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Renesas Electronics Corporation

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M16C/80 Group

Method of A-D Conversion and Accuracy

1. Abstract

The following article introduces method of A-D conversion and accuracy.

2. Introduction

The explanation of this issue is M16C/80 Group.

3. Contents

3.1 Method of A-D Conversion (10-bit mode)

(1) The A-D converter compares the reference voltage (Vref) generated internally based on the contents of the successive comparison register with the analog input voltage (VIN) input from the analog input pin. Each bit of the comparison result is stored in the successive comparison register until analog-to-digital conversion (successive comparison method) is complete. If a trigger occurs, the A-D converter carries out the following:

1. Fixes bit 9 of the successive comparison register.

Compares Vref with VIN: [In this instance, the contents of the successive comparison register are "1000000002" (default).]

Bit 9 of the successive comparison register varies depending on the comparison result as follows.

If $V_{ref} < V_{IN}$, then "1" is assigned to bit 9.

If $V_{ref} > V_{IN}$, then "0" is assigned to bit 9.

2. Fixes bit 8 of the successive comparison register.

Sets bit 8 of the successive comparison register to "1", then compares Vref with VIN.

Bit 8 of the successive comparison register varies depending on the comparison result as follows:

If $V_{ref} < V_{IN}$, then "1" is assigned to bit 8.

If $V_{ref} > V_{IN}$, then "0" is assigned to bit 8.

3. Fixes bit 7 through bit 0 of the successive comparison register.

Carries out step 2 above on bit 7 through bit 0.

After bit 0 is fixed, the contents of the successive comparison register (conversion result) are transmitted to A-D register i.

Vref is generated based on the latest content of the successive comparison register. Table 1 shows the relationship of the successive comparison register contents and Vref. Table 2 shows how the successive comparison register and Vref vary while A-D conversion is in progress. Figure 1 shows theoretical A-D conversion characteristics.

Table 1. Relationship of the successive comparison register contents and Vref

Successive approximation register : n	Vref (V)
0	0
1 to 1023	$\frac{V_{REF}}{1024} \times n - \frac{V_{REF}}{2048}$

Table 2. Variation of the successive comparison register and Vref while A-D conversion is in progress (10-bit mode)

	Successive approximation register	Vref change
A-D converter stopped	$\begin{matrix} \text{b9} & & & & & & & & & & \text{b0} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}$	$\frac{V_{REF}}{2}$ [V]
1st comparison	$\begin{matrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}$	$\frac{V_{REF}}{2} - \frac{V_{REF}}{2048}$ [V]
2nd comparison	$\begin{matrix} \text{n9} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \uparrow & & & & & & & & & & \\ \text{1st comparison result} & & & & & & & & & & \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} - \frac{V_{REF}}{2048}$ [V] $\left(\begin{matrix} \text{n9} = 1 & + & \frac{V_{REF}}{4} \\ \text{n9} = 0 & - & \frac{V_{REF}}{4} \end{matrix} \right)$
3rd comparison	$\begin{matrix} \text{n9} & \text{n8} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \uparrow & \uparrow & & & & & & & & & \\ \text{2nd comparison result} & & & & & & & & & & \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} \pm \frac{V_{REF}}{8} - \frac{V_{REF}}{2048}$ [V] $\left(\begin{matrix} \text{n8} = 1 & + & \frac{V_{REF}}{8} \\ \text{n8} = 0 & - & \frac{V_{REF}}{8} \end{matrix} \right)$
10th comparison	$\begin{matrix} \text{n9} & \text{n8} & \text{n7} & \text{n6} & \text{n5} & \text{n4} & \text{n3} & \text{n2} & \text{n1} & 0 \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} \pm \frac{V_{REF}}{8} \pm \dots \pm \frac{V_{REF}}{1024} - \frac{V_{REF}}{2048}$ [V]
Conversion complete	$\begin{matrix} \text{n9} & \text{n8} & \text{n7} & \text{n6} & \text{n5} & \text{n4} & \text{n3} & \text{n2} & \text{n1} & \text{n0} \end{matrix}$ <p>This data transfers to the bit 0 to bit 9 of A-D register i.</p>	

