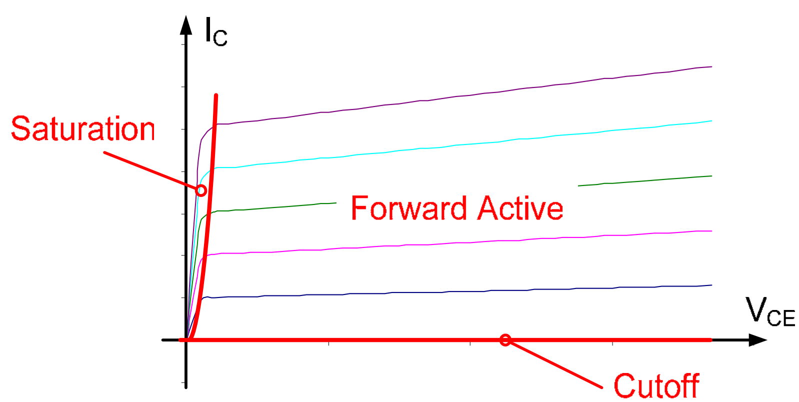
EE 230
Lecture 36

Data Converters

Review from Last Time:

Small Signal Model of BJT

3-terminal device



Forward Active Model:

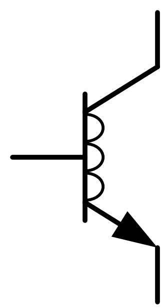
$$I_C = J_S A_E e^{\frac{V_{BE}}{V_t}}\left(1+\frac{V_{CE}}{V_{AF}}\right)$$

$$\mathbf{I_B} = \frac{\mathbf{J_S A_E}}{\boldsymbol{\beta}}\mathbf{e}^{\frac{\mathbf{V_{BE}}}{\mathbf{V_t}}}$$

Usually operated in Forward Active Region when small-signal model is needed

Review from Last Time:

Small Signal Model of BJT



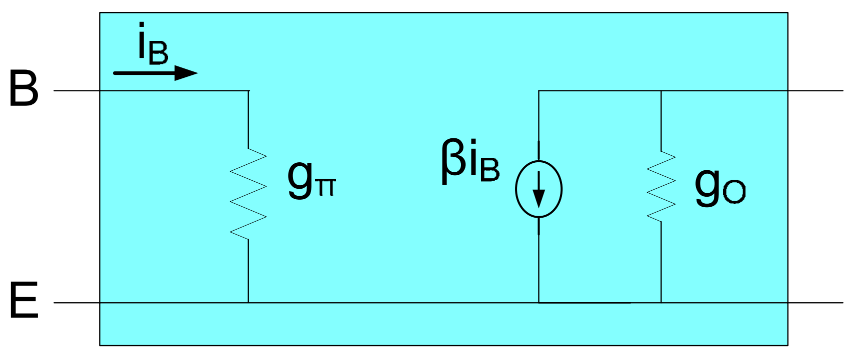
$$i_B = g_\pi v_{BE}$$
$$i_C = g_m v_{BE} + g_o v_{CE}$$

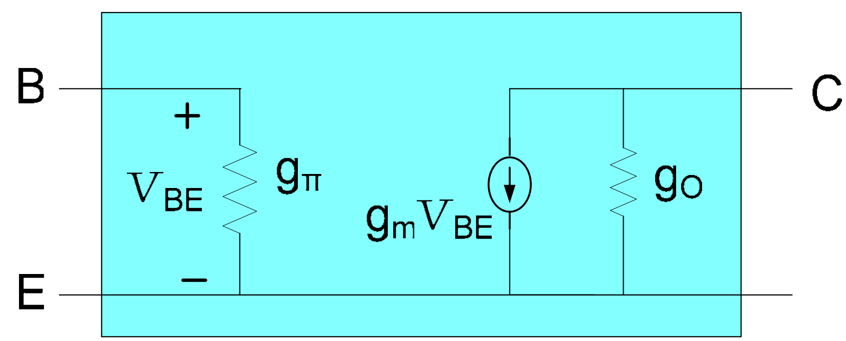
$$g_\pi = \frac{I_{CQ}}{\beta V_t} \qquad g_m = \frac{I_{CQ}}{V_t} \qquad g_o = \frac{I_{CQ}}{V_{AF}}$$

