EDISP

(English) Digital Signal Processing

Jacek Misiurewicz

e-mail: jmisiure@elka.pw.edu.pl

Institute of Electronic Systems

Warsaw University of Technology

Warsaw, Poland

February 25, 2015

General information

Lectures   2h/week, Thu, 08:15-10

Labs $\approx$4h/2weeks: Monday 8:15-12, room 022. See the schedule.
First meeting for all students – 9:15, see webpage or the blackboard
Labs start with an "entry test"!!!

Contact   J. Misiurewicz, (jmisiure@elka.pw.edu.pl) room 447.

Web page   *http://staff.elka.pw.edu.pl/˜jmisiure/*
$\longrightarrow$ Slides on the evening before lecture (usually ;-))

Homeworks   Announced as a preparation for the tests.

Exams   Two short tests within lecture hours (see the lab schedule) and a final exam during the winter exam session (TBA).

Scoring:

2x10%	=	20%	tests
6x5%	=	30%	lab + entry test (lab 0 – not scored)
		50%	final exam
2x2%	=	4%	extra for homeworks (maybe even more)

Short path   `if [(score≥41)&&(tests≥15)&&(test2≥5)]; then score*=2; fi`
"if" conditions are evaluated once, before re-doing tests etc.

Books

base book The course is based on selected chapters of the book:

A. V. Oppenheim, R. W. Schafer, *Discrete-Time Signal Processing*, Prentice-Hall 1989 (or II ed, 1999; also previous editions: *Digital Signal Processing*).

free book A free textbook covering some of the subjects can be found here: `http://www.dspguide.com/pdfbook.htm` *The book is slightly superficial, but nice*

good book Edmund Lai, *Practical Digital Signal Processing for Engineers and Technicians*, Newnes (Elsevier), 2003

exercise book Vinay K. Ingle, John G. Proakis, *Digital Signal Processing using MATLAB*, Thomson 2007;*Helps understand Matlab usage in the lab (but is NOT a lab base for us)*

Additional books available in Poland:

R.G. Lyons, Wprowadzenie do cyfrowego przetwarzania sygnałów (WKiŁ 1999)

Craig Marven, Gilian Ewers, Zarys cyfrowego przetwarzania sygnałów, WKiŁ 1999 [en: A simple approach to digital signal processing, Wiley & Sons, 1996]

Tomasz P. Zieliński, Od teorii do cyfrowego przetwarzania sygnałów, WKiŁ 2002

You may also buy/borrow a laboratory scriptbook for a Polish language course (Cyfrowe Przetwarzanie Sygnałów, red. A Wojtkiewicz, Wydawnictwa PW) – but our lab is different!

A schedule was here - see the webpage for an updated version!

What Is EDISP All About ;-)

Theory Discrete-time signal processing

Practice Digital signal processing

Application examples:

Filters Guitar effects, radar, software radio, medical devices...

Adaptive filters Echo canceller, noise cancellation (e.g. hands-free microphone in a car),...

Discrete Fourier Transform/FFT Signal analyzer, OFDM modulation, Doppler USG, ...

Random signals Voice compression, voice recognition....

2D signals Image processing, USG/tomography image reconstruction, directional receivers, ...

Upsampling/Interpolation CD audio output, ...

Oversampling CD audio D/A conversion (example)

Please have a look at the black/green-board.

Notice & remember some things:

- Upsampling
- Filtering (and what happens to the signal spectrum)
- Frequency response (frequency characteristics) of a filter

