EBU5375 Signals and systems: Signals and Systems applications to Telecommunication Systems

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Agenda

Quick review

Principles of digital communications: Baseband transmission

Multiplexing in the frequency domain

Bandpass transmission

Models of physical media

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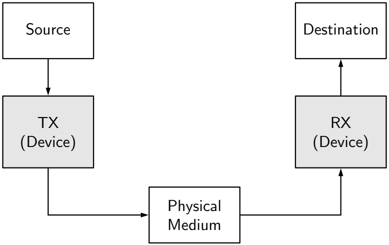
Basic model of communications system



- 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

In digital communications, **information is represented as a sequence of bits**. Which one of the following statements is true about digital communications?

(a) In digital communications, we transmit DT signals through physical media.

(b) In digital communications, we transmit CT signals through physical media.

(c) In digital communications, we transit DT signals for digital sources (such as text) and CT signals for analog sources (such as speech).

Time and frequency relationship

Which of the following statements is true?

(a) Signals that are narrow in time occupy a wide frequency band.
(b) Signals that change quickly in time occupy a wide frequency band.
(c) Signals that are wide in time occupy a wide frequency band.

What are we learning this week?

1. Applications of Signals and Systems to IoT Engineering: Overview.
2. Sampling Theory and Interpolation.
3. **Applications of Signal Theory to Telecommunication Systems.**

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Quick review

Principles of digital communications: Baseband transmission

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Digital communication systems: Overview

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.

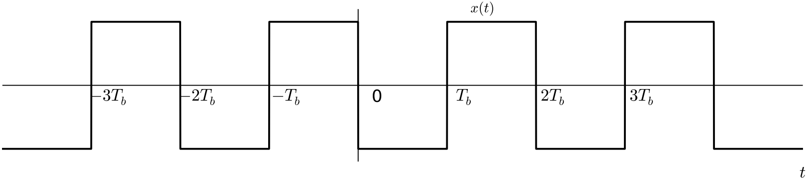
The time between two consecutive waveforms is called the **bit time**, T_b and based on it, we can calculate the transmission **bit rate** (the number of bits transmitted per second) as $R_b = 1/T_b$.

Baseband transmission

In baseband (or lowpass) transmission we use **waveforms whose Fourier transform is lowpass**. For instance, we can represents digits 0 and 1 by the waveforms $s_0(t)$ and $s_1(t)$ defined as:

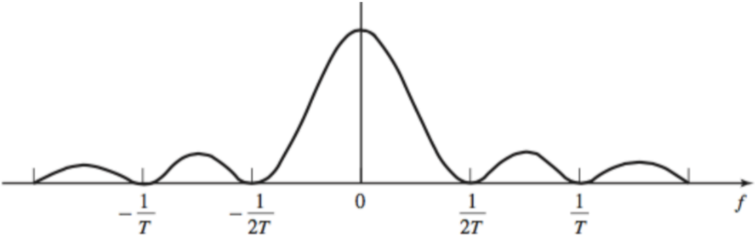
$$s_0(t) = \begin{cases} -1 & |t| < T_b/2 \\ 0 & \text{otherwise} \end{cases} \qquad s_1(t) = \begin{cases} 1 & |t| < T_b/2 \\ 0 & \text{otherwise} \end{cases}$$

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



Baseband transmission

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



where $T = T_b$ and the bandwidth is usually taken as $B = 1/2T$. Notice that:

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

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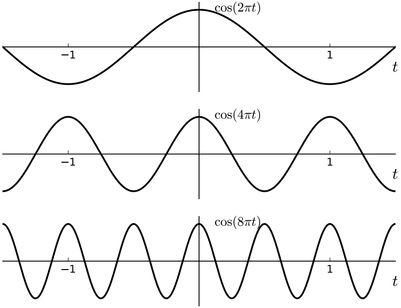
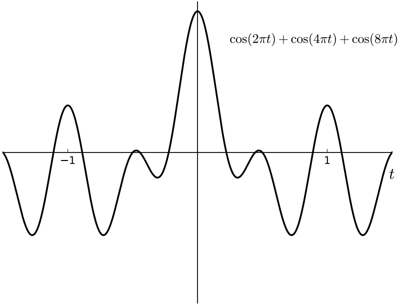
Transmitting multiple signals: Time domain

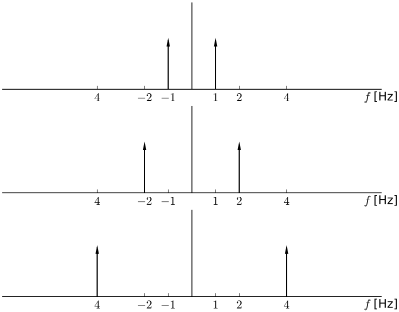
In this example, we transmit three sinusoidal signals through the same physical medium. The resulting signal is the sum of the three sinusoidal signals. How can we extract each one of them in the receiver?