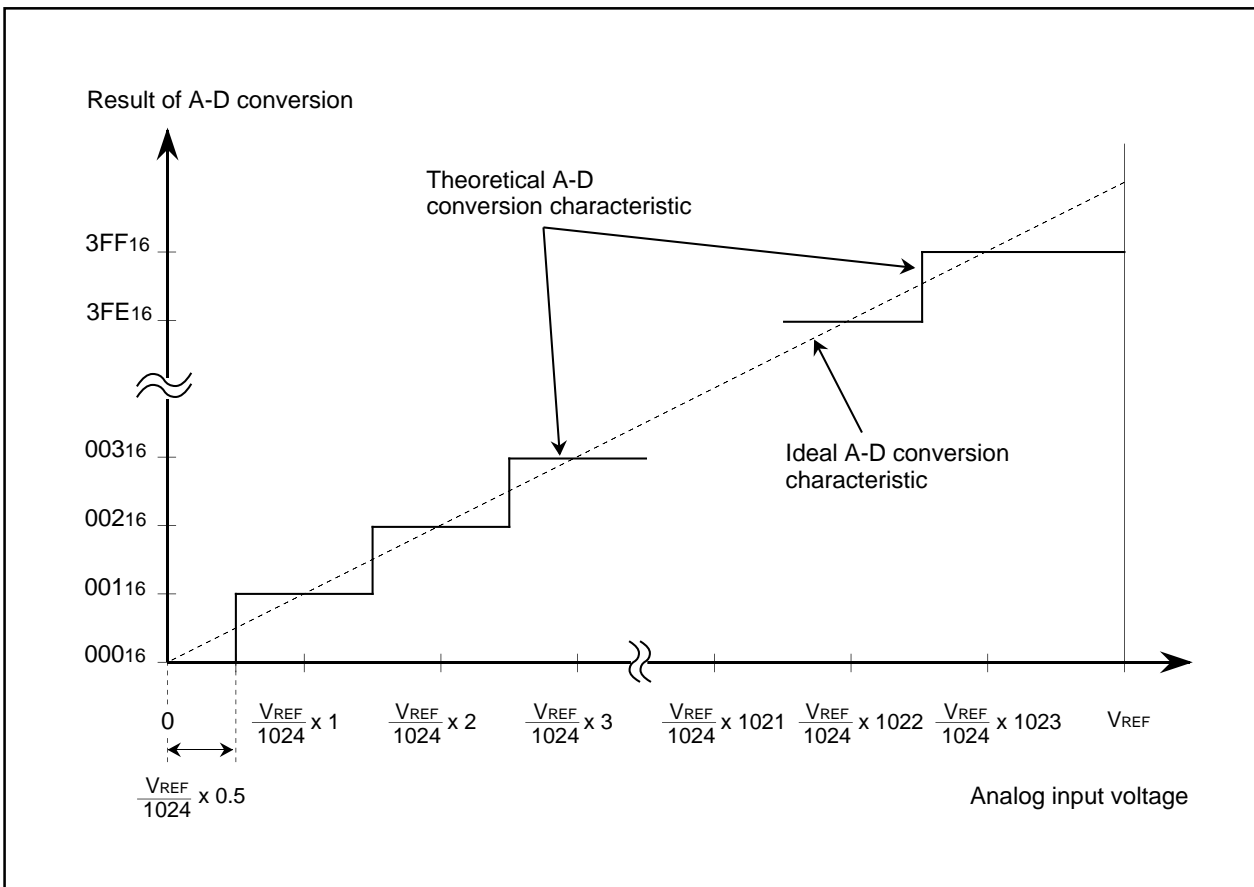


Figure 1. Theoretical A-D conversion characteristics (10-bit mode)

3.2 Method of A-D Conversion (8-bit mode)

(1) In 8-bit mode, 8 higher-order bits of the 10-bit successive comparison register becomes A-D conversion result. Hence, if compared to a result obtained by using an 8-bit A-D converter, the voltage compared is different by $3 V_{REF}/2048$ (see what are underscored in Table 3), and differences in stepping points of output codes occur as shown in Figure 2.