Signal classes

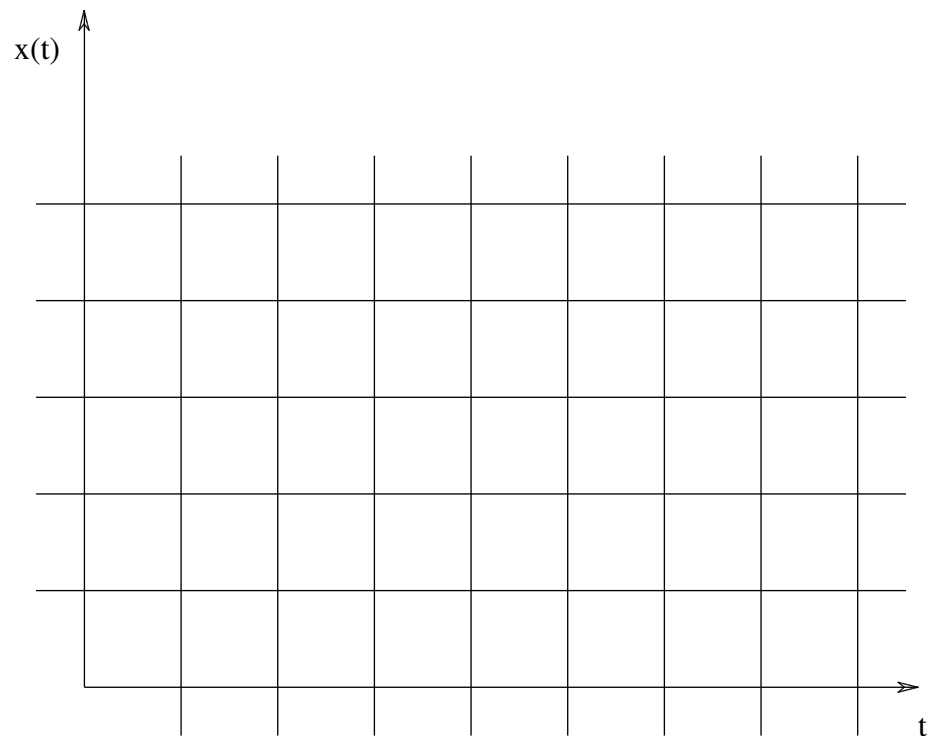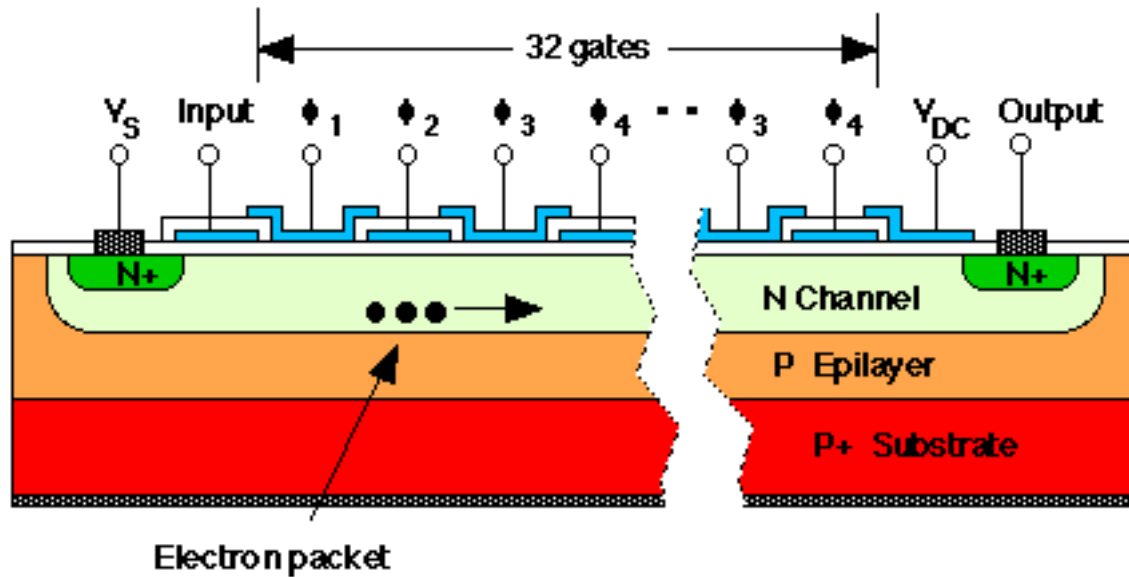Continuous or Discrete **amplitude** and **time**.

