Chapter 1 Signals and Signal Processing

1.1 Signals, Information, Interference, and Noise

1.2 Signal Classification

time	amplitude
continuous	continuous
discrete (sampling)	discrete (quantization)

Analog and Digital Signals

- Dc or ac
- Narrowband or broadband
- Signal conditioning
- ADC
- Quantization noise $\pm \frac{q}{2}$, $q = 1\,LSB = \frac{V_{in}}{2^n}$, $V_{in} = 2^n q$

reference to ground

Single-ended Signals

Ex. 1.1

- Unipolar or bipolar
- Grounded or floating or driven off ground with common-mode signal

Differential Signals

$v_d = v_H - v_L$, $v_c = \frac{v_H + v_L}{2}$

- Differential voltage and common-mode voltage
- Grounded or floating or isolated
- Balanced or unbalanced

Ex 1.2

Low-impedance or High-impedance Signals

- Voltage source for low-impedance signal : Thevenin
- Current source for high-impedance signal : Norton
- Current signals: single-ended or differential

~~Ex 1.3~~

" signal "

→ noise

1.3 Dynamic Range (DR) and Signal-to-Noise Ratio (SNR)

Fig 1.7, Fig 1.8

Ex) ADC

- DR = Measurement (= span) range / Resolution or DR = 20log{(Max-Min)/Resolution} [dB]
- Sensitivity → detectable minimal variation
- SNR = 10log(Signal Power/Noise Power) [dB]

Ex) Gaussian

↳ useful for random signals.

1.4 Functions in Analog Signal Processing

Linear and Nonlinear Functions

- Homogeneity and addition , ~~time-invariant and time-varying~~
- Superposition principle ⇐ linear and time-invariant
- Time-invariant or time-varying
- Transfer function of a linear and time-invariant system
- Ideal transfer function
- Amplitude and phase distortion

fig 1.9

$p(f) = H(f)\, s(f)$

output input

$p(t) = k\, s(t - t_0)$

$p(f) = k\, e^{-j2\pi f t_0} s(f)$

$H(f) = k \angle -2\pi f t_0$

Amplitude and Level Matching

- Amplification: range matching
- Level shifting: level or zero matching

Ex 1.4

Impedance Adaptation (Buffering)

- Source and load
- Loading effect
- Buffering

Ex 1.5

Domain Conversions

fig 1.11 Table 1.1

- Voltage or current
- Frequency or time
- Amplitude or phase
- Pulse width and others

Filtering

passive filter
active filter

Linearization

- differential: $s(t) + u(t) - (-s(t) - u(t)) = 2s(t)$
- filtering
- division, etc.

Interference Compensation

Level Comparison and Threshold Detection

fig 1.12

Terminal Matching Fig 1.13

1.5 Errors in Analog Signal Processing

Error Classification

- Absolute error or relative error
- Magnitude error or phase error
- Additive error or zero (offset) error
- Multiplicative (gain or slope) error
- Nonlinear error

$$\begin{cases} e = \text{Actual value} - \text{Ideal Value} \\ \varepsilon = \dfrac{e}{\text{Ideal Value}} \times 100\ (\%) \end{cases}$$

Ex 1.6

Systematic Errors

- Calibration

Random Errors

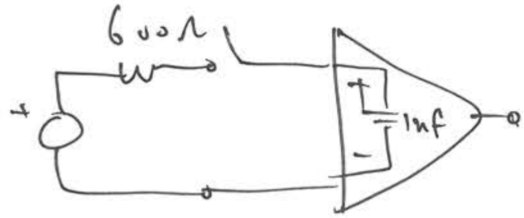
- Averaging

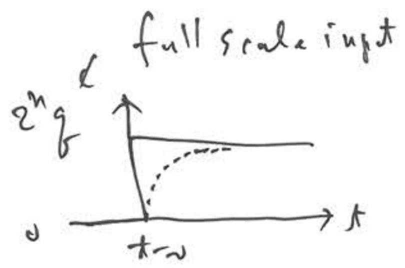
Static Errors

Dynamic Errors

- Transient error : p34-35
- Steady-state error : p36-37 fig

Ex 1.7





$$\varepsilon = \frac{q/2}{2^n q} = 2^{-(n+1)}$$

$$t_\varepsilon = -\tau \ln \varepsilon = (600 \times 1\times10^{-9}) \ln 2^{-(n+1)}$$

