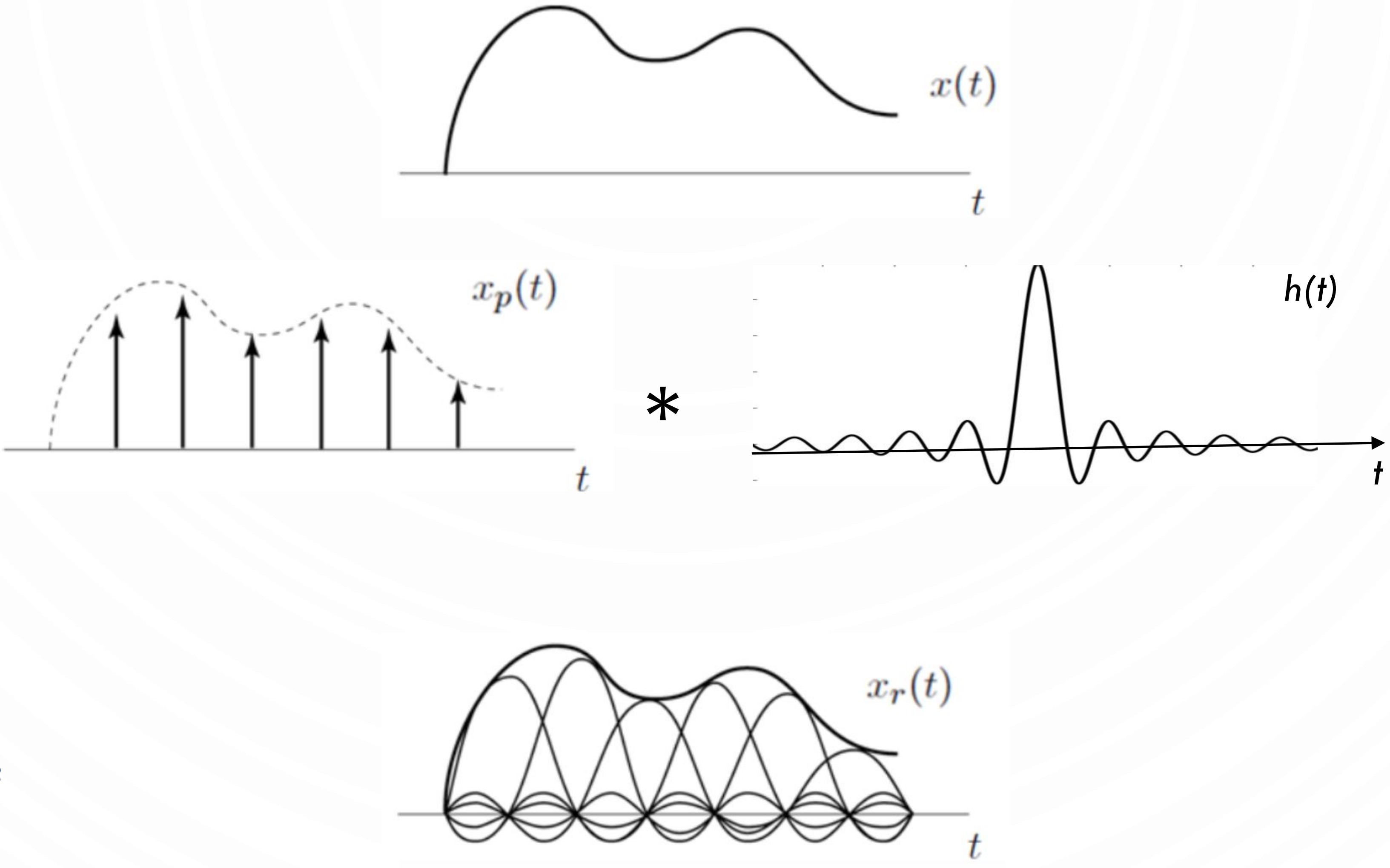
- Continuous time
- Continuous real values

INTERPOLATION: FREQUENCY DOMAIN





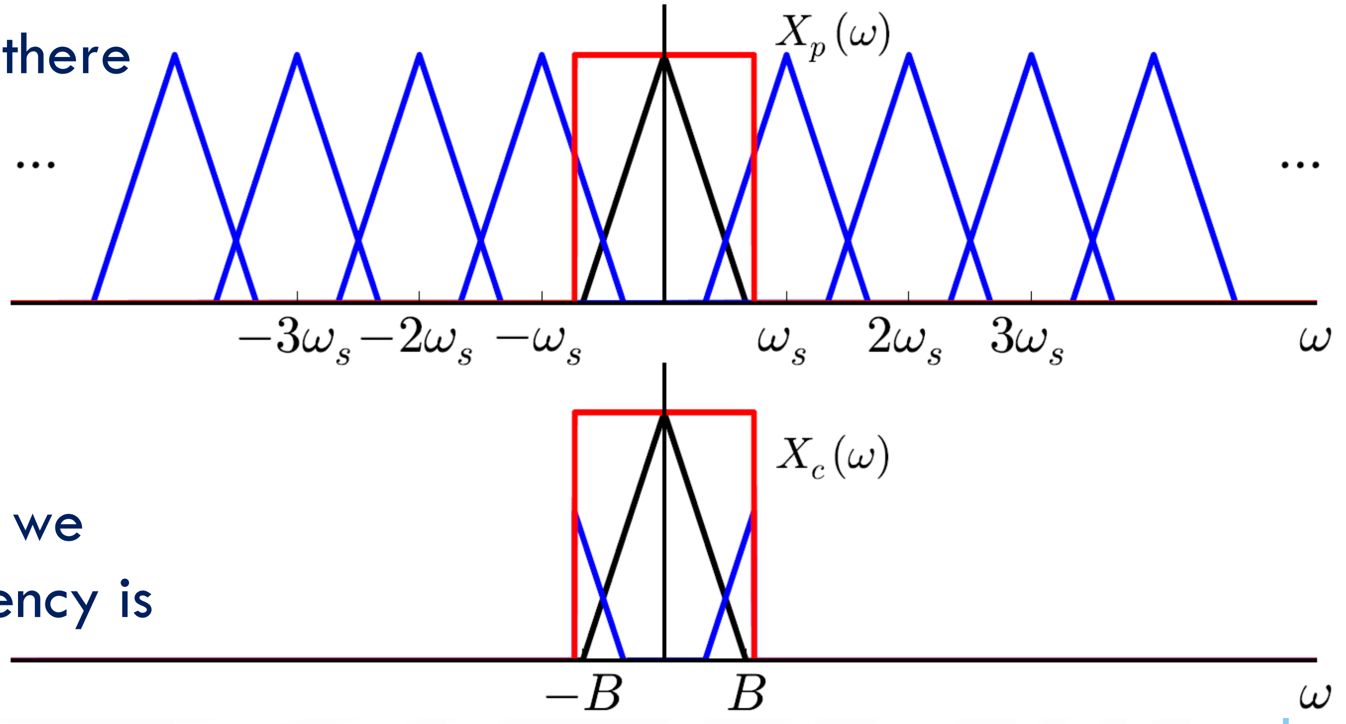
INTERPOLATION: Time Domain



Interpolation: Undersampling and Aliasing

If we undersample a signal (ω_s is too low), there is overlap between the replicas of $X(\omega)$ in $X_p(\omega)$. This is called aliasing.