CA-CT $\longrightarrow$ "analog" signals

DA-CT $\longrightarrow$

CA-DT $\longrightarrow$ CCD, SC, SAW devices

DA-DT $\longrightarrow$ digital devices

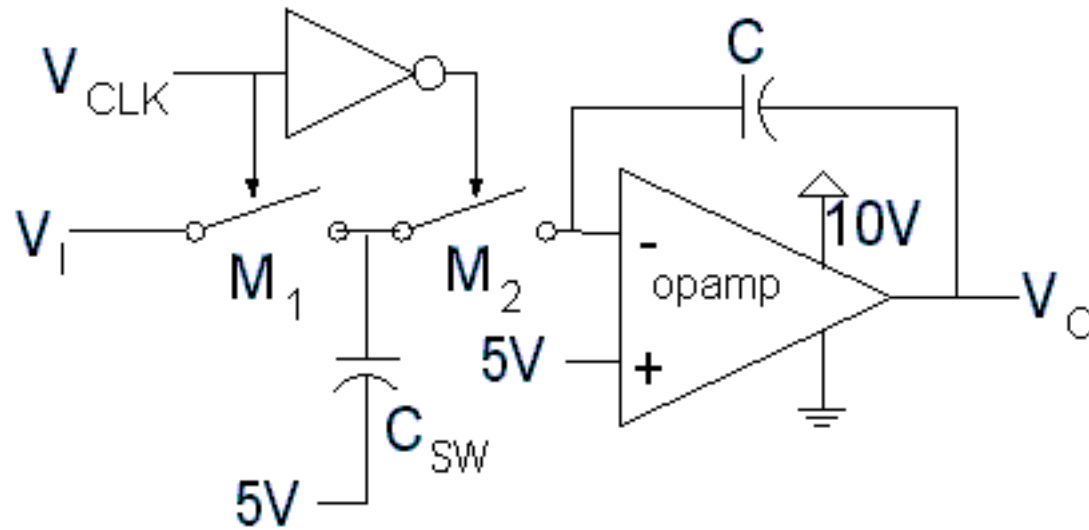We'll speak mainly about DT properties; only in some subject DA will be of importance.

CCD device (side remarks)

32 gates

Y_S Input ϕ_1 ϕ_2 ϕ_3 ϕ_4 - - ϕ_3 ϕ_4 Y_{DC} Output

N+

N+

N Channel

P Epilayer

P+ Substrate

Electron packet

Charge is transferred on the clock edge (discrete time!).

Clock is usually polyphase (2-4 phases).

SC device (side remarks)

DT signal representations

DT signal $\longleftrightarrow$ a number sequence

$$x[n] = \{x(n)\}$$

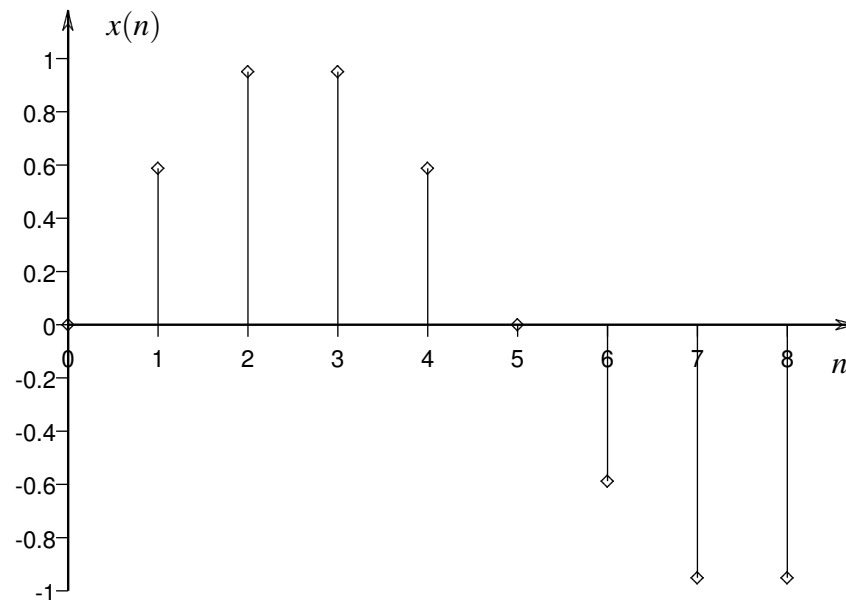$x[n]$ is a number sequence (or . . .)

