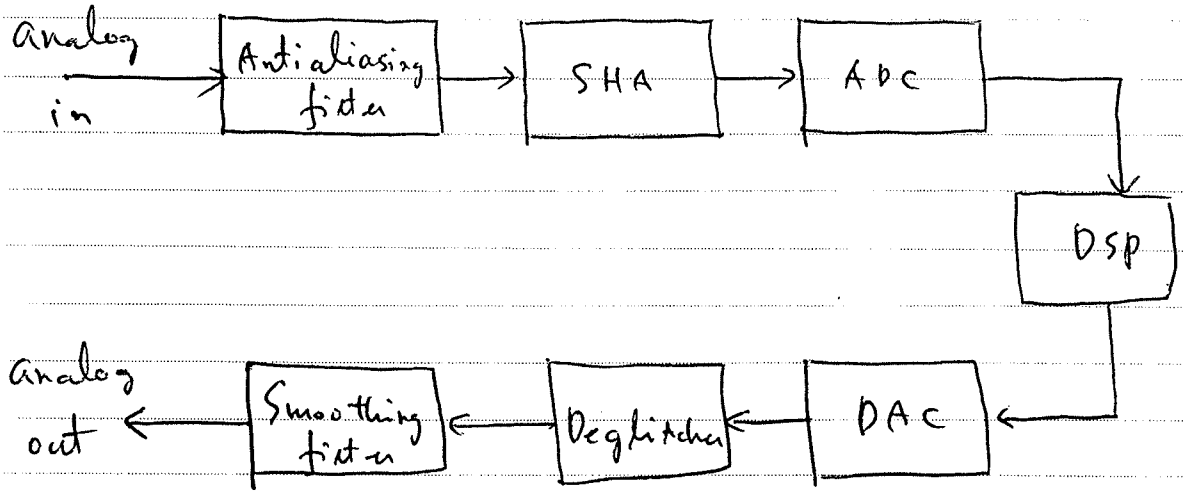
Chapter 12 D/A and A/D Converter

* Sampled data system



12.1 Performance Specifications

$b_1 b_2 \cdots b_n$: n-bit word

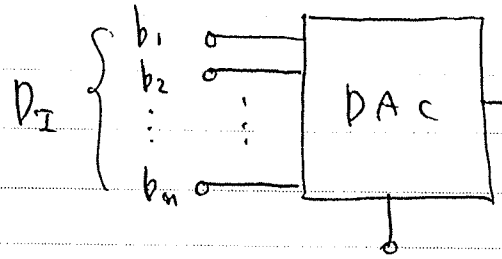
b_1 ↑ MSB b_n ↑ LSB

$D = b_1 2^{-1} + b_2 2^{-2} + \cdots + b_n 2^{-n}$: fractional binary value

또는

$D = b_1 2^{n-1} + b_2 2^{n-2} + \cdots + b_n 2^{0}$: decimal value

* DAC



$$v_o = K V_{REF} D_I$$
$$= V_{FSR}\left(b_1 2^{-1} + b_2 2^{-2} + \cdots + b_n 2^{-n}\right)$$

- K : scale factor
- V_{REF} : reference voltage
- V_{FSR} : full-scale range (2.5 V, 5 V, or 10 V)

Current output 의 경우 : $i_o = K I_{REF} D_I$
$= I_{FSR} D_I$
($I_{FSR} = 1.0\,mA$, typically)

V_{REF} 의 가변 : MDAC (multiplying DAC)

- Resolution = $V_{FSR} / 2^n$ = LSB
- Dynamic range = DR = $20 \log_{10} 2^n$
- V_{FSV} = full-scale value = $(1 - 2^{-n}) \times V_{FSR}$

Ex) (2-bit DAC, $V_{FSR} = 10$ V

- Resolution = LSB = $\frac{10}{2^{12}} = 2.44\,mV$
- $V_{FSV} = (1 - 2^{-12}) \times 10 = 9.9976$ V
- DR = 72.25 dB

~~② fig 12.3 (p 517) : offset error and gain error~~

* DAC Specifications

{ Absolute accuracy = $\left| \text{Actual output} - V_{FSR} D_I \right|_{max}$

Absolute accuracy $\leq \frac{1}{2}$ LSB of D_I.