If there is aliasing, $X_c(\omega)$ will contain both $X(\omega)$ and part of the replicas $X(\omega + \omega_s)$ and $X(\omega - \omega_s)$. In order for us to avoid it, we need to make sure that the sampling frequency is high enough, specifically $\omega_s \geq 2B$.



What are the rules then?

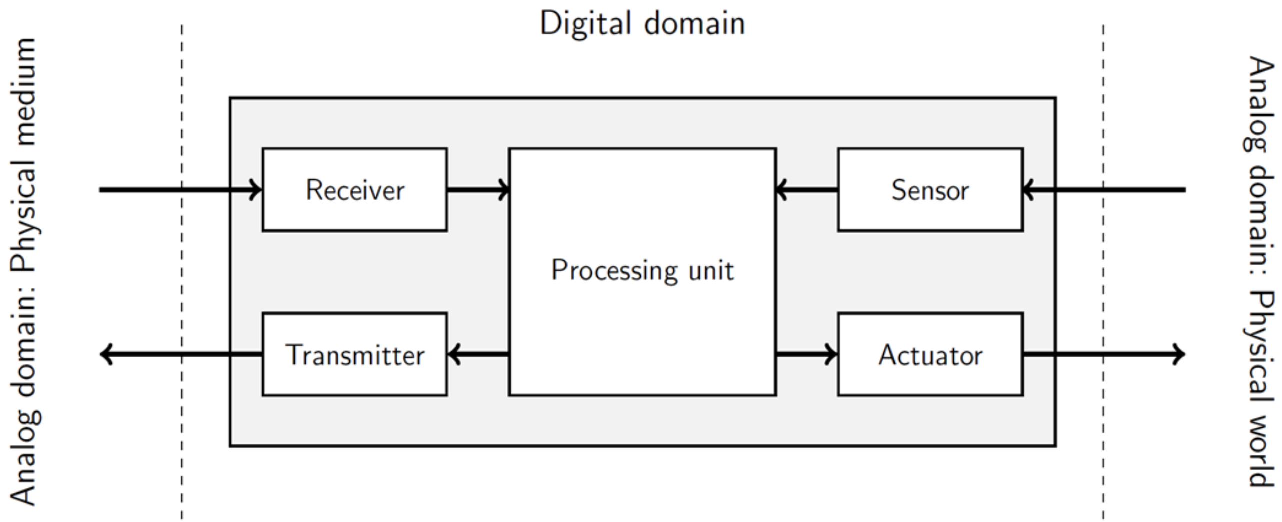
Let x(t) be a band-limited signal with $X(\omega) = 0$ for $|\omega| > B$. Then x(t) is **uniquely** determined by its samples $x(nT_s)$; $n = 0;\pm1;\pm2;\pm3;\ \ldots$
if $\omega_s \geq 2B$, where $\omega_s = 2\pi/T_s$.

Given these samples, we can reconstruct x(t) by generating an impulse train in which successive impulses are separated by T_s units of time and have the amplitudes of successive samples. If this impulse train is processing it through a lowpass filter with gain Ts and cutoff frequency ω_c such that $B < \omega_c < \omega_s - B$, the resulting signal is **exactly** x(t).

This theorem is also called Nyquist or Nyquist-Shannon Theorem and 2B is known as Nyquist frequency.

AGENDA

1. Principles of digital communications: Baseband transmission
2. Multiplexing in the frequency domain
3. Bandpass transmission
4. Models of physical media



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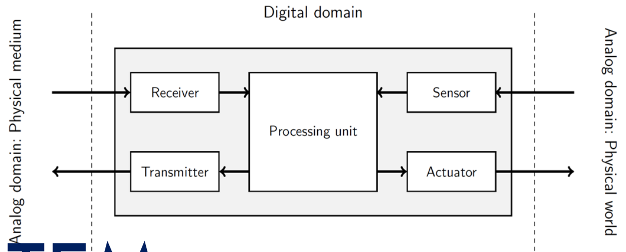


BASIC MODEL OF COMMUNICATIONS SYSTEM

source → TX (device) → Physical medium → RX (device) → destination

- The **source** is the entity that generates information.
- The **destination** is the entity that the information is sent to.
- The **transmitter** (TX) generates physical signals to transmit information produced by the source through a **physical medium.**
- The **receiver** (RX) extracts the information from the physical signal and passes it onto the destination.

DIGITAL COMMUNICATIONS: OVERVIEW

source → TX (device) → Physical medium → RX (device) → destination

Digital communication systems **represent and transmit** information in digital format, i.e. essentially 0s and 1s.

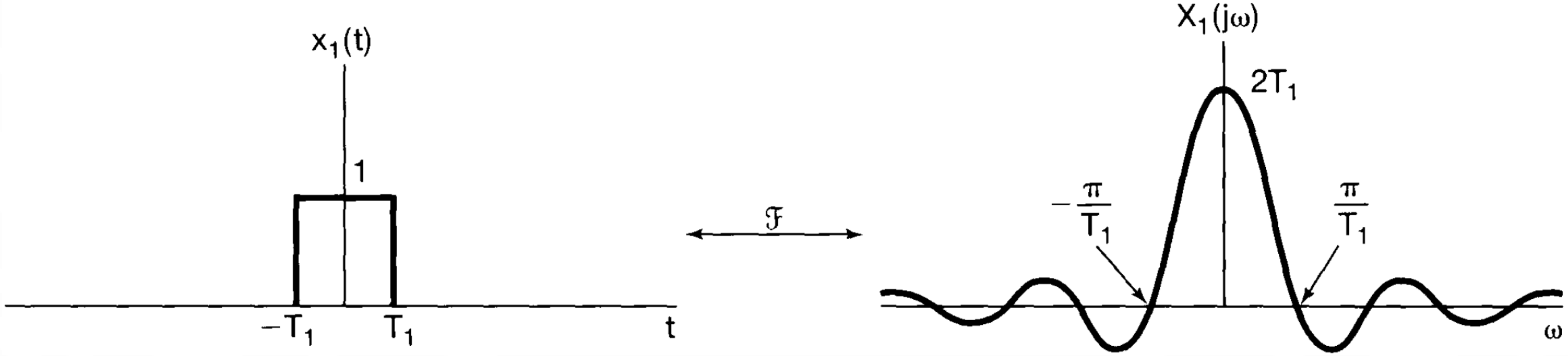
One way of doing this is by using **different CT waveforms** for representing the digit 1 and the digit 0. The receptor extracts the transmitted bits by identifying the received waveforms.