$x(n)$ is a $n-$th sample

$\longrightarrow$ $x(n)$ is *undefined* for $n \notin \mathbb{Z}$

- it *may* come from sampling of analog signal

- but it may also be inherently discrete
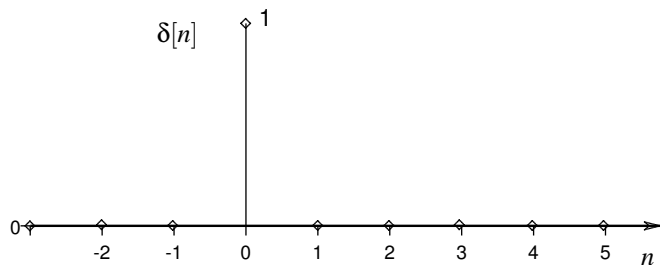
- n may correspond to: time, space, . . .

However, the most popular interpretation is: periodic sampling in time.
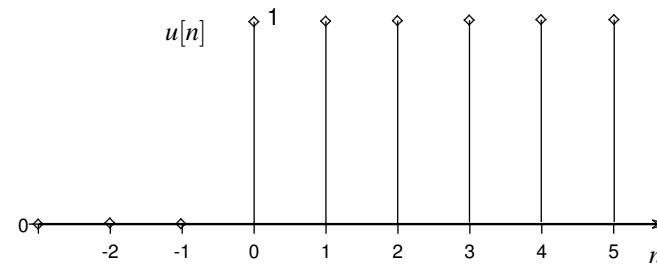
Number sequence (or DT signal) operations; basic sequences

operation	notation	definition
sum	$z[n] = x[n] + y[n]$	$\forall n \;\; z(n) = x(n) + y(n)$
scale	$z[n] = \alpha \cdot y[n]$	$\forall n \;\; z(n) = \alpha \cdot y(n)$
shift	$z[n] = x[n - n_0]$	$\forall n \;\; z(n) = x(n - n_0)$
difference	$z[n] = x[n] - y[n]$	$\forall n \;\; z(n) = x(n) - y(n)$
product	$z[n] = x[n] \cdot y[n]$	$\forall n \;\; z(n) = x(n) \cdot y(n)$
scalar product	$c = \langle x[n],\; y[n] \rangle$	$c = \sum_n x(n) \cdot y^*(n)$

Unit sample sequence (DT impulse)
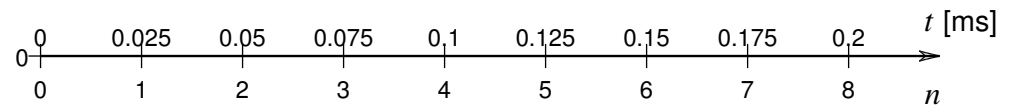

Unit step sequence

$$\delta[n] = u[n] - u[n-1]$$

$$u[n] = \sum_{k=0}^{\infty} \delta[n-k]$$

Periodic sampling

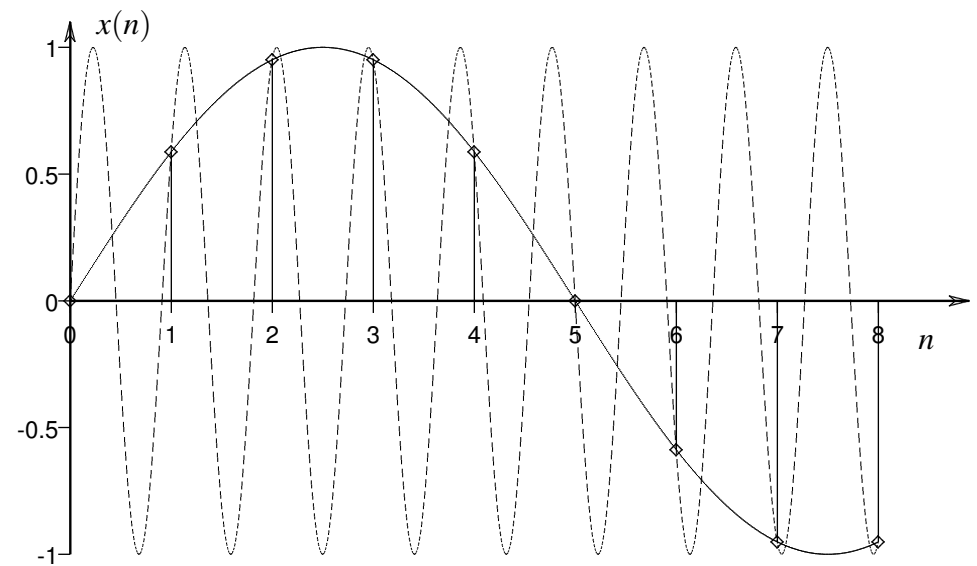$$n \longleftarrow \longrightarrow n \cdot T_s$$

