EBU4375: SIGNALS AND SYSTEMS

LECTURE 1: PART 1 (INTRODUCTION)

September 2023

Queen Mary
University of London

LECTURERS

Dr Maged Elkashlan

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Weeks 1&2

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Weeks 3&4

(module organiser)

COURSE CONTENT AND SCHEDULE

- The main topics covered by this course are organised as follows:
  - Week 1: Signals and systems in the time domain.
  - Week 2: Continuous-time signals in the frequency domain.
  - Week 3: Discrete-time signals in the frequency domain.
  - Week 4: Sampling theory and communication systems.

RECOMMENDED TEXTBOOKS

- Signals and Systems (2nd edition), Alan V. Oppenheim, Alan S. Willsky and S. Hamid Nawab, ISBN 978-0136511755.
- Signals and Systems For Dummies, Mark Wickert, ISBN978-1118475812

PRE-REQUISITE KNOWLEDGE

- Complex numbers
- Graphing and functions (trigonometric, exponentials)
- Series
- Integration

ASSESSMENT

- Exam: **75%**
- Course Work: **25%**
  - Class test covering material from weeks 1 and 2: **10%**
  - On-line test covering weeks 3 and 4: **5%**
  - Four lab experiments: **10%**
    - 2.5% for each Lab
  - Three marked quizzes: (**up to 6 bonus points**)
    - Each quiz could give you 0, 1, or 2 bonus points, depending on your score
    - All bonus points will be added to the CW which is **capped at 25%**

TIMETABLE

- LECTURES: Each group (IoT_G1 and IoT_G2) will have 4 teaching blocks/weeks dedicated to EBU4375:
  - Block 1 (Week 3) by Maged: 11-15th September
  - Block 2 (Week 7) by Maged: 9-13th October
  - Block 3 (Week 10) by Mona: 30th October – 3rd November
  - Block 4 (Week 14) by Mona: 27th November – 1st December
- TUTORIALS: Each topic/block will include one tutorial session which will be live with the lecturer and will include exercises to consolidate the learning from the lectures.
- LABORATORY: Each topic/block will include one MATLAB exercise which will be supervised by Tas and will include marked lab sheet.

LECTURE GROUPS, LAB GROUPS, AND CLASSES (1)

- LECTURES/TUTORIALS :
  - IoT_G1: Classes 11-13
  - IoT_G2: Classes 14-16

	Monday	Tuesday	Wednesday	Thursday	Friday
08:00-09:35			3-519		
09:50-11:25			3-519		
11:30-12:15			3-211		3-211
13:00-14:35	3-537	3-537		3-519	3-519
14:45-16:25	SEE LAB TAB				
16:35-18:10	3-519	3-519		3-519	3-519
18:30-19:15				OH	
19:20-20:55					

Lecture IoT_G1
Lecture IoT_G2
Tutotial IoT_G1
Tutorial IoT_G2
Office Hour

LECTURE GROUPS, LAB GROUPS, AND CLASSES (2)

- LABS : It is MANDATORY to stick to your lab group
  - Lab_G1: Classes 11-12
  - Lab_G2: Classes 13-14
  - Lab_G3: Classes 15-16
- 4 LABS for each group:

<table>
<tr><th></th><th></th><th>Teaching Building</th><th>Classroom</th></tr>
<tr><td rowspan="3">Monday
15:40-16:25
LAB1: 18 Sep
LAB2: 23 Oct
LAB3: 6 Nov
LAB4: 4 Dec</td><td>LAB_G1</td><td>TB4</td><td>103</td></tr>
<tr><td>LAB_G2</td><td>TB4</td><td>138</td></tr>
<tr><td>LAB_G3</td><td>TB1 (weeks 4,9,11);
Foreign Language
Training (week 15)</td><td>101 (weeks 4,9,11);
301 (week 15)</td></tr>
</table>

- Each LAB is individual work.
- You will be asked to submit pre-lab work and lab sheet after completing the experiment
- The final exam will include questions related to the LABs

HOW TO STUDY FOR THIS MODULE:

- Spend 30 minutes before the lecture to go through the slides.
- ATTEND every lecture – it will include material that is <u>not in the slides.</u>
- ATTEND every tutorial – discussions and Q&A are <u>not included in solutions.</u>
- Spend 30 minutes before each lab – submit the pre-lab .txt file (MAKE SURE YOU PRESS SUBMIT).
- ATTEND each of your lab sessions and SUBMIT your worksheet ontime.
- ASK questions in lectures, tutorials, student forum, lab sessions, office hours.
- BE READY for quizzes in any lecture or tutorial.
- Any issues, any concerns, any requests, anything please ASK.