Observe

$$g_m V_{BE} = g_m \left[\frac{i_b}{g_\pi}\right] = \left[\frac{g_m}{g_\pi}\right] i_b \qquad \frac{g_m}{g_\pi} = \frac{I_{CQ}/V_t}{I_{CQ}/\beta V_t} = \beta$$

$$\therefore \quad g_m V_{BE} = \beta i_b$$





Alternate equivalent small-signal models of the BJT

Review from Last Time:

Recall:

Alternative Approach to small-signal analysis of nonlinear networks

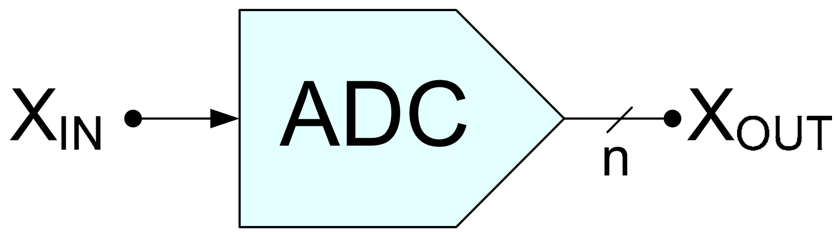
1. **Linearize nonlinear devices**
   (have small-signal model for key devices!)

2. **Replace all devices with small-signal equivalent**

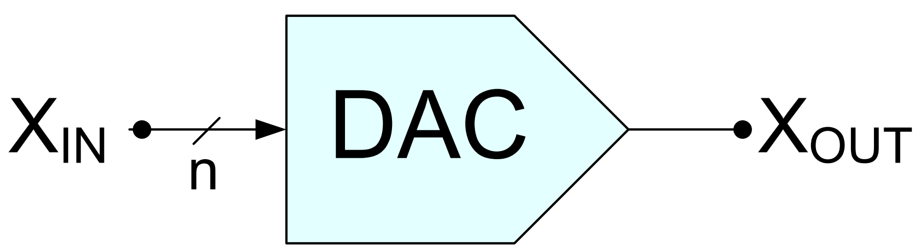
3. **Solve linear small-signal network**

Data Converters

Standard Symbols:



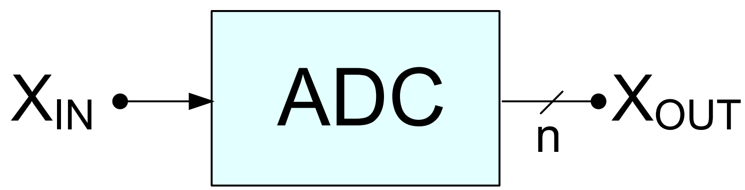
Analog to Digital Converter



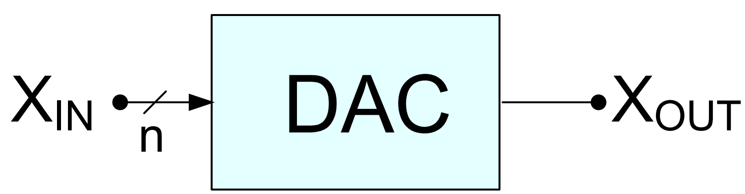
Digital to Analog Converter

Data Converters

Other Symbols:

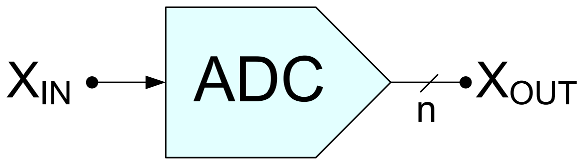


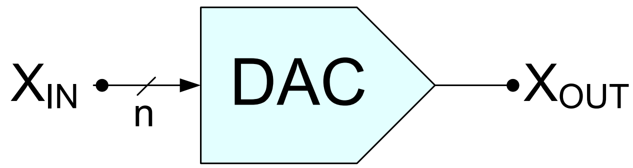
Analog to Digital Converter



Digital to Analog Converter

Data Converters



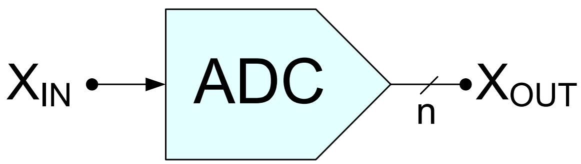


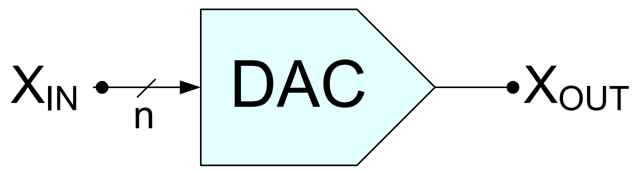
	X_{IN}	X_{OUT}
ADC	Analog	Digital
DAC	Digital	Analog