Table 3. The comparison voltage in 8-bit mode compared to 8-bit A-D converter

		8-bit mode	8-bit A-D converter
Comparison voltage V_{ref}	n = 0	0	0
	n = 1 to 255	$\frac{V_{REF}}{2^8} \times n - \frac{V_{REF}}{2^{10}} \times 0.5$	$\frac{V_{REF}}{2^8} \times n - \frac{V_{REF}}{2^8} \times 0.5$

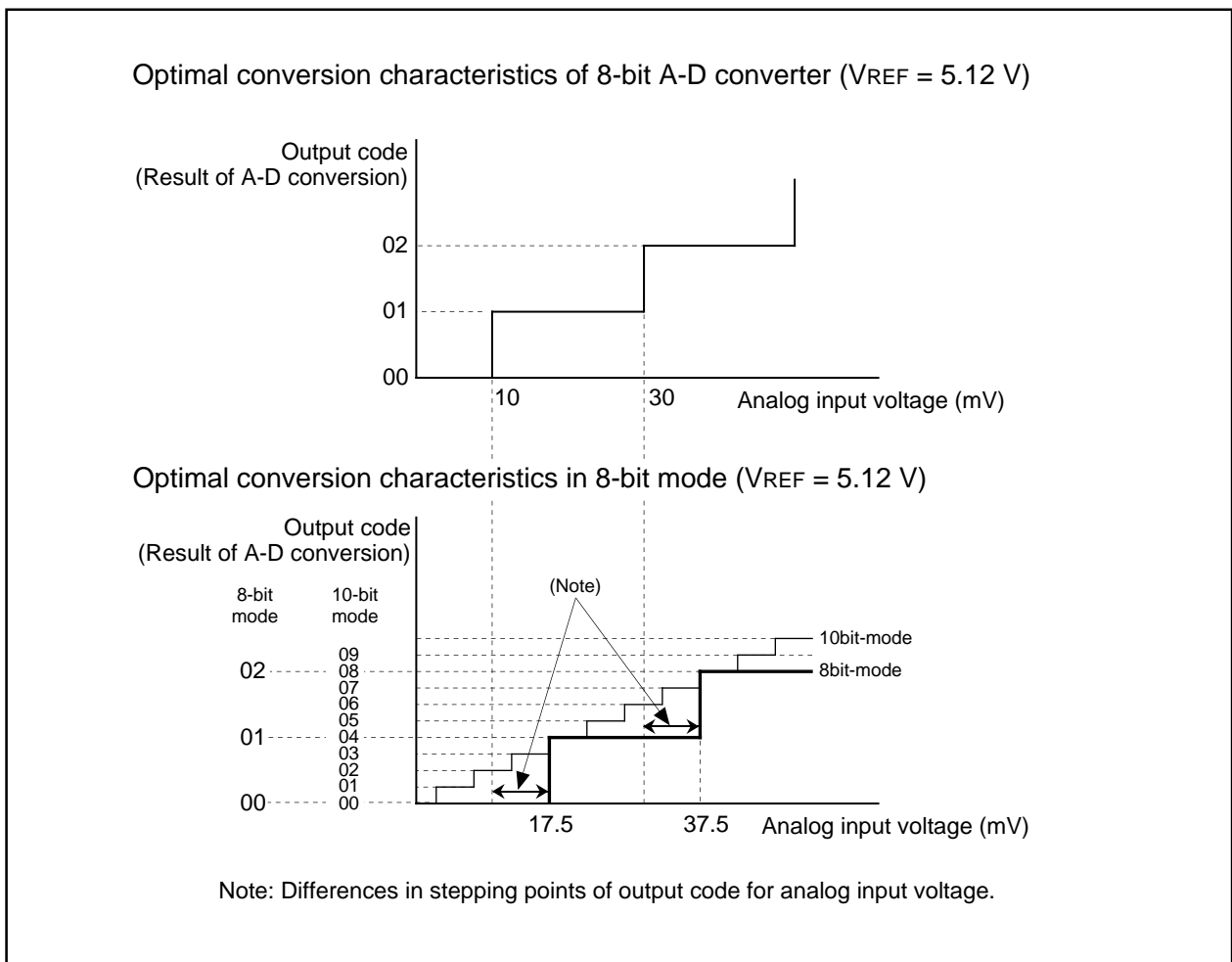


Figure 2. The level conversion characteristics of 8-bit mode and 8-bit A-D converter