EBU4375: SIGNALS AND SYSTEMS

LECTURE 1: PART 2

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What is a signal?

- In our context the signal will be a function of time
- That is, a physical variable that changes with time
- The physical variable could be pressure, temperature, vibration, etc.
- These variables can be converted to electrical signals (voltage or current) using a transducer (sensor)

What is a signal?

- ~ 90% engineering/physics involves study or application of vibrations and waves of many forms

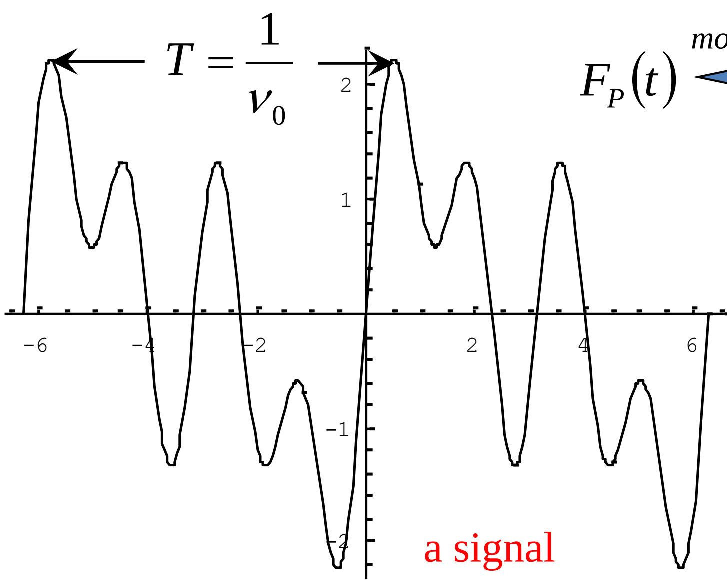
$$\underbrace{\text{acoustics, fluid mechanics, optics, electromagnetics, astronomy, quantum mechanics, information theory}}$$

$\boxed{\text{a } \textbf{signal} \text{ and its } \textbf{spectrum}}$

What is a signal?

e.g. 1

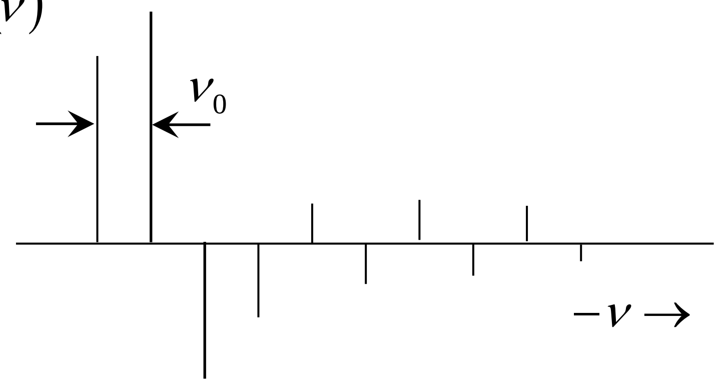
- a musician plays a <u>steady</u> note (for example ($\nu_0 = 256\,Hz$) on a violin
- a microphone (or generally a transducer) produces a voltage $V(t)$, proportional to the instantaneous air pressure $F_P(t)$
- $F_P(t)$ can be displayed as a <u>periodic</u> signal on an oscilloscope



a signal

$$F_P(t) \xleftrightarrow{\textit{modular}\text{ transform}} A(\nu)$$

and



its spectrum

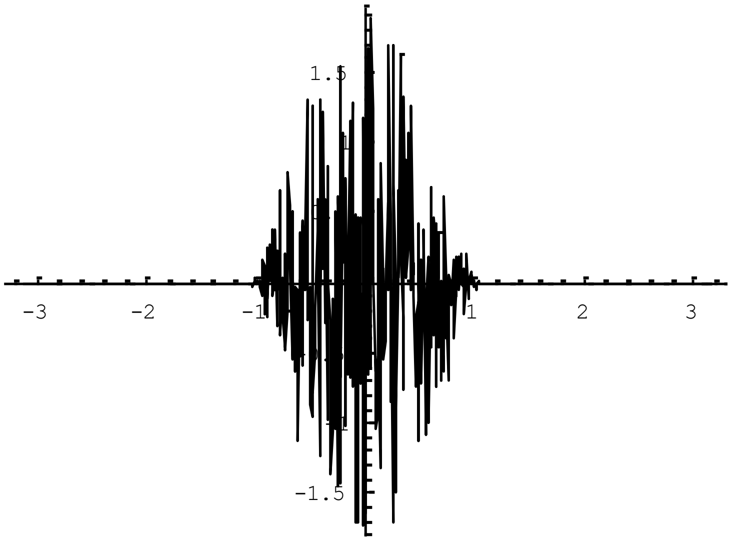
- $F_P(t)$ not a boring sinusoid, i.e., it has *harmonics* ($\nu_m = m\nu_0\,; \quad m \in N$)

