# 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**.

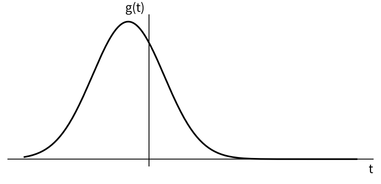
- Examples: Audio signals, video signals, sensor data, etc.

## System

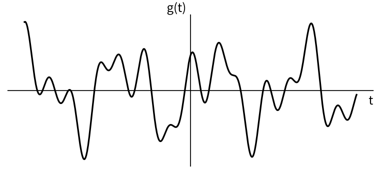
Signals may be processed further by systems, which may modify them or extract additional infromation from them.
Thus, a system is an entity that processes signals (**inputs**) to yield another set of signals (**outputs**).

- 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.

# Energy vs Power Signals




(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.

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

- 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.**

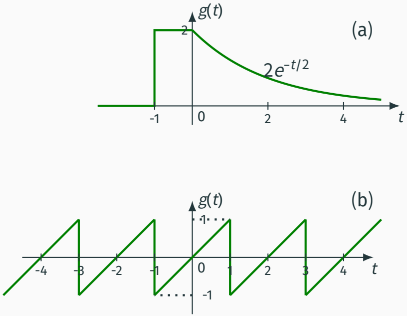



**Fig. 2.2:** *Signal for Example*

### Fig. 2.2 (a)

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

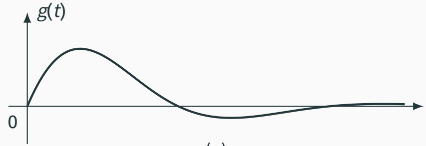
$$E_g = \int_{-\infty}^{\infty} |g(t)|^2 dt = \int_{-1}^{0} (2)^2 dt + \int_{0}^{\infty} 4e^{-t} dt = 4 + 4 = 8$$

### Fig. 2.2 (b)

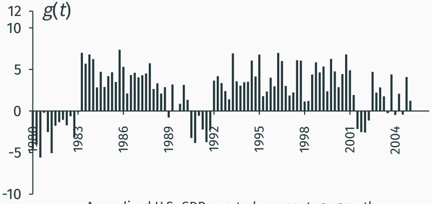
Power signal. Averaging $|g|^2(t)$ over an infinitely large interval is equivalent to averaging it over one period (2 seconds).

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

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



(a)



(b)

**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.

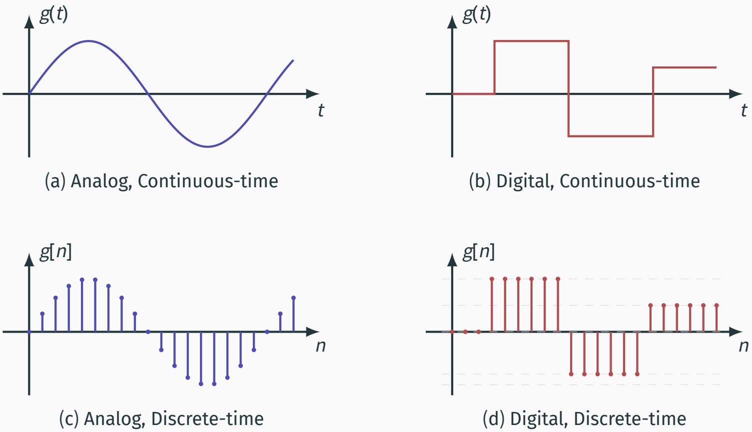



**Fig. 2.4:** *Classification of signals based on amplitude and time domains*

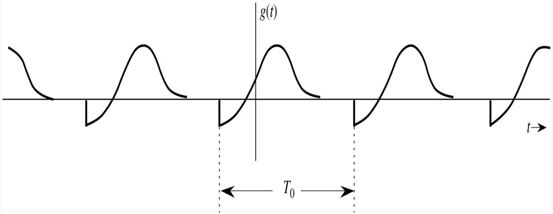
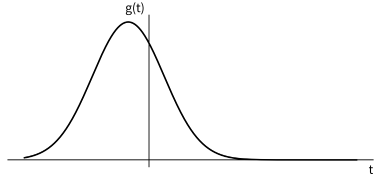



**Fig. 2.5:** *Periodic signal of period $T_0$*

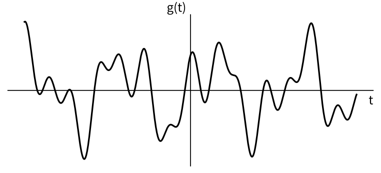
**Fig. 2.5**

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 $g(t)$.