$n = 12$ bit $\Rightarrow$ $t_\varepsilon = 5.5\,\mu s$

Ex 1.8

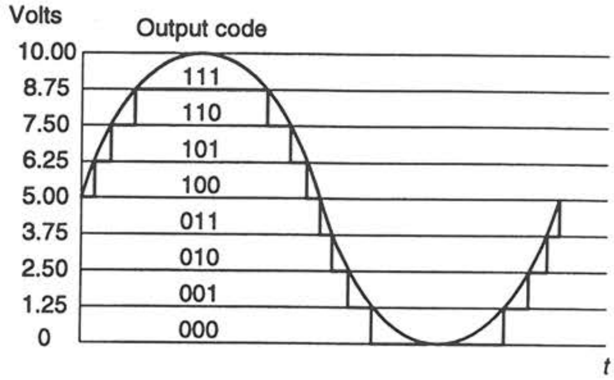


FIGURE 1.2 Sine waveform and its digitized version using a three-bit code.

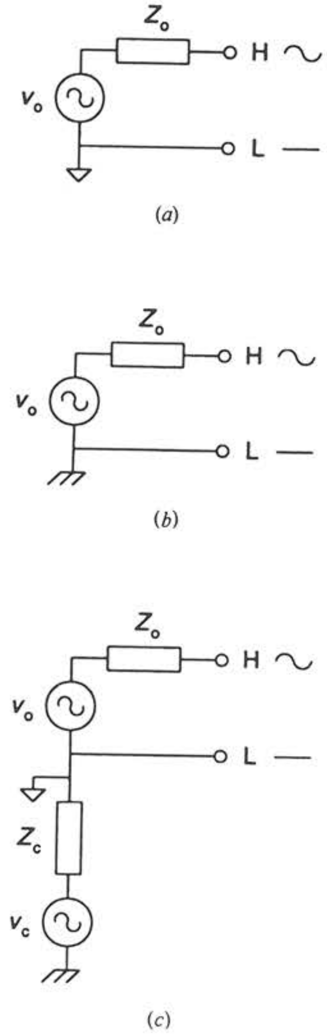
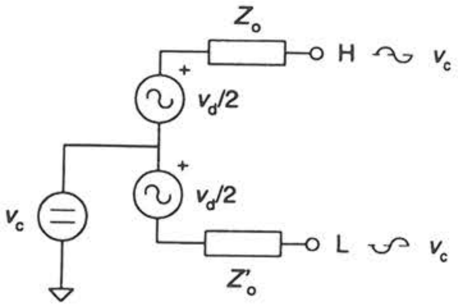
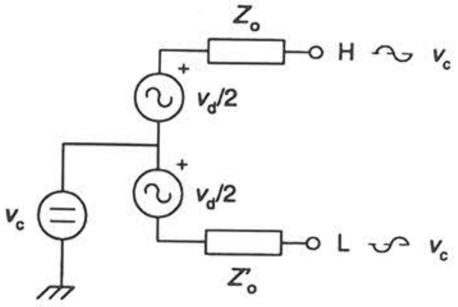


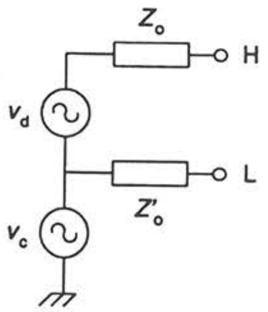
FIGURE 1.3 (*a*) Single-ended and floating signal. (*b*) Single-ended and grounded signal. (*c*) Single-ended signal with a common-mode voltage, v_c.

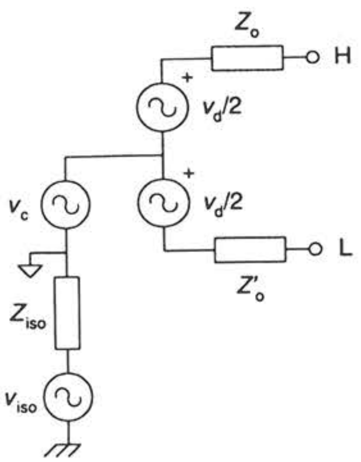


(a)



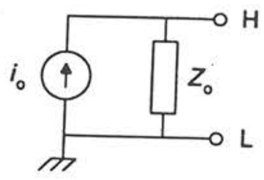
(b)