- $F_P(t)$ can be analysed to reveal the amplitudes $A_m(\nu_m)$ and phases $\phi_m(\nu_m)$ of the *harmonics*
- *phase* describes *retardation* of one wave (or vibration), with respect to another

What is a signal?

e.g. 2

- suppose the sound now is aperiodic (e.g. a drumbeat, a clap or a crash)
- to describe $F_P(t)$ now requires not just $\{A_m, \phi_m\}$, but a *continuous* range of frequencies



crash spectrum: all frequencies present (each in an infinitesimal amount)

Classification of Signals and Properties

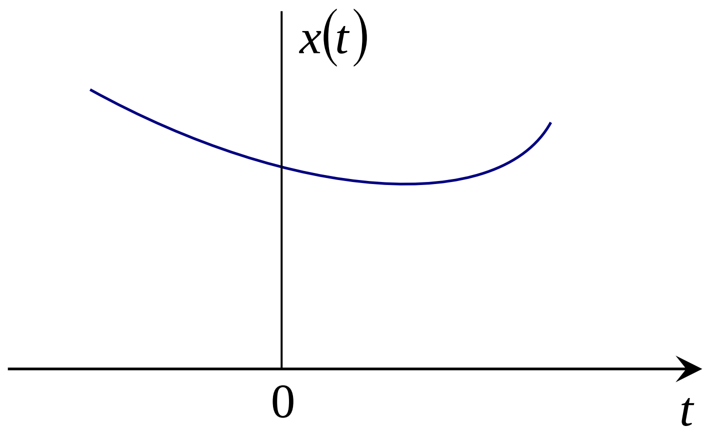
- *methods* used for *processing* a signal or *analysing* the response of a system to a signal significantly depend on the characteristic attributes of the signal.

- certain techniques apply to only specific types of signals – <u>hence the need for classification</u>

  - continuous-time (CT) & discrete-time (DT)
  - analogue and digital
  - periodic and aperiodic
  - deterministic and stochastic (random)
  - even and odd
  - energy and power

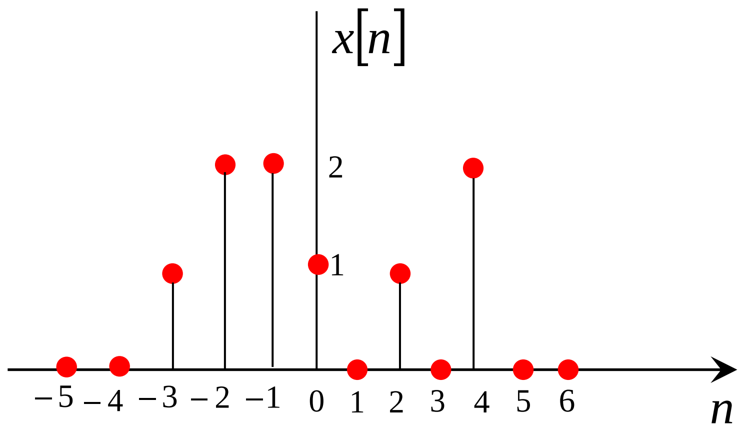
Continuous-Time (CT) and Discrete-Time (DT) Signals