The time between two consecutive waveforms is called the **bit time,** T_b and based on it, we can calculate the transmission bit rate (the number of bits transmitted per second) as $R_b = 1/T_b$.

BASEBAND TRANSMISSION

In **baseband** (or lowpass) transmission we use waveforms whose Fourier transform is **lowpass.**

In baseband transmission, **most of the power is concentrated at low frequencies,** hence the name baseband or lowpass transmission

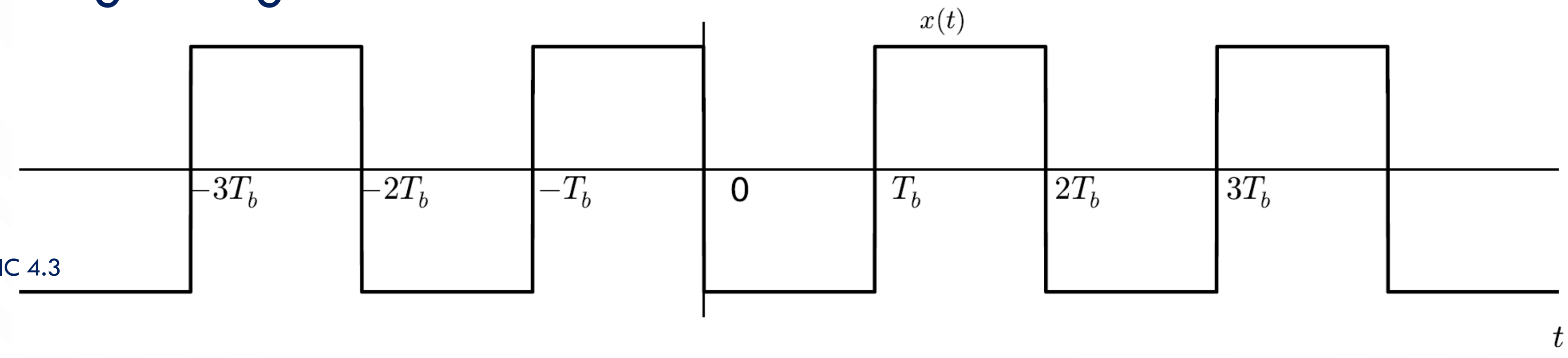


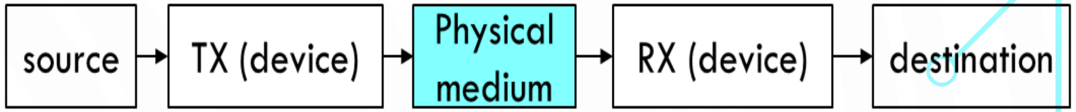
BASEBAND TRANSMISSION

For instance, we can represent digits 0 and 1 by the waveforms $s_0(t)$ and $s_1(t)$ defined as:

$$s_0(t) = \begin{cases} -1 & |t| < T_b/2 \\ 0 & \text{otherwise} \end{cases} \qquad s_1(t) = \begin{cases} 1 & |t| < T_b/2 \\ 0 & \text{otherwise} \end{cases}$$

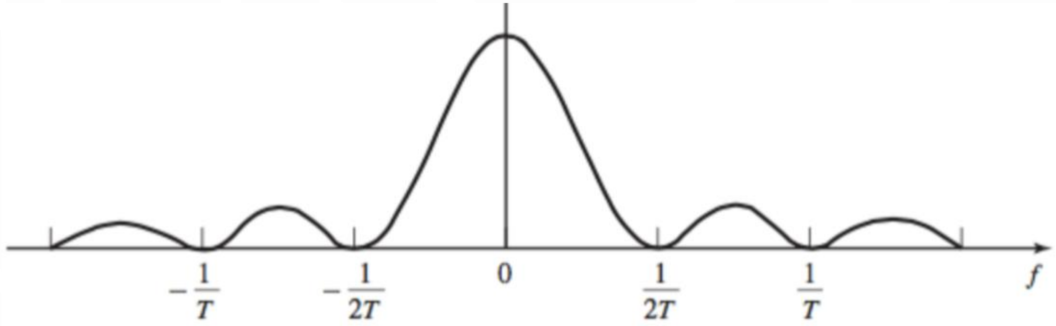
The digital sequence 010101010 can then be transmitted by producing the following CT signal:





BASEBAND TRANSMISSION

Given the following baseband channel or filter (**physical medium**) with B=1/2T:



The lowest possible bit time T_b that would be transmitted through this channel is equal to T. => The highest data rate of a signal that can be $R_b=1/T_b=1/T$:

- If T_b⬇, then R_b⬆ and B⬆: **Broadband** is equivalent to **high data rate.**
- If T_b⬆, then R_b⬇ and B⬇: **Narrowband** is equivalent to **low data rate.**
- Have you heard of NB-IoT?