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




(a) Signal with finite energy




(b) Signal with finite power

**Fig. 2.1** *Energy vs Power Signals (Recap)*

### Fig. 2.1(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. 2.1(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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$$g(t) = \tag{2.8}$$

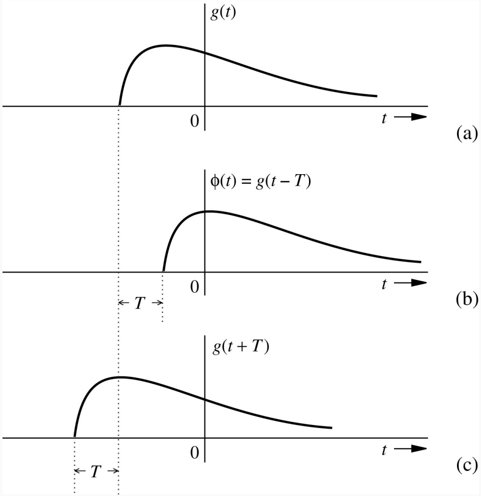


**Fig. 2.6:** *Time shifting a signal*

**Fig. 2.6 Time shifting a signal**

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

# Time scaling a signal

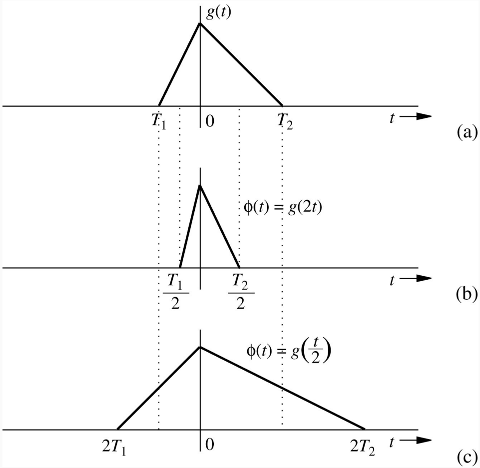


**Fig. 2.7:** *Time scaling a signal*

**Fig. 2.7 Time scaling a signal**

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$$g(t) = \tag{2.10}$$

# Examples of time compression and time expansion of signals

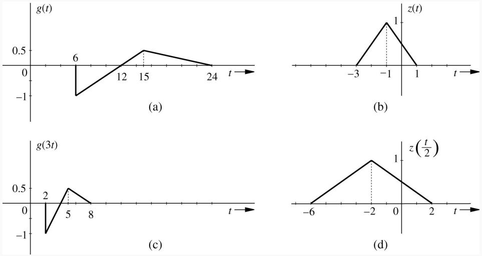


**Fig. 2.8:** *Examples of time compression and time expansion of signals*

**Fig. 2.8**

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

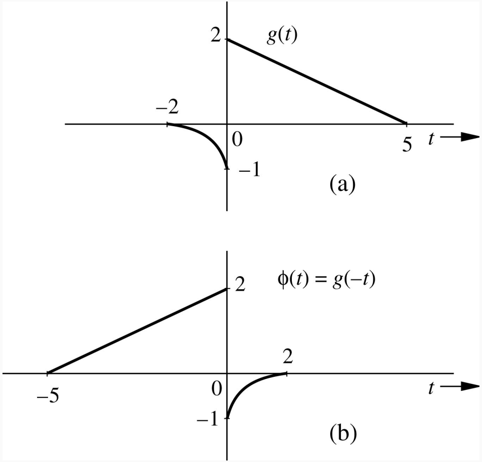


**Fig. 2.9:** *Time inversion (reflection) of a signal*

**Fig. 2.9**

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$$g(t) = \qquad (2.12)$$

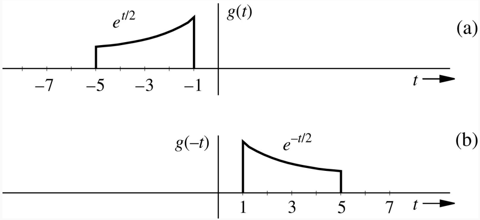


**Fig. 2.10:** *Example of time inversion*

**Fig. 2.10**

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

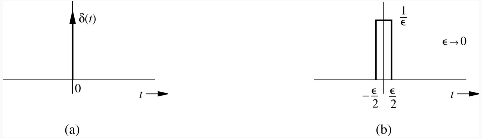


**Fig. 2.11:** *(a) Unit impulse and (b) its approximation*

**Fig. 2.11**

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$$g(t) = \qquad (2.14)$$

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

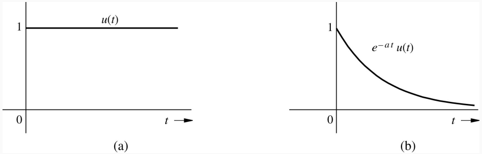