Continuous-time signals



and

Discrete-time signals



t continuous variable $\Rightarrow$

$x(t)$ continuous-time signal

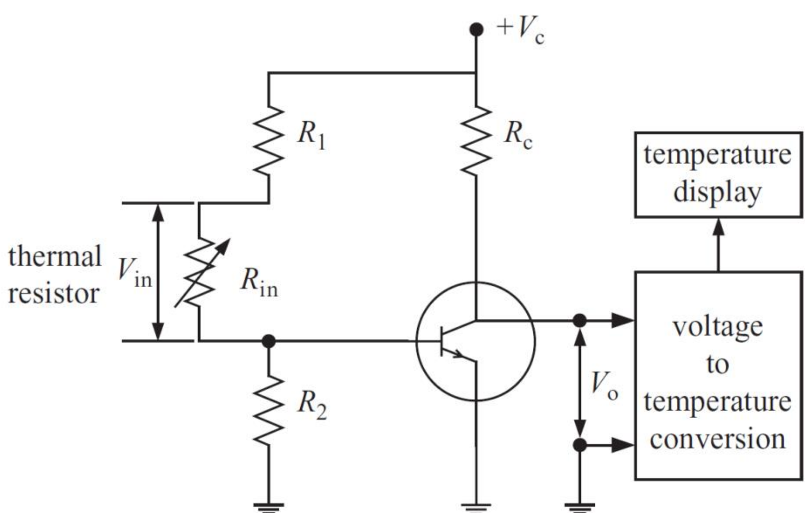
n discrete variable $\Rightarrow$

$x[n]$ discrete-time signal

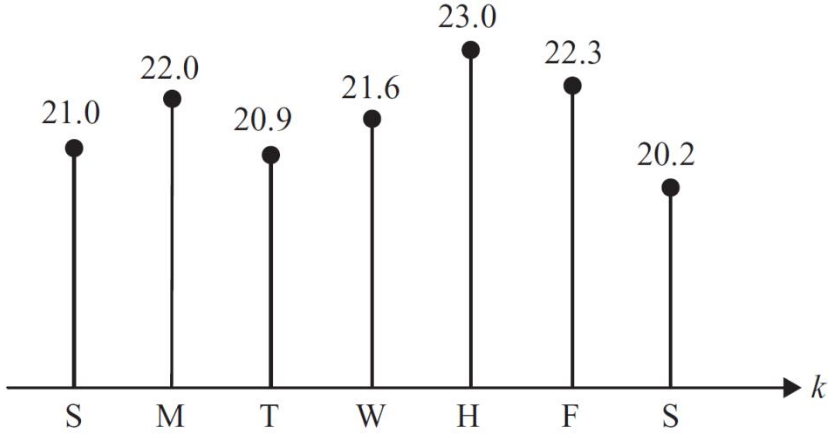
Continuous-Time (CT) and Discrete-Time (DT) Signals

a DT signal is denoted with square parenthesis as

$$x[kT], \quad k = 0, \pm 1, \pm 2, \pm 3, \ldots,$$



a digital thermometer



output signals

Continuous-Time (CT) and Discrete-Time (DT) Signals

- a DT signal $x[n]$ may represent a phenomenon for which the *independent* variable is *inherently* discrete, e.g. sun-set, sun-rise, tidal-patterns etc..
- $x[n]$ may otherwise result from *sampling* a *continuous-time* signal resulting in:

$$x(t_0), x(t_1), \cdots x(t_n), \cdots \equiv x[0], x[1], \cdots x[n], \cdots \quad or \quad x_0, x_1, \cdots, x_n, \cdots$$

- when sampling at regular intervals with a uniform sampling period T_S, then

$$x_n = x[n] = x(nT_S)$$

- A DT signal is typically defined in one of two ways:
  1. a rule is used for generating the n^{th} term e.g.

$$x[n] = x_n = \begin{cases} \dfrac{1}{2^n} & n \geq 0 \\ 0 & n < 0 \end{cases}$$

or

$$\{x_n\} = \left\{1, \frac{1}{2}, \frac{1}{4}, \cdots, \frac{1}{2^n}, \cdots\right\}$$

Continuous-Time (CT) and Discrete-Time (DT) Signals

2. explicit listing of the terms in the sequence e.g.

$$\{x_n\} = \{\cdots, 0, 0, 1, 2, 2, \underset{\uparrow}{1}, 0, 1, 0, 2, 0, 0, \cdots\}$$

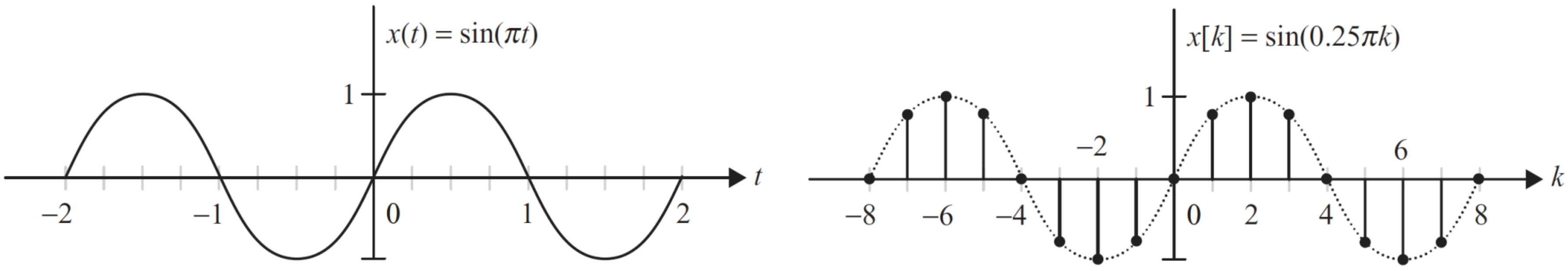
or $$\{x_n\} = \{1, 2, 2, \underset{\uparrow}{1}, 0, 1, 0, 2\}$$