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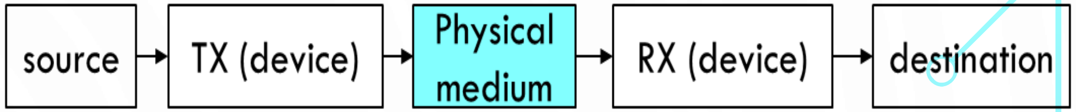
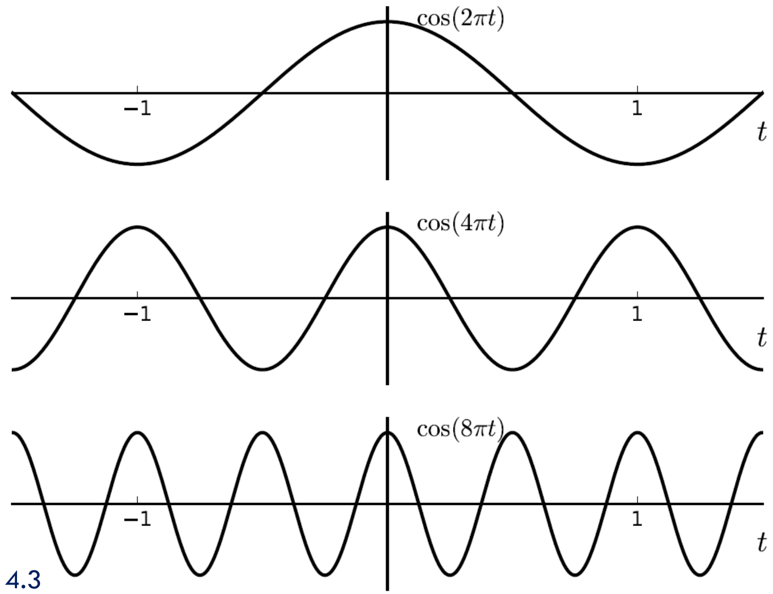
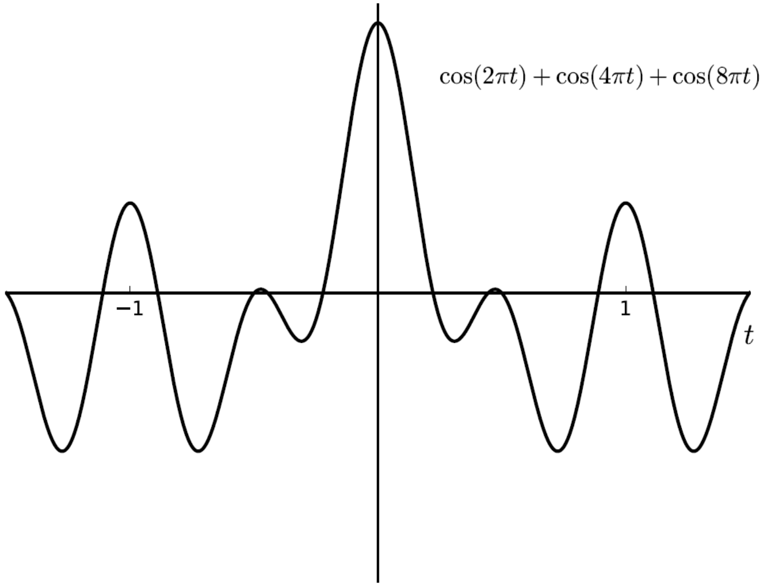


TRANSMITTING MULTIPLE SIGNALS: Time domain

In this example, we transmit three sinusoidal signals through the same physical medium. The resulting signal is the sum of the three sinusoidal signals. How can we extract each one of them in the receiver?





TRANSMITTING MULTIPLE SIGNALS

Take 5 minutes to think about this and go to Mentimeter!

Let's go to Mentimeter!!!
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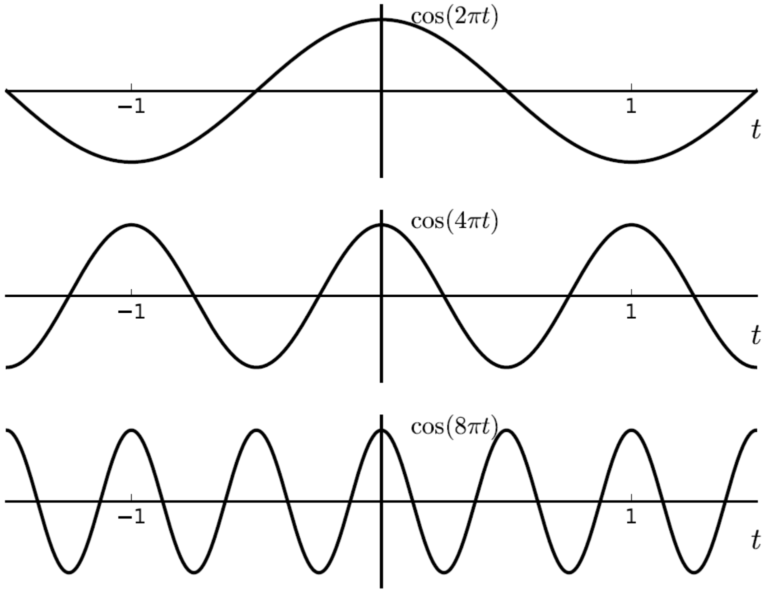
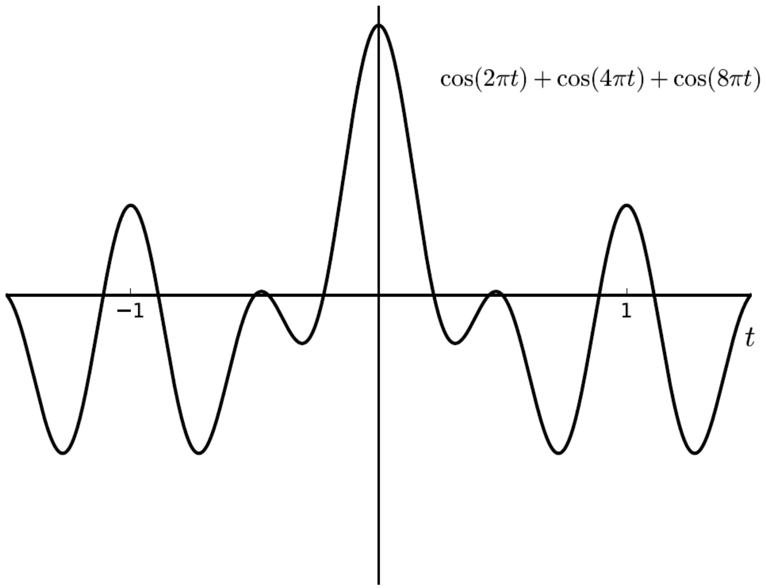
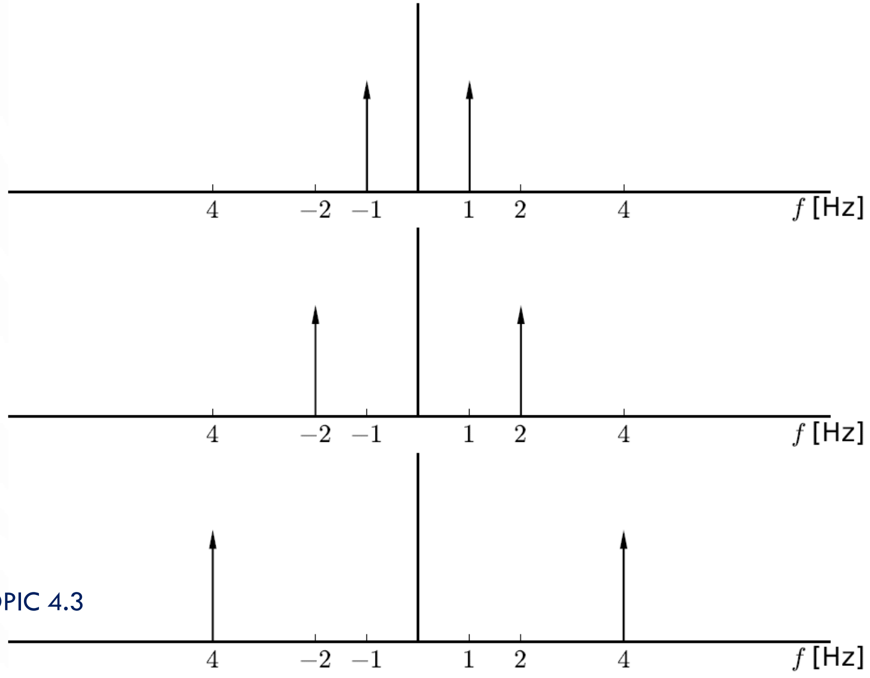
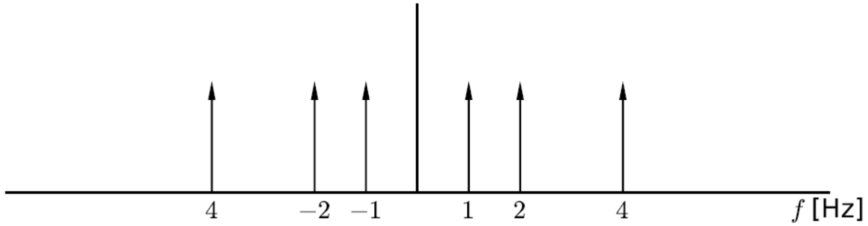