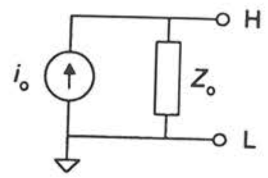


(d)

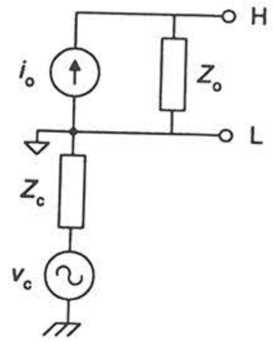
FIGURE 1.4 Differential signals. (a) Differential and floating signal. (b) Differential and grounded signal with common-mode voltage to ground. (c) Equivalent circuit for (b) when $v_d \ll v_c$. (d) Differential and floating signal with isolation-mode voltage.



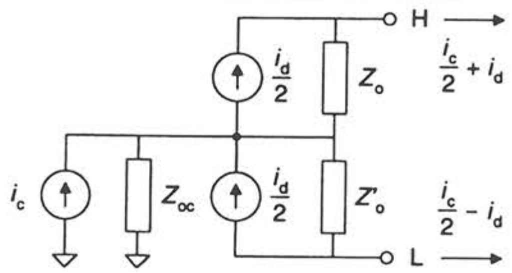
(a)



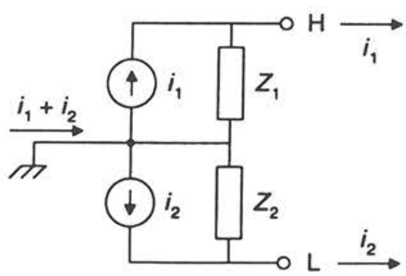
(b)



(c)



(a)



(b)

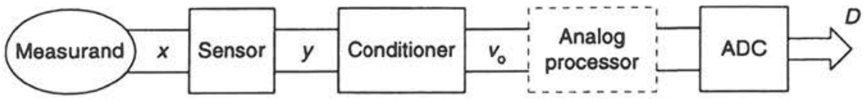


FIGURE 1.7 General structure of a system that obtains a digital code D from a measurand x.