The $\uparrow$ marks the position of the 0^{th} (i.e. $n = 0$), term.
By convention no marker fixes $n = 0$ as the 0^{th} term,
and $x[n] = 0$, $n < 0$

Sequence Algebra:

$$\{c_n\} = \{a_n\} \pm \{b_n\} \rightarrow c_n = a_n \pm b_n$$
$$\{c_n\} = \{a_n\}\{b_n\} \rightarrow c_n = a_n b_n$$
$$\{c_n\} = \alpha\{a_n\} \rightarrow c_n = \alpha a_n \qquad \alpha = \text{constant}$$

Continuous-Time (CT) and Discrete-Time (DT) Signals

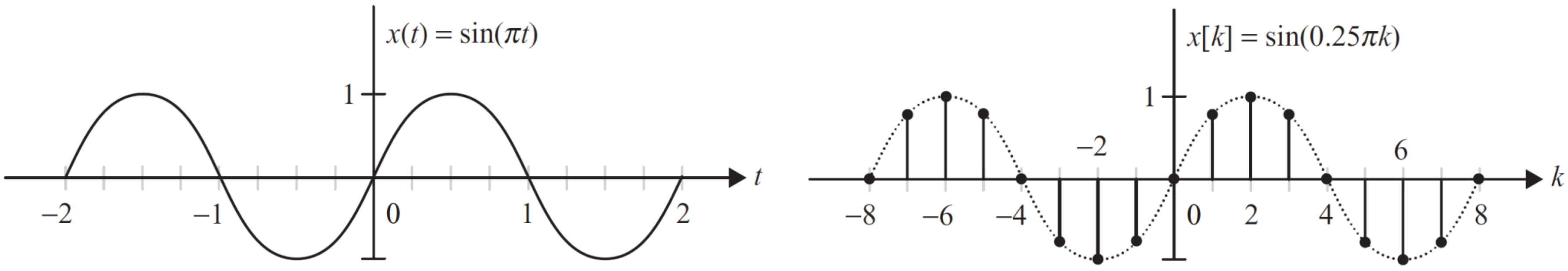


(a)

(b)

(a) CT sinusoidal signal $x(t)$ specified in Example 1.1; (b) DT sinusoidal signal $x[k]$ obtained by discretizing $x(t)$ with a sampling interval $T = 0.25$ s.

Continuous-Time (CT) and Discrete-Time (DT) Signals



(a) (b)

Example

Consider the CT signal $x(t) = \sin(\pi t)$.

Discretize the signal using a sampling interval of $T = 0.25$ s,

and sketch the waveform of the resulting DT sequence for the range $-8 \le k \le 8$.

Continuous-Time (CT) and Discrete-Time (DT) Signals

Solution

By substituting $t = kT$, the DT representation of the CT signal $x(t)$ is given by

$$x[kT] = \sin(\pi k \times T) = \sin(0.25\pi k).$$

For $k = 0, \pm 1, \pm 2, \ldots$, the DT signal $x[k]$ has the following values:

$$x[-8] = x(-8T) = \sin(-2\pi) = 0, \qquad x[1] = x(T) = \sin(0.25\pi) = \frac{1}{\sqrt{2}},$$

$$x[-7] = x(-7T) = \sin(-1.75\pi) = \frac{1}{\sqrt{2}}, \qquad x[2] = x(2T) = \sin(0.5\pi) = 1,$$

$$x[-6] = x(-6T) = \sin(-1.5\pi) = 1, \qquad x[3] = x(3T) = \sin(0.75\pi) = \frac{1}{\sqrt{2}},$$

$$x[-5] = x(-5T) = \sin(-1.25\pi) = \frac{1}{\sqrt{2}}, \qquad x[4] = x(4T) = \sin(\pi) = 0,$$

$$x[-4] = x(-4T) = \sin(-\pi) = 0, \qquad x[5] = x(5T) = \sin(1.25\pi) = -\frac{1}{\sqrt{2}},$$

$$x[-3] = x(-3T) = \sin(-0.75\pi) = -\frac{1}{\sqrt{2}}, \qquad x[6] = x(6T) = \sin(1.5\pi) = -1,$$

$$x[-2] = x(-2T) = \sin(-0.5\pi) = -1, \qquad x[7] = x(7T) = \sin(1.75\pi) = -\frac{1}{\sqrt{2}},$$

$$x[-1] = x(-T) = \sin(-0.25\pi) = -\frac{1}{\sqrt{2}}, \qquad x[8] = x(8T) = \sin(2\pi) = 0,$$

