Chapter 2. Signals and Signal Space

Communication Theory - 2026

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EE / KNU

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Definition: Signal and System

Signal

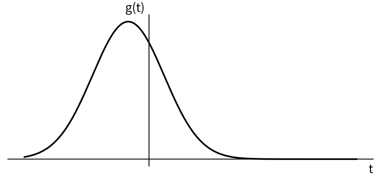
A signal is a set of information or data.
The signals are functions of the independent variable **time t**.

- Examples: Audio signals, video signals, sensor data, etc.

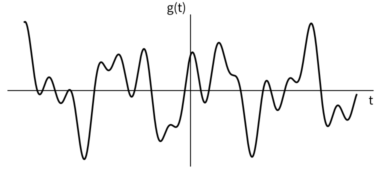
System

Signals may be processed further by systems, which may modify them or extract additional infromation from them.
Thus, a system is an entity that processes signals (**inputs**) to yield another set of signals (**outputs**).

- For example, an antiaircraft radar system processes the received signals (inputs) to determine the position and velocity of an aircraft (outputs).
- More examples: Amplifiers, filters, modulators, demodulators, etc.



(a) Signal with finite energy



(b) Signal with finite power

Fig. 2.1: *Examples of signals*

Energy Signal

A signal is said to be an energy signal if its energy is finite and its average power approaches zero.

$$E = \int_{-\infty}^{\infty} |g(t)|^2 dt < \infty, \quad P \to 0$$

Power Signal

A signal is said to be a power signal if its average power is finite and its energy approaches infinite.

$$P = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} |g(t)|^2 dt < \infty, \quad E \to \infty$$

Units of Signal Power

- The standard units of signal energy and power are the ”joule” and the ”watt”.
- However, in practice, it is often customary to use logarithmic scales to describe signal power.
- A signal with average power of P watts has power of either P_{dBw} or P_{dBm}.

$$\boxed{P_{dBw} = [10 \cdot \log_{10} P] \text{ dBw}}$$

$$\boxed{P_{dBm} = [30 + 10 \cdot \log_{10} P] \text{ dBm}}$$

- For example,

$$P_{dBm} = -30 \text{ dBm} = 10^{-6}\text{W}.$$

Q. Determine the suitable measures of the signals in Fig. 2.2.

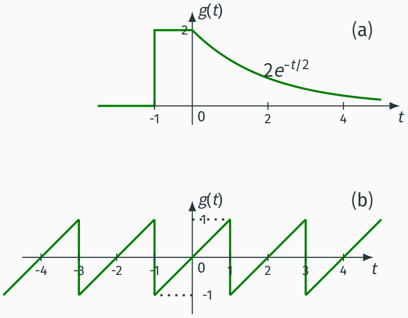


Fig. 2.2: *Signal for Example*

Fig. 2.2 (a)

Energy signal. Power approaches 0 as $|t| \to \infty$.

$$E_g = \int_{-\infty}^{\infty} |g(t)|^2 dt = \int_{-1}^{0} (2)^2 dt + \int_{0}^{\infty} 4e^{-t} dt = 4 + 4 = 8$$

Fig. 2.2 (b)

Power signal. Averaging $|g|^2(t)$ over an infinitely large interval is equivalent to averaging it over one period (2 seconds).

$$\begin{aligned} P_g &= \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} |g(t)|^2 dt = \frac{1}{T} \int_{-T/2}^{T/2} |g(t)|^2 dt \\ &= \frac{1}{2} \int_{-1}^{1} t^2 dt = \frac{1}{3} \end{aligned}$$

Classification of Signals

1. Continuous time and discrete time signals
2. Analog and digital signals
3. Periodic and aperiodic signals
4. Energy and power signals
5. Deterministic and probabilistic signals

Figure 2.3 Continuous vs Discrete Time Signals

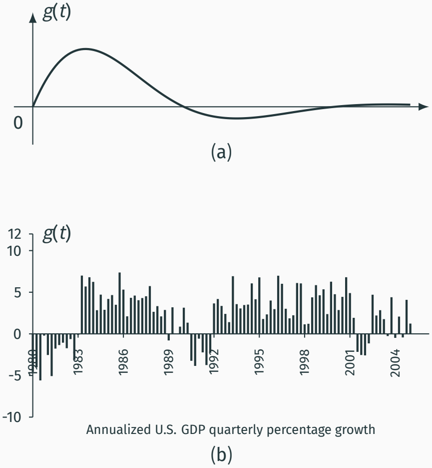


Fig. 2.3: *Continuous vs Discrete Time Signals*

Fig. 2.3 (a)

Continous time signals are specified for every value of time *t*. Many examples including:

- Audio recordings in analog media like LP, magnetic cassette, or reel-to-reel tapes.
- Signals received through AM/FM radio channel.