**Fig. 2.12:** *(a) Unit step function $u(t)$. (b) Causal exponential $e^{-at}u(t)$*

**Fig. 2.12**

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$$g(t) = \qquad (2.15)$$

# Signals versus Vectors

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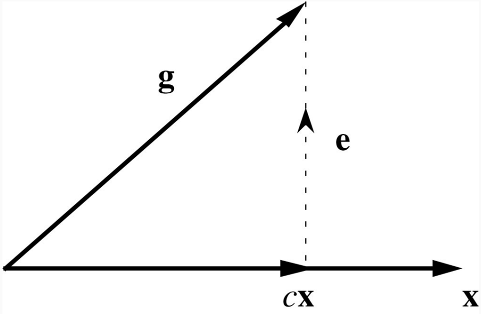


**Fig. 2.13:** *Component (projection) of a vector along another vector*

**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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$$g(t) = \qquad (2.17)$$

# Decomposition of a Signal and Signal Components

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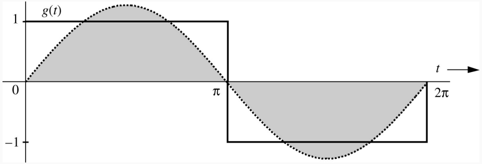


**Fig. 2.15:** *Approximation of square signal in terms of a single sinusoid*

**Fig. 2.15**

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

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# Energy of the Sum of Orthogonal Signals

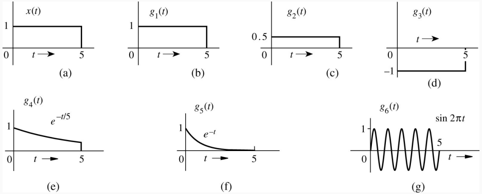


**Fig. 2.16:** *Signals for Example 2.6*

**Fig. 2.16**

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$$g(t) = \qquad (2.19)$$

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# Correlation Functions

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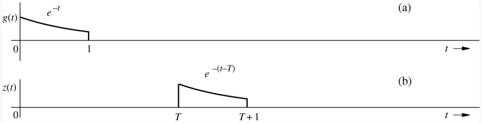


**Fig. 2.17:** *Physical explanation of the auto-correlation function*

**Fig. 2.17**

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$$g(t) = \qquad (2.20)$$

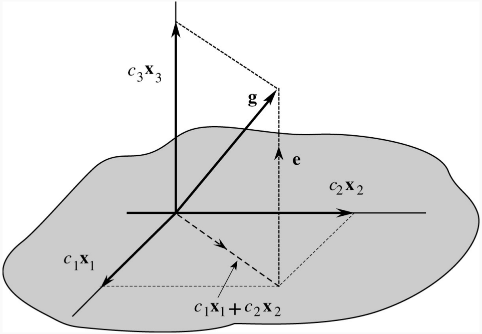


**Fig. 2.18:** *Representation of a vector in three-dimensional space*

**Fig. 2.18**

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$$g(t) = \qquad (2.21)$$

# Orthogonal Vector Space

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# Orthogonal Signal Space

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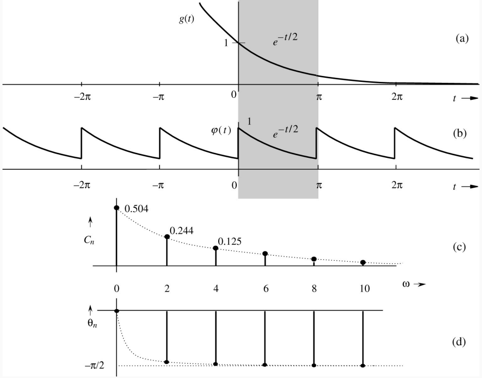