Table 4. Variation of the successive comparison register and Vref while A-D conversion is in progress (8-bit mode)

	Successive approximation register	Vref change
A-D converter stopped	$\begin{matrix} b9 & & & & & & & & & & b0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}$	$\frac{V_{REF}}{2}$ [V]
1st comparison	$\begin{matrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}$	$\frac{V_{REF}}{2} - \frac{V_{REF}}{2048}$ [V]
2nd comparison	$\begin{matrix} n9 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \uparrow & & & & & & & & & & \\ \text{1st comparison result} & & & & & & & & & & \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} - \frac{V_{REF}}{2048}$ [V] $\begin{matrix} n9 = 1 & + & \frac{V_{REF}}{4} \\ n9 = 0 & - & \frac{V_{REF}}{4} \end{matrix}$
3rd comparison	$\begin{matrix} n9 & n8 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \uparrow & \uparrow & & & & & & & & & \\ \text{2nd comparison result} & & & & & & & & & & \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} \pm \frac{V_{REF}}{8} - \frac{V_{REF}}{2048}$ [V] $\begin{matrix} n8 = 1 & + & \frac{V_{REF}}{8} \\ n8 = 0 & - & \frac{V_{REF}}{8} \end{matrix}$
...
8th comparison	$\begin{matrix} n9 & n8 & n7 & n6 & n5 & n4 & n3 & 1 & 0 & 0 & 0 \end{matrix}$	$\frac{V_{REF}}{2} \pm \frac{V_{REF}}{4} \pm \frac{V_{REF}}{8} \pm \dots \pm \frac{V_{REF}}{256} - \frac{V_{REF}}{2048}$ [V]
Conversion complete	$\begin{matrix} n9 & n8 & n7 & n6 & n5 & n4 & n3 & n2 & 0 & 0 & 0 \\ \underbrace{\hspace{10em}} & & & & & & & & & & \\ \text{This data transfers to bit 0 to} & & & & & & & & & & \\ \text{bit 7 of A-D register i.} & & & & & & & & & & \end{matrix}$	