Analog variables: Voltage, Current, time, charge, occasionally other physical variables

Digital variables: Usually represented in binary form but other forms occasionally used (e.g. gray, Thermometer code)

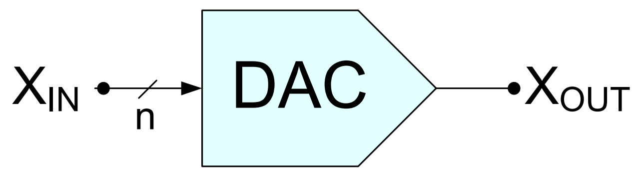
Data Converters

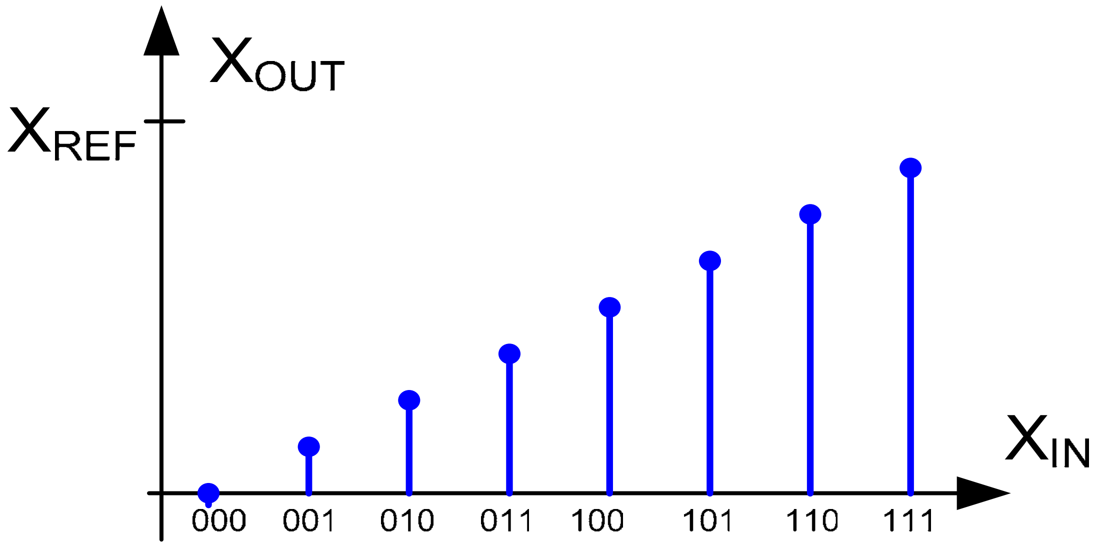




Applications: Dominantly the interfaces between the continuous-time Continuous-amplitude physical environment and a digital system such as a computer, microprocessor, microcontroller, or finite state machine