TRANSMITTING MULTIPLE SIGNALS : Frequency domain

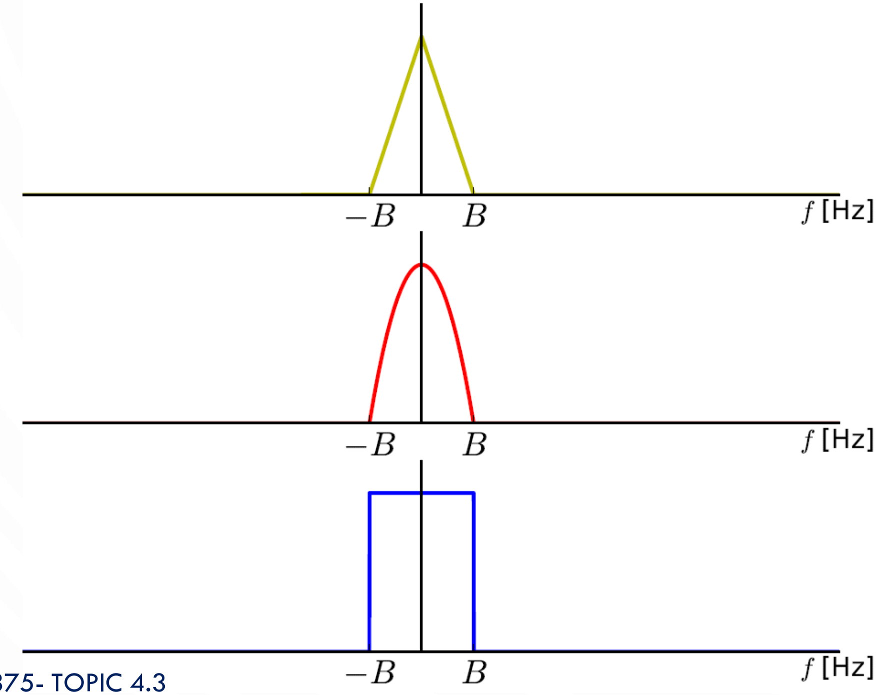
In the frequency domain, we can clearly distinguish each one of the sinusoidal signals that we added in the previous example. By looking at the frequency domain it is easy to see that what we need to do is bandpass filter our signal!