**Fig. 2.19:** .

### Fig. 2.19

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

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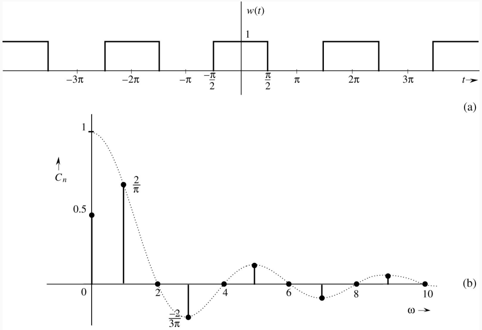


**Fig. 2.20:** .

**Fig. 2.20**

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

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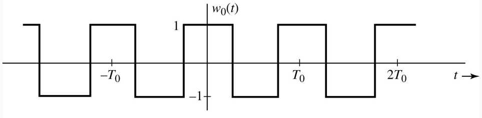


**Fig. 2.21:** .

**Fig. 2.21**

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$$g(t) = \tag{2.24}$$

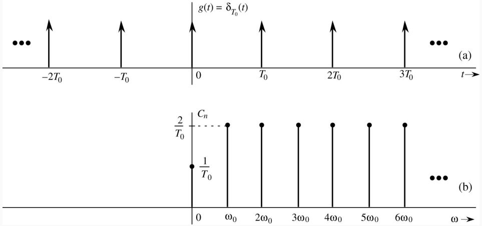


**Fig. 2.22:** .

**Fig. 2.22**

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

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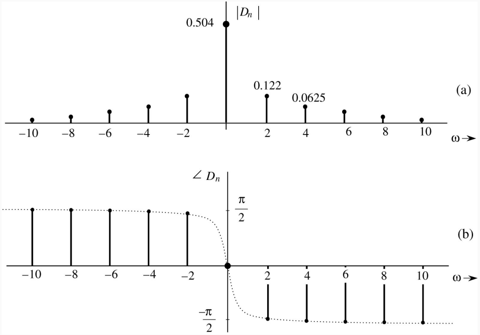


**Fig. 2.23:** .

**Fig. 2.23**

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

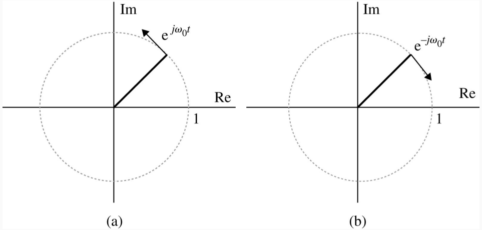


**Fig. 2.24:** .

**Fig. 2.24**

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

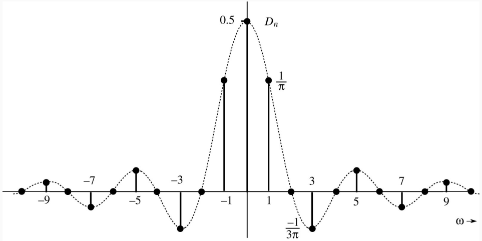


**Fig. 2.25:** .

**Fig. 2.25**

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

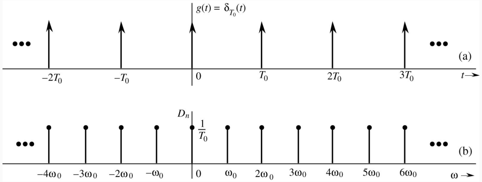


**Fig. 2.26:** .

**Fig. 2.26**

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

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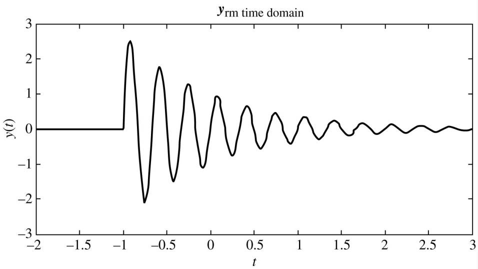