Fig. 2.3 (b)

Discrete time signals are specified only at discrete points of $t = nT$. Many examples including:

- The quarterly gross domestic product (GDP), stock market daily averages, and monthly sales of a corporation.
- Audio signals formatted by MP3, HE-AAC, FLAC, or ALAC.

Figure 2.4 Classification of Signals

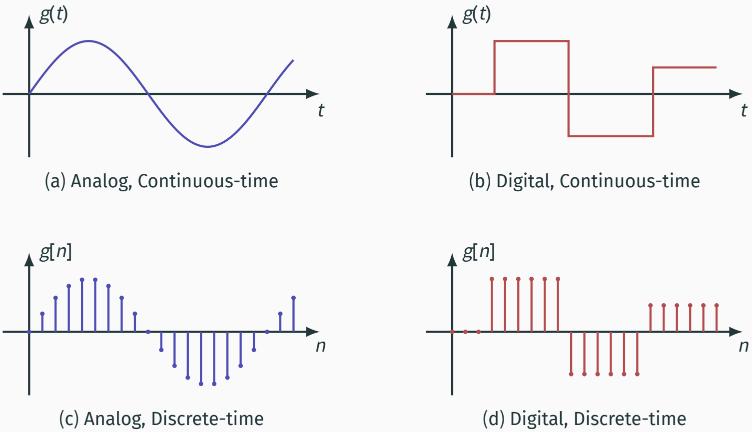


Fig. 2.4: *Classification of signals based on amplitude and time domains*

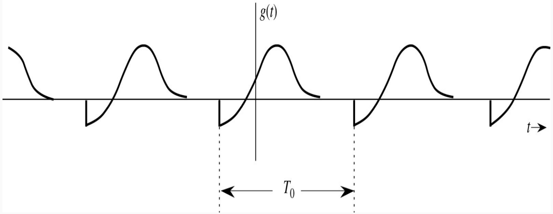


Fig. 2.5: *Periodic signal of period T_0*

Fig. 2.5

A signal $g(t)$ is **periodic** if there exists a positive constant T_0. The smallest value of T_0 in Eq. (2.0) is the **period** of $g(t)$.

$$g(t) = g(t + T_0) \quad \text{for all t} \qquad (2.5)$$

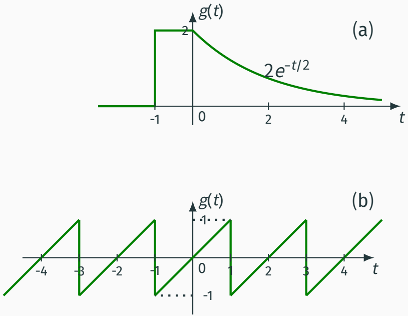


Fig. 2.2: *Energy vs Power Signals (Recap)*

Fig. 2.2(a) Energy Signal

A signal is said to be an energy signal if its energy is finite and its average power approaches zero.

$$\int_{-\infty}^{\infty} |g(t)|^2 dt < \infty \tag{2.6}$$

Fig. 2.2(b) Power Signal

A signal is said to be a power signal if its average power is finite and its energy approaches infinite.

$$0 < \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} |g(t)|^2 dt < \infty \tag{2.7}$$