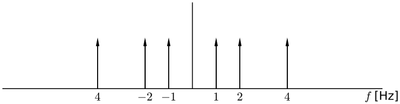




Transmitting multiple signals: Frequency domain

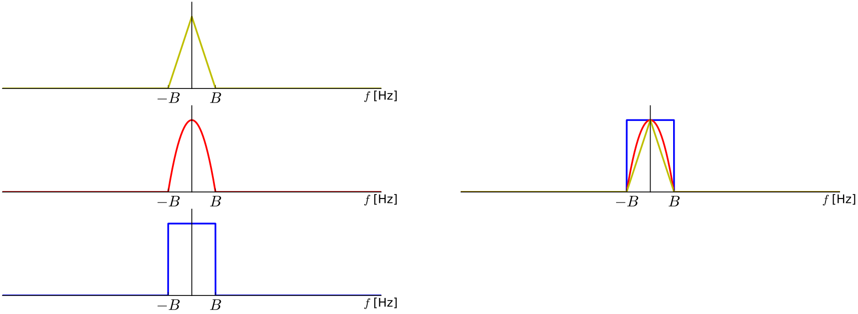
In the frequency domain, we can clearly distinguish each one of the sinusoidal signals that we added in the previous example. By looking at the frequency domain it is easy to see that what we need to do is **bandpass filter** our signal!





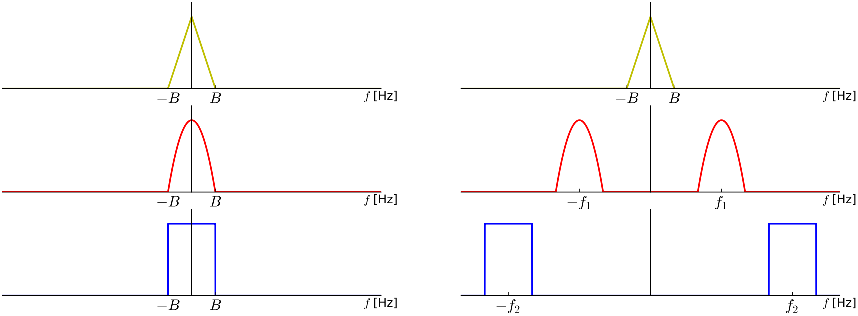
Transmitting multiple signals: Frequency domain

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?



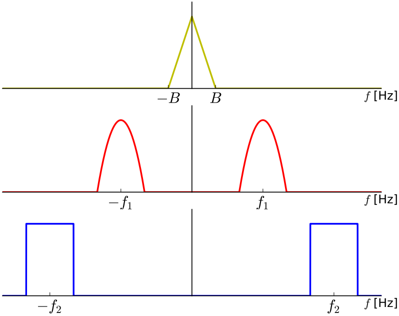
Multiplexing: Frequency translation

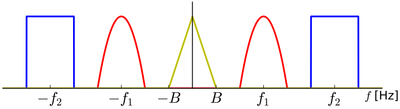
We can translate each signal to a different frequency band by multiplying by sinusoidal signals with different frequencies.



Multiplexing: Frequency translation

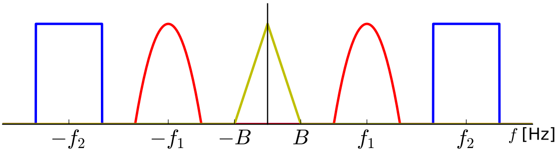
Then we transmit them through the same medium. Note that now we are not only sending bandpass signals!





Frequency-domain de-multiplexing

But how do we recuperate each individual signal?



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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**:

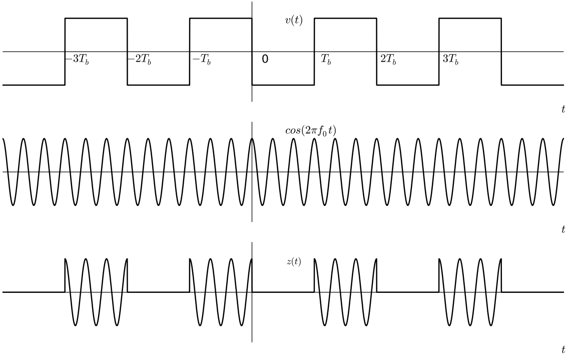
- If we modify A, we produce an **amplitude modulation**.
- If we modify f, we produce a **frequency modulations**.
- If we modify ϕ, we produce a **phase modulations**.

Digital modulations techniques

An example of amplitude modulation is the following. Take the signal $v(t)$ from the previous example and obtain the signal $z(t)$ defined as

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

We get:



Bandpass transmission: Digital modulations

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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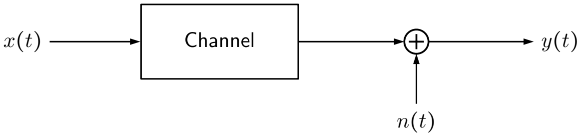
The physical medium: Channel and noise

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 $H(\omega)$ (or $H(f)$).
- **Noise** and **interference** are modelled as an addition of an **external signal** $n(t)$.



$$
\begin{aligned}
y(t) &= x(t) * h(t) + n(t) \\
Y(f) &= X(f) * H(f) + N(f)
\end{aligned}
$$

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

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

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

Understanding the channel