**Fig. 2.27:** .

**Fig. 2.27**

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

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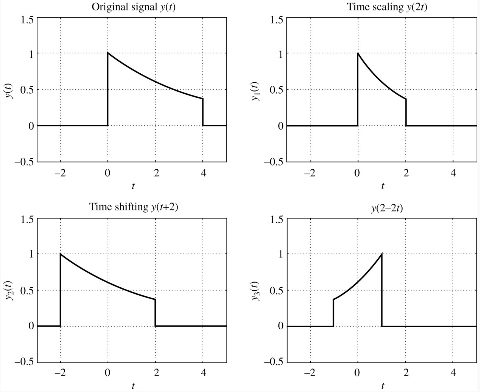


**Fig. 2.28**

**Fig. 2.28**

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

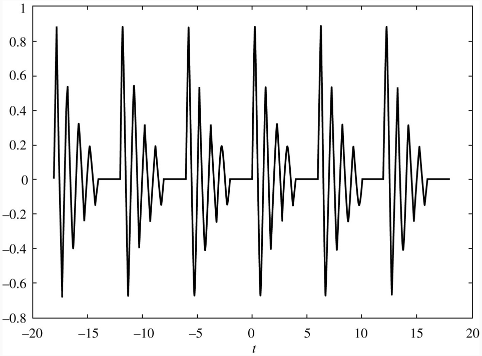


**Fig. 2.29:** .

**Fig. 2.29**

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

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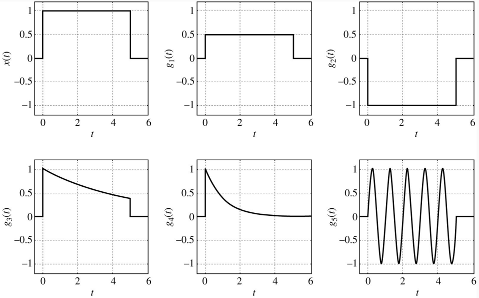


**Fig. 2.30:** .

**Fig. 2.30**

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$$g(t) = \tag{2.33}$$

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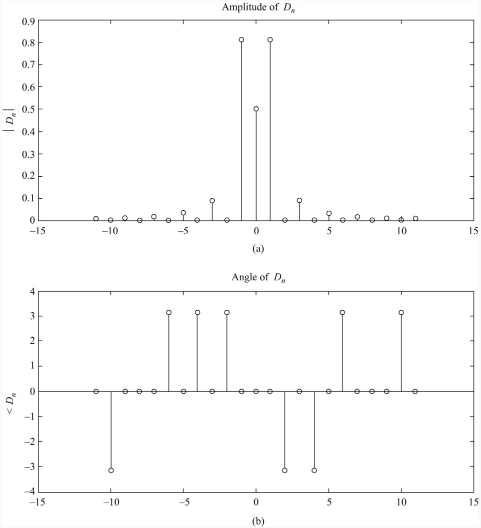


**Fig. 2.31:** .

## Fig. 2.31

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

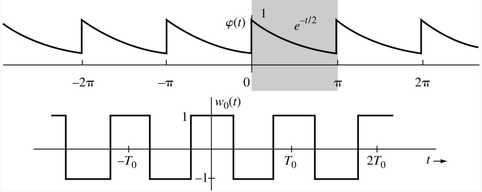


**Fig. 2.32:** .

**Fig. 2.32**

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

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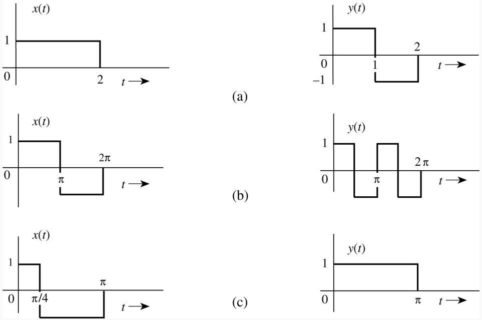


**Fig. 2.33:** .

**Fig. 2.33**

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

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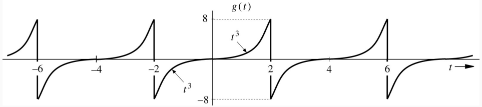