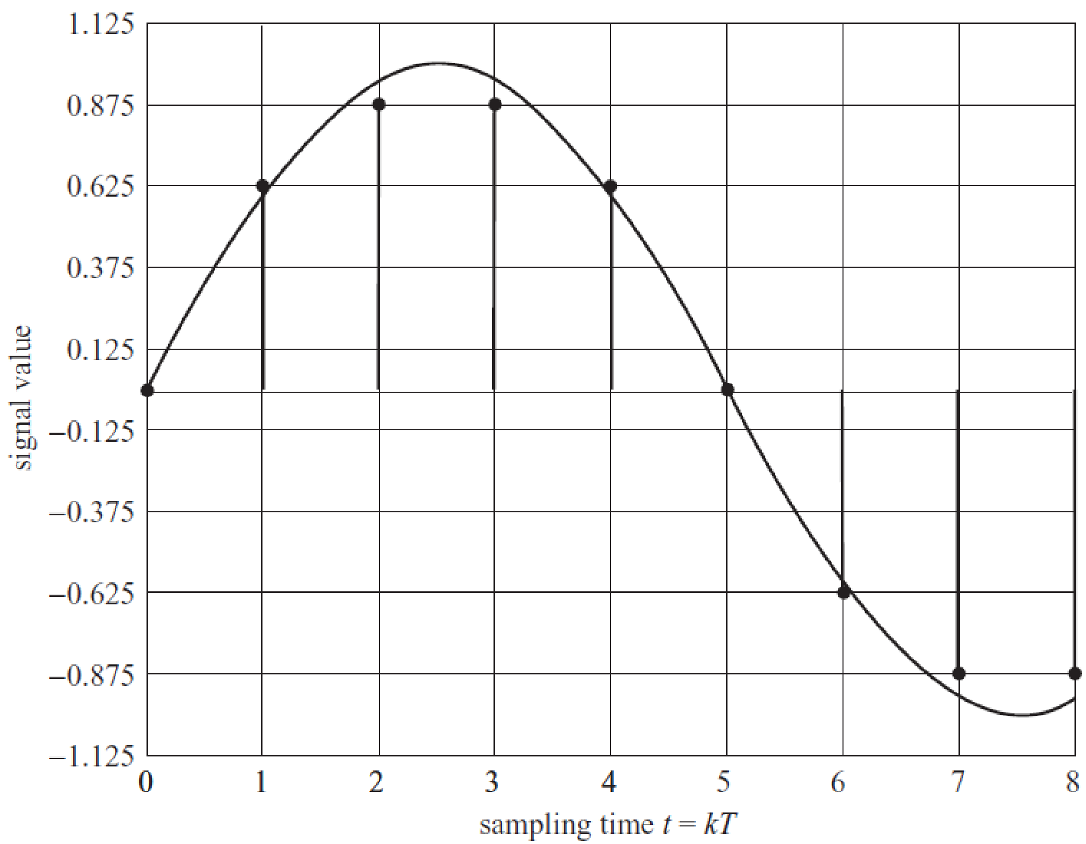
$$x[0] = x(0) = \sin(0) = 0.$$

Analogue (continuous-valued) and Digital (discrete-valued) Signals

• if a continuous-time signal $x(t)$ *can take on* ***any*** *value* in the continuous interval (a, b): $a \to -\infty, b \to \infty$, then the continuous-time signal is called *analogue*.

• if a discrete-time signal $x[n]$ *can take on only a* ***bounded*** number of quantum values then the discrete-time signal is called *digital*.

Analogue (continuous-valued) and Digital (discrete-valued) Signals



Analog signal with its digital approximation. The waveform for the analog signal is shown with a line plot; the quantized digital approximation is shown with a stem plot.