Deterministic and Random Signals

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$$g(t) = \tag{2.8}$$

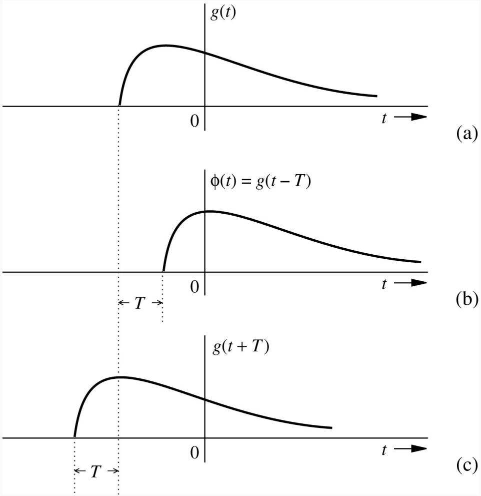

Fig. 2.6: *Time shifting a signal*

Fig. 2.6 Time shifting a signal

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$$g(t) = \tag{2.9}$$

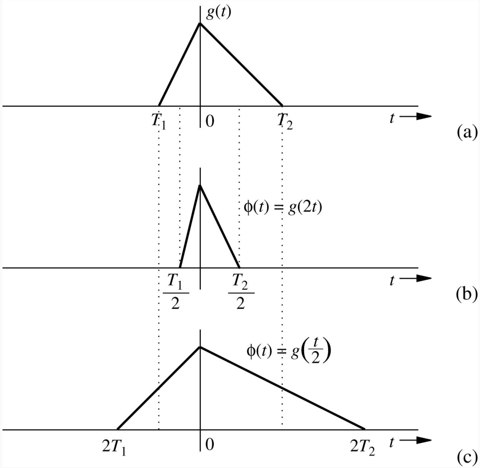

Fig. 2.7: *Time scaling a signal*

Fig. 2.7 Time scaling a signal

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$$g(t) = \qquad (2.10)$$

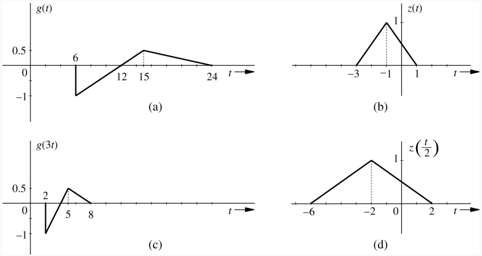

Fig. 2.8: *Examples of time compression and time expansion of signals*

Fig. 2.8

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$$g(t) = \tag{2.11}$$

Time inversion (reflection) of a signal

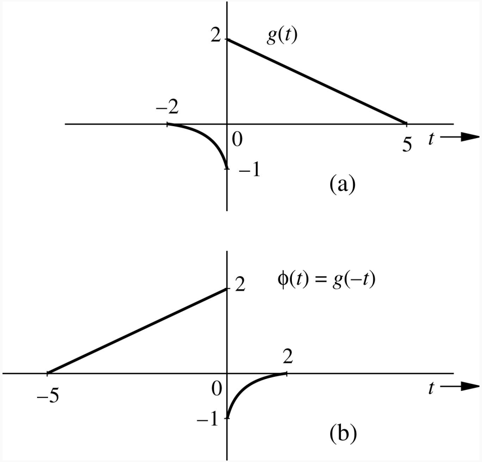

Fig. 2.9: *Time inversion (reflection) of a signal*

Fig. 2.9

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$$g(t) = \tag{2.12}$$

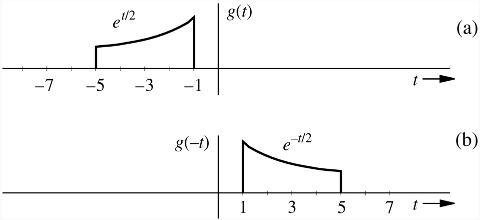

Fig. 2.10: *Example of time inversion*

Fig. 2.10

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$$g(t) = \tag{2.13}$$

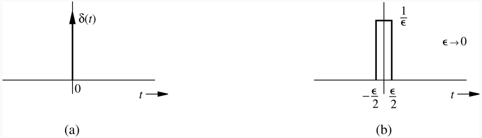

Fig. 2.11: *(a) Unit impulse and (b) its approximation*

Fig. 2.11

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$$g(t) = \tag{2.14}$$

(A) Unit step function $u(t)$. (B) Causal exponential $e^{-at}u(t)$

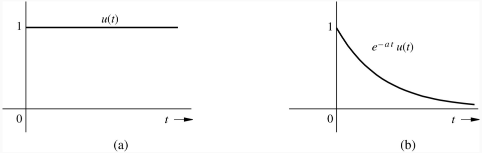

Fig. 2.12: *(a) Unit step function $u(t)$. (b) Causal exponential $e^{-at}u(t)$*

Fig. 2.12

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$$g(t) = \tag{2.15}$$

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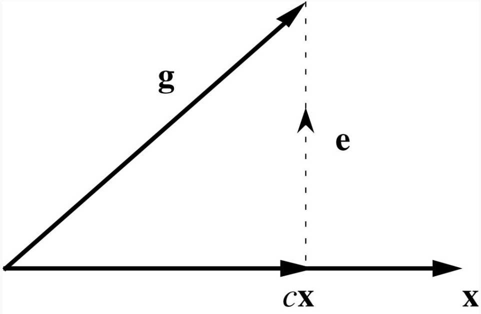