**Fig. 2.34:** .

**Fig. 2.34**

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

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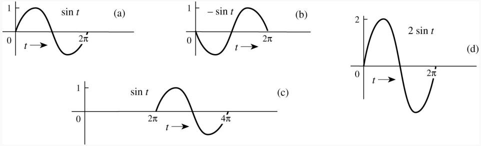


**Fig. 2.35:** .

**Fig. 2.35**

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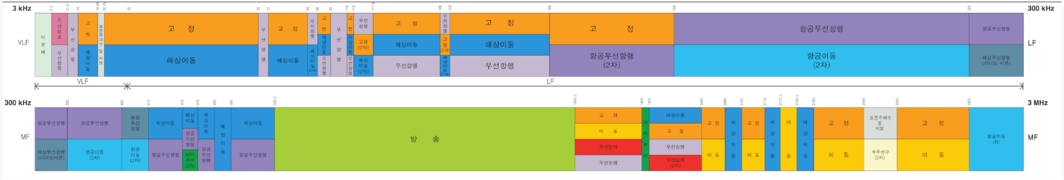
$$g(t) = \qquad (2.38)$$

# 1. Low Frequency Bands (VLF ~ MF)



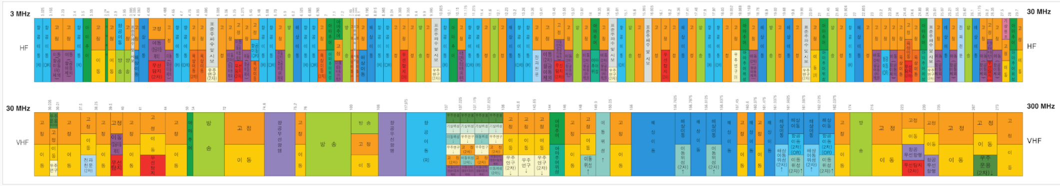

## Key Services

- **VLF/LF**: 해상/잠수함 통신, 항공 무선 표지 (Beacon)
- **MF**: AM Radio (535~1605 kHz), 해상 이동 업무

## Characteristics

- **지표파(Ground Wave)**: 지표면을 따라 멀리 전파됨
- 회절성이 매우 강함 (산/건물 통과 유리)
- 안테나 크기가 매우 커야 함 (λ가 길기 때문)

# 2. Mid-Range Frequency (HF ~ VHF)



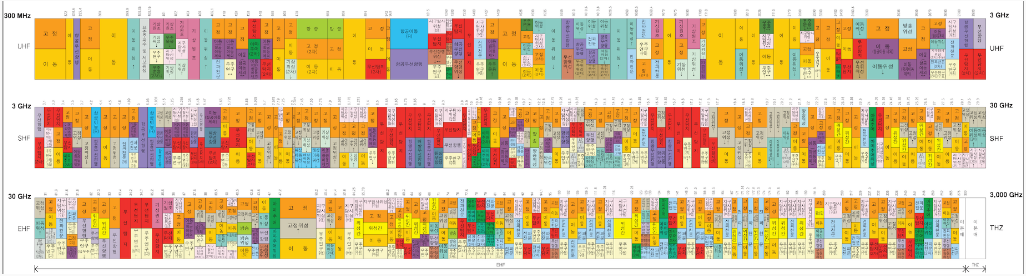

### Key Services

- **HF**: 단파 방송, 아마추어 무선(HAM), 비상 통신
- **VHF**: FM Radio (88~108 MHz), 지상파 DMB, 업무용 무전기

### Characteristics

- **Sky Wave (HF)**: 전리층 반사를 이용한 원거리(국제) 통신
- **Line-of-Sight (VHF)**: 직진성 시작, 장애물 영향 받음
- 음질이 좋고 잡음에 강해짐