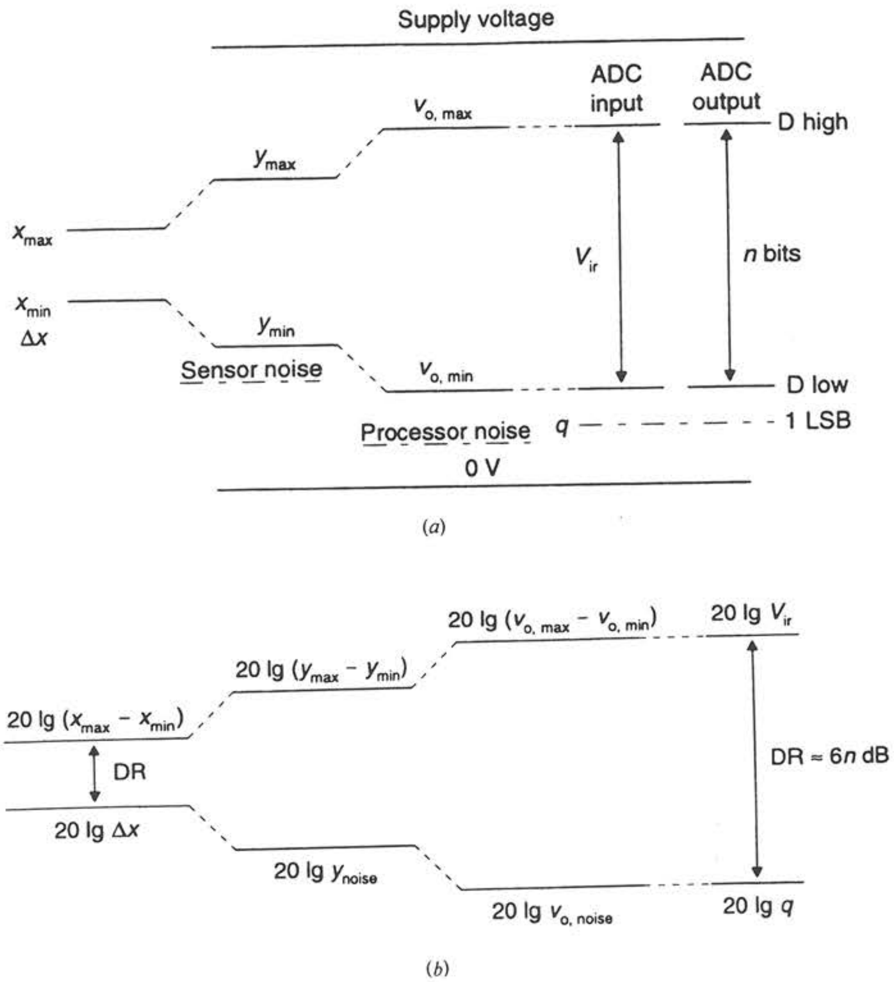


FIGURE 1.8 Measurement and signal range (*a*) and dynamic range (*b*) for the system in Figure 1.7.

TABLE 1.1 Common Terminology for Components and Circuits for Signal Amplification and Domain Conversion

	Output	
Input	Voltage	Current
Voltage	Voltage amplifier Voltage buffer Voltage-controlled voltage source (VCVS)	Transconductance amplifier Transadmittance amplifier Voltage-controlled current source (VCCS)
Current	Norton amplifier Current integrator Transimpedance amplifier Current-controlled voltage source (CCVS)	Current mirror Current conveyor Current amplifier, current pump Current-controlled current source (CCCS)

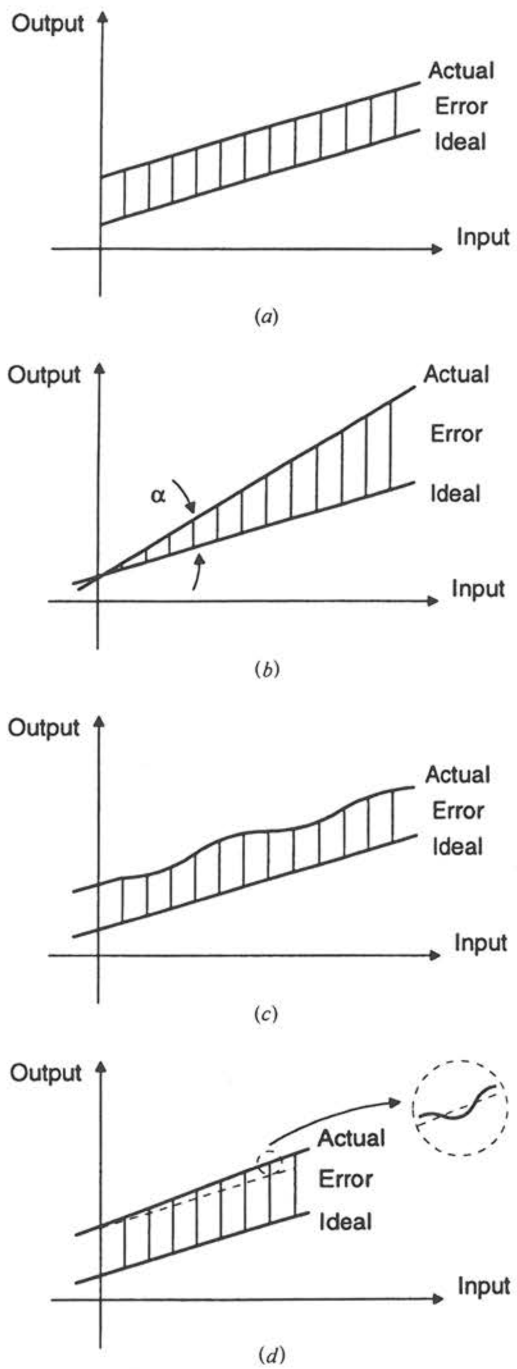


TABLE 1.2 Time t_ϵ After Which the Relative Transient Error for a Step Input to a Low Pass First-Order System with Time Constant τ Will Be Smaller Than a Given ϵ

ϵ	t_ϵ	ϵ	t_ϵ
10^{-2}	4.6	10^{-4}	9.2
2^{-8}	5.5	2^{-14}	9.7
10^{-3}	6.9	2^{-16}	11.1
2^{-10}	6.9	2^{-18}	12.5
2^{-11}	7.6	2^{-20}	13.9
2^{-12}	8.3	2^{-22}	15.3
2^{-13}	9.0		