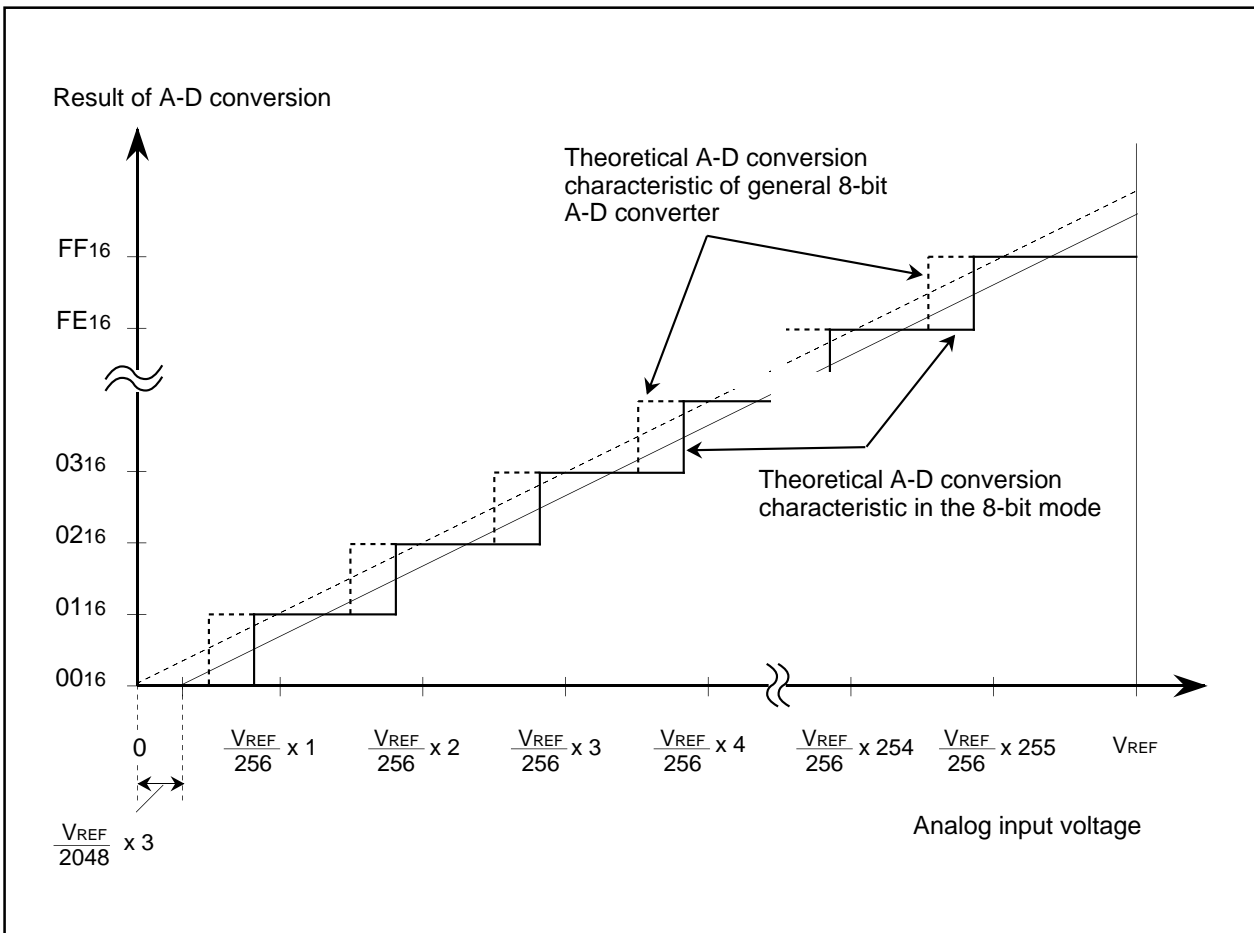


Figure 3. Theoretical A-D conversion characteristics (8-bit mode)

3.3 Absolute Accuracy and Differential Non-Linearity Error

3.3.1 Absolute accuracy

Absolute accuracy is the difference between output code based on the theoretical A-D conversion characteristics, and actual A-D conversion result. When measuring absolute accuracy, the voltage at the middle point of the width of analog input voltage (1-LSB width), that can meet the expectation of outputting an equal code based on the theoretical A-D conversion characteristics, is used as an analog input voltage. For example, if 10-bit resolution is used and if V_{REF} (reference voltage) = 5.12 V, then 1-LSB width becomes 5 mV, and 0 mV, 5 mV, 10 mV, 15 mV, 20 mV, ... are used as analog input voltages. If analog input voltage is 25 mV, "absolute accuracy $\pm 3\text{LSB}$ " refers to the fact that actual A-D conversion falls on a range from "002₁₆" to "008₁₆" though an output code, "005₁₆", can be expected from the theoretical A-D conversion characteristics. Zero error and full-scale error are included in absolute accuracy.

Also, all the output codes for analog input voltage between V_{REF} and V_{CC} becomes "3FF₁₆".