◎ Static error { offset error, gain error } Fig 12.3

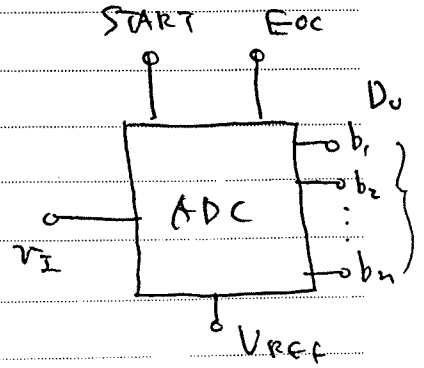
{ Integral nonlinearity (INL) = relative accuracy
Differential nonlinearity (DNL)

◎ Dynamic error
- Settling time = t_s (band = $\pm \frac{1}{2}$ LSB)
  ~ 10ns ~ 10 μs
- Glitch : spikes at the output

* ADC

$$D_o = b_1 2^{-1} + b_2 2^{-2} + \cdots + b_n 2^{-n}$$

$$= \frac{V_I}{K V_{REF}} = \frac{V_I}{V_{FSR}}$$

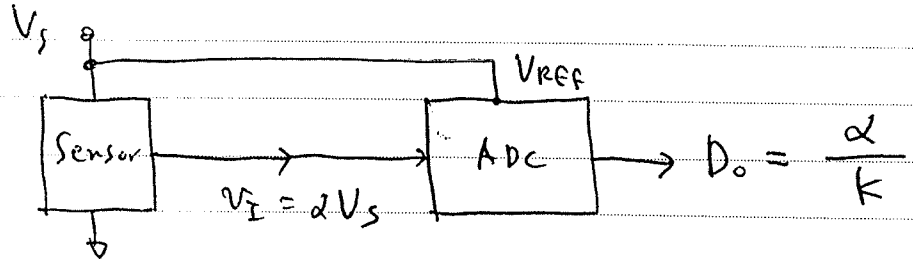


Control signals
{ START : start of conversion
EOC : end of conversion

Output { parallel
serial

μP interface { latch
buffer (3-state)
control logic

◎ Ratiometric conversion



⇒ { reference independent conversion
high accuracy from moderate reference

◎ Fig 12.5 : 3-bit ADC, $V_{FSR} = 1\ V$

◎ n-bit ADC

- Code ranges = 2^n intervals

(191) 3-bit ADC ⇒ 011 (code)

V_I : $\frac{3}{8} \pm \frac{1}{16}\ V$

- Quantization error or quantization noise

⇒ $e_q = \pm \frac{1}{2}$ LSB

(n ↑ ⇒ e_q ↓)

Fig 12.5 (b) 에서 e_q의 rms 값을 구하면

$$E_q = \frac{\frac{1}{2}LSB}{\sqrt{3}} = \frac{V_{FSR}}{2^n\sqrt{12}}$$

(예) v_I가 sinusoid, $v_{I,max} = \frac{V_{FSR}}{2}$ (for max. SNR)

$$SNR_{max} = 20\log_{10}\frac{\frac{V_{FSR}}{2}/\sqrt{2}}{V_{FSR}/2^n\sqrt{2}}$$ ← rms

$$= 6.02n + 1.76 \text{ dB}$$

($n\uparrow \Rightarrow SNR\uparrow$)

* ADC Specifications

- Offset error
- Gain error
- Differential nonlinearity
- Integral 〃
- Stability.

Conversion time : < 10 ns ~ 수십 ms

$$ENOB = \frac{S/(N+D) - 1.76\text{dB}}{6.02}$$

ENOB ← effective number of bits

$S/(N+D)$: Signal-to-noise-plus-distortion ratio

12.2 D/A Conversion Technique

* Weighted-Resistor DAC
  Fig 12.7 (p572)

$$V_o = -\frac{R_f}{R} V_{REF}\left(b_1 2^{-1} + b_2 2^{-2} + \cdots + b_n 2^{-n}\right)$$

  - Large resistance spread } 비실용적
  - Switch resistance
  - 6-bit DAC 이상의 사용

* Weighted-Capacitor DAC
  Fig 12.8 (p573)

  - Wide capacitance spread.
  - 10bit 이상

* Potentiometric DAC
  Fig 12.9 (p573)
  - Large number of resistors
  - 8 bit 이하