$$x(n) = x_a(nT_s)$$

$$n = t/T_s, \quad T_s = 0.025 \, [\mathrm{ms}]$$

Misinterpretations

$\longrightarrow$ we do not know what is between points

a) $sin(n \cdot (1/5) \cdot \pi)$ or

b) $sin(n \cdot (2 + 1/5) \cdot \pi)$?

We have to **know** which one to choose $\longrightarrow$ sampling theorem

Sampling rates in audio processing

`http://en.wikipedia.org/wiki/Sampling_rate`

In digital audio, common sampling rates are:

- 8,000 Hz - telephone, adequate for human speech

- 22,050 Hz - radio

- 32,000 Hz - miniDV digital video camcorder, DAT (LP mode)

- 44,100 Hz - audio CD, also most commonly used with MPEG-1 audio (VCD, SVCD, MP3)
  compatible with PAL (625 line) and NTSC (528 line) dot frequency

- 48,000 Hz - digital sound used for miniDV, digital TV, DVD, DAT, films and professional audio

- 96,000 or 192,000 Hz - DVD-Audio, some LPCM DVD tracks, BD-ROM (Blu-ray Disc) audio tracks, and HD-DVD (High-Definition DVD) audio tracks

- 2.8224 MHz - SACD, 1-bit sigma-delta modulation process known as Direct Stream Digital, (Sony and Philips)

Frequency in a DT signal

	CD audio system	DAT audio system
Sampling:	44100 Hz	48000 Hz
Nyquist:	22050 Hz	24000 Hz
t_s	22.676μs	20.833μs
1kHz: samples per period	44.1	48
1kHz: moved from CD to DAT	1kHz	48/44.1=1.0884 kHz