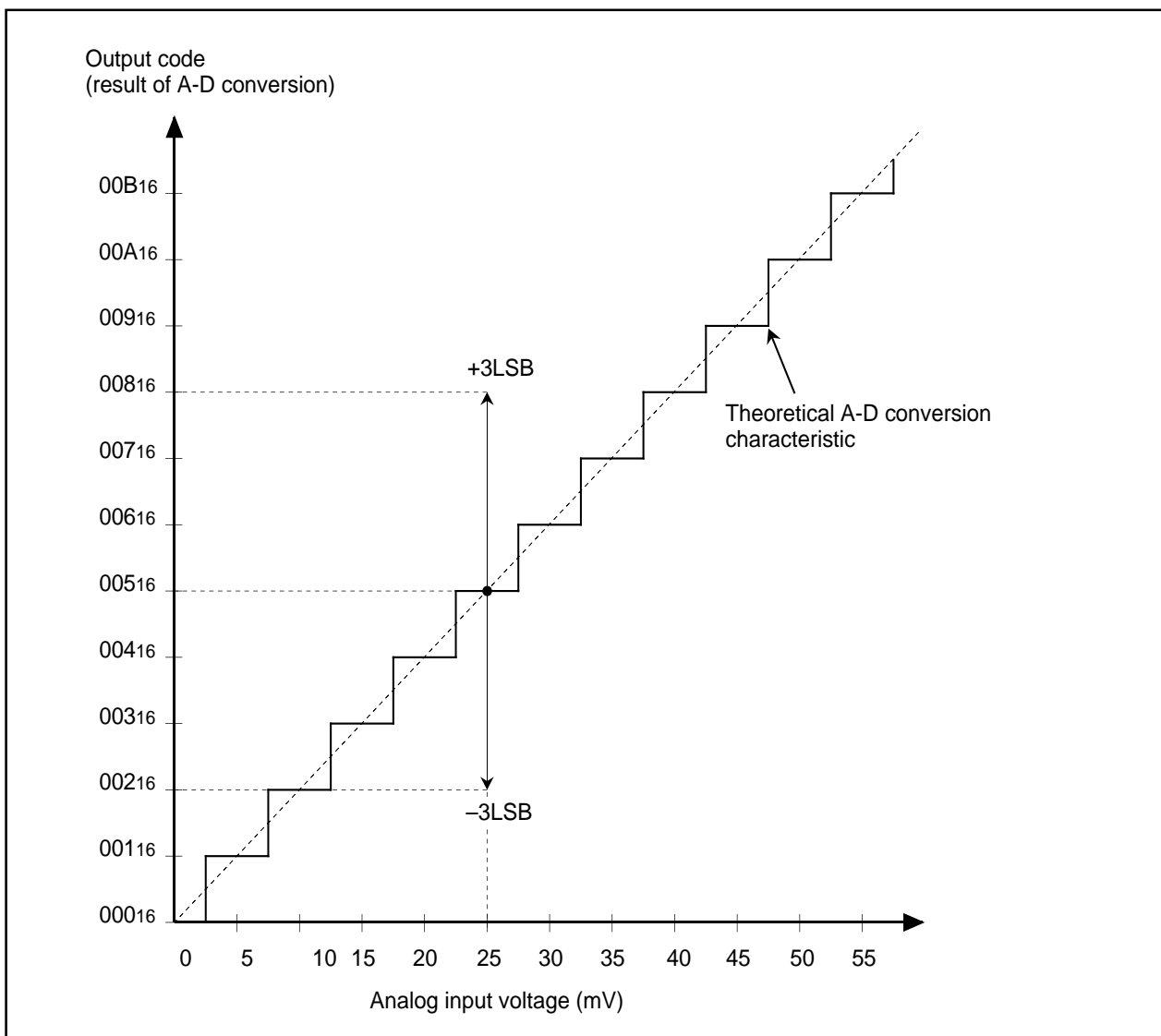


Figure 4. Absolute accuracy (10-bit resolution)

3.3.2 Differential non-linearity error

Differential non-linearity error refers to the difference between 1-LSB width based on the theoretical A-D conversion characteristics (an analog input width that can meet the expectation of outputting an equal code) and an actually measured 1-LSB width (analog input voltage width that outputs an equal code). If 10-bit resolution is used and if VREF (reference voltage) = 5.12 V, “differential non-linearity error = ± 1LSB” refers to the fact that 1-LSB width actually measured falls on a range from 0 mV to 10 mV though 1-LSB width based on the theoretical A-D conversion characteristics is 5 mV.