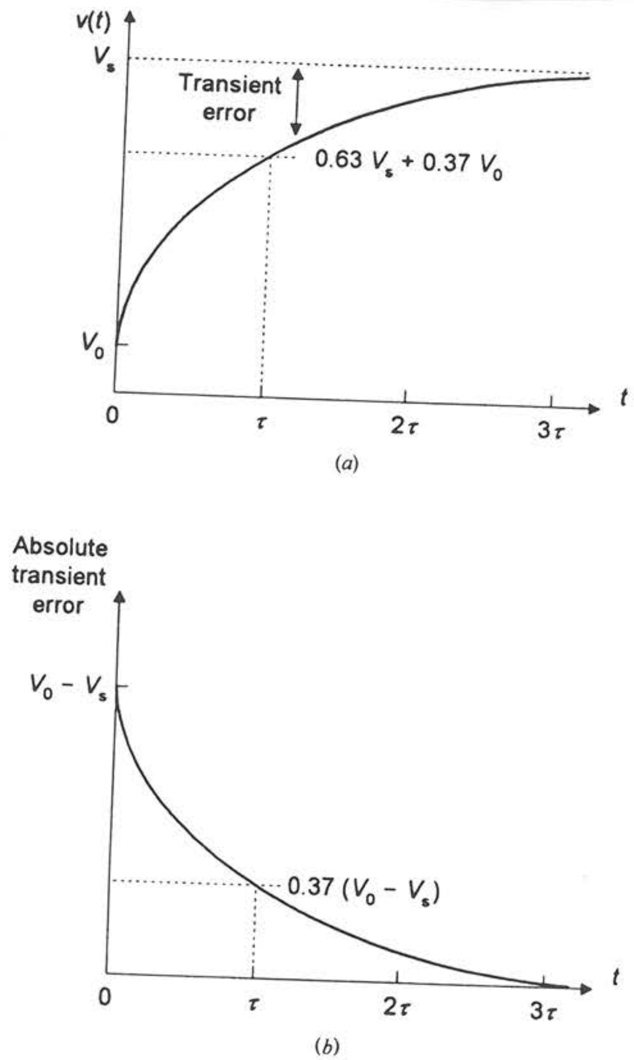


FIGURE 1.15 (*a*) Step response of a first-order low-pass system; (*b*) the resulting absolute transient error.

TABLE 1.3 Corner Frequency f_c for a Low-Pass First-Order System When the Maximal Amplitude Error Accepted for Frequencies Below f_ϵ is ϵ

ϵ	f_c/f_ϵ	ϵ	f_c/f_ϵ
10^{-2}	7	10^{-4}	71
2^{-8}	11.3	2^{-14}	91
10^{-3}	22.4	2^{-16}	181
2^{-10}	22.6	2^{-18}	362
2^{-11}	32	2^{-20}	724
2^{-12}	45.5	2^{-22}	1448
2^{-13}	64		

* ASP p19 Ex 1.4

온도 측정 범위 : $-40°C - +55°C$

Resolution : $0.1°C$

MLM Sensitivity : $1mV/°C$

ADC input range : $0 - 10V$

① $$DR = 20 \log_{10} \frac{55-(-40)}{0.1} = 59.55 \, dB$$

$\Rightarrow$ 각 stage 의 DR > 60 dB

ADC : $DR \doteq 6n = 60 \Rightarrow n = 10$ bit

② MLM output

$$y_{max} - y_{min} = S(x_{max} - x_{min})$$
$$= (1 \, mV/°C)(55+40)°C = 95 mV$$

③ Gain , $$G = \frac{10-0}{0.095} = 105$$

④ MLM 출력 잡음 ~~최대치~~

$$y_{noise} = (1 \, mV/°C)(0.1°C) = 0.1 \, mV$$

± 증폭기 출력 잡음 ~~최대치~~ $(\pm \frac{q}{2}$

$$\pm V_{noise} = \pm \frac{q}{2} = \pm \frac{1}{2} \cdot \frac{10}{2^{10}} = \pm 4.9 \, mV$$

⑤ $(1 \, mV/°C)(-40°C) = -40 mV \xrightarrow{\times G} -4.2V$

$\Rightarrow$ Level shifting of $+4.2V$

$\Rightarrow 0 - (1 \, mV/°C)(55°C)(105) = 0 - 9.975 V$

참고 증폭기는 사용하지 않는 경우

Resolution : $(0.1°C)(1mV/°C) = 0.1\ mV$

$$2^n = \frac{10V}{0.1mV} = 10^5 \Rightarrow n = 16.6$$

$\Rightarrow$ 17 bit ADC