Fig. 2.13: *Component (projection) of a vector along another vector*

Fig. 2.13

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$$g(t) = \tag{2.16}$$

Fig. 2.14: *Approximations of a vector in terms of another vector*

Fig. 2.14

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$$g(t) = \tag{2.17}$$

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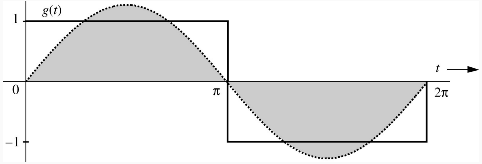

Fig. 2.15: *Approximation of square signal in terms of a single sinusoid*

Fig. 2.15

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$$g(t) = \qquad (2.18)$$

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Energy of the Sum of Orthogonal Signals

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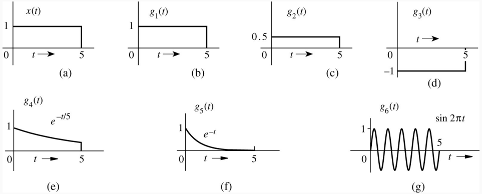

Fig. 2.16: *Signals for Example 2.6*

Fig. 2.16

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$$g(t) = \tag{2.19}$$

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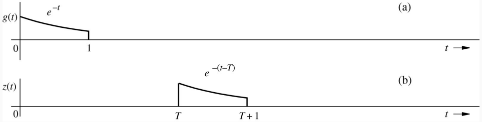

Fig. 2.17: *Physical explanation of the auto-correlation function*

Fig. 2.17

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$$g(t) = \tag{2.20}$$

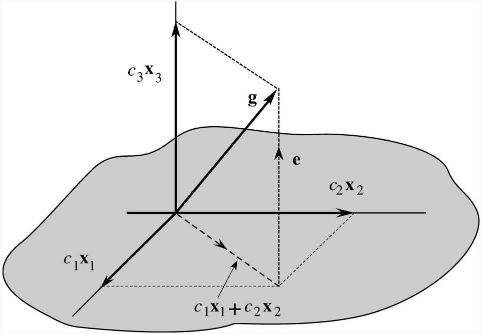

Fig. 2.18: *Representation of a vector in three-dimensional space*

Fig. 2.18

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$$g(t) = \tag{2.21}$$

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Orthogonal Signal Space

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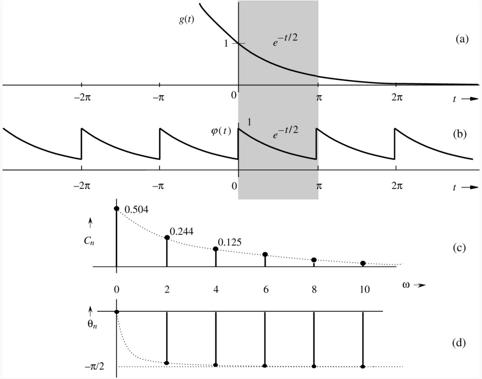

Fig. 2.19: .

Fig. 2.19

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$$g(t) = \qquad (2.22)$$

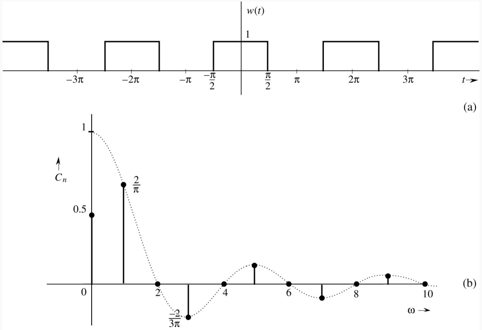

Fig. 2.20: .