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LECTURE 1: PART 3

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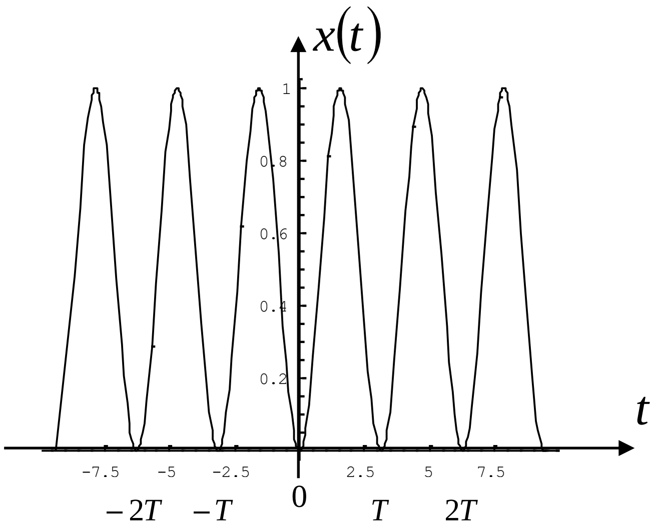
Periodic and Aperiodic Signals (CT Signals)

A <u>continuous-time signal</u> $x(t)$ is periodic with period T , if there is $T > 0$ such that

$$x(t+mT) = x(t): \quad m \in Z \quad \text{for all } t$$

The smallest +ve value of T for which the periodicity holds is the fundamental period T_0

- Where T_0 does not exist $x(t)$ is termed <u>*aperiodic*</u>.



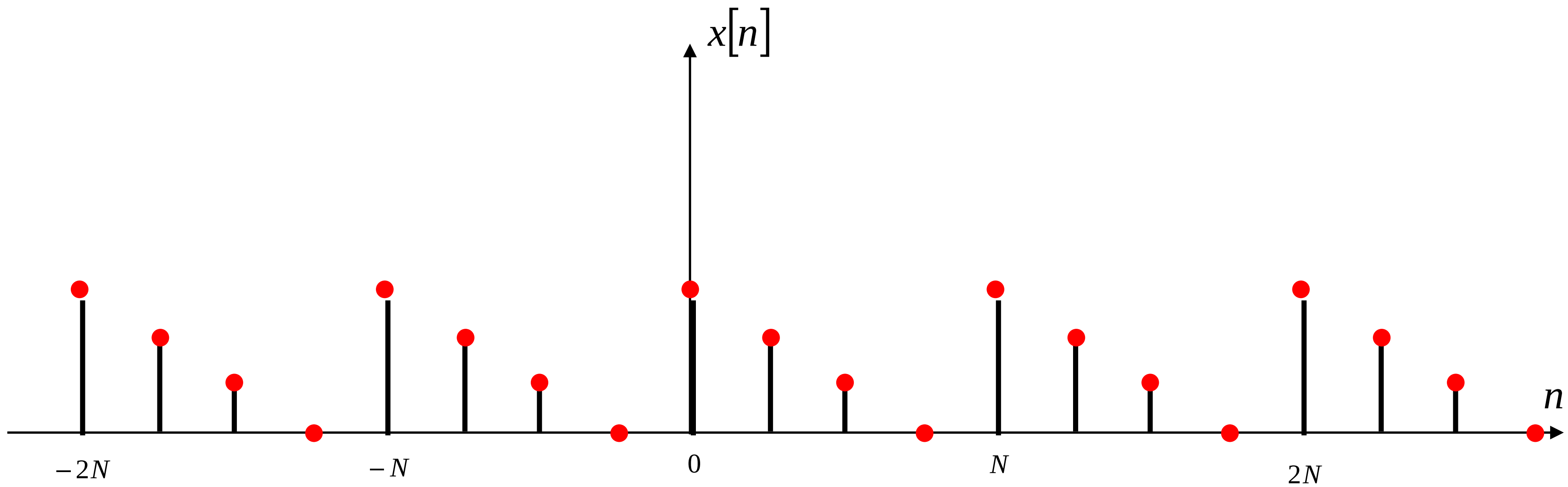
Periodic and Aperiodic Signals (DT Signals)

A <u>discrete-time signal</u> $x[n]$ is periodic with integer-period N, if there is $N > 0$ such that