# 3. High Frequency Bands (UHF ~ EHF)



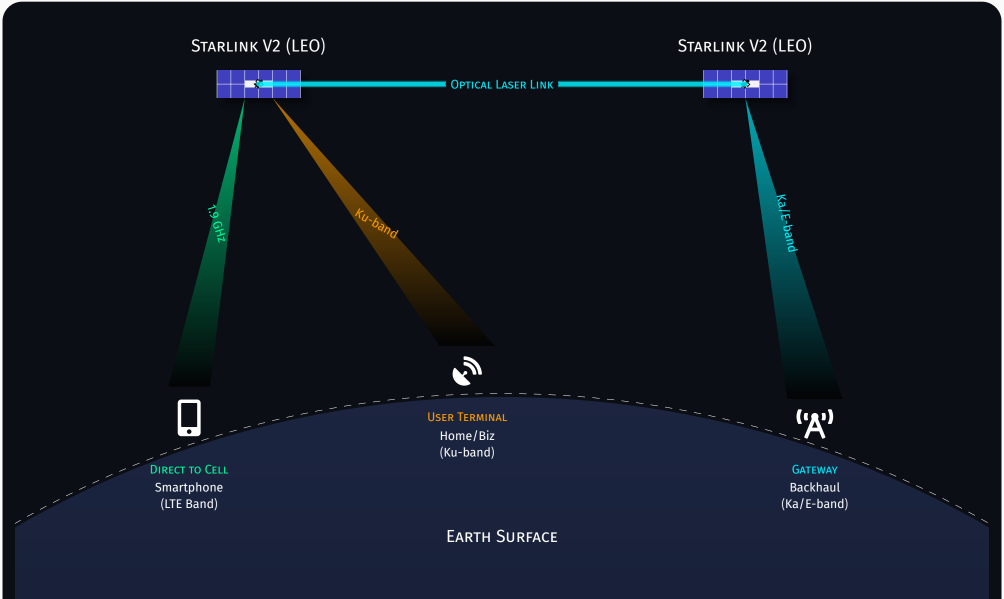

### Key Services (Most Active)

- **UHF**: Mobile (LTE/5G), Wi-Fi(2.4G), GPS, DTV
- **SHF/EHF**: Satellite, Radar, 5G mmWave, Wi-Fi 6E/7

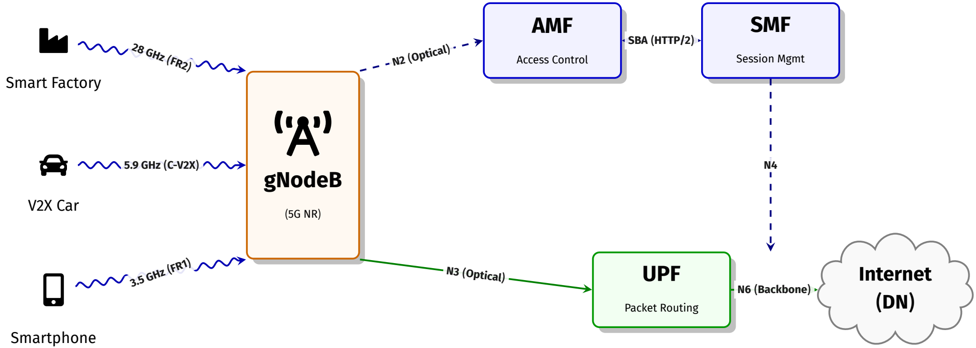
### Characteristics

- 빛에 가까운 강한 직진성
- **Wide Bandwidth**: 초고속 대용량 데이터 전송 가능
- 장애물(비, 벽)에 의한 감쇄 심함

# Starlink Network Architecture



# 5G Terrestrial Network Architecture (PLMN)



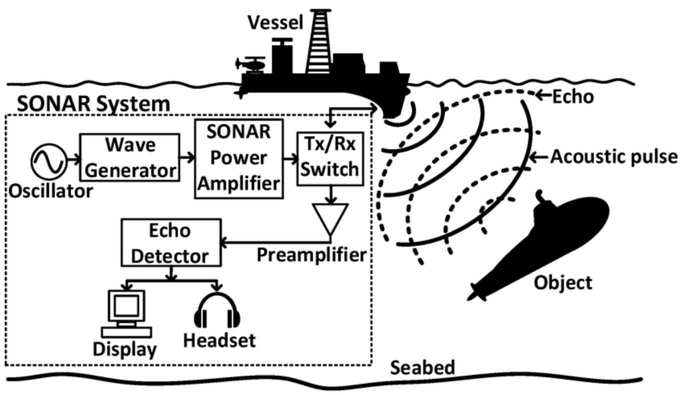



**Fig. 2.36:** *General Architecture of SONAR System*

Source: MDPI J. Mar. Sci. Eng. 2023, 11(7), 1279

# Summary