Fig. 2.20

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$$g(t) = \qquad (2.23)$$

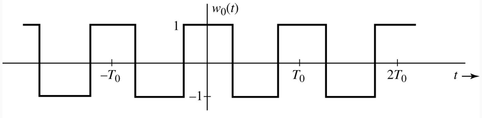

Fig. 2.21: .

Fig. 2.21

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$$g(t) = \qquad (2.24)$$

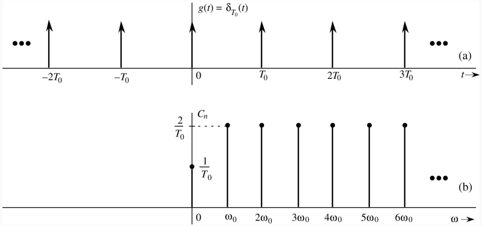

Fig. 2.22: .

Fig. 2.22

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$$g(t) = \qquad (2.25)$$

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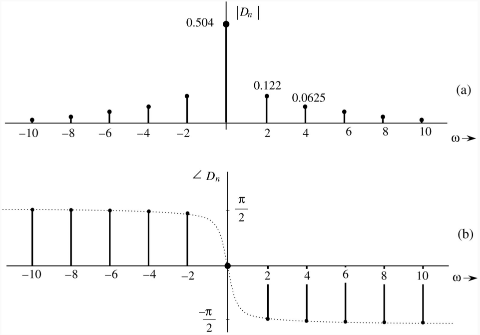

Fig. 2.23: .

Fig. 2.23

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$$g(t) = \qquad (2.26)$$

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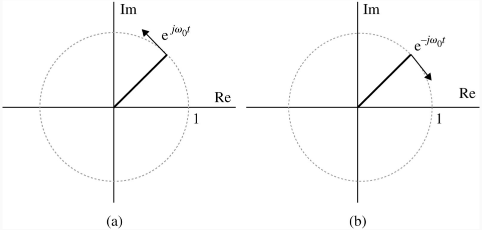

Fig. 2.24: .

Fig. 2.24

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$$g(t) = \qquad (2.27)$$

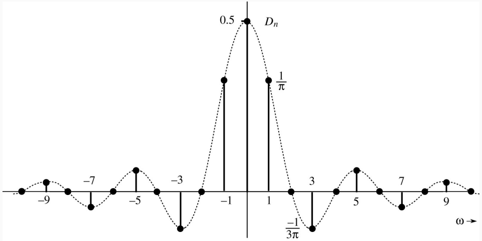

Fig. 2.25: .

Fig. 2.25

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$$g(t) = \qquad (2.28)$$

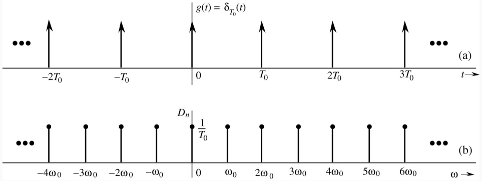

Fig. 2.26: .

Fig. 2.26

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$$g(t) = \qquad (2.29)$$

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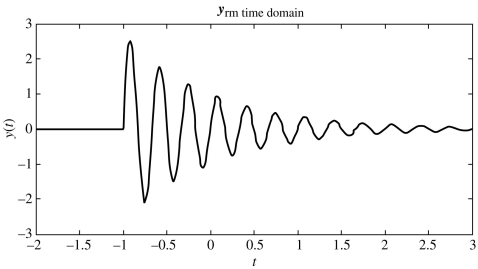

Fig. 2.27: .