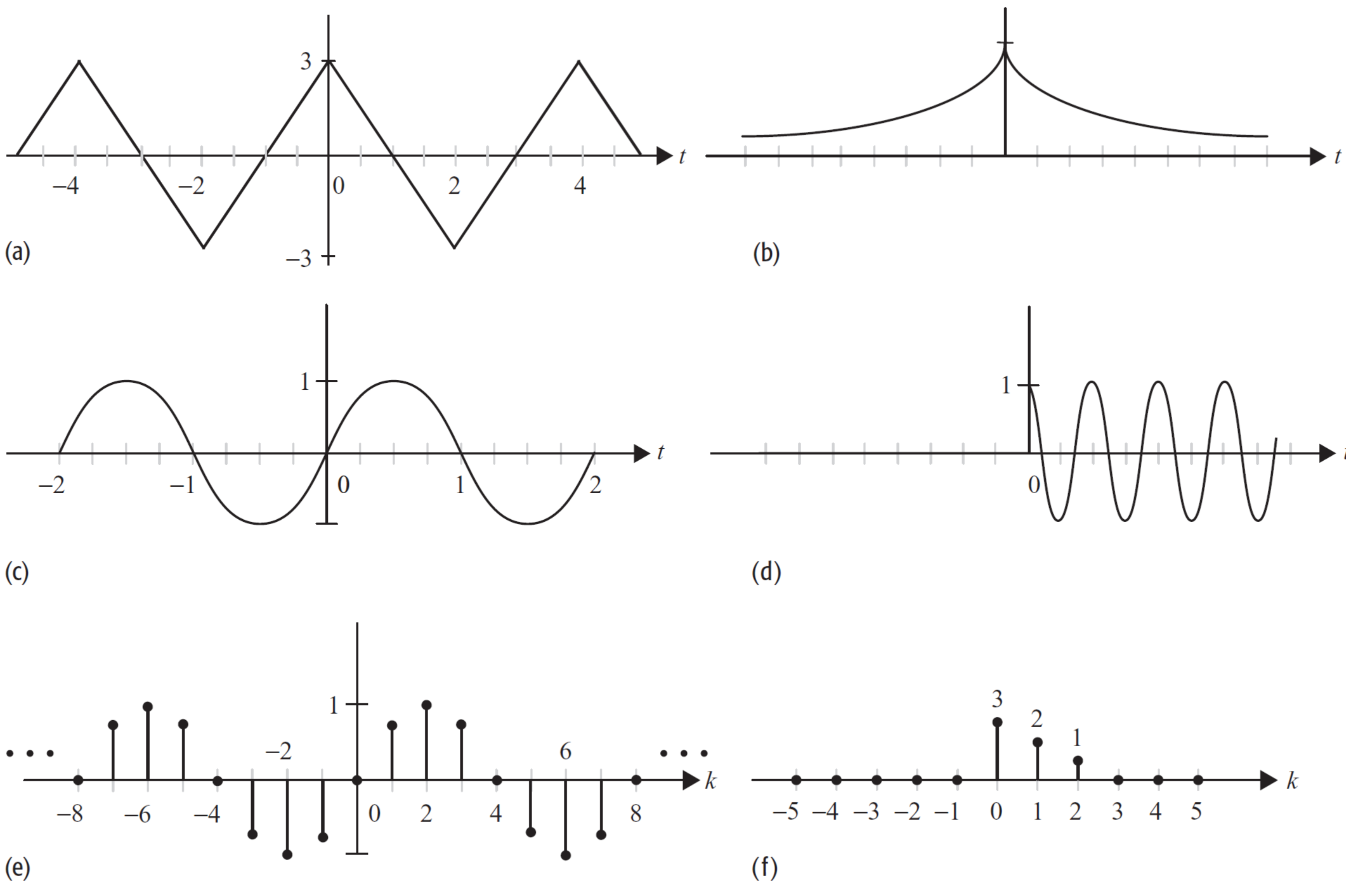
$$x[n+mN] = x[n]: \quad m \in Z \quad \text{for all } n$$

The smallest +ve value of N for which the periodicity holds is the fundamental period N_0

- Where N_0 does not exist $x[n]$ is termed *<u>aperiodic</u>*



Periodic and Aperiodic Signals (Examples of CT and DT Signals)



Examples of periodic ((a), (c), and (e)) and aperiodic ((b), (d), and (f)) signals. The line plots (a) and (c) represent CT periodic signals with fundamental periods T_0 of 4 and 2, while the stem plot (e) represents a DT periodic signal with fundamental period $K_0 = 8$.

Periodic and Aperiodic Signals (CT and DT Signals)

Mathematically, the fundamental frequency is

$$f_0 = \frac{1}{T_0}, \text{ for CT signals,} \quad \text{or} \quad f_0 = \frac{1}{K_0}, \text{ for DT signals}$$

the *angular frequency* is

$$\omega_0 = \frac{2\pi}{T_0}, \text{ for CT signals,} \quad \text{or} \quad \Omega_0 = \frac{2\pi}{K_0}, \text{ for DT signals.}$$

Periodic and Aperiodic Signals (Example of CT Signals)

Example

Let $x_1(t) = \cos(\pi t/2)$ and $x_2(t) = \cos(\pi t/3)$

What are the fundamental periods of $x_1(t)$ and $x_2(t)$

What is the fundamental period of the sum $x_1(t) + x_2(t)$