Data Converters



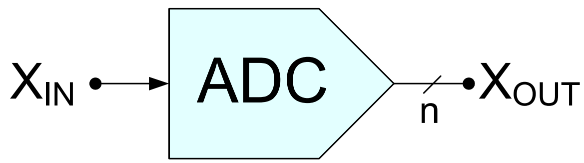


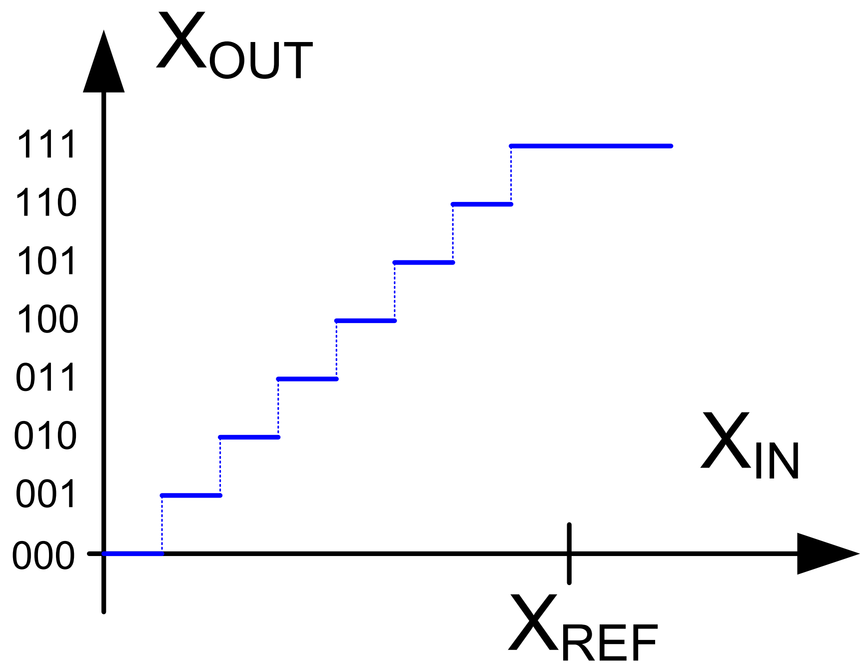
B: [b_1 b_2....b_n]

An ideal DAC

(Some specific shifted versions of this DAC would also be termed an ideal DAC)

Data Converters



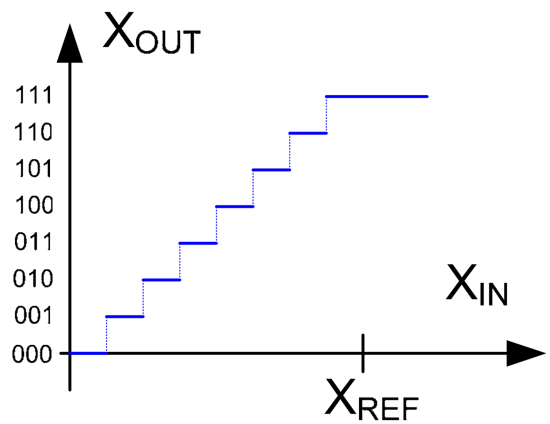


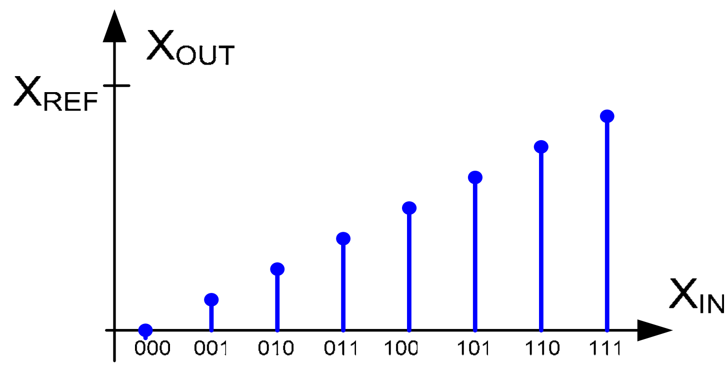
B: [b_1 b_2….b_n]

An ideal ADC

(Some specific shifted versions of this ADC would also be termed an ideal ADC)

Data Converters





Terminology:

B: [$b_1\, b_2 \ldots . b_n$]

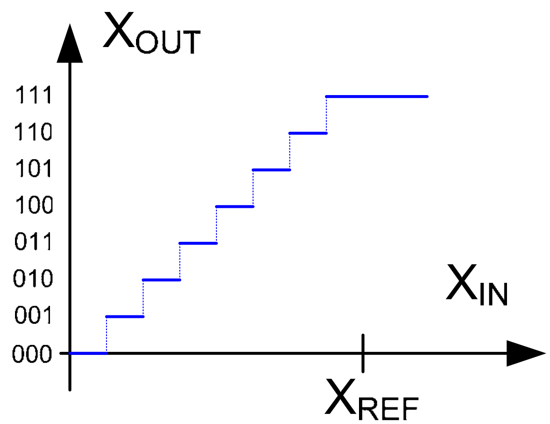
b_1: Most Significant Bit (MSB)
b_n: Least Significant Bit (LSB)