We need a good definition of frequency!
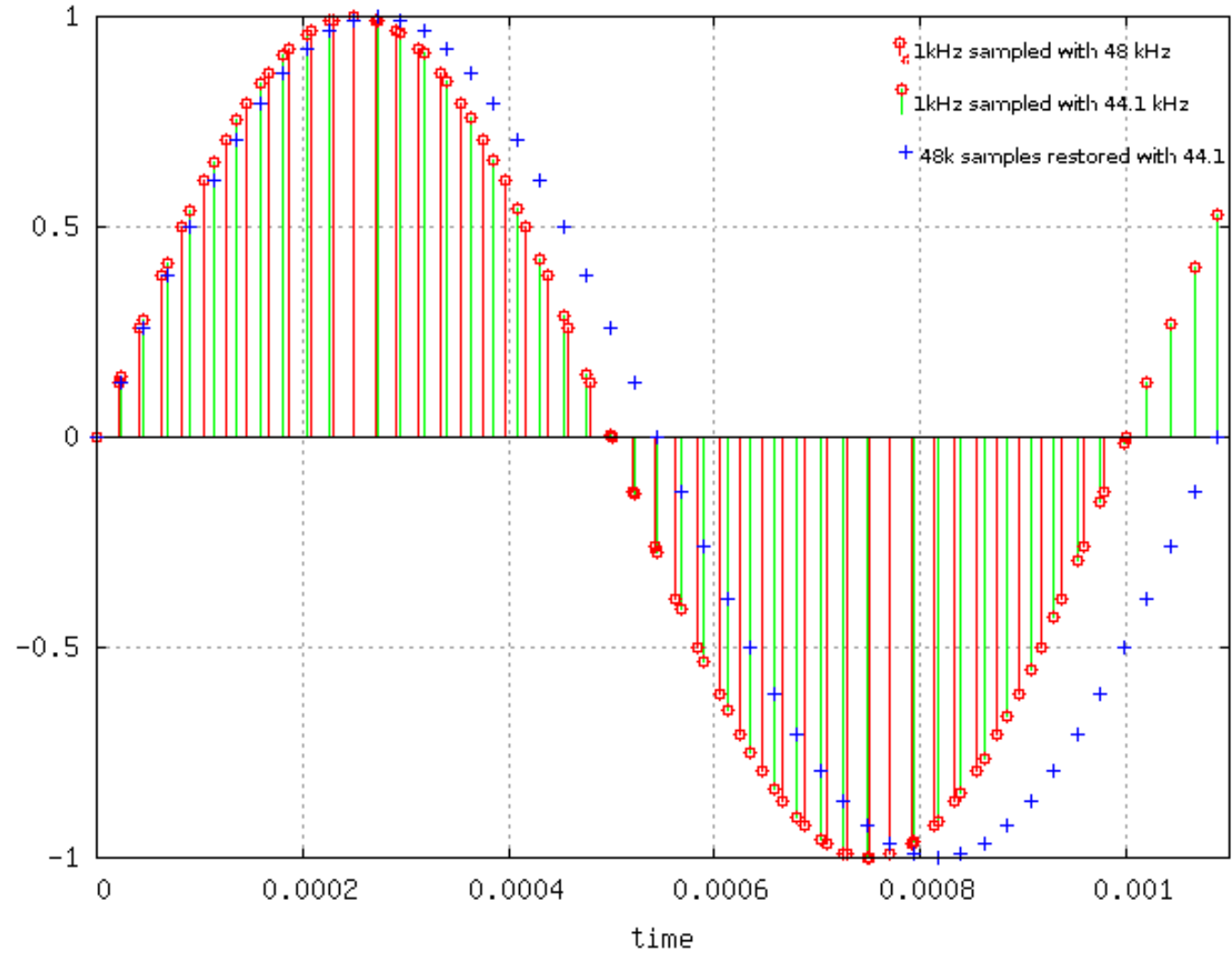
DT signal frequency concept

Continuous time cosine:		Discrete time cosine:	Normalized...
$x_a(t) = \cos \omega t$ $\qquad \omega \in \mathbb{R}$ $\omega = 2\pi f$		$x(n) = \cos \omega n T_s$ $x(n) = \cos 2\pi f \, n \frac{1}{f_s}$ $x(n) = \cos \theta n$	...time: $n = t/T_s$ ...frequency: $f_n = \frac{f}{f_s}$ ...ang. freq.: $\theta = 2\pi \frac{f}{f_s}$
$T = \frac{1}{f} = \frac{2\pi}{\omega}$ $x(t) = x(t + kT)$	$\leftarrow$ period ? $\rightarrow$	$N_0 = \frac{1}{f_n} = \frac{2\pi}{\theta}$ $x(n) = x(n + kN)$ $x(n+N)$ defined only if $N \in \mathbb{Z}$	
Always	$\leftarrow$ periodic $\rightarrow$	only if $N_0 = N/M$ (!!)	

Normalized angular frequency θ: interval of 2π may be assumed as $[0, 2\pi)$ or $[-\pi, \pi)$.

$$\cos n(\theta + k \cdot 2\pi) = \cos(n\theta + n \cdot k \cdot 2\pi) = \cos n\theta$$

Normalized frequency example

$$x_a(t) = \cos \omega t \text{ with } \omega = 1000 \cdot 2 \cdot \pi \text{ (1kHz)}$$

Let us sample it with $f_s = 48\ kHz$

$$x(n) = x_a(nT_s) = x_a(n/f_s) = \cos(1000 \cdot 2\pi \cdot n/48000) = \cos(\tfrac{2\pi}{48}n)$$

or

$$x_a(t) = \cos \omega t \text{ with } \omega = 2000 \cdot 2 \cdot \pi \text{ (2kHz)}$$

Sampled with $f_s = 96\ kHz$

$$x(n) = x_a(nT_s) = x_a(n/f_s) = \cos(2000 \cdot 2\pi \cdot n/96000) = \cos(\tfrac{2\pi}{48}n)$$

$\longrightarrow$ signals identical after sampling

- Extract important parameter: $\theta = \frac{2\pi}{48}$

- ... and we may write it down as $x(n) = \cos(\theta n)$

$\longrightarrow$ Normalized (angular) frequency $(2\pi) \cdot \frac{f}{f_s}$ determines the properties of the sampled signal, and now it is not important what was the frequency of x_a (only how it was related to f_s).