Fig. 2.27

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$$g(t) = \qquad (2.30)$$

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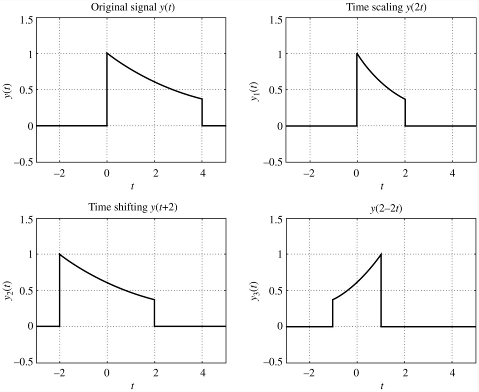

Fig. 2.28

Fig. 2.28

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$$g(t) = \qquad (2.31)$$

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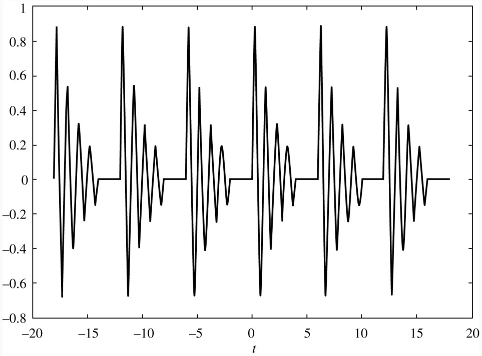

Fig. 2.29: .

Fig. 2.29

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$$g(t) = \qquad (2.32)$$

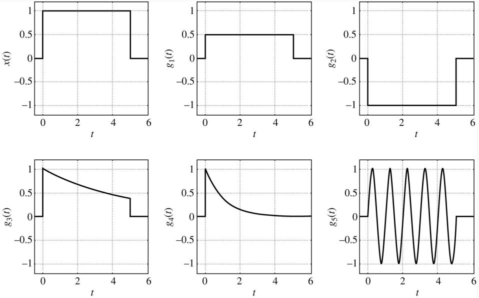

Fig. 2.30: .

Fig. 2.30

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$$g(t) = \qquad (2.33)$$

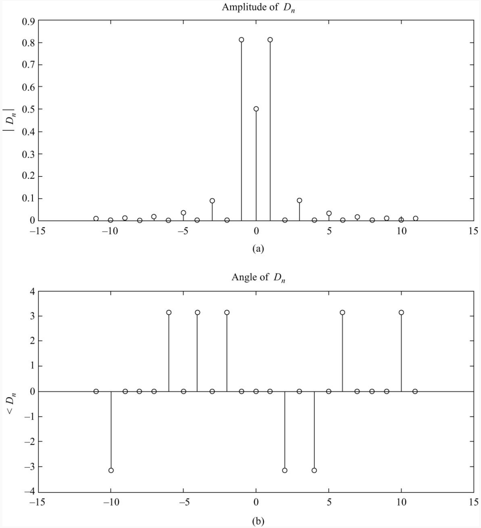

Fig. 2.31: .

Fig. 2.31

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$$g(t) = \qquad (2.34)$$

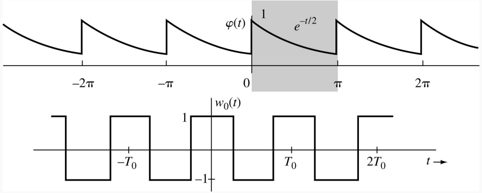

Fig. 2.32: .

Fig. 2.32

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$$g(t) = \qquad (2.35)$$

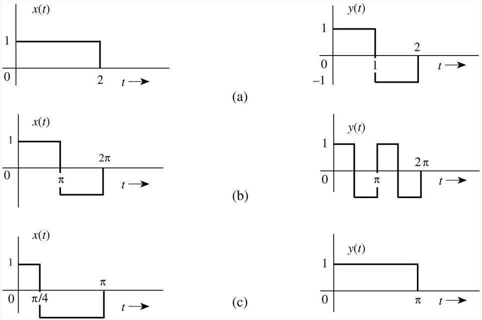

Fig. 2.33: .

Fig. 2.33

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$$g(t) = \qquad (2.36)$$

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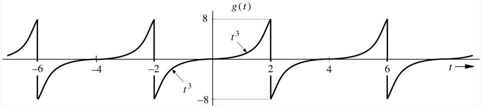

Fig. 2.34: .

Fig. 2.34

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$$g(t) = \qquad (2.37)$$

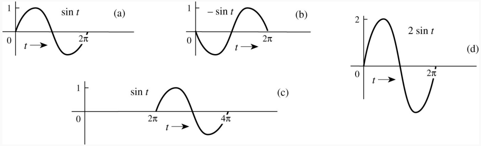

Fig. 2.35: .

Fig. 2.35

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$$g(t) = \tag{2.38}$$

Summary