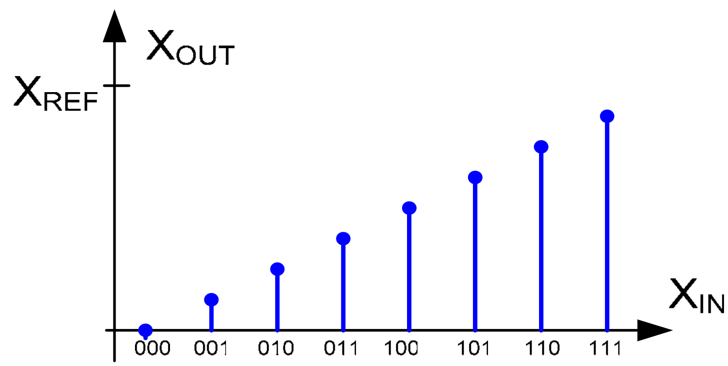
Resolution: Defines number of distinct levels for DAC or Boolean outputs for ADC. If there are N distinct levels, resolution generally defined as $n = \log_2 N$ thus, $N = 2^n$

X_{REF}: specifies the full-scale range of the data converter. Input range for ADC or output range for DAC is usually

$$X_{REF}\left(\frac{2^n-1}{2^n}\right) \overset{\text{n large}}{\simeq} X_{REF}$$

Data Converters





Terminology:

LSB (or X_{LSB}) : Analog change (in input to ADC or output of DAC) corresponding to one LSB digital change

$$X_{LSB} = \frac{X_{REF}}{2^n}$$

Transition Points (for ADC): values of X_{IN} where output changes by 1 LSB
(an n-bit ADC has N-1 transition points partitioning input into N distinct intervals)

Decimal Equivalent: Decimal equivalent of **B: [b_1 b_2….b_n]**

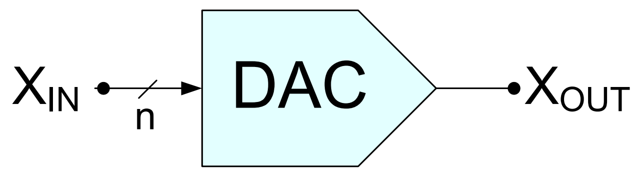
$$D(B) = \left(\frac{b_1}{2} + \frac{b_2}{4} + \ldots + \frac{b_n}{2^n} \right) \longrightarrow D(B) = \sum_{k=1}^{n} \frac{b_k}{2^k}$$

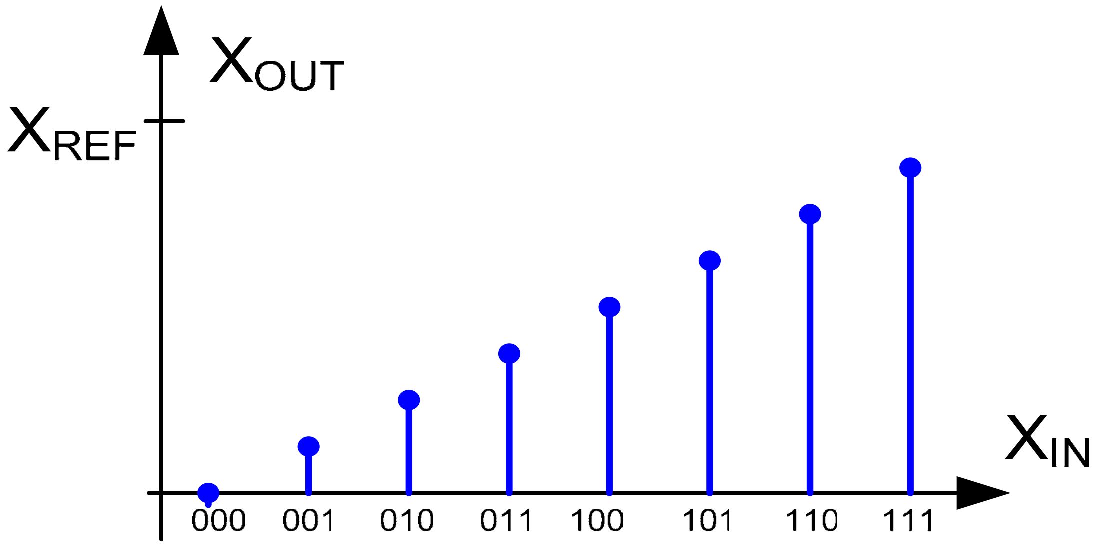
Number of levels for different resolution

n	N	
1	2^1	2
2	2^2	4
3	2^3	8
4	2^4	16
5	2^5	32
6	2^6	64
7	2^7	128
8	2^8	256
9	2^9	512

n	N	
10	2^{10}	1024
11	2^{11}	2048
12	2^{12}	4096
13	2^{13}	8192
14	2^{14}	16384
15	2^{15}	32768
16	2^{16}	65536
20	2^{20}	1,048,576
24	2^{24}	16,772,216