Periodicity example

Periodicity of a *number series* is not the same as the periodicity of a CT signal

250Hz sine sampled with 1kHz

300Hz sine sampled with 1kHz
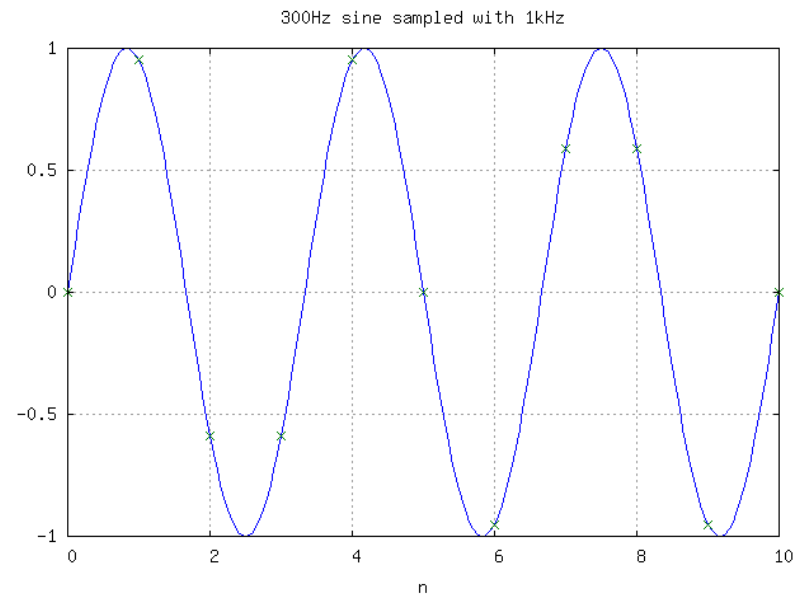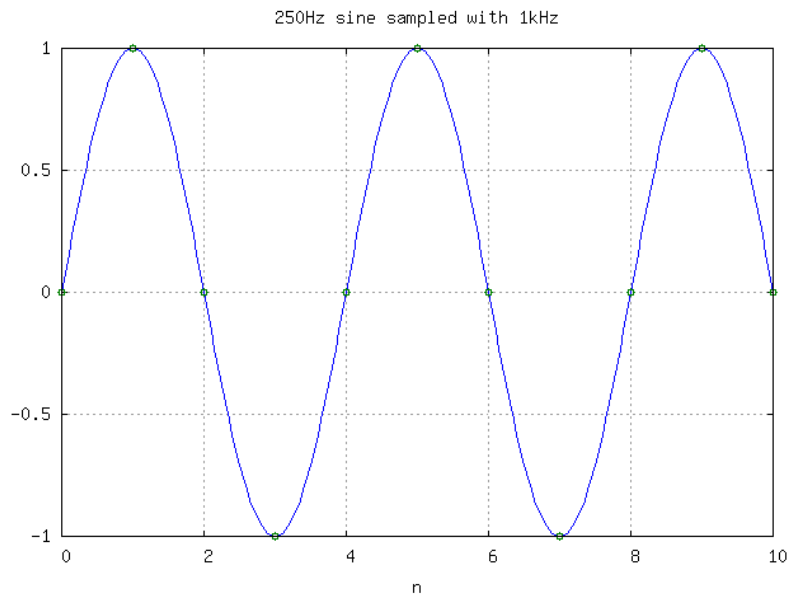
Period of a sine wave is a real number: $x(t)$ exists for $t \in \mathbb{R}$.

With a number series the period must be an integer, because $x(n)$ exists only for $n \in \mathbb{Z}$.