* R-2R Ladder
  - Fig 12.12 (p577)
  - Most popular

* Bipolar DAC

12.3 MDAC Applications

* MDAC : Fig 12.22 (p587), R-2R ladder

* Applications
  - Digitally programmable attenuator (Fig 12.23)
  - " " amplifier (Fig. 12.23)
  - " " filter (Fig 12.24)
  - " " oscillator (Fig. 12.25)

12.4 A/D Conversion Techniques

* DAC-Based ADC : Fig 12.26 (p591)
* Successive-Approximation ADC (SA ADC) : Fig. 12.28 (p593)
* Charge Redistribution ADC (CR ADC); Fig. 12.29 (p594)
* Flash ADC : Fig 12.31 (p596)
* Subtracting ADC : Fig 12.32 (p597)
* Pipelined ADC : Fig 12.33 (p598)
* Integrating-Type ADC : Fig 12.34 (p599)

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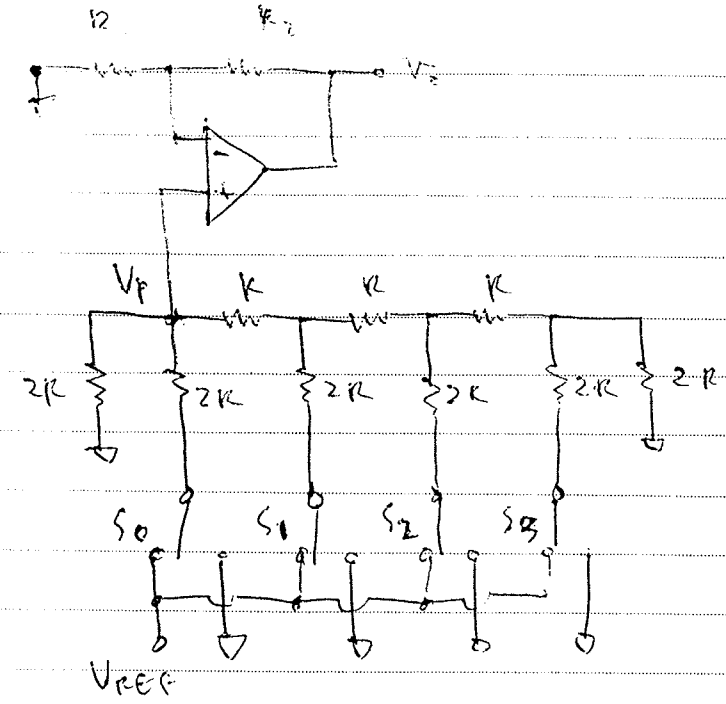
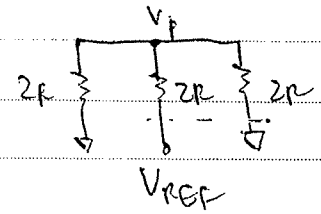
12.5 Oversampling Converters (Σ-Δ ADC)

* Nyquist - Rate Sampling.

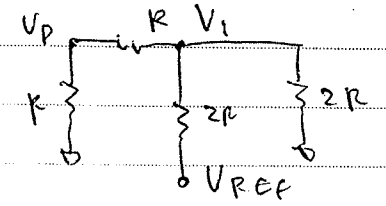


(i) S_0 ON (i.e V_{REF})



$$V_p = \frac{1}{3} V_{REF}$$

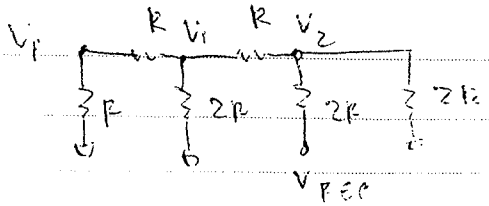
(ii) S_1 ON



$$V_1 = \frac{1}{3} V_{REF}$$

$$V_p = \frac{1}{2} V_1 = \frac{1}{2} \times \frac{1}{3} V_{REF}$$

(iii) S_2 ON



$$V_2 = \frac{1}{3} V_{REF}$$

$$V_1 = \frac{1}{2} \times \frac{1}{3} V_{REF}$$

$$V_p = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{3} V_{REF}$$