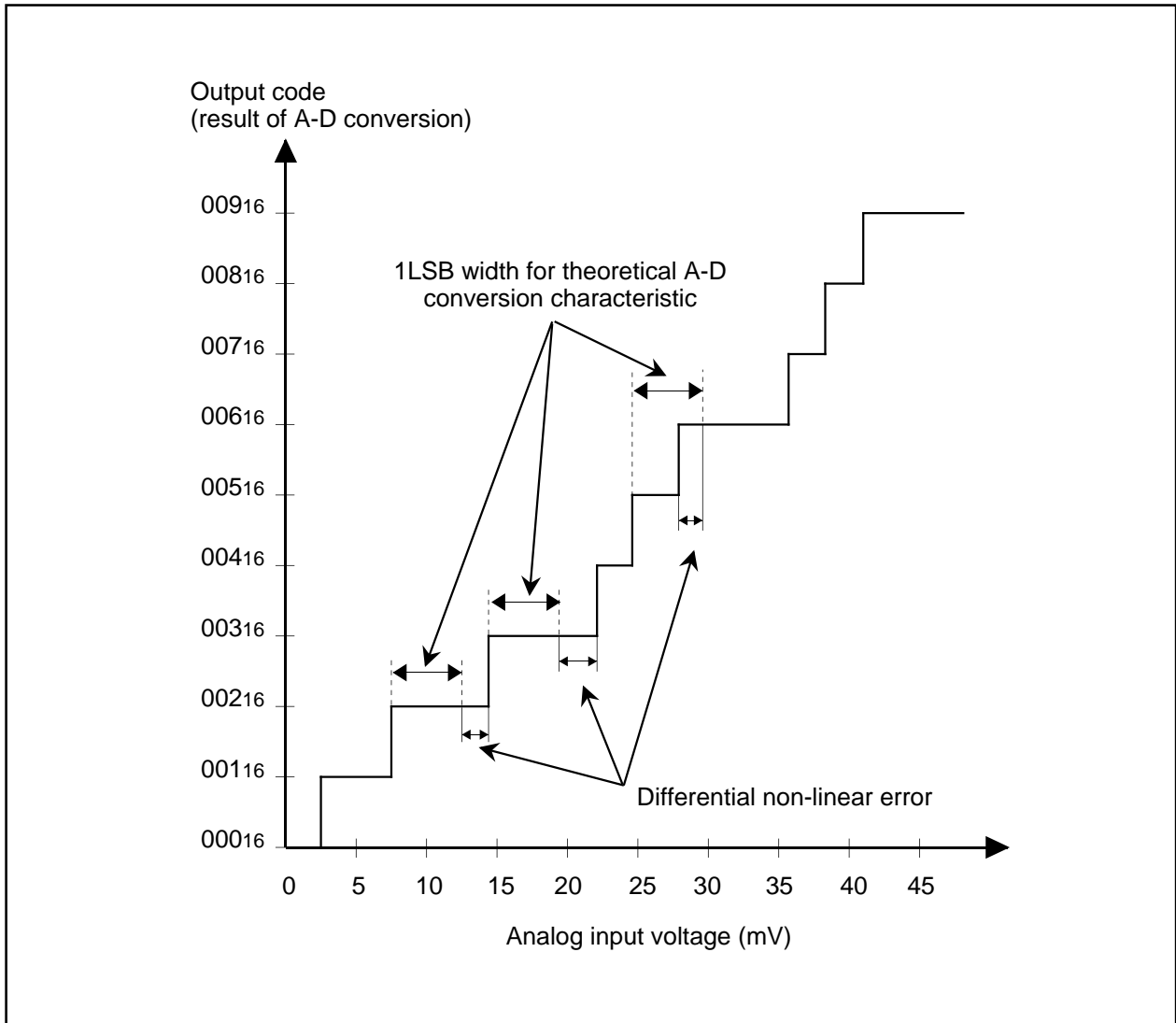


Figure 5. Differential non-linearity error (10-bit resolution)

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