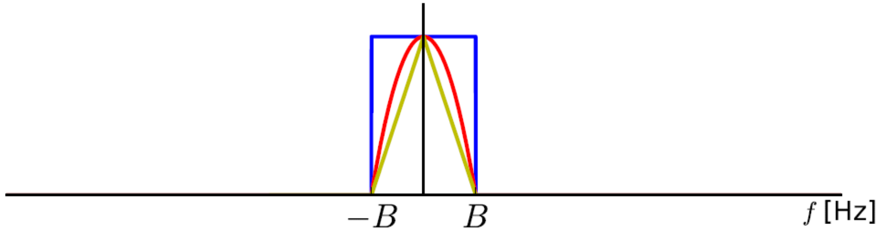




TRANSMITTING MULTIPLE SIGNALS : Frequency domain

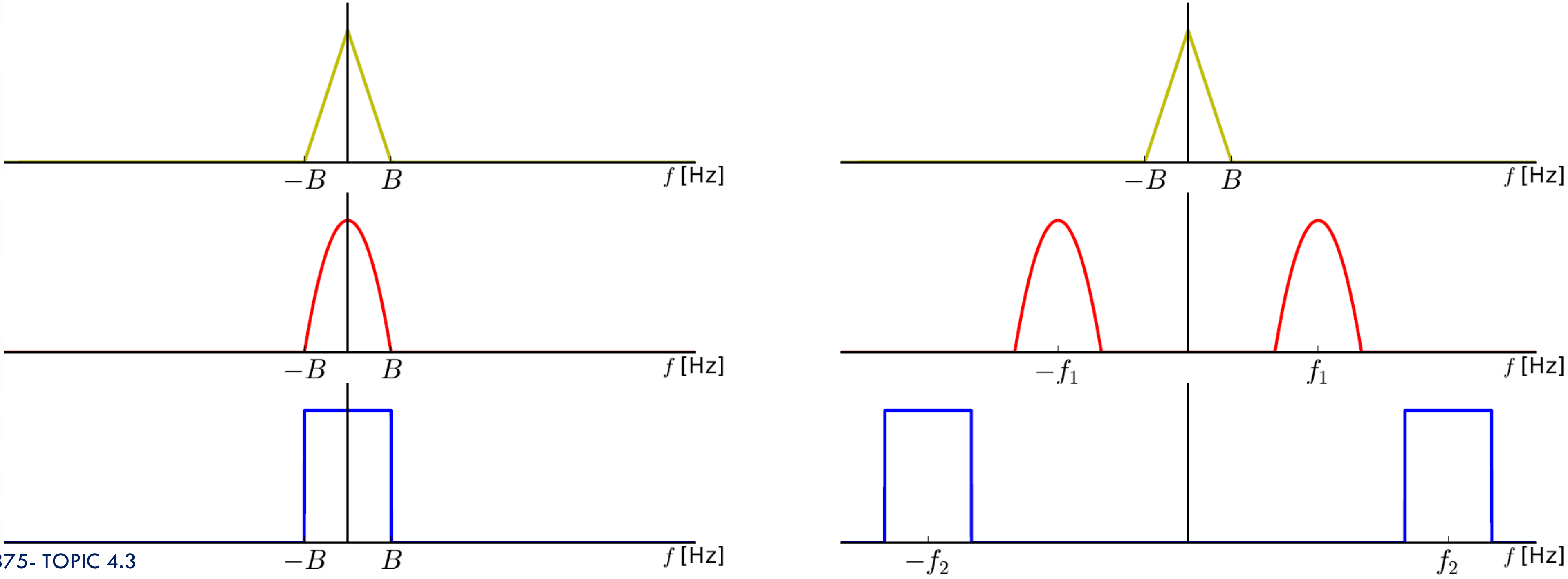
If signals are in different frequency bands, we can separate them by bandpass filtering. However, what can we do if our signals use the same frequency band?





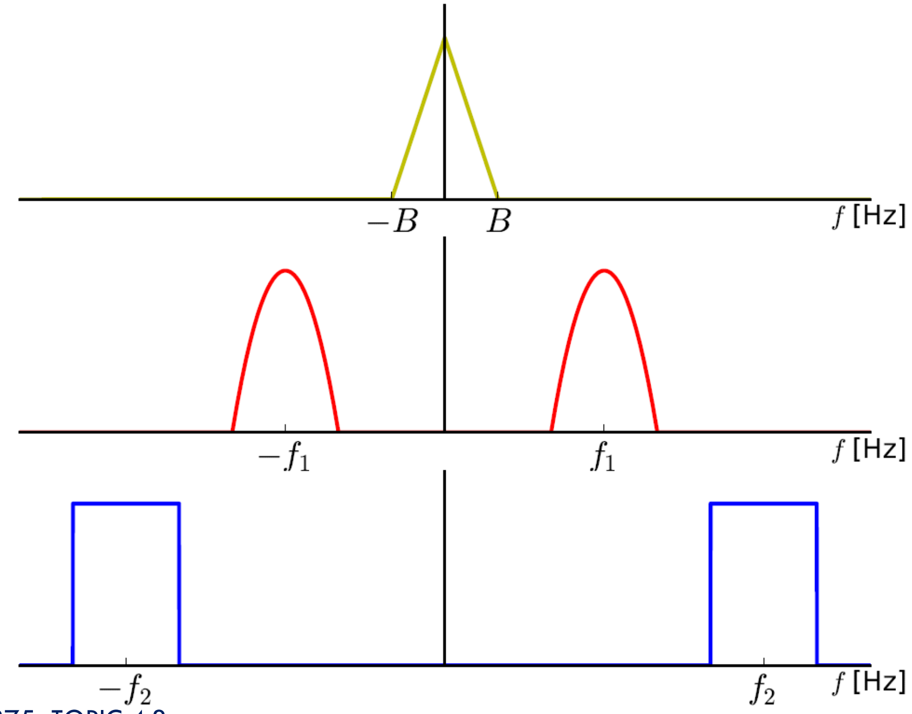
MULTIPLEXING: Frequency Translation

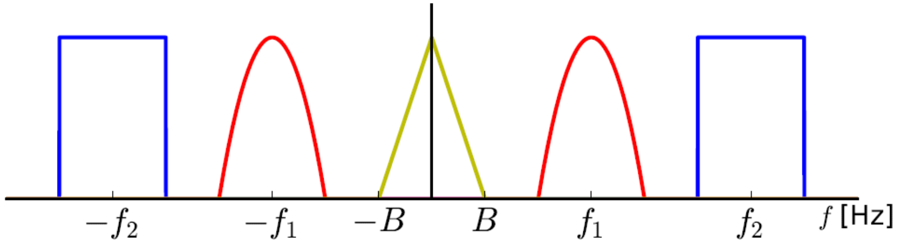
We can translate each signal to a different frequency band by multiplying by sinusoidal signals with different frequencies.



MULTIPLEXING: Frequency Translation

Then we transmit them through the same physical medium.





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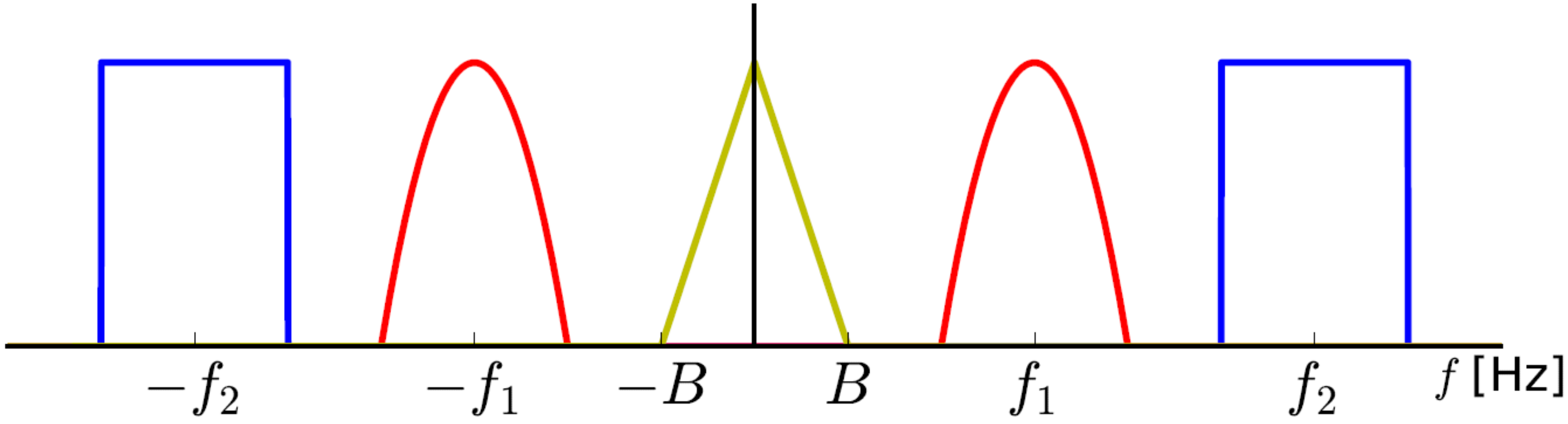
DE-MULTIPLEXING: Frequency Domain

But how do we recuperate each individual signal?
Take 5 minutes to think about this and go to Mentimeter!