Data Converters



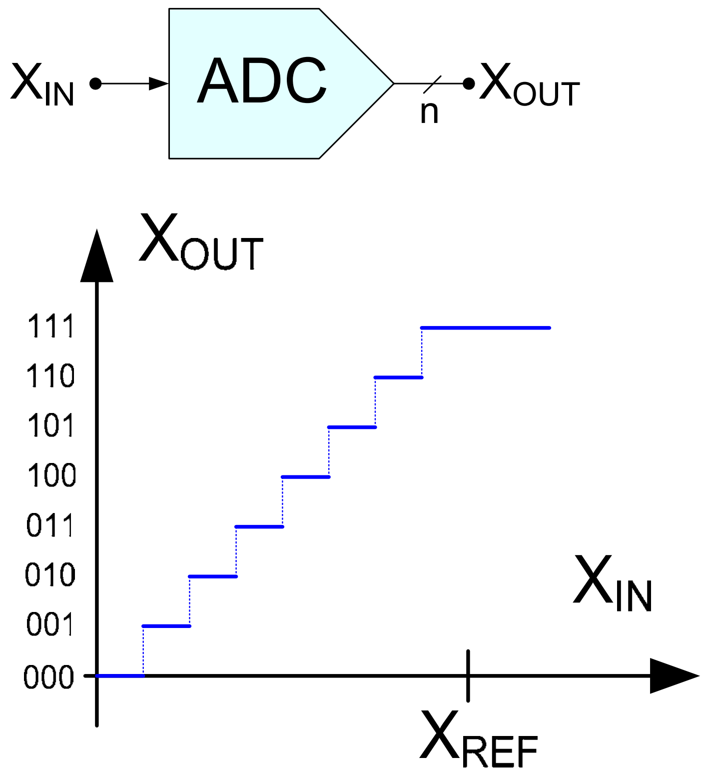


B: [b_1 b_2....b_n]

<u>An</u> ideal DAC

$$X_{OUT} = X_{REF} D(X_{IN}) = X_{REF} \sum_{k=1}^{n} \frac{b_k}{2^k}$$

Data Converters



B: [b_1 b_2....b_n]

<u>An</u> ideal ADC

$$X_{OUT} = B \qquad X_{REF} D(B) < X_{IN} < X_{REF} D(B) + X_{LSB}$$

Example

Determine V_{LSB} for a 16-bit ADC if X_{REF} is a voltage of 1V.

$$X_{LSB} = \frac{1V}{2^{16}} = 15.25\mu V$$

Observe X_{LSB} is very small and for a 16-bit ADC, must resolve an input signal to $\pm X_{LSB}/2 = \pm 7.5\mu V$

Example

Determine the number of bits of resolution, n, required in an ADC if it is to be used in a DMM that has accuracy corresponding to m decimal digits

Resolution of an m-digit DMM is $V_{REF}/10^m$

Thus equating the resolution of an ADC represented in binary form to that of the DMM, we obtain the expression

$$\frac{V_{REF}}{2^n} = \frac{V_{REF}}{10^m}$$

It thus follows that $m = n\log_{10}2$

Solving for n, we obtain $n = \dfrac{m}{\log_{10}2}$

If m=6, n=20

If m=7, n=23+

If V_{REF}=1V, V_{LSB}=0.95μV

If V_{REF}=1V, V_{LSB}=112nV

Very high resolution is required in applications such as this!

Data Converters

- Discrete implementations of data converters are seldom used
  - Not cost effective
  - Too large
  - Vary difficult to maintain acceptable accuracies of components
- Integrated data converters usually have voltage or current as input or output variables
  - If conversion of other physical units is required, a transducer precedes or follows a voltage or current data converter