Is this still considered baseband transmission?

AGENDA

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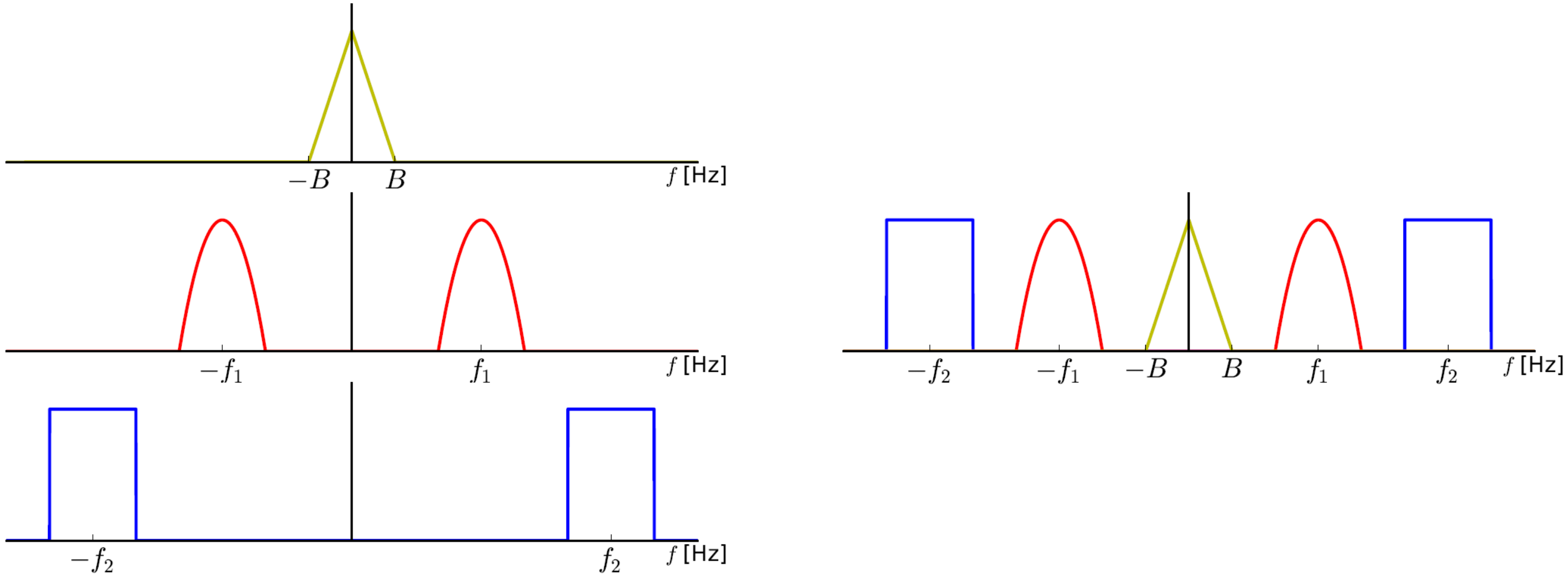
TRANSMITTING MULTIPLE SIGNALS

We have demonstrated that it is possible to transmit multiple signals even if each falls in the same frequency band by multiplexing at the transmitter and demultiplexing at the receiver.
By doing so, we've moved away from baseband to **bandpass transmission.**



DIGITAL MODULATION TECHNIQUES

Sinusoidal signals are known as carriers in communications systems because they are used to carry information.

$$c(t) = A\cos(2\pi f t + \phi)$$

By modifying A, f or ϕ with an information signal v(t) we can use a carrier to transport the information contained in v(t). We call this process modulation:

- If we modify A, we produce an amplitude modulation.
- If we modify f, we produce a frequency modulations.
- If we modify ϕ, we produce a phase modulations.

BASEBAND TRANSMISSION (REPEATED)

For instance, we can represent digits 0 and 1 by the waveforms $s_0(t)$ and $s_1(t)$ defined as:

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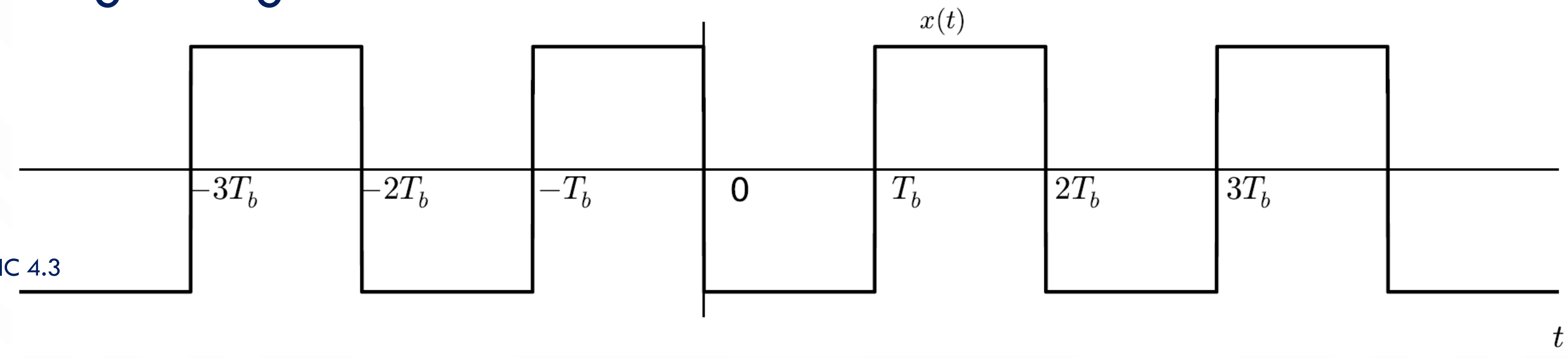
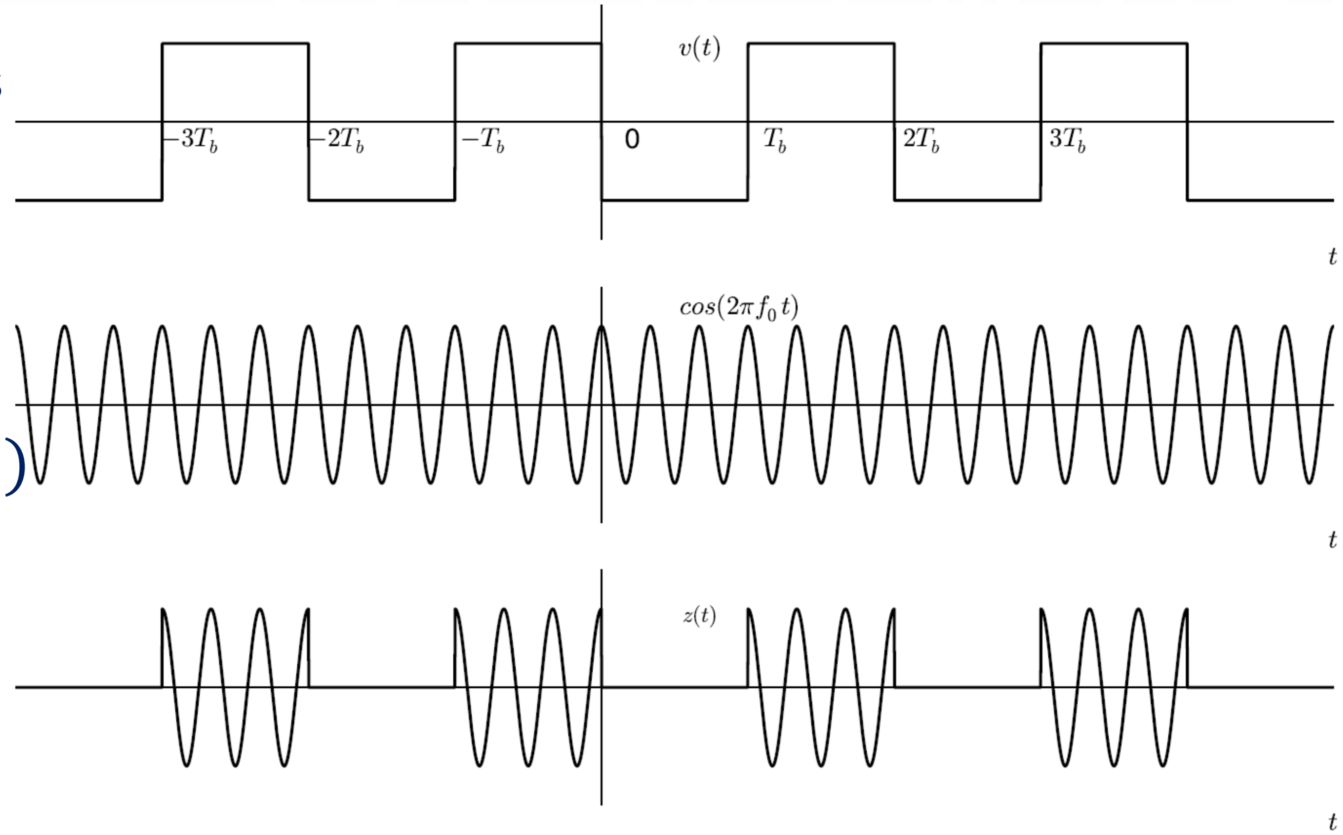


DIGITAL MODULATIONS TECHNIQUES

An example of amplitude modulation is the following. Take the signal v(t):



$$\mathrm{c(t)} = \cos(2\pi f_0 t + \phi)$$

$$z(t) = [v(t) + 1] \cos(2\pi f_0 t + \phi)$$

Bandpass transmission: Digital modulation

Digital modulations produce **bandpass signals**, i.e. signals whose power is contained within a band of frequencies away from f = 0. Therefore, we can use **modulations** to **multiplex signals** in the frequency domain, by using **different carriers.**

For the example in the previous slide, we can demonstrate that::

$$Z(f) = V(f + f_0) + V(f - f_0) + \delta(f + f_0) + \delta(f - f_0)$$

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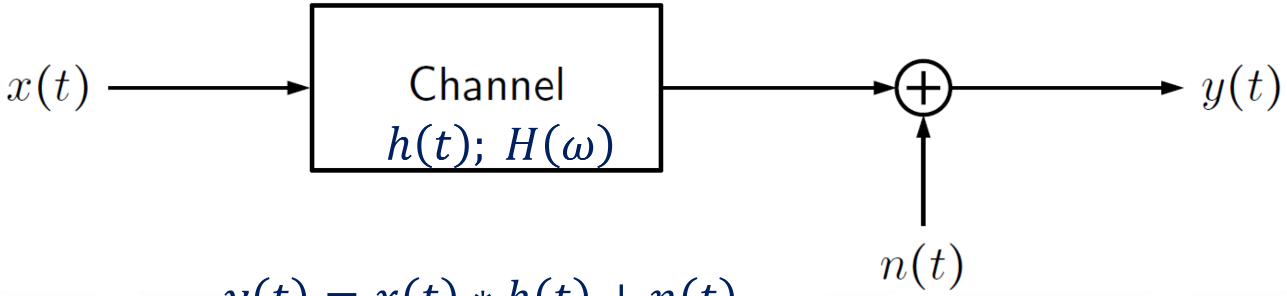
The physical medium: Channel and noise

When signals travel through a physical medium, they are **attenuated**, **distorted** and contaminated with **noise** and other **interferences**:

- Attenuation and distortion are modelled by a channel, usually an LTI system characterised by h(t) and H(ω) (or H(f)).
- Noise and interference are modelled as an addition of an external signal n(t).



$$y(t) = x(t) * h(t) + n(t)$$

$$Y(\omega) = X(\omega) \times H(\omega) + N(\omega)$$

Understanding the channel

By analysing the channel, different modulation techniques can be devised which allow to

- Reduce the attenuation and distortion.
- Transmit multiple signals at the same time (share the medium)

Example: Assume that you need to transmit simultaneously two baseband information signals $x_1(t)$ and $x_2(t)$ with bandwidth B through a channel with frequency response.

$$H(f) = \begin{cases} 1 & \left| |f| - f_H \right| < 1{,}5B \\ 0 & \text{otherwise} \end{cases}$$

Design a suitable modulation for transmitting your information signals and a suitable receiver.

